Exercise Therapy in the Management of Musculoskeletal Disorders

Edited by Fiona Wilson, John Gormley and Juliette Hussey

WILEY-BLACKWELL
Exercise Therapy in the Management of Musculoskeletal Disorders
Pthomegroup
Exercise Therapy in the Management of Musculoskeletal Disorders

Edited by

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In recent years, the balance of evidence has led to exercise as the treatment of choice in musculoskeletal dysfunction. This has seen a shift in focus in both undergraduate and postgraduate training towards exercise therapy with an accompanying demand for appropriate texts. This book addresses this need and covers the fundamentals of using exercise as a treatment modality in the broad range of pathologies including osteoarthritis, inflammatory arthropathies and osteoporosis. It is anticipated that this book will provide a good progression from the fundamental principles described in this text and would specifically relate these principles to specific areas and pathologies.

The specific aims of this book are to:

- Provide the student with a comprehensive overview of the role of exercise therapy in the management of musculoskeletal disorders
- Evaluate the evidence for use of exercise therapy as a treatment modality
- Educate the student in the potential of exercise as a treatment modality
- Provide practical ideas for use of exercise therapy in the management of musculoskeletal disorders in different areas of the body and for differing pathologies
- Promote the use of exercise among physiotherapists.

This book is primarily aimed at undergraduate physiotherapy students and postgraduate physiotherapists and other clinicians who are starting to design rehabilitation programmes for patients. An emphasis of the book is the relevance of evidence but there is also a practical bias with ideas of rehabilitation programmes and specific exercises.
To
Olly and Daisy,
Sean,
Robert and Gavin
The Principles of the Use of Exercise in Musculoskeletal Disorders
Pthomegroup
Introduction

John Gormley

Historical perspectives

In many countries physiotherapy or physical therapy is the one of the largest health care professions after medicine and nursing. One of the major modalities of treatment at a physiotherapist’s disposal is exercise. Examining the history of the profession demonstrates that exercise is a fundamental component of treatment. Indeed many would argue that exercise is the most important treatment available to physiotherapists. The use of exercise in both the prevention and treatment of disease and disorders pre-dates the formation of the physiotherapy profession. This chapter examines the history of exercise and its role in disease management.

History of exercise

The use of exercise to promote health was recognised in China in approximately 2500 BC, when Hua T’o, a Chinese surgeon, promoted exercise based on the movement of animals (MacAuley, 1994). The ancient Greeks encouraged physical wellbeing and the greatest exponent of exercise was Galen. In his work, De Sanitate Tuenda dealt with the beneficial effects of exercise. In explaining how exercise worked, the amount of exercise and the types of exercise, he used numerous case studies to illustrate his ideas (Bakewell, 1997). What is clear is that not only was the importance of exercise recognised by the Greeks, but also the need for a prescription, encompassing not only the type of exercise, but also the dose or amount necessary for wellbeing. Galen believed that exercise in a moderate form was beneficial but that excess was dangerous as it worked by balancing the effects of eating and drinking, and therefore it was important to avoid excess of either.

In the seventeenth century, the Italian mathematician Giovanni Borelli (1608–1679) first described the body as a machine and used mathematics to describe the functioning of the body. This was the first attempt to apply scientific principles to human movement and Borelli would be regarded as the father of biomechanics. As the body was described as a machine with moving parts, it could be concluded that it needed movement for optimum effectiveness (Bakewell, 1997). In 1740, a French doctor, Nicolas Andry (1658–1742) wrote a book entitled L’Orthopedie, in which he described the need for
correct posture to prevent and treat deformities of the spine and also the need for active exercise rather than passive movement.

The idea that exercise was beneficial for the human body was hampered in the eighteenth century by a number of renowned British physicians including John Hunter (1728–1793), who promoted rest for the treatment of ‘disablements’ (Buckwalter, 1995). One of the greatest exponents of the use of rest was the Liverpool physician Hugh Owen Thomas (1834–1878), who is regarded as the father of British orthopaedics and during his career invented the Thomas splint for a fractured femur. He advocated that healing was enhanced by rest and that early mobilisation only caused adhesions. It is interesting that this philosophy is contrary to modern-day treatments for musculoskeletal disorders.

Contrary views to this prevailing opinion were put forward by Julius Wolff (1836–1902) and Just Lucas-Championniere (1843–1913). Wolff proposed Wolff’s Law: that mechanical stress altered bone and that bone was laid down at sites of stress and reabsorbed at sites where there was little stress. Lucas-Championniere, a French physician, argued that rest was detrimental to the musculoskeletal system and that fractures (especially those near joints) were best treated by early mobilisation and by massage. Although Wolff and Lucas-Championniere’s theories have been subsequently proved to be correct, it was not until the mid 1950s that early exercise and mobilisation in the treatment of fractures started to become accepted.

Exercise and physiotherapy

The major changes in the use of exercise came about in the twentieth century, with an increase in knowledge and with the formation of the physiotherapy profession. The origins of the physiotherapy profession can be traced back to 1894 as the Society of Trained Masseuses, which became a legal and professional organisation in 1900 as the Incorporated Society of Trained Masseuses. In 1920, exercise was incorporated as part of the profession when the Incorporated Society of Trained Masseuses amalgamated with the Institute of Massage and Remedial Gymnastics. In 1944 the society was renamed the Chartered Society of Physiotherapists. Treatment at this time primarily consisted of exercise, electrotherapy and massage. Gymnasia were a common sight in physiotherapy schools and exercise was a major component of the physiotherapy curriculum, which required students to undertake physical education classes.

Physiotherapists at this time, however, were not autonomous professionals as they had their treatments prescribed by doctors. In 1977, physiotherapists gained professional autonomy, therefore allowing them to treat patients as they felt appropriate. The fact that up to 1977 physiotherapists were unable to carry out treatment as they thought appropriate was not conducive to either innovation or to research. Despite physiotherapists using exercise on a daily basis, most of the advances in exercise therapy came from the fields of exercise physiology, biomechanics and medicine. This research led to a greater understanding of how the body works and how exercise can benefit all the major systems in the body.

The changes in 1977 and the movement of physiotherapy education into universities provided an opportunity for increased innovation and research in exercise therapy. Furthermore, in 1986 the Remedial Gymnasts Board was disbanded and remedial gymnasts became members of the physiotherapy profession. It is therefore surprising that interest in exercise as a treatment appeared to decrease in the 1990s. The reasons for this are unclear but are probably multifaceted, spanning changes in undergraduate curricula, increased specialisation and new technology. In recent years there has been a renewed interest in exercise and its beneficial effects not only among physiotherapists but also in health care in general.

The benefits of exercise

Exercise has beneficial effects on the cardiovascular system and the musculoskeletal system and indeed other body systems, but it is in the cardiovascular and musculoskeletal systems that the effects are most obvious. Aerobic exercise leads to a decreased demand on the heart at any particular workload with decreased blood pressure and decreased heart rate, increased stroke volume and consequently at
a given heart rate, an increased cardiac output. Muscles become more efficient in extracting oxygen from the circulating blood through an increase in the number and size of mitochondria. In bone, there is an increase in the density of weight-bearing bones and therefore is recommended for the prevention of osteoporosis in at-risk groups, e.g. post-menopausal women. Exercise also has beneficial effects on the density of bone in non-weight-bearing bones. Upper limb athletes, e.g. tennis players, have greater bone density in their dominant arm compared with their non-dominant arm (Kontulainen et al., 1999).

Strength training in itself will not necessarily lead to the changes in blood pressure, heart rate and stroke volume as seen with aerobic exercise. At the level of muscle there will be an increase in the size of fast twitch muscle fibres, which accounts for the hypertrophy of muscles and also neuromuscular adaptations, leading to a more efficient muscle contraction. Strength training increases the strength of ligaments and tendons and can lead to increased bone density. The increase in bone density seen in resistance training is greater compared with the changes seen in aerobic training. Cumulatively exercise has effects throughout the body.

Exercise is an active treatment which needs the co-operation and assent of the individual to be treated. Exercise programmes and exercise prescriptions therefore rely on the participation of the individual, and will not be successful if an individual is not compliant with their prescription. The lack of compliance or adherence to exercise programmes is one of the greatest reasons for poor results. Individuals often want a ‘quick fix’, i.e. a painkiller or a manipulation, so exercise may not be popular with many patients. It is therefore important that physiotherapists explain and educate people about their condition and their exercise programme in order to achieve high levels of adherence.

This chapter reviewed how the use of exercise has developed over the centuries. The following chapter examines the practical application of exercise in the management of musculoskeletal disorders.

References

The Role of Exercise in Managing Musculoskeletal Disorders

Fiona Wilson

SECTION 1: INTRODUCTION AND BACKGROUND

Chapter 1 reviewed how the use of exercise has developed over the centuries. This chapter will examine the practical application of exercise in the management of musculoskeletal disorders. The intention is not to be too condition- or joint-specific as these areas will be examined in detail later in the book. The aims of this chapter are to:

- Review current evidence and emerging bias towards exercise as a modality of choice over the past 10 years
- Discuss different areas of exercise: aerobic training; strength training; range of movement and flexibility exercise; proprioceptive and balance training
- Examine modalities and techniques employed when prescribing exercise.

Evidence for the role of exercise in managing musculoskeletal disorders

A search of the literature was conducted using the keywords musculoskeletal ± disorder, disease, injury, dysfunction and exercise. The search engines that were employed were: Medline, PubMed, Cinahl, Science Direct, PEDro, Cochrane Database of Systematic Reviews and Google Scholar. A number of trials have focused on the efficacy of therapeutic exercise in specific areas of disorder such as low back pain and whiplash. Other trials are less specific and have examined the influence of exercise on pain or disability associated with musculoskeletal disorders.

A small number of trials have examined the role of exercise on long-term musculoskeletal health in a large cohort. These trials are both prospective and longitudinal in design. Bruce et al. (2005) studied the long-term impact of running and other aerobic exercise...
exercises on musculoskeletal pain in a cohort of healthy ageing male and female seniors. The prospective study was carried out over 14 years. The cohort of 866 individuals was stratified into runners and community-based controls. Pain was the primary outcome measure and was assessed in annual surveys. The subjects were further stratified into ‘ever-runners’ and ‘never-runners’ to include runners who had stopped running. It was found that runners had a lower body mass index (BMI) and less arthritis than community controls, and although they reported slightly more fractures, this result was not significant. Likewise, the ever-runners had lower BMI and less arthritis than controls. Exercise was associated with significantly lower pain scores in both the runners and ever-runners when compared with controls. The authors concluded that consistent exercise patterns over the long term in physically active seniors are associated with about 25% less musculoskeletal pain than reported by sedentary controls.

Berk et al. (2006) concluded that exercise can have a beneficial effect on postponement of disability due to musculoskeletal disease, even if introduced at a later stage in life. A prospective cohort of 549 patients was studied annually for 16 years using a Health Assessment Disability Index as the outcome measure. All patients were given a rating to describe their levels of general activity at baseline and at the end of the study. While active exercisers performed well at the end of the study in comparison with the cohort that had remained sedentary, it was found that participants who were initially inactive but increased their activity levels as the study progressed achieved excellent end-of-study values, which were similar to the values in those who were active throughout. The authors concluded that exercise has benefits for the musculoskeletal system even if introduced later in life. The implications for the clinician of the above studies relate to the importance of education for all patients and that exercise can be introduced at any time for any patient to provide benefit to the musculoskeletal system. The studies also clearly point to the fact that lack of activity is a risk factor for musculoskeletal disease.

Establishment of risk factors for any disorder or disease is one of the first lines of long-term management for any clinician. A small number of studies have specifically addressed exercise/activity and its relationship to the onset of musculoskeletal disorders. Heesch et al. (2006) examined this relationship between levels of physical activity and stiff or painful joints in a 3-year prospective study. In a cohort of 8770 women (mid-age and older) it was found that both mid-age and older women who were active at low, moderate or high levels had significantly lower odds of reporting stiff or painful joints than their sedentary counterparts. This was particularly noted in the older age group and the authors suggested that this study was the first to show a dose–response relationship between physical activity and arthritis symptoms. While the previous study focused on older women, Pihl et al. (2002) examined whether the physically active lifestyle of physical education teachers reduced their risk of musculoskeletal disorders when compared with sedentary controls. The researchers established that the lifestyle of physical education teachers led them to have significantly lower adjusted risk of all musculoskeletal disorders as well as improved body composition in comparison with the control group.

The evidence reviewed above and that which will follow in the book, on balance, supports therapeutic exercise in the management of musculoskeletal disorders. However, it is pertinent to examine the role of exercise or activity in itself as a risk factor for musculoskeletal disease. There are two main areas where exercise or activity has been established as increasing the risk of developing musculoskeletal disorders, that is, in sport and in certain occupations. Increasing evidence from the past decade has strengthened the relationship between occupational activities and the risk of developing and accelerating osteoarthritis (Conaghan, 2002). McLindon et al. (1999) established that the number of hours of heavy physical activity was linked to the risk of radiographic knee osteoarthritis with the risk increasing in obese people. However, the injuries were associated with heavy lifting and high levels of squatting and kneeling. Kujala et al. (1994) demonstrated an increased risk of developing osteoarthritis in the lower limbs in former male elite athletes in a retrospective study of 2049 subjects. However, the evidence is still biased towards moderate levels of activity having beneficial effects on the musculoskeletal system for both management and prevention of musculoskeletal disorders. Studies which highlight exercise as a risk factor for disorders consistently identify high levels of loading as being the causative element, and clinicians who prescribe exercise must be aware of this.
In conclusion, exercise has been shown in a number of high-quality trials to have benefits both in the management and prevention of musculoskeletal disorders. While there is some evidence that exercise may have harmful effects on the musculoskeletal system in the form of disease or injury, this is almost exclusively associated with abnormal or high levels of loading.

Do moderately intense cardio 30 minutes a day, 5 days a week
Or
Do vigorously intense cardio 20 minutes a day, 3 days a week
And
Do 8–10 strength-training exercises, 8–12 repetitions of each exercise twice a week.

The clinician who is prescribing exercise must consider the two main principles of training, which are overload and specificity. When considering the components of fitness, these principles can be most effectively applied to aerobic fitness, muscle strength, and endurance and flexibility. The principle of overload states that for an organ or tissue to improve its function, it must be exposed to loading at a level to which it is not accustomed (ACSM, 2000). The principle of specificity states that training effects form an exercise modality are specific to the exercise performed and the muscles involved. This is seen when high-repetition, low-load exercise produces an increase in muscular endurance but little increase in strength. Conversely, high-load and low-repetition exercise will increase strength but will have little effect on endurance (ACSM, 2000).

SECTION 2: PRACTICAL APPLICATION OF EXERCISE

Components of fitness

The components of fitness may be described as the following: aerobic or cardio-respiratory fitness; muscle strength and endurance; flexibility or range of motion (ROM); and body composition (American College of Sports Medicine (ACSM), 2000). However, a frequent inclusion in recent years is balance, co-ordination and proprioception (Shankar, 1999). Body composition depends on many factors including genetics, activity levels and diet, and for the purposes of this text will be addressed primarily in Chapter 15, which deals with obesity. Therefore, the components of fitness which will be referred to throughout this text may be summarised as:

- Aerobic or cardio-respiratory fitness
- Muscle strength and endurance
- Flexibility or ROM
- Balance, co-ordination and proprioception.

Exercise prescription

Prescription of exercise requires a clear understanding of the components of fitness and knowledge of appropriate levels of intensity, frequency and duration of each element that will be suitable for each patient. Beyond prescribing specific exercise, the health benefits of general exercise should be considered, particularly at initial assessment. In 2007, the ACSM revised its guidelines for levels of physical activity that are required to see health benefits. For healthy adults under age 65, it is now recommended that they (ACSM, 2008):

- Do moderately intense cardio 30 minutes a day, 5 days a week
- Or
- Do vigorously intense cardio 20 minutes a day, 3 days a week
- And
- Do 8–10 strength-training exercises, 8–12 repetitions of each exercise twice a week.

Traditional clinical treatment sessions would frequently introduce exercise to include one or more components at the end of a modality, such as manipulation. However, best practice is to structure a programme and to ensure that all components are covered. It is common to focus on one area such as strength training and neglect to include other areas in the patient’s treatment plan, which demonstrates a lack of consideration for the patient’s general health. Focusing on one area such as strength training does not consider the overall benefits of all components of fitness to the musculoskeletal
system, as outlined in the previous chapter. A programme that is designed into the phases listed above is more likely to cover all components of fitness in a more structured way.

**Warm-up**

The warm-up facilitates a transition for the body to move from a state of rest to exercise. It allows the heart rate to achieve a steady increase to exercising levels, facilitates increased blood flow to muscles and may increase soft tissue extensibility and thus enhance performance and reduce injury. The warm-up should consist of around 10 minutes of low-intensity exercise which facilitates activity in large joints such as the hips, knees and shoulders and uses large muscle groups. A good example of such exercise would be deep knee bends with arm swinging or step-ups.

Stretches should follow this activity with specific joint and muscle groups targeted individually for the patient. Consideration should also be given to the level of loading which specific muscle groups will experience during the activity which will follow. A generic stretching programme should be avoided as this may fail to target important areas for individual patients and may lead to lengthy stretching programmes that interrupt the flow of the warm-up. Stretching and flexibility are discussed later in this chapter.

The final stage of the warm-up will allow the heart rate to reach the target exercise levels and thus will include more high-level aerobic activity, which may start to replicate that used during the endurance phase.

**Endurance phase**

The endurance phase develops cardio-respiratory fitness and should comprise about 10–60 minutes of continuous or intermittent aerobic activity. This should be set at a level that is appropriate for the patients and is based on previous assessment of levels of fitness. Activities which use large muscle groups should be employed for optimal effect. The duration of this phase should be inversely related to the intensity of the activity. Resistance training and specific exercise in a rehabilitation programme may be included in this phase (ACSM, 2000).

**Recreational activities**

Inclusion of games, skills or challenges following the endurance phase may make the programme more interesting and encourage the patient to adhere to the programme. This may be particularly important in the rehabilitation of an athlete or an individual with an occupational injury.

**Cool-down**

The purpose of the cool-down is to facilitate a graduated return to the pre-exercise state. It allows heart rate and blood pressure to return to normal and enhances lactate removal. The format should be very similar to the warm-up and should include exercise of diminishing intensity. In practical terms, it presents an opportunity for the clinician to further assess the patient’s response to the programme.

**Prescription of aerobic exercise**

The benefits of aerobic exercise for the musculoskeletal system were outlined in the previous chapter. The aim of prescription of aerobic exercise is to generate an improvement in maximal oxygen consumption (VO$_{2\text{max}}$). The VO$_{2\text{max}}$ of an individual defines their aerobic capacity and is a measure of their maximal oxygen uptake. Endurance training has the effect of making the cardio-respiratory system more efficient when the training is performed regularly, and consequent improvements will be seen in the VO$_{2\text{max}}$. As the VO$_{2\text{max}}$ and heart rate of an individual are related in a linear fashion, measurement of heart rate during exercise is a good reflection of the individual’s VO$_{2\text{max}}$ or aerobic capacity. It must be remembered that changes not only take place in the cardiac and pulmonary systems but also at a localised muscular level. Changes in VO$_{2\text{max}}$ are directly related to the intensity, frequency and duration of the prescribed exercise and these elements should be given primary consideration in exercise prescription.

**Type of exercise**

There are many factors to consider when prescribing aerobic exercise for the patient with a
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...can make the exercise more challenging such as adding definite arm movements with weights in the hands, as seen in power walking (Fig. 2.1), which encourages the recruitment of more muscle groups and enhances the aerobic effect. Nordic walking uses poles in the hands, which not only encourages greater use of the trunk and upper limbs but also enhances stability for those who may be challenged by balance (Fig. 2.2).
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A lower limb injury may commence aqua jogging using a flotation vest, which will ensure that similar muscle groups and kinematics will be employed during rehabilitation. It should also be remembered that an athlete will have a much higher starting point in terms of fitness and may need to be prescribed higher intensity exercise as their goal is to maintain fitness rather than achieve it.

Exercise intensity

There are a number of different methods of setting the exercise intensity but the mode which may be most practical and simple for the musculoskeletal clinician involves prescribing as a percentage of maximum heart rate (HR\text{max}). The ACSM (2008) recommends between 55/65% up to 90% of HR\text{max} to achieve benefit. While those individuals whose are very unfit at the start of the programme would require prescription at the lower end of intensity, those who are fit would be working at the upper end of intensity. For the average individual, prescription at 70–80% of HR\text{max} would be suitable to see improvement. Best practice requires establishment of the patient's HR\text{max} by means of a progressive physiological or 'step' test. However, the equation which estimates the HR\text{max} (below) may be used when this is not available, i.e.

\[
\text{Estimated HR}_{\text{max}} = 220 - \text{age}.
\]

Exercise duration

The duration of exercise is governed by the intensity as high intensity exercise will require shorter duration periods than low intensity to achieve the same benefits. The ACSM guidelines outlined earlier in the chapter should be reviewed to establish minimum requirements for each patient. In general, for the average individual who is exercising at 70–80% of HR\text{max}, a duration of 20–30 minutes excluding warm-up and cool-down will be sufficient to benefit the patient. As mentioned previously, this should be adapted accordingly for the very unfit or conversely, the very fit patient.

Exercise frequency

Exercise frequency for the musculoskeletal patient may be governed by clinical visits which may be
limited to once or twice per week. However, optimal benefits will be achieved with three to five sessions per week. This demands adherence by the patient that may be achieved in a number of ways, the most successful of which requires that the patient is supervised in a clinic or gym. However, this is both costly and not practical, particularly as long-term benefits are only achieved by maintenance of the programme following discharge. Training diaries may be useful as are classes at a local gym, and the aim should be to educate the patient regarding the importance of maintaining the exercise frequency. Of course, for the Olympic athlete who is already doing two aerobic training sessions daily, this should be replicated in rehabilitation to maintain fitness. The patient who is starting from a very low fitness level may achieve benefits by starting at two sessions per week. Although the frequency must be adjusted for each patient, the ultimate goal for the average individual should be to at least meet the minimum requirements as recommended by the ACSM and outlined earlier in the chapter.

Progression of the programme

The rate of progression of the programme will depend on the patient and their goals, which will have been established at the original assessment. As this text is concerned with rehabilitation of musculoskeletal injury, it will also depend on the rate of resolution of the injury. The intensity, duration and frequency of exercise may be low (40–50% HRmax), short (15 minutes) and limited to three times per week for the patient who is commencing the programme. The ultimate aim would be that this patient will have progressed to moderately intense exercise for 30 minutes, five times a week, or vigorously intense exercise for 20 minutes, three times a week. The programme should be commenced with caution, and assessment should always be ongoing and the patient’s response to the programme should be constantly monitored. As the patient finds that the programme becomes less challenging, which may be demonstrated when the established exercise intensity is no longer enough to reach heart rate goals, then intensity, frequency and duration may be increased gradually and with caution. Maintenance of improvement should be considered at discharge and a programme should be planned which the patient may adapt to their lifestyle to facilitate long-term benefits.

Prescription of muscle strength and endurance exercise

Strength is regarded as the maximum force that a muscle can exert and endurance refers to the ability to maintain the force over time. Both are required for normal function of muscles and different muscles have different functions. Some muscles have a greater proportion of slow twitch or type I fibres and thus demonstrate greater endurance, such muscles are associated with functions such as postural control. Other muscles have a greater proportion of fast twitch or type II fibres and are associated with rapid generation of force. Resistance training improves the capacity of a muscle to generate and/or maintain force. When prescribing resistance training, the overload principle should be applied. This may be achieved by increasing the load, the number of repetitions or the number of weight-training sessions above levels normally experienced. Muscle strength is developed by using low repetitions, typically 8–12 repetitions, with a resistance or weight which is close to the maximum that may be lifted or moved. To improve muscle endurance, high repetitions with low load are employed.

Types of resistance

Huber and Wells (2006) define the modes of resistance exercise as isometric (constant length), isotonic (constant tension), isokinetic (constant velocity) and plyometric (increased length). The most commonly used resistance exercise is isotonic muscle work in the form of free or machine-based weights. Resistance may be manual, given by the clinician, or mechanical, in the form of resistance from machine, free, pulley or elastic-based weights.

Isometric exercise

Isometric resistance may be given by the therapist, gravity or by a constant weight. Isometric exercise
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is beneficial when low loading and low levels of balance and control are required. It is also useful in rehabilitation of musculoskeletal injury when range of joint motion is limited or when there is a desire to strengthen a muscle in a particular point in a movement arc. There is a lack of consensus regarding time of contraction, but 10 seconds is a good minimum starting point. Isometric exercise may be selected to work a small group of muscles. Multiple muscle groups may be exercised isometrically by using a more complex activity such as a squat while holding a medicine ball (Fig. 2.4).

**Isotonic exercise**

Isotonic exercise may be facilitated using machine, elastic resistance, pulleys, hydraulic or free weights with or without gravity assistance or resistance. One of the advantages of this method is that it is frequently measurable in that the weight can be fixed at a specific resistance (measured in kilograms). This enhances prescription and measurement of progression. Machines and pulleys frequently help isolate activity to a joint or limb by fixing the rest of the patient’s body. The disadvantage of this is that incorrect technique and ‘trick movements’ may be easily applied, decreasing the efficacy of the exercise as the patient compensates for muscle weakness by activating other muscle groups. Free weights using hand-held weights, bars and discs such as Olympic weights, elastic resistance and gym balls among others are perhaps the most effective but most challenging mode of muscle strengthening. Free weights require good control and good technique that should be taught by the therapist prescribing the exercise. Trick movements are common when free weights are employed particularly as a patient tries to employ gravity or momentum to aid movement of a weight. Figure 2.5a demonstrates poor technique in a squat exercise; the weight is too heavy and the patient cannot maintain good position of the lower limbs as they return to a standing position. In Figure 2.5b, the weight is lighter and the patient is encouraged to keep the hips and knees in the midline to facilitate the correct exercise.

**Plyometric exercise**

Plyometric exercise prescription is based on the physiological principle that a maximum contraction follows a maximum stretch during an eccentric action. A concentric action follows an eccentric action to produce an optimum concentric action (Huber and Wells, 2006). A typical example is a high jump followed by a deep squat. Such exercise is most suitable in the rehabilitation of athletes where it will replicate their sport and thus apply the principle of specificity well.

**Open versus closed kinetic chain exercise**

It is pertinent at this point to make a short note regarding the benefits of open versus closed kinetic chain exercise. The kinetic chain refers to the limb which is linked by a series of joints. In a closed kinetic chain, the end of the chain is in contact with or ‘planted’ on a surface so the foot or the hand will be resisted by the surface, for example, when performing a standing squat. In an open kinetic chain, it is not fixed and can move freely as seen when sitting on a stool and swinging the lower leg forwards. The type of muscle activity which is observed is quite different in the two types of exercise. One of the advantages of the closed kinetic...
chain is that multiple muscle groups are recruited and that there are increased proprioceptive demands on the joints.

Intensity, frequency and volume of exercise

The intensity of exercise is measured by establishing the 1RM, which is the maximum weight that an individual can lift or move once through the full ROM. Strength gains will be established when the weight is set at 60–70% of the 1RM and repetitions of up to 15 performed twice a week (see ACSM guidelines above). To improve endurance, lighter weights and higher repetitions are prescribed. When rehabilitating a musculoskeletal injury, it may not be possible to establish the 1RM; in this instance a conservative estimate with careful monitoring may be the most appropriate approach. There are many theories regarding muscle strengthening and the reader is encouraged to explore this further to develop a more comprehensive understanding.

Strength and endurance training is frequently at the core of a programme to rehabilitate a patient with a musculoskeletal disorder. The later chapters of this book will describe the joint-specific approaches to this modality with supporting evidence. As many patients have multiple pathologies, other factors must be considered in the prescription of strengthening exercise, in particular its effect on blood pressure. Increases in blood pressure during high resistance exercise, particularly isometric exercise, are much greater than that during continuous aerobic exercise. Thus prescription of resistance exercise for the patient with both musculoskeletal and cardiovascular disease must be considered carefully.

Prescription of range of motion or flexibility exercise

The area that appears to inspire the greatest controversy in inclusion in fitness programmes is that of prescription of stretching exercises, which are also known as flexibility or ROM exercises. The area of greatest debate is around the benefits of stretching programmes in reducing risk of musculoskeletal injury. There is a wealth of research in the area and the reader is encouraged to analyse this in a critical manner. Many of the studies lack robust methodology and there still appears to be no clear consensus (Thacker et al., 2004; Fradkin et al., 2006; Small et al., 2008) although many experienced clinicians and patients alike (particularly athletes) present anecdotal evidence of its efficacy. Some of this research is presented in the later chapters dealing with specific joints. For the purposes of this chapter, a simplistic view is taken in
that a healthy and functioning joint will move through its full ROM and rest in a neutral position, allowing those around it to do likewise. When there is limitation of ROM, which may be due to many factors including muscle shortness or imbalance, the normal function of the whole kinetic chain is compromised. Thus a fitness programme should aim to achieve optimal ROM of joints and extensibility of soft tissues to enhance function with an argument that it may also reduce risk of injury.

A number of different types of exercise increase ROM: passive, active and active-assisted.

**Passive exercise**

Passive ROM exercise is the most simple and must be performed by a clinician on a patient. Such a movement will be performed during routine assessment of a patient with a musculoskeletal disorder to establish joint integrity and limitations of movement. It is useful when active movement is painful, as in the case of muscular injury, but of course it is labour intensive. Passive ROM exercise will frequently be a starting point with little stretching taking place, however, to progress the joint ROM, the joint should be stretched at the end of range except in cases where further damage or instability may occur.

**Active range of motion**

Active ROM exercise involves the patient actively taking the joint through the full ROM. Stretches may then be added on to increase the ROM by pushing the movement beyond its original end point. Such exercises can be easily included in an aerobic programme. The sedentary patient who is starting a programme may have limited ROM in a number of joints as a result of inactivity and may benefit from inclusion of very simple ROM exercises, which often are well placed in the warm-up section of a programme.

**Active-assisted range of motion exercise**

Some patients may be unable to achieve full ROM actively but with limited help may reach target levels. Use of the other limb or props such as sticks or pulleys may help the patient move the joint further (Fig. 2.6).

**Types of stretching**

Stretching exercises should complement ROM exercise and good practice demands that stretching is preceded by active or passive ROM exercise to assess the integrity and limitations of a joint. The addition of stretching exercise allows increases in the ROM. There are a number of different types of stretches, which are frequently described as static, proprioceptive neuromuscular facilitation (PNF) and ballistic.

**Static stretching**

A static stretch involves moving a joint to its end point or slowly stretching a muscle until mild discomfort is experienced. The position is held for an extended period of time. There is no consensus regarding the optimal time to hold the stretch and anywhere between 10 and 30 seconds has been suggested. However, most clinicians would suggest that a stretch time of at least 20 seconds and preferably 30 seconds or more is required to observe a relaxation in the muscle as the stretch response of the muscle spindle subsides, which allows further
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Movement or stretch. The stretch can be performed by a therapist, who assists in achieving optimum length of the muscle or joint ROM, or a patient may apply overpressure themselves to facilitate the same action. This is probably the safest type of stretch.

PNF

PNF stretching involves activating either the agonist or antagonist muscles immediately before a stretch is performed. This is based on the theory of reciprocal inhibition in which the maximum activation of one muscle inhibits activation of its antagonist, thus allowing optimal relaxation and stretching. This type of stretching often includes the ‘hold-relax’ technique, where a therapist stretches a muscle to resistance, resists an isometric contraction of a muscle for around 10 seconds, following which the therapist asks the patient to relax and stretches the muscle further. In Figure 2.7a the therapist resists an isometric contraction of the hip extensors and follows this with a stretch (Fig. 2.7b).

Ballistic stretching

Ballistic stretching involves bouncing movements with the aid of momentum to increase ROM, for example kicking a straight leg in the air to increase hip ROM and lengthen hamstrings. It is less popular as it has been suggested that the rapid movement involved may activate the muscle spindle and thus reduce the potential to increase ROM. This type of stretching may not be suitable for many patients with musculoskeletal disorders but is popular with athletes (following a static stretch) as it replicates movements performed during sporting activity.

Frequency, intensity and duration

Compared with the other areas of fitness, there is limited consensus regarding optimal dosage required to achieve good ROM and flexibility. A good rule to follow would be to include stretches in the warm-up of any aerobic or strengthening programme and to pay regular attention to those muscle groups or joints where limitations have been noted. The ACSM (2000) suggests:

Type: A general stretching routine that exercises major muscle and/or tendon groups using static or PNF techniques

Frequency: A minimum of 2–3 days per week

Intensity: To a position of mild discomfort

Duration: 10–30 seconds for static, 6-second contraction followed by 10–30 seconds of assisted stretch for PNF

Repetitions: three to four for each stretch.
Prescription of proprioception, co-ordination and balance exercise

The concepts of balance, co-ordination and proprioception are important to consider when assessing and rehabilitating normal function in the patient. Balance may be defined as either static, which is the ability to maintain a position, or dynamic, which is the ability to move smoothly between positions. Co-ordination is the ability to produce a smooth, ordered movement and proprioception is the ability to identify joint position in space. Thus these concepts are all functions of the nervous system and are necessary to achieve normal movement. There is emerging evidence that musculoskeletal injury can compromise these functions, particularly proprioception, and so it is important to include exercises to address deficits in rehabilitation. These concepts will be discussed in the joint-specific chapters but the reader is encouraged to investigate further to glean knowledge of examining these disorders in patients.

There is limited literature regarding prescription of exercise in these areas, particularly when considering frequency, intensity and duration. However, it would be pertinent to ensure that the balance, co-ordination and proprioceptive systems are challenged throughout the rehabilitation programme while doing other exercises and are accordingly done daily if possible. The simplest way is to introduce unstable surfaces on which the patient performs their normal exercise as seen in Figure 2.8, which illustrates a patient with a shoulder injury performing a press-up on a wobble board to introduce a balance and proprioceptive component to rehabilitation.

Introduction of exercise which moves out of the simple planes of movement will make the exercise challenging and stimulating to the systems discussed above. Increasing balance demands by making the base smaller or standing on one foot introduces further challenge. The revolution in computer games, which have now become interactive, means that programmes have been introduced which simulate real movement without risk of injury, stimulating use of all systems above. Their use in rehabilitation is likely to increase, particularly with the use of imagination by those working in rehabilitation (Fig. 2.9).

References

Introduction

There are numerous diseases and conditions that can affect the musculoskeletal system and its consequent function. These range from diseases of the joints to osteoporosis, back pain, spinal disorders, childhood musculoskeletal disorders, and injury or trauma to the musculoskeletal system. Since musculoskeletal disorders are believed to be one of the most common causes of severe long-term pain and physical disability and affect hundreds of millions of people, it is important to understand the impact of these disorders on function to be able to determine effective treatment pathways and preventative strategies. However, before one can understand musculoskeletal dysfunction one needs to understand normal function and its assessment.

What is normal function?

Function can be defined as the special work performed by an organ or structure in its normal state (Roper, 1987). In the context of the musculoskeletal system this is the ability of the body to move and interact within its environment. An understanding of movement, particularly human movement is important to therapists, doctors, biomechanists, orthotists as well as many other health professionals. It is equally important that this understanding or description of motion can be communicated between specialists in a consistent and meaningful manner.

The study of human movement is often referred to as kinesiology and can take place at a segmental local level or at a whole body level. In understanding movement it is important to appreciate the systems involved in creating this movement, many of which involve simple mechanical and physical principles. When considering movement, several systems are working together in harmony to produce normal function including muscles, bones, and ligaments.

The concept of integrated systems was introduced by Panjabi (1992) in describing the function of the spine. He proposed that to move and function normally, the spine requires a series of systems working together, namely: a control system (the central nervous system), a system of active elements (the muscles), and a system of passive elements (the vertebrae and discs). It was further proposed that a dysfunction of any part of one of these systems
could lead to: (1) an immediate response from the other systems to compensate; (2) a long-term adaptation response of one or more systems; or (3) an injury to one or more components of any system. In the first, function would be impaired, in the second, although apparently normal, the stabilising system would be altered and in the third—dysfunction/back pain would present. Although our understanding at present of the control system is limited, there has been extensive research to understand the mechanics of movement from the perspective of the passive and active systems.

Many factors can influence the working of the systems described above, including environmental influences such as gravitational fields (Davey et al., 2004) and objects within that environment, for example workplace surroundings (Davis and Marras, 2003) and physiological factors, namely the effects of fatigue, training, etc. (Fulton et al., 2002; Holt et al., 2003), and psychosocial factors (Pincus et al., 2002; Marras, 2005). Of particular interest is the relationship of mechanical influences induced by our environment and lifestyle on the health and functioning of our locomotor system, an area worthy and in need of further exploration (Brinkman et al., 2002). What is relevance of this statement?

In simplistic terms the body can be considered as consisting of a skeleton that provides a rigid framework which acts as a series of struts and levers. These struts and levers in turn can be moved by the actions of muscles, and can also be used to protect and support vulnerable soft tissues and organs. This framework of bones or struts is connected through joints and it is at these joints that growth is permitted, and force in the form of compression (a force that squeezes things together), tension (a force that pulls apart two connected structures), shear (a force that causes two adjacent layers or surfaces to slide relative to each other) and torsion (a force that causes to structures to twist on each other) loads are transmitted and movement occurs. These forces and movements in turn are generated by the action of muscles. As well as moving joints, muscles can also be used to stabilise joints. These roles are often occurring at the same time as the muscle and act not only to allow the motion but also to convey the functional load that this motion creates and keep the joint stable.

For a joint to be stable it must be in equilibrium, which means that after any slight displacement it will return to its original position and if it was unstable it would buckle and fail. To understand stability, one must consider gravity and its effects. Gravity is the attractive force the earth has on the mass of an object, and our weight, for instance, is the combined effect of this mass and gravity. This weight can then be thought of as a force that acts through a single point, which in mechanical terms is called the centre of mass or centre of gravity. This point in the upright human is approximately around the umbilicus. When a body is in an unsupported state, gravity will act to create a force that will accelerate and move this body so it is no longer in equilibrium. If, however, it has a supported or stable base it would not move. Simplistically for a body to be stable, the centre of gravity/mass must lie within the base of support of that body to stop it from toppling over. So in considering motion of the body one also has to think about what is happening to keep the body in a stable state to allow this motion to occur.

The skeletal framework is often subdivided into the axial or central skeleton, which comprises the head, neck and trunk, and the appendicular skeleton, which comprises of the upper (arm, forearm and hand) and lower limb (thigh, leg and foot). Motion is considered within each system. However, all these systems need to link together and like all structures or buildings these need to be based on stable foundations. This means that in assessing a body region, one cannot neglect the rest of the body. For humans, the axial or central skeleton as its name suggests could be considered as ‘mission control’ in terms of stability. If it is not stable then the rest of the body’s function will be compromised. Unfortunately for humans, the spine in mechanical terms is considered ‘inherently unstable’, and research on cadaveric spines devoid of musculature has shown that the spine in the neutral position with the pelvis fixed will buckle under loads of around 20 N (Panjabi et al., 1989). This load would be considerably less if the pelvis had not been fixed. Thus for the spine, its base of support, i.e. the pelvis and its muscular system, are of importance for stability to be achieved, and without such stability the appendicular system may lack optimal functionality. Therefore care should be taken when using the term ‘core stability’ as this involves not only the muscles acting on the spine, of which there are numerous, but also on the muscles that achieve a stable base of support.
for the spine, namely the muscles acting on the pelvis i.e. gluteals, oblique abdominal and lower abdominals.

Biomechanics of movement

Winter (1990) defines the biomechanics of human movement as the interdisciplinary that describes, analyses and assesses human movement. Movement is often defined in terms of either kinematics or kinetics or both. Kinematics is the term used in the description of a movement and as such, includes the pattern and speed of movement, and the coordination and displacement of the different body segments relative to some form of spatial reference system. Kinetics, by contrast, is the study of the forces associated with motion and these include both internal forces, i.e. those resulting from muscle activity etc., and external forces, i.e. those generated from external loads or bodies. For example, considering a person who is walking, a kinematic assessment would include the phases of gait and a description of the motion occurring, for example, at the knee; a kinetic assessment however, would be a description of the forces generated at the knee during the phases of gait. These forces can rarely be directly measured and kinetic analysis frequently requires some form of mathematical link segment modelling. This type of modelling, however, relies on appropriately measured kinematic and anthropometric data. Anthropometric measures include dimensions, weight, shape, centre of gravity, and other properties of the body segments according to race, age and sex, and a number of databases describing these are available (Dempster, 1955; Chandler et al., 1975; Pheasant, 1996).

Thus the kinematic assessment of motion is an important factor in understanding the biomechanics of movement. In the clinical environment, motion is assessed at a very primary level by the human eye. Although one gains an appreciation of what is occurring, it is a subjective measure and one that places huge overload on the observer, particularly if it is a complex and fast movement. Furthermore, what is seen then needs to be described and recorded. However, if measurements of the movement are performed quantitatively the task of documentation is easier, objective and more likely to be repeatable. Using quantitative techniques of analysis, databases of normal and abnormal can be developed permitting more detailed analyses with time. The choice of measurement and analysis technique is, however, dependent on the situation/task to be assessed, the person, the facilities and equipment available.

A description of movement, whether quantitative or qualitative, requires use of standard reference terminology. Clinicians tend to use the anatomical position as the reference position when describing motion and then make use of the following directional terms:

Superior – towards the head
Inferior – away from the head
Anterior – the front of the body
Posterior – the back of the body
Medial – towards the midline of the body
Lateral – away from the midline of the body
Proximal – close to the centre of the body
Distal – away from the centre of the body

A limitation of this method is that it only describes the position of one body segment relative to another and it does not give information on where in space is the body segment. To be able to achieve this necessitates a spatial reference system. This reference system can either be relative or absolute; a relative system requires that all coordinates are reported relative to an anatomical co-ordinate system while an absolute system reports the coordinates to an external spatial reference system.

Movement from the anatomical position are then described using anatomical reference planes which divide the body into equal parts, lie at right angles to each other and intersect at the centre of gravity of the body (Fig. 3.1). These planes are as follows.

- The frontal plane – which is also referred to as the coronal or z axis, is a vertical plane that divides the body equally into front and back halves.
- The sagittal plane – which is also referred to as the antero-posterior plane or x axis, is a vertical plane that divides the body equally into left and right halves.
- The transverse plane – which is also referred to as the horizontal plane or y axis, is a horizontal plane that divides the body into equal upper and lower halves.

Further to the planes of motion are three axis of rotation which each lie perpendicular to the plane
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ment would involve a description of the transla-
tions (linear movements) and rotations the segment
makes around each axis of motion relative to a
fixed point in space. Descriptions of both linear and
angular motion include the magnitude or degree of
motion occurring, and its respective velocities and
accelerations.

Furthermore, motion can be considered to be
either static or dynamic. Static motion is where a
body is in a constant state of motion that is at rest
with no movement or moving with a constant
velocity, while dynamic motion is where motion is
occurring and creating accelerations or decelerations.
Sometimes a complex dynamic motion is
broken into phases or ‘snap shot’ moments of time
and this is usually referred to as quasi-static motion.

With all the tools to describe motion one needs
to consider how to assess it. There are many factors
that influence the choice of methodology when it
comes to assessing motion, including logistics such
as time, facilities, equipment available, costs as well
as the depth and repeatability of the assessment
required, which in turn depends upon how this
information is to be used and what level of preci-
sion, accuracy and repeatability is required.

Observed analysis

Traditionally in medical fields, there is a reliance on
qualitative description of motion. This often takes
the form of direct observations of the movement
that is occurring and forms the primary level of
assessment. Although quick, cheap and effective, it
places a huge overload on the skills of even the most
experienced clinicians due to the complexity of
joint movements in most functional tasks. It also
lacks robustness as different observers will focus on
different aspects of the movement and describe
them in different ways.

The use of video footage of movement is often
used to overcome these problems as it facilitates the
reviewing and freezing of the images. However, any
assessment remains descriptive and limited objec-
tive measures can be made. Software is increasingly
available to perform measures from video footage
or digital photographs, but the terms or frames of
reference need to be consistent when the images are
obtained and any information derived is limited to
each utilising different technologies. The most simple is the single axis potentiometer, which has a potentiometer at the junction of the two goniometer arms. Movement of the arms changes the resistance output of the potentiometer and this is calculated into an angular change. This approach relies on accurate identification of the joint’s centre of rotation. In the late 1980s flexible goniometers using strain gauge technology were developed. These are lightweight and easy to use, without the need to locate the joint’s centre of rotation. They are able to measure motion in real time, permitting assessments of not only range but also joint velocity and acceleration. Further developments have meant that they are now able to measure single and multi-axis motion and come in a variety of sizes and dimensions for use in the different regions of the body (Fig. 3.2). Although they are primarily limited to measuring local movement of a body system rather than whole body movement, they are capable of robust repeatable measures (Goodson et al., 2007).

Using similar principles, electromagnetic systems have been developed to measure changes in angle. These devices consist of an electromagnetic source and a number of sensors that move in the resultant magnetic field (Fig. 3.3). Movement changes the electromagnetic field between the sensor and source and these changes are translated into measurements of movement. These systems are robust and permit

**Kinematic assessment methods and measurement tools**

To take an assessment up the next level, some form of measurement needs to be made. This can be done with measurement tools that can essentially be divided into goniometers, imaging tools such as X-rays, and optical motion analysis system. Each tool will be considered in turn.

**Goniometers**

Routinely, many therapists use a simple hand-held goniometer consisting principally of a protractor with arms, which permits measurement of joint angles relative to an assumed centre of joint rotation. Used in its simplest form, it is cheap but in many ways clumsy, and it is difficult to obtain repeatable measures of a joint angle. It is also further limited to simple end-range measurements.

Engineering technology has expanded on this with a variety of electrogoniometers in existence,
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Care must also be taken with investigating the accuracy, precision, validity and repeatability of motion systems, since there is no such thing as the perfect measurement. When determining the accuracy of a piece of equipment one needs to see how well the system measures each motion component with respect to a gold or known standard. Precision on the other hand is how close together a group of measurements are to each other. This means that your instrument might be very precise but inaccurate, a common feature in many measurement tools. Reliability is the variability of the measurements obtained by one person (intra-operator) measuring the same parameter repeatedly, and one can also assess reliability between two different people measuring the same parameter (inter-operator). Validity, by contrast, is a measure of how representative your measurement is of the actual motion occurring, and this often requires comparison with some form of imaging measurement.

Imaging

Often considered the ‘gold standard’ method for kinematic assessment, imaging has frequently been used to assess range of motion in joints. The simplest systems used are those utilising two-dimensional X-ray images taken at the limits of joint range from which measures can be obtained (Dvorak et al., 1993; Frobin et al., 2002). Many researchers have attempted to overcome the two-dimensional nature of these measures by using stereo-radiography techniques (Pearce, 1985). Such imaging is limited particularly with respect to normative studies due to ionising radiation exposure. This problem and that of the static nature of the measurements has been overcome in part through the development of videofluoroscopy techniques (Shapeero et al., 1988; Sun et al., 2000) but this modality is associated with increased exposure to ionising radiation, thus limiting its widespread usage. It was hoped that the development of cine magnetic resonance imaging
emit infrared light, or by passive markers such as light reflecting devices. This allows the identification of bony landmarks and the estimation of the centre of rotation of a joint, etc. To be able to capture all markers during a movement task usually requires three to six cameras, thereby increasing the complexity of the analysis; and yet despite this, the movement of some markers has to be interpolated. Such systems are growing in number and availability. They are however, expensive, require detailed calibration, are not always portable and are time consuming to set up and use correctly. Like all dynamic motion analysis systems they produce vast quantities of data and it is wise to consider how one will analyse these prior to commencing measurement. Most research to date using optical motion systems has focused on gait analysis.

**How can kinematic assessments be used?**

There are many uses for kinematic assessment and the method used is often governed by the intended use of the information. For therapists these uses are
Assessment of muscles

An alternative way of looking at a movement or injury is to look at the functioning of the muscles. Usually there is a complex interaction of different muscles occurring to generate movement, and the intention here is not to explore this in detail but to give indication of approaches that could be used to look at this more closely.

One method of exploring muscle function is based on monitoring the electrical signal associated with the contraction of the muscle, namely the electromyogram or EMG. This signal gives an indication of voluntary muscular activity and it is known to increase as the tension in the muscle increases. The signal can be detected by using either surface electrodes or needles electrodes. Surface electrodes are less invasive but still only record from the motor units underlying that area. The signal can be influenced by cross-talk from underlying muscles and closely associated muscles and surface electrodes cannot assess deep muscle groups. Needle electrodes permit the analysis of activity in deeper muscles, but are invasive and often uncomfortable and isolate activity to that of the motor units in contact with the electrode. Furthermore EMG only permits an assessment of the activity that is occurring and not of the force being produced, thus limiting its usefulness. A detailed account of EMG is beyond the scope of this chapter but a number of texts and other publications are available on this technique.

For more complex and fast movement patterns, particularly gait or dynamic activities such as running, it is often difficult to observe the movements that are occurring. Using appropriate motion analysis techniques one can either focus on the region of interest or perform a more detailed analysis of the global movement. This permits comparisons between subjects or allows one to perform serial measurements which can provide information on alterations to movement patterns as a result of injury or as a result of coaching or therapy intervention. For instance, Holt et al. (2003) were able to identify patterns of movement of the spine in competitive rowers during rowing and relate these to the force generated at the handle of a rowing ergometer. This provided a model to investigate the implications of fatigue, ergometer type (Steer et al., 2006), level of experience (McGregor et al., 2004), and level of intensity (McGregor et al., 2005). The information obtained in real time provided biofeedback to coaches and athletes that led to changes in training and coaching. Performance was therefore enhanced as the athletes were more biomechanically efficient for the same physiological workload (McGregor et al., 2007). Through kinetic modelling this information could also be used to understand the loading that occurs at specific regions of the body during the motion which will provide insight into injury mechanisms. Such techniques can be applied to a variety of activities and sports and are also used in the animation and robotic industry.
ures can be applied to both concentric and eccentric work of the muscles. These systems also allow static or isometric assessment. Such systems were once very popular in the field of performance and rehabilitation but have fallen out of fashion and are currently used primarily in the research field. They can, however, provide useful information on joint symmetry and information on performance at different velocities which give indicators of explosive strength and power. A key issue with these systems is the poor levels of repeatability (Hupli et al., 1997; Hill et al., 2005b; Laheru et al., 2007). However, despite this they can still be used to provide important information on relative strength ratios, weaknesses and fatigue (Parkin et al., 2001; McGregor et al., 2004).

References


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SECTION 1: INTRODUCTION AND BACKGROUND

Cervical spine dysfunction is widely prevalent and forms a large percentage of the therapist’s caseload both in the public and private sectors. After back pain, neck pain is the most frequent musculoskeletal cause of consultation in primary care worldwide (Binder, 2007). It has been estimated that 67% of people in Western populations will have neck pain at some point in their lives (Cote et al., 1998; Vernon and Humphries, 2007) and that 300 per 100,000 inhabitants will experience whiplash-associated disorder (WAD; Holm et al., 2008). Bourghouts et al. (1999) estimated the total cost of neck pain in the Netherlands in 1996 to be €686 million, with about 1.4 million workdays lost. In an epidemiological study of professional rugby players, the incidence of injuries to the cervical and lumbar spine was approximately 11 injuries per 1000 match-playing hours and 4 per 1000 training hours (Fuller et al., 2007).

Acute neck pain can be caused by sudden application of external forces, such as an acceleration/deceleration mechanism, or internal forces, such as over-reaching, or by repetitive micro-trauma caused by consistent poor posture or repetitive strain situations. The natural history of acute neck pain is thought to involve no more than several days to a few weeks for significant recovery (Vernon and Humphries, 2007). The prognosis of chronic neck pain is more vague. Many people can be affected for up to 2 years’ post-injury. Caroll et al. (2008) report that 50–85% of people who have suffered neck pain do not experience complete resolution of their symptoms. Brison et al. (2000) reported that 44% of those involved in a rear-end collision complained of neck stiffness at 6 months after the incident. Chronic neck pain produces a high level of morbidity by affecting the activities of daily living and quality of life (Webb et al., 2003; Wolsko et al., 2003). As is the case with low back pain, cervical pain is being recognised as a ‘multifaceted phenomenon incorporating physical impairment, psychological distress and social interruption’ (Harvey and Cooper, 2005). For an in-depth classification of subgroups of neck pain the reader is referred to Guzman et al. (2008).

This section will first outline the common cervical spine pathologies seen by physiotherapists and discuss the impairments in the neuro-musculoskeletal system caused by these pathologies. The evidence supporting the use of exercise in the management of the impairments will then be presented. In Section 2, the concepts discussed in Section 1 will be practically applied in the clinical setting.
Cervical spine dysfunction and neuromuscular impairment

Most neck pain is ‘non-specific’, with symptoms having a postural or mechanical basis (Binder, 2007). However a number of conditions have been identified in the research:

- Spondylosis
- WAD
- Cervical postural syndromes
- Disc dysfunction
- Acute torticollis
- Acute nerve root pain
- Cervicogenic headache/dizziness
- Brachial plexus injury/‘stingers’.

Several approaches have been put forward for the treatment of these conditions; however, recently there has been greater emphasis on therapeutic exercise in the management of neck pain, regardless of pathology. This is due to an increasing amount of research concluding that the pattern of neuromuscular dysfunction is very similar regardless of the underlying cause (Falla et al., 2004; Jull et al., 2004a).

When discussing exercise and the cervical spine it is essential to have a thorough understanding of the relevant functional anatomy and the concept of stability dysfunction/uncontrolled movement. The reader should refer to Panjabi et al. (1998) and Comerford et al. (2008) for further clarification of these areas.

Efficacy of exercise for cervical dysfunction

Systematic reviews have concluded that exercise is of benefit to individuals with mechanical neck pain or WADs (Sarig-Bahat, 2003; Kay et al., 2005; Hurwitz et al., 2008).

Aerobic exercise

There is very little evidence in the literature to support the use of aerobic exercise in the management of neck pain. In a study examining the effect of exercises such as stepping and dynamic exercises of the trunk and extremities in women with neck pain, Takala et al. (1994) found no significant difference in neck pain between the exercise and control groups. However, the general concept that cardiovascular exercise has a hypoalgesic effect can be applied to patients with neck pain.

Muscle strength and endurance training

The overall impression from the recent substantial evidence for exercise and neck pain is that stability dysfunction and functional control should be addressed early on with low load-specific exercises. Once an individual is able to control their area of uncontrolled movement through range and function, general strengthening exercises can be prescribed.

The needs of each individual must be addressed and rehabilitation tailored appropriately. If the patient is an elite athlete, end-stage rehabilitation must be aggressive to return them to their original condition. Failure to do this could result in treatment failure and the patient ‘breaking down’.

The research on low load-specific muscle re-education has demonstrated the following pertinent findings:

- Isometric function of the cranio-cervical flexors can be improved with deep flexor exercises with a resultant decrease in pain (O’Leary et al., 2007).
- Manipulative therapy combined with exercise therapy can reduce the symptoms of cervical headache and the effects are maintained for at least 12 months (Jull et al., 2002).
- Patients with neck pain show a reduced ability to maintain an upright posture. An exercise programme aimed at strengthening the cranio-cervical flexors showed an increased ability to maintain an upright posture (Falla et al., 2007).

The research for high load resistance training has demonstrated the following mixed results:

- Patients with chronic neck pain can benefit from a 6-week neck-strengthening programme including low load and high load resistance training. Patients completing the programme had a significant improvement in disability, pain and isometric neck muscle strength in different directions (Chiu et al., 2004).
A long-term Finnish study by Ylinen et al. (2003) demonstrated that both strength and endurance training for 12 months are effective methods for decreasing pain and disability in women with chronic neck pain. Stretching and aerobic exercise alone proved to be a much less effective form of training than strength training. The improvements were maintained at 3-year follow-up assessments and the results indicated that exercise may not need to be performed regularly for the remainder of the participants’ lives (Ylinen et al., 2007).

Studies by Bronfort et al. (2004), Highland et al. (1992), and Jordan et al. (1998) have suggested that there is a reduction in pain and improvement in function with high load-resistance training. Viljanen et al. (2003) found that a programme of dynamic muscle training and relaxation was no better than ordinary activity for women office workers. A combination of isometric exercise, postural correction and use of a neck support pillow has been shown to be effective in the management of chronic neck pain. Isometric exercise in isolation has no effect (Helewa et al., 2007).

A systematic review by Sarig-Bahat (2003) concluded that there is strong evidence supporting the use of dynamic-resisted exercises but that they are no more effective than endurance training, body awareness and passive physiotherapy. Kay et al. (2005) concluded that there is strong evidence of benefit favouring a multi-modal care approach of exercise combined with mobilisations or manipulation for mechanical neck pain. From a best evidence synthesis of the literature from 1980 to 2006 Hurwitz et al. (2008) conclude that for WAD, educational videos, mobilisation and exercise appear to be the most effective form of management.

To summarise, there is some indication that both low load training and high load strength training may be beneficial in the management of neck pain.

**Range of movement and flexibility exercises**

Active range of motion exercises consist of any exercises that include active movement without resistance. A systematic review by Sarig-Bahat (2003) found strong evidence to support the effectiveness of early active mobilising exercises in acute whiplash patients based on the findings of McKinney (1989a), Rosenfeld et al. (2000) and Soderlund et al. (2000).

**Sensorimotor and proprioceptive exercise**

Rehabilitation exercises to improve sensorimotor deficits aim to restore co-ordinated movement or cervicocephalic kinaesthesia using visual training techniques. Systematic studies have demonstrated that a programme of eye fixation/proprioception exercises included in a complete rehabilitation programme is associated with strong to moderate evidence for reducing pain and improving function in mechanical neck pain and whiplash, with or without headache (Sarig-Bahat, 2003; Kay et al., 2005). Joint positioning can be improved with home exercises of eye, head and arm co-ordination (Humphreys and Irgens, 2002). A comparative study of conventional proprioceptive training and cranio-cervical flexion training found that both regimens were effective in retraining joint position sense, implying that either programme can improve sensorimotor function in patients with neck pain (Jull et al., 2007b).

**SECTION 2: PRACTICAL USE OF EXERCISE**

**Aerobic exercise**

When prescribing aerobic exercise for individuals with neck pain, it is important to consider the following points:

- **Posture.** If a patient presents with symptoms related to a poking chin posture, with uncontrolled movement into upper cervical extension, he/she should be advised to avoid activities such as breaststroke, as this may aggravate the condition. Rowing or cycling may have a similar effect.

- **Overhead movement.** If it has been noted that a patient has uncontrolled movement into
example, a patient presents with central low cervical spine pain. She reports that reading aggravates her pain. On assessment, the patient has stiffness into flexion at the mid-cervical spine but to compensate she moves into excess flexion at the low cervical spine (Figs 4.2a and 4.2b). On analysis, reading aggravates this patient’s symptoms because she is looking down while reading and she has uncontrolled range of movement into lower cervical flexion, which puts the soft tissues and cervical joints under stress. To control the symptoms, the therapist must instruct the patient to try to stabilise the lower cervical spine while moving into flexion (Fig. 4.2c). This can be done by explaining to the patient that you want her to move from higher up in the cervical spine, like a ‘nodding’ movement while keeping the lower neck still. This is not a ‘normal movement’, but the aim of the exercise is to teach the patient how to control the uncontrolled movement into flexion. The therapist can give auditory, visual and manual feedback to help the patient achieve this. Instruct the patient to move through only that much range as the restriction allows or as far as the ‘give’ is dynamically controlled. Scapula control is very important and patients need to be made aware of correct scapula positioning during the exercise (Mottram, 2003). The exercise should not reproduce the patients’ symptoms. This is the first exercise that should be taught to the patient, as she can use it immediately to help her to control her symptoms. It needs to be repeated slowly, 15–20 repetitions, two to three

**Impact.** If patients have a shear or area of ‘give’, high-impact exercise such as aerobics or running may have a detrimental effect.

A static bike work-out, using a large mirror for visual feedback, may be the best form of aerobic exercise, as it is low impact and the patient can control neutral head position (Fig. 4.1). Walking has also been recommended (Soderlund et al., 2000).

### Endurance and strength training

#### Endurance training

Comerford and Mottram (2007) take the following four-point approach to rehabilitation.

(1) Teach the patient to control movement in the direction of symptom provocation, i.e. control the ‘give’ and move the restriction

This strategy is the key to controlling symptoms, as it helps to unload the tissues under stress. For
times per day. The patient should perform these exercises until the movement starts to feel familiar and it is easy to do. Start with the patient sitting against the wall, then progress to sitting away from the wall, standing, leaning forwards over the bed and then leaning back over the bed with their arms supporting them. Exercises can be progressed by asking the patient to repeat the exercises on an unstable surface such as a Swiss ball or Sit-Fit™.

The key is to control the excess movement from one or occasionally two areas. On observing the patient’s movement patterns you may need to control:

- A ‘give’ into flexion in the upper cervical spine, by positioning the upper cervical spine in neutral and moving the lower cervical spine from extension to flexion and back again. The low cervical spine is moved by tilting the head forward from the base of the neck. The exercise should be repeated slowly for 15–20 repetitions, two to three times a day.
- A ‘give’ into extension in the upper cervical spine, by positioning the upper cervical spine in neutral, maintaining this neutral position and moving the low cervical spine through range from flexion to extension. Instruct the patient to perform a backward head tilt. Extension should occur at the low cervical spine. The exercise should be repeated for 15–20 repetitions, two to three times a day.
- A ‘translation’ into extension in the mid-cervical spine, by positioning the upper and mid cervical spine in neutral, maintaining this neutral position and moving through range from flexion to extension. Extension should occur at the low cervical spine. Repeat the exercise but instruct the patient to extend from the upper cervical spine by performing a chin lift. Repeat the exercise for 15–20 repetitions, two to three times per day.
- ‘Chin poke’, or lateral flexion during rotation, by positioning the cervical spine and scapula in neutral and rotating the head through the available range without the substitution strategies. The patient should rotate through the whole cervical spine. Repeat for 15–20 repetitions, two to three times per day.
- ‘Chin poke’ or rotation into side flexion, by positioning the cervical spine and scapula in neutral and side bending the head through the available range without the substitution strategies. The patient should side bend through the whole cervical spine. Repeat for 15–20 repetitions, two to three times per day.
- A ‘give’ into side flexion at the lower cervical spine, by positioning the cervical spine and scapula in neutral and tilting the head through

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**Figure 4.2** (a) Static posture. (b) Patient demonstrating lower cervical ‘give’ into flexion. Note how the mid-cervical spine remains in lordosis. (c) Controlling the ‘give’ and moving the restriction.
the available range of upper cervical side bending. Instruct the patient to tilt the head at the base of the skull. The patient should be sitting or standing, keeping the occiput against the wall. Repeat 15–20 for repetitions, two to three times per day.

- A ‘give’ into side flexion at the upper cervical spine, by positioning the cervical spine and scapula in neutral, tilting the head through the available range of lower cervical side bending by tilting the head at the base of the neck. The patient should be sitting or standing, keeping the occiput against the wall. Repeat 15–20 for repetitions, two to three times per day.

It is important that the symptoms experienced by the patient are related to the site of ‘give’. A patient may present with a combination of these dysfunctions but the clinician must decide which dysfunction is most relevant to the patient’s symptoms. It may be necessary to use manual therapy for articular or myofascial restriction in combination with the above movement for re-education.

(2) Teach the patient to control translation in a neutral joint position

This exercise is for the local stability muscles and aims to regain normal muscle stiffness in order to control translation. These exercises are low load and aim to stimulate the anterior and posterior local stabilisers in neutral. Several tests must be completed to assess the function of these local stabilisers and the rehabilitation of these muscles then uses the test positions.

(a) Testing deep flexors of the cervical spine

The cranio-cervical flexion test (Fig. 4.3) (Comerford and Mottram, 2007, adapted from the work by Jull et al., 2004b, cited in Boyling et al., 2004) assesses the deep neck flexors, i.e. rectus capitis anterior and lateralis ± longus capitis and deep multifidus.

1. Position the patient in supine with the cervical spine, temporomandibular joints and scapulae in a neutral position.
2. Place a small rolled-up towel under the top of the back of the head to support the cervical spine in neutral.
3. Place the pressure biofeedback under the cervical lordosis, folded and clipped.
4. Inflate the pressure biofeedback to a base pressure of 20mmHg.

Instruct the patient to slide their head up the towel using a nodding action until the pressure increases from 20mmHg to 22mmHg; then ask the patient to hold for 5 seconds. Relax back to 20mmHg, then increase the pressure to 24mmHg using the same action and hold for 5 seconds. Then relax back to 20mmHg and then increase the pressure from 20mmHg to 26mmHg and hold again for 5 seconds. This test should be repeated twice without substitution or fatigue. The patient must achieve cranio-cervical flexion during the test. Substitution strategies may include loss of neutral position and palpable or visible contraction of the sternomastoid, scalenes or hyoids (Falla et al., 2003).

Rehabilitation of the deep flexors: If the patient does not have ideal recruitment, i.e. cannot sustain the holds or uses substitution strategies, the deep flexors must be retrained. The pressure that can be achieved using the biofeedback device, without substitution, and cranio-cervical flexion noted. Ask the patient to hold this pressure for 10 seconds and repeat 10 times. As the patient improves the ability to hold, the incremental pressures will become easier. There must be no co-contraction rigidity – this is manifested by dominance of the superficial global mobility muscles holding the head rigid. Once the patient has learnt the correct movement with the biofeedback, this exercise should start in sitting and progress to standing. To progress rehabilitation, the anterior stabilisers need to be functionally loaded, by positioning the patient in supine
The Cervical Spine

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(4) Substitution strategies include active upper cervical extension, movement such as the head pushing down, indicating scalene and co-contraction rigidity, or contraction of the sternocleidomastoid.

Rehabilitation of the deep extensors: If the patient does not have ideal recruitment, the deep suboccipital extensors must be retrained. The patient holds their head themselves with the index and middle fingers along the occiput. They slowly and gently try to move the head passively into upper cervical flexion with their hands, while simultaneously trying to resist this motion. The resistance should be against very light pressure. Instruct the patient to hold for 10 seconds and repeat for 10 repetitions. This can be performed in different postures. The patient should beware of aggravating symptoms, particularly if there is neural sensitivity relating to headaches or dural sensitivity. To progress rehabilitation, load the posterior stabilisers functionally, by positioning the patient in prone and neutral. The operator should hold the patient’s head with the forehead resting on the operator’s hand. Instruct the patient to keep the head stationary as the operator removes the supporting hand. The patient should be able to hold the position for 15 seconds for 2 repetitions without fatigue or substitution strategies. For a home programme, patients should sit at a table with neutral alignment and keep their head in neutral for about 15 seconds for two repetitions without any give into upper cervical flexion, substitution or fatigue. There should be no movement.

(3) Teach the patient to actively control the full available range of movement

This involves the rehabilitation of the global muscle system. These muscles must control full passive inner range and any hypermobile outer range. The ability to control rotation is a particularly important role of these muscles. For stability control, the eccentric role of these muscles is more important than their concentric role. To rate these muscles, three factors must be considered:

and having their head resting in neutral in the physiotherapist’s hand. The patient is instructed to keep the head stationary as the physiotherapist removes the supporting hand. On testing the patient should be able to support their head in neutral for about 15 seconds for two repetitions without fatigue or substitution strategies. The superficial mobility muscles will be active but should not dominate. Abnormal substitution strategies include chin poke and low cervical flexion. For a home programme, patients should start this exercise in supported incline sitting about 10–15° from the vertical (e.g. against an ironing board) and just lifting their occiput clear without substitution strategies and holding for 10 × 10 seconds. The angle of supported sitting can then be increased to 45°. The exercise can thereafter be done in different postures and progressed again with the use of unstable surfaces.

(b) Testing the deep extensors of the cervical spine

For the deep suboccipital extensor test (Fig. 4.4; adapted from Kennedy, 1998):

(1) Position the patient in supine with the cervical spine and scapulae in neutral. Keeping the jaw relaxed will help to keep the temporomandibular joints in neutral.

(2) Support the patient’s occiput with the fingertips.

(3) Instruct the patient to keep the head in neutral as the therapist attempts to gently move the head into upper cervical flexion (using a suboccipital distraction action). On testing the patient should be able to maintain this position isometrically against this light resistance for 15 seconds for two repetitions without any give into upper cervical flexion, substitution or fatigue. There should be no movement.

Figure 4.4 Test for deep extensor function.
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Does the inner range shortening of the muscle = the passive range of movement of the joint? For stability control, if muscle active = joint passive, can the muscle support the neck in this position? If the muscle can support the neck in its inner range, can it eccentrically control the lowering through the range of motion, in a smooth manner, without the loss of trunk and scapular stability?

Exercises for the rehabilitation of the global mobility muscles must start in basic postures and progress to functional positions such as sitting at a desk, or made sport-specific for the athletic population.

Patients presenting with upper or mid-cervical extension and rotation stability dysfunction: Rehabilitation of the anterior global stabiliser muscles (longus colli, oblique fibres and longus capitis) is a priority for patients with upper or mid-cervical extension and rotational stability dysfunction, as these muscles eccentrically control extension.

Testing the anterior global stabiliser muscles in mid-inner range:

- Position the patient in supine and neutral.
- With the back of the subjects head resting in neutral on the operators hand, instruct the subject to lift their head forward through range into full flexion and rotation (chin towards the sternum and at least half range rotation). At this point the operator passively supports the head and assesses if there is any more range available. If the operator can see more passive range than the patient was able to achieve actively, the patient has failed the test. If no more range can be seen from the passive assessment, instruct the patient to hold that inner range position for 15 seconds and then lower the head back to neutral. This should be completed twice. The patient should be able to hold the head and lower down to neutral smoothly with no substitution strategies.
- Substitution strategies may include chin poke due to dominant sternomastoid, and shoulder girdle elevation/protraction due to dominant scalenes. If the plane of the face stays horizontal as the head lifts forwards, a combination of sternomastoid and scalenes are dominant. If the hyoids are dominant the patient will not be able to talk normally. Other strategies are the head pushing down or sideways, or rotation of the shoulder girdle or trunk.

Rehabilitating the anterior global stability muscles in mid-inner range: Reproduce the movement, but only to the range that is controlled. Initially, train without rotation i.e. hold in midline. Once 10 × 10 seconds holds in full range have been achieved, progress onto holds in flexion and rotation. If control is very poor this exercise can be started in incline sitting and progressed into supine.

Testing the anterior global stability muscles in outer range:

1. Position the patient in sitting tall and supported with a neutral spine, with the mouth closed and a neutral bite (jaw not clenched).
2. Instruct the patient to flex the upper cervical spine and then independently extend the lower cervical spine. Maintaining the low cervical spine in extension slowly extend the upper cervical spine by allowing the chin to lift towards the ceiling (initially only quarter range) and return to neutral, leading with active upper cervical flexion. Make sure the chin does not protrude; and the occiput must not lift vertically. The chin must move down and inwards and the occiput must move up. If control is good at quarter range, progress to half and then three-quarters, and finally full range upper cervical extension.

Rehabilitating the anterior global stability muscles in the outer range: Reproduce the movement, but only in the range that is controlled. Initially hold for 10 × 10 seconds in the midline and progress to adding rotation. If control is poor, this exercise can be started in incline sitting. It is important to regain inner range control before training outer range to prevent aggravating the patient’s symptoms.

Patients presenting with low cervical flexion and rotation stability dysfunction: Rehabilitation of the posterior low-cervical global stabiliser muscles (multifidus, spinalis, and semispinalis cervicus) is a priority for low cervical flexion and rotation stability dysfunction.
The Cervical Spine

This will be covered briefly in exercises for range of motion.

Strength training

Once the patient has been able to correct the stability dysfunction, overload training can be started. It is important to include functional postures as soon as possible, as this helps to retrain the sensorimotor system. Exercises can be combined with scapular and lumbar spine stability work. It is essential that rehabilitation be taken to its end stage. Functional activities and sporting activities rely on the successful combination of basic stability and strength of the entire body, moving with different forces, at various speeds. Functional training is 'training that conditions the body consistent with its integrated movement and/or use' (Santana, 2000).

Thera-Band®, pulleys and bungees can provide resistance, however, head harnesses and free weights are useful with elite athletes such as professional rugby players. Swiss balls and 'sit-fits' are useful for isometric exercises. A strength training programme should include exercises for the shoulders, upper back and chest. Ylinen et al. (2003) suggest dumbbell shrugs, presses, curls, bent over rows, flies or pullovers, completing three sets of 20 repetitions. The following text includes examples of cervical spine resistance exercises for patients who have progressed from stability training. Sensorimotor exercises need to be added to complete the programme. It is assumed that the patient has warmed up (including self-resisted isometric cervical exercises and gentle cervical self stretches).

(1) **Isometric exercises using the sit-fit**: Flexion, extension, side flexion (left and right). Stand 2–3 foot lengths from the wall. Place the sit-fit against wall (Fig. 4.5a). Keeping the cervical spine in neutral, the patient should place their head on the sit-fit and lean into the wall. Hold for 20 seconds. To progress this exercise, move the feet further away from the wall, and to progress again, the patient could stand on one leg or add in arm movement with weights. This exercise can also be completed with a Swiss ball on the floor (Fig. 4.5b).

(2) **Concentric/eccentric exercises with Thera-Band**: Flexion; flexion plus oblique
right and left; extension; extension plus oblique right and left; side flexion.

These exercises can be completed in standing or sitting. Ensure that the patient can complete the movements without the dysfunction they originally presented with. The eccentric movement back into neutral must be slow and controlled. Ten repetitions × 2 sets in each direction should be completed.

Elite athletes such as professional rugby players may need more resistance, such as the 1-minute circuit exercises shown in Figure 4.7. It is important that these exercises are done under the supervision of the clinician, with no pain and only after successful progression of resistance exercises. These exercises could also be used as part of a prehabilitation session (Steele, 2007).

Range of movement/ flexibility exercises

General sustained self-stretches for the cervical spine have been taught for many years and are well known. Holding time for the stretches range from
Figure 4.7 Resisted cervical exercises for elite rugby players (forward positions). (a) Flexion hold plus shoulder press. (b) Extension hold plus one arm fly. (c) Isometric flexion with trunk flexion. (d) Extension hold plus deep squat.
Figure 4.7 (Continued) (e) Lateral lunge plus side flexion hold. (f) Isometric extension plus bilateral fly. (g) Deep squat starting position. (h) Head bridge.
The Cervical Spine

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pain related to low cervical flexion, upper cervical extension and rotation stability dysfunction. To assess whether the scalenes are overactive, position the patient in supine with the occiput on the bed. The therapist’s hand supports the cervical lordosis as seen in Figure 4.9b and the other hand stabilises the first rib. The patient’s head is then positioned to bias the particular scalene:

- Anterior scalene – half range rotation towards the stabilised rib and then 15° side bend away
- Middle scalene – no rotation and 15–20° side bend away
- Posterior scalene – one third rotation away and then 20–25° cervical side bend away.

To stretch the scalene, the patient actively repositions the test movement until either muscle resistance stops the movement or stability is lost. The physiotherapist then passively supports this position. The subject is asked to exhale and the stretch is held for 20–30 seconds and repeated three to five times (Fig. 4.9b).

The levator scapulae often appear overactive in patients presenting with cervical extension and rotation stability dysfunction. To test if the levator scapulae are overactive, position the patient in supine with the scapulae midway between elevation and depression, and the head forward in flexion to resistance. Rotate and side bend the head away until either muscle resistance stops or muscle tension causes a loss of proximal shoulder position. Ideally with the operator providing head fixation, there should be no further increase in neck range into side bend, when the muscle is unloaded by hitching the shoulder. The patient should be able to reproduce passive range without substitution or loss of proximal control. To stretch the levator scapulae, actively reproduce the test movement and passively support this position. Actively retract and depress the scapula and hold this stretch for 20–30 seconds, then repeat the stretch three to five times. The stretch should be felt mainly at the neck angle rather than the upper cervical spine (Fig. 4.9c).

Sensorimotor and proprioceptive rehabilitation

Treleaven (2008) regards the inclusion of rehabilitation of the sensorimotor system in cervical spine disorders to be as important as lower limb proprioception retraining following an ankle or knee injury.
Motor control

It has been demonstrated that individuals with neck pain have altered motor control. Clinical assessment and rehabilitation of the cervical sensorimotor system has three components (Whiplash and Neck Pain Research Unit, Sterling, 2005):

- Cervical joint position sense
- Standing balance
- Oculomotor function.

Cervical joint position sense (Whiplash and Neck Pain Research Unit, Sterling, 2005)

A small laser pointer can be mounted onto a headband. The patient is seated 90 cm away from the wall and asked to look straight ahead. This point is marked on the wall. The patient is then blindfolded and instructed to return to this point as accurately as possible following either left and right rotation or extension. The patient indicates verbally when they think they have returned to this position.

Figure 4.9 (a) Ligamentum nuchae stretch. (b) Scalene stretch. (c) Levator scapulae stretch.
Exercises to improve standing balance are based on the tests and can be integrated with functional activities.

Oculomotor function (Sterling, 2005)

- **Eye follow** – the patient keeps the head still and follows a moving target with the eyes; from side to side, up and down, progressing to an H pattern (Fig. 4.10). The trunk is then rotated (up to 45° neck torsion) or to a point just short of pain. Again the head is kept still, and the test of following a moving target with the eyes is repeated (rotating the trunk biases the cervical receptors compared with the vestibular receptors). Keeping the head still, the patient follows saccadic movements at randomised eye positions. The starting position, speed and focus point can be altered accordingly. The therapist should monitor the patient’s ability to follow the target. Jerky eye movements, dizziness, unsteadiness or nausea are noted. Exercises to improve eye follow function are based on the results of the tests described above.
- **Gaze stability** – ask the patient to keep the eyes focused on a point while moving the head.

Alternative test for cervicohead repositioning accuracy (Comerford and Mottram, 2007): The patient is positioned in four-point kneeling. The head and neck are passively positioned in neutral alignment, and then the patient actively moves (turning side to side, looking up/down) and attempts to return to the neutral position. This is performed twice and rated with the following scale:

- **Good**: the patient accurately and confidently returns to the neutral position both times without making adjustments.
- **Average**: The patient returns to neutral position with reasonable accuracy but lacks the confidence – may need to make several adjusting movements or is ‘not quite sure’.
- **Poor**: The patient cannot return to the neutral position and is often very unsure of the correct position.

Standing balance (Sterling, 2005)

Clinical examination of standing balance involves progressively challenging the postural control system by altering foot position, visual input and the supporting surface. Each test should be assessed for 30 seconds and sway or rigidity noted. The progression can be as follows:

- Comfortable → narrow stance
- Firm → soft surface (e.g. 10cm dense foam)
- Eyes open → eyes closed
- Double leg → single leg.

**Figure 4.10** Eye follow exercise.
actively or passively in all directions. The therapist should note any reproduction in symptoms, such as inability to focus or dizziness. Progress to asking the patient to close their eyes, move their head and then open their eyes again to check that the eyes have maintained a stable gaze on the target. This tests imaginary gaze. To improve gaze stability, start with exercises in supine looking at the ceiling, and progress to exercises in sitting or standing. To progress this exercise, peripheral vision can be restricted by using a pair of swimming goggles that have been blackened out except for a small area in the centre of each eye.

Eye/head co-ordination:

(1) Rotate the eyes and head to the same side left and right.

(2) The eyes move first to a target. The patient then turns the head ensuring the eyes are kept focus on the target.

(3) The eyes move first and then the head to look between two targets placed either horizontally or vertically, maintaining focus between the two points.

(4) The eyes and head are rotated to the opposite side, left and right.

Exercises to improve eye follow are based on the tests which assess ability to follow a moving target (see above) (Sterling, 2005).

In conclusion, current literature supports the use of exercise in the management of mechanical neck pain, whiplash and cervicogenic headache. When designing a therapeutic exercise programme for individuals with neck pain, it is essential that all relevant components are included. Specific functional stability work is essential and is the key to symptom relief and strength training that prepares the body for function, return to work or sport. Sensorimotor training can be started the day the patient presents to the clinician and is an essential part of rehabilitation.

SECTION 3: CASE STUDIES AND STUDENT QUESTIONS

Case study 1

A 45-year-old right-handed painter presents with central neck pain and mild dizziness, following a rear-end collision 2 weeks ago. He returned to work but found that this aggravated the problem and he has had to take sick leave. On examination the patient has a head-forward-hinge posture, with the hinge at the mid-cervical spine.

Movements: flexion – no immediate pain but the lower cervical spine is relatively flexible into flexion compared to the upper cervical spine; extension – pain at half range over crease at the mid-cervical spine, where there is an area of relative flexibility into extension and low cervical extension is restricted. Right rotation is painful on the right and asymmetrical, with an increase in relative flexibility at the mid-cervical spine. Left rotation causes a mild pulling sensation. On palpation, ↓ C 4/5 is painful (soft end-feel) and CS/6/7 is stiff, with a hard end-feel. PPIVMs (passive physiological intervertebral movements) reveal that C4/5 is hypermobile into extension and rotation and hypomobile into flexion with C5/6/7 stiff into extension. Cervical repositioning is assessed as being poor, with mild defects in standing balance and gaze stability.

Hypothesis: This patient has low cervical flexion give and a mid-cervical extension give.

Exercise programme

Treatment 1

(1) Control site and direction of movement. Teach the patient to control extension at the mid-cervical spine and move into extension from the low cervical spine. Position the patient in sitting with the upper and mid-cervical spine in neutral. Ask the patient to move through range from flexion to extension, maintaining neutral at the upper and mid-cervical spine. Use a mirror and your hands to guide the patient so that movement occurs at the lower cervical spine. Teach the patient rotation control in a similar manner. Check that the
Case study 1—cont’d

patient can do the exercises correctly without feedback. The patient needs to practise these exercises for 15–20 repetitions two to three times per day and then built to 1–2 minutes until it feels natural and familiar.

(2) Teach scapular stability exercises (Mottram, 2003).

(3) Hold a pen in front of the patient and ask him to move his head slowly into small ranges of flexion, left and right rotation and left and right side flexion, while keeping the gaze set on the pen. This should be repeated three times, two to three times per day.

(4) Ask the patient to try to balance on one leg for 30 seconds and repeat twice on each leg.

(5) He should aim for a 30-minute walk every day.

Treatment 2

(1) Teach the patient to control the uncontrolled hypermobility at C4/5. (a) Using the pressure biofeedback, teach the patient to recruit the deep flexors in neutral and hold for 10 seconds for 10 repetitions. Teach him to do this as a home exercise using the wall as feedback. (b) Teach the patient to recruit the deep suboccipital extensors and hold for 10 seconds for 10 repetitions. Once the patient can do this correctly, teach the home exercise using his own hands to give resistance.

(2) Progress exercise 1 from day 1. Ask the patient to repeat this exercise in standing and progress with the right upper limb in the functional position he uses for work.

(3) Teach scapula stability exercises holding a paintbrush.

(4) Progress the balance exercises to closed eyes.

(5) Progress the gaze stability exercises by asking the patient to close their eyes, move their head and then open their eyes to check the eyes have maintained a stable gaze on the target.

(6) Continue with walking.

Treatment 3

(1) Teach the patient to actively control the full available range of movement of extension and rotation, by aiming to rehabilitate the anterior stabilisers in inner and outer range.

(a) In incline sitting ask the patient to flex the neck as far as possible without substitution strategies. Hold 10 × 10 seconds in the midline. Progress the exercise to supine and then flexion and rotation holds. Once the patient has trained the anterior stabilisers in inner range, progress to outer range by instructing the patient to flex the upper cervical spine and then independently extend the lower cervical spine. This will help to unload the structures under strain due to the uncontrolled movement at the mid-cervical spine. Add in functional arm movements as able.

(2) Re-educate the posterior stabilisers by positioning the patient in prone, resting on the elbows with the head hanging in flexion. The patient should maintain the upper cervical spine in neutral and lift the head with independent extension and rotation of the low cervical spine. Hold for 10 × 10 seconds.

(3) Teach the patient to increase the extensibility of the right scalenes using the left hand for resistance and following the stretch procedure as discussed.

(4) Progress the balance exercises to wobble board work.

(5) Progress the gaze stability exercise, using the goggles to restrict peripheral vision.

Treatment 4

(1) Progress exercise 1 in treatment 3 by using Thera-Band® to resist extension and flexion.

(2) Progress into functional loading activities. For example, control cervical extension and maintain good scapulothoracic patterning, while elevating the arm through scaption with a 1 kg weight. Use different speeds and different angles. Another example is an exercise to replicate lifting a ladder. Start with a 65 cm Swiss ball and ask the patient to control the cervical extension as he picks up the ball from a chair and lifts it to a higher surface while looking up. Progress the exercise to lifting a box.

(3) Progress the gaze stability exercises into functional applications.

(4) Ask the patient to continue with walking or add in static bike cycling.
Case study 2

A 31-year-old front row rugby player presents to you after having sustained a ‘stinger injury’ during a tackle in a game last week. There are no residual symptoms and he has no neck pain. Craniovertebral instability tests and vertebrobasilar insufficiency (VBI) tests are clear. This is the second stinger injury in 2 months. A magnetic resonance (MR) image shows mild spinal stenosis.

Management

The patient has been doing an exercise programme that includes:

1. Exercises to improve a mild flexion give at the lower cervical spine
2. Neural dynamic mobilisations for the median nerve
3. Stretches for the anterior scalenes
4. Stability exercises for the glenohumeral joint and thoracic spine, including rotator cuff exercises in functional positions
5. Proprioceptive training for the cervical spine, thoracic spine and glenohumeral joint
6. Tackle technique training with the coach.

The following is an example of an exercise programme for cervical strengthening. (To be completed 2–3× week as part of the rehabilitation programme. Full exercise programme must include progressions of the exercises just described.)

Warm-up

- 10 minutes on a bike.
- Manual isometric holds 10 seconds, flexion, extension, left and right lateral flexion and left and right rotation.
- Cervical self-stretches all ranges × 5.
- Deep cervical flexor holds 10 × 10 seconds.
- Deep suboccipital extensor holds 10 × 10 seconds.
- Upper limb mobilisations for the median nerve (ULNT1).

Circuit – 1 minute per exercise with 30 seconds rest. Circuit to be completed twice.

1. Flexion/extension/left side flexion/right side flexion holds with sit-fit against the wall.
2. Extension hold plus deep squat.
3. Flexion hold plus deep squat.
4. Lateral lunge plus side flexion hold.
5. Arm steps plus extension hold – using a weighted neck harness; position the patient in a press-up position directly in front of wall bars. Instruct the individual to walk up the wall bars with their hands. The cervical spine must be kept in neutral.
6. Three-way front lunge – position the individual in standing about 1.2m (4ft) from wall bars with their back to the wall. Attach a head strap over the forehead and attach the strap to the wall bars with Thera-Band® or bungee. Instruct the individual to step into a running position, i.e. step standing with running arm position. The cervical spine must remain in neutral.
7. Trunk roll-out – start in a supine position with the thoracic spine resting on a Swiss ball. Maintain cervical spine and trunk in neutral while rolling over the ball by flexing and extending the knees. The end position is when the ball reaches the occiput.

Warm down – relaxation drill in supine plus visualisation of correct tackling technique.

Case study 3

A 60-year-old medical secretary presents with insidious-onset neck pain. She has a 2-year history of mild, intermittent headache over the right temporal region associated with mild right neck ache. Her job involves a significant amount of reading and she feels this may be aggravating her headaches. Her neck ache increases as the day goes on. X-rays show that she has a loss of disc height at C3, 4 and 5 cervical discs with associated degeneration. Her doctor has diagnosed cervical spond-
Case study 3—cont’d

Ylosis and feels that the headache may be related to her neck. He has ruled out any other medical condition. On assessment she has a chin poke posture.

Movements: Flexion three-quarters range (resistance > pain) increase in relative flexibility of the lower cervical spine into flexion; extension half range (onset of pain = onset of resistance): left rotation/side flexion half range (resistance > pain), right rotation/side flexion half range (resistance = pain). On palpation C1/2 is stiff and painful, with unilateral right postero-anterior accessory movement being very sore early in range over C2/3. During the cranio-cervical flexion test the patient is unable to sustain target pressure levels of 24 mmHg for a period of 5 seconds without the chin poking out and the right sternocleidomastoid becoming significantly overactive. Cervical joint position sense and balance is assessed as being ‘poor’. The patient has been attending physiotherapy for 3 weeks and has found that manual therapy for the upper cervical spine has helped, but has not resolved the problem. In addition her home programme has included static bike work, basic flexion control exercises, deep flexor and deep extensor exercises, anterior stabiliser exercises in inner range, cervical repositioning exercises and various oculomotor exercises.

Hypothesis: this woman has a low cervical flexion give, which is improving but has not yet completed mid-stage rehabilitation into function.

Management

Treatment 1

(1) Position the patient in sitting with a light Thera-Band™ around the head to provide resistance into extension. This exercise aims to improve eccentric control of cervical flexion. Instruct the patient to maintain the upper cervical spine in neutral, move the low cervical spine slowly through range from flexion to extension and back into flexion to do a backward head tilt. Make sure the patient extends through the low cervical spine. Progress this exercise to sitting on a Swiss ball.

(2) Position the patient in her working posture at a desk with a book. Complete deep flexor exercises 10 × 10 seconds in this position. Progress this exercise either by sitting on a Swiss ball or Sit-Fit™.

(3) With the patient in prone check that the patient is able to recruit the deep extensors. If she is able to do this progress the exercise to lying prone on a firm bed with the head overhanging the edge of the bed. Ask the patient to position the cervical spine in neutral, while recruiting the deep extensors. Hold for 10 × 10 seconds and try to increase the holding time.

(4) Once the patient has been training inner range anterior stabilisers and is able to hold in end-range flexion and rotation without substitution strategies, progress to outer-range anterior stabiliser exercises. Position the patient in sitting with a neutral spine. Maintain the low cervical spine in extension slowly, extend the upper cervical spine by allowing the chin to lift towards the ceiling a quarter range. Hold for 10 seconds × 10 at a quarter range. Then try to do this exercise at half range, three-quarters range and full range. Add in rotation and repeat the exercise. Then add in isometric resistance at different ranges.


(6) Check that as the deep flexors are improving (using the biofeedback), the right sternocleidomastoid is becoming less dominant. If the sternocleidomastoid seems shortened get the patient to sit with the occiput and thorax against the wall. Instruct the patient to rotate her head half range towards the right and side flex away. Actively slide the occiput up the wall (upper cervical flexion) and hold for 20–30 seconds, repeating three to five times.

(7) If the suboccipitals still seem tight, instruct the patient to lie supine with the hands bringing the head into upper cervical flexion and then actively slide the occiput up tall. Hold the stretch for 20–30 seconds and repeat three to five times.
Student questions

(1) How would you describe the patient’s posture in Figure 4.2a?
(2) Which muscles may be dominant or tight in this type of posture?
(3) What is the difference between a ‘global mobiliser’ muscle and a ‘global stabiliser’ muscle?
(4) If a patient presents with two areas of ‘give’ how would you decide which area is the clinical priority?
(5) Why do you need to be careful when prescribing suboccipital extensor stretches to patients with neural irritability?
(6) A patient presents to you with neck pain. (He also has chronic obstructive pulmonary disease). Which muscles are likely to be overactive and contributing to the neck dysfunction?
(7) How many repetitions of exercise would you recommend when using Thera-Band® for resistance?
(8) What advice would you give to your patient following completion of an exercise programme?
(9) Why is it important to vary the speed, range and starting positions of exercises?
(10) Give three exercises for the rehabilitation of the cervical sensorimotor system. How would you progress these exercises for the following appointment?

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References


SECTION 1: INTRODUCTION AND BACKGROUND

There is paucity of evidence supporting the use of exercise therapy in the management of conditions of the thoracic spine and rib cage. This could reflect the less frequent presentation to the clinician of injuries in this specific area. However, there has been increasing interest in the thoracic spine by clinicians because of several reasons: the recognition of the thoracic spine as an important source of pain; the role of thoracic curvature in determining overall spinal posture; the influence of thoracic mobility on movement patterns in other regions of the spine (Edmondston and Singer, 1997). The thorax is inherently more stable when compared with areas such as the lumbar spine. Much of the research has focused on specific conditions, notably ankylosing spondylitis (AS), scoliosis and osteoporosis. Other conditions such Scheuermann’s disease, rotational instability and acute locked thoracic spine present frequently to the clinician but there is little evidence in the literature to support a particular treatment regimen. However, regional areas of the spine – that is, the cervical, thoracic and lumbar spines – should not be considered in isolation and dysfunction in any of these areas will ultimately affect adjacent structures. When considering the thoracic spine, exercises that are also applied to the lumbar spine must be considered. The reader will note that much of the lumbar spine exercise approach refers to trunk stability and thus by anatomical definition will have influence on the thoracic spine as many muscle groups will be shared by each region.

Evidence for the use of exercise in the management of disorders of the thoracic spine and rib cage

Research regarding the role of exercise in cervical and lumbar spine conditions frequently considers patients stratified into groups which are non-specific in diagnosis. However, in the case of exercise and the thoracic spine, it is common to consider the issue in terms of specific conditions, and these are reviewed below.

AS is a well-defined condition and the use of exercise in patients with AS has been consistently documented. It must, of course, be noted that the presentation of AS is not confined to the thoracic
spine but that symptoms in this area are often the most notable feature of the disease, particularly in mid to early presentation. Daghrud et al. (2004) performed a Cochrane systematic review of physiotherapy interventions for AS. They compared six trials with a total of 561 participants. Two trials compared home exercises with no therapy and concluded that home exercises improved movement in the spine and fitness more than no therapy at all. The home exercises were carried out for 4–6 months and were tailored to each individual by a therapist. These programmes did not appear to have any beneficial effect on pain levels. Three other studies compared home exercises to supervised group exercise outside the home. The group exercises were found to improve movement in the spine and overall wellbeing, but did not improve fitness anymore than the home exercise programmes. The group therapy was carried out for a period of 3 weeks to 9 months and included physical training, aerobic exercise, hydrotherapy, sports activities and stretching. The final study compared two groups that both did weekly group exercises for 10 months; however, one group went to a spa resort for 3 weeks of physiotherapy. It was found that spa therapy plus group exercise improved pain, fitness and overall wellbeing more than weekly group exercises. The conclusion was that home exercises are better than no exercises and improved both movement in the spine and fitness; group exercises are better than home exercises and improve pain, stiffness, movement of the spine and overall wellbeing. It should be noted that the specific exercises were not described, although a general summary stated that exercises are helpful to people with AS.

Fernández De Las Peñas et al. (2005) evaluated the impact of a 4-month protocol of flexibility and strengthening exercises versus conventional exercises for AS. The conventional intervention consisted of 20 exercises: motion and flexibility exercises of the cervical, thoracic and lumbar spine; stretching of the shortened muscles and chest expansion exercises. The experimental protocol was based on the global posture re-education method (GPR), which employs specific stretching and strengthening exercises to improve posture. The results were monitored by changes in activity, mobility and functional capacity. Both groups showed an improvement in all measures. The intergroup comparison showed that the GPR group obtained a greater improvement than the control group in all but one of the clinical measures. The authors concluded that exercise was beneficial in the treatment of AS and that a programme specifically geared towards postural re-education may have further benefits.

Ince et al. (2006) investigated the effects of a 12-week exercise programme in patients with AS. Thirty patients were included in the randomised controlled trial and were assigned to either an exercise programme or the control group. The exercise programme consisted of 50 minutes of multi-modal exercise (aerobic, stretching and pulmonary exercises), three times a week for 3 months. Measurements were taken of spinal mobility and chest expansion. The spinal movements of the exercise group improved significantly but those of the control group showed no significant change. Physical work capacity and vital capacity values improved in the exercise group but decreased in the control group. The conclusion was that a multi-modal exercise programme is beneficial in the management of AS.

Exercise protocols are frequently employed in the conservative management of idiopathic scoliosis on two accounts: improvement of respiratory and musculoskeletal function. Ferraro et al. (1998; cited in Hawes, 2003) reported stabilisation of the spinal curvature and rib hump among 34 children with mild scoliosis over a 2-year period of treatment, which included daily taught exercises. Solberg (1996) demonstrated improved appearance and reduced spinal curvature in 10 children with mild scoliosis following a 5-month daily exercise programme. Weiss et al. (2003) examined the effect of exercise on the progression of idiopathic scoliosis in children. The cohort consisted of one group of untreated children and another group that received scoliosis inpatient rehabilitation, which was delivered as an individual exercise programme. The results showed that the scoliosis inpatient rehabilitation programme demonstrated reduced progression of the condition in comparison with the non-exercise group.

Santos Alves et al. (2006) analysed the impact of a physical rehabilitation programme on respiratory function on a group of 34 patients with idiopathic scoliosis. Patients completed three weekly sessions of 60 minutes of exercise, which included stretching and aerobic exercises. Improvements were found in pulmonary capacities and volumes, and performance on a 6-minute walking test. Although this was
not a specific musculoskeletal programme it demonstrates the importance and benefits of an aerobic programme to patients with this condition.

Osteoporosis is a condition that affects all the bones of the body in all population groups. While it is not the purpose of this chapter to discuss osteoporosis, specific postural changes in the thoracic spine are well documented. Exercise has been shown to generally have a positive impact. Sinaki et al. (2005) examined the influence of kyphotic posture associated with osteoporosis and the incidence of falls. Twelve women with osteoporosis-related kyphosis were assessed for balance and various strength measurements. This group was compared with 13 non-osteoporotic controls. The study demonstrated that the osteoporotic women had weaker back extensor and lower extremity strength, poorer balance and slower gait in comparison with the control group. This influenced their propensity to fall. The authors argued that treatment options should include exercises that address these deficits. Gold et al. (2004) enhanced the argument that exercises were beneficial in the management of osteoporosis based on the findings of their randomised controlled trial of 185 post-menopausal women. All women in this study had sustained at least one osteoporotic vertebral fracture. The exercises included progressive strengthening and stretching exercises. The conclusions of the study were that weak trunk extension strength and psychological symptoms associated with vertebral fractures can be improved in older women using group treatment. Katzman et al. (2007) demonstrated in a group of older women that kyphosis could be modified with the help of a multidimensional group exercise programme. A cohort of women with thoracic curvature of 50° or more underwent a supervised exercise programme twice a week for 12 weeks. Following the programme, significant improvements were seen such as reduced thoracic kyphosis, improved strength, improved range of motion (ROM) and physical performance.

Conditions that are seen less often in a physiotherapy department, such as spinal tuberculosis, have also been shown to benefit from physiotherapy and a rehabilitation programme. Nas et al. (2004) included 47 patients in a rehabilitation programme both pre- and early post-operatively. Aerobic and strengthening exercises were employed and progressed, with assessment of the patients at regular intervals. The final outcome was that 70% of patients were independent at the end of the programme and the authors concluded that this was the result of application of an appropriate rehabilitation strategy.

Aerobic exercise

The general principles of the effect of aerobic exercise on the musculoskeletal system should be applied to all conditions affecting the thoracic spine. This is particularly important when it is noted that many conditions such as AS, which present with specific thoracic symptoms, are systemic in nature. There is little research suggesting that specific aerobic conditioning has an effect on thoracic spine conditions. There is some positive research in this area in relation to the lumbar spine and it would be logical to apply the same principles to the thoracic spine, although this is an area where further study is required.

The biomechanics of the thorax and the mechanism of respiration should be considered. The thorax is made up from a number of different types of joint, which affects the various degrees of freedom. However, in shallow respiration, movements will always occur in these joints and it is logical to conclude that the increase in respiration rate associated with increased activity would cause increased movements in the joints with associated benefits.

Muscle strength and endurance

The role of muscle endurance in postural control and activity of the trunk is discussed in depth in Chapter 6. Spinal stability and position sense theories may be applied to the thoracic spine as they are to the lumbar spine, although the thorax is more stable due to the presence of the rib cage, and the morphology and orientation of the facet joints. Postural changes in the thorax are frequently seen as an increased kyphosis and while some of these changes may be due to structural changes in the vertebrae and associated joints (as in osteoporosis and AS) some are due to poor endurance, particularly in the paraspinal muscles. None of the studies reviewed above examined the particular role of strengthening exercise in the rehabilitation of thoracic spine disorders. However, a number of the
studies reviewed in the chapters examining the lumbar and cervical spine referred to the ‘cervico-thoracic’ spine or the ‘thoraco-lumbar’ spine and these should be revisited by the student.

Range of motion and flexibility

To understand the factors that limit ROM in the thoracic spine, simple biomechanics of the region need to be considered. Much of the testing of the thoracic spine has taken place on a cadaveric spine with the rib cage removed. However, to understand the contribution of the rib cage to spinal stability, there is a requirement for the unit, i.e. the spine plus intact rib cage, to be tested under conditions of loading. Watkins et al. (2005) demonstrated that the presence of the rib cage significantly limits motion in the thoracic spine and thus enhances stability. Testing the complete thoracic unit under conditions of loading showed that the presence of the rib cage increased the stability of the thoracic spine by 40% in flexion/extension, 35% in lateral bending and 31% in axial rotation. The most notable movement in the thoracic spine is axial rotation, which is a reflection of the coronal orientation of the facet joints particularly in the upper and middle regions. Flexion is limited by the rib cage and a prime limitation to thoracic extension is the shape of the spinous processes. Many individuals will demonstrate a very limited extension from the neutral position. Edmondston et al. (2007) showed that postural position has an influence on the range of motion in the thoracic spine. Testing of axial rotation in different sitting postures (neutral, end-range flexion and end-range extension) demonstrated a significant decrease in the range of thoracic rotation in flexion compared with the neutral and extended postures.

Thus, the thoracic spine is an area where ROM is limited by its structure but decreases in ROM by disorders or pain will still have a significant effect on function. Further, decreased thoracic movement, particularly at the cervico-thoracic junction and the thoraco-lumbar junction will cause increase motion demands on the cervical and lumbar spines, respectively, and may lead to a hypermobile segment or pathological changes. As noted above, thoracic extension is noted as a small movement from the neutral position and is frequently limited in patients with poor posture, poor lumbar or cervical stability or in diseases such as osteoporosis where there are morphological changes in the vertebrae. Maintenance of thoracic extension with ROM exercises is vital to allow a neutral postural position to be achieved. Thoracic flexion is rarely limited although axial rotation is frequently noted to be limited, particularly in the presence of thoracic facet joint disease. Good thoracic and thus trunk rotation is essential for normal functioning, particularly in activities such as gait. Normal kinematics of the shoulder, cervical and lumbar joints are particularly dependent on normal thoracic biomechanics and posture (Kebaetse et al., 1999) and limitation of thoracic movements have been noted as a precursor to disorders in these areas.

Balance and proprioception

The role of balance and proprioception in function in the thoracic spine is very poorly represented in literature. This is not surprising given the structural stability afforded to this region. No published studies have provided clear links between abnormal pathology in this area and proprioceptive deficits as in the cervical and lumbar spines. However, some studies have noted co-ordination patterns of the trunk which are essential for normal gait and changes in these patterns have been associated with neurological disease such a stroke and Parkinson’s disease (Kubo et al., 2006). In the absence of specific evidence it may be hypothesised that deficits similar to those noted in other spinal areas would be observed, albeit in an attenuated fashion due to the structural stability of this area. Further research is required in this area.

Disorders of the thoracic spine

The most common disorders of the thoracic spine are: intervertebral joint sprain, facet joint disease or dysfunction, paraspinous muscle strain, costovertebral joint sprain, Scheuermann’s disease, and osteoporosis. Less common are rib fractures, thoracic disc disorders, T4 syndrome and AS. However, cardiac, respiratory and metastatic causes of pain must also be considered (Singer, 2006).
Scheuermann’s disease

Scheuermann’s disease is an osteochondrosis of the spine that mainly occurs in adolescents, usually males in their last 2–3 years of growth. It is a disturbance in the normal growth of the vertebral epiphyseal ring. If the compressive forces in the spine are sufficient it may cause a wedge deformity in the vertebral body causing a kyphosis of the thoracic spine and an associated increase in lumbar lordosis.

Small disc herniations in the vertebral end plate, called Schmorl’s nodes, are sometimes identified on X-rays. The condition often remains asymptomatic but can become painful after activity. Treatment usually consists of moderation of activities to minimise repetitive flexion and extension movements of the spine but with an active exercise programme. These exercises should include stretching the thoraco-lumbar fascia and hamstrings along with strengthening of the trunk muscles. Postural correction also plays a vital role in minimising the thoracic kyphosis. Aerobic exercises should be carried out to maintain general body fitness. In severe cases, if there is significant wedging of more than 5° at more than one level, a brace to restore the normal curvature of the spine may be considered.

Scoliosis

Scoliosis is a lateral deformity of the spine which is always accompanied by rotation particularly in the thoracic spine; therefore the term scoliosis is not a diagnosis but a descriptive term. In the majority of cases, a specific cause is not found and such cases are termed idiopathic, or of unknown cause. They are most commonly seen in adolescent girls.

Scoliosis can affect children from birth through to adolescence. Adolescent scoliosis is the most common type of idiopathic scoliosis. It usually starts around the time of puberty, in girls more often than boys, and may ultimately require surgery if it cannot be controlled using braces. Infantile scoliosis may resolve as the child grows but needs to be kept under observation. Pulmonary and cardiac function may be compromised if the curvature is severe, which would urgently need surgery.

Ankylosing spondylitis

Boulware et al. (2003) define AS as ‘an inflammatory disease of unknown aetiology, characterized by prominent inflammation of spinal joints and adjacent structures, leading to progressive and ascending bony fusion of the spine’. Males are affected more than females (3:1) and the age of onset is typically from adolescence to 35 years. The disease is part of the group of disorders called seronegative spondyloarthropathies, which are characterised by the following: rheumatoid factor negativity; sacroiliitis; axial involvement; peripheral arthritis; enthesopathy; eye involvement; familial clustering and frequent presence of human leucocyte antigen (HLA) B27 (Boulware et al., 2003). The patient often presents with chronic low back pain and stiffness although its inclusion in this chapter is a reflection of its common early presentation of pain and stiffness in the thoracic spine. Thoracic mobility is greatly decreased as a result of the disease with reduced respiratory expansion observed as the disease progresses. Normal curvature of the spine increases and the patient will present with a flexed, stiff and kyphotic thoracic spine. X-rays demonstrate changes which are specific to the disease with the vertebrae presenting with typical changes to a ‘bamboo’ appearance. The cervical spine is frequently affected at a later stage in the disease. The disease also may present with cardiac, respiratory, renal, neurological or gastrointestinal symptoms. Management of the condition is aimed at treating pain and inflammation and maintaining mobility, particularly of the thorax, which is essential for normal respiratory function. Exercise should include ROM modalities and strengthening for the thoracic spine with particular efforts towards maintaining thoracic extension and a neutral postural position of the spine. Other exercise approaches have been discussed earlier in this chapter.

SECTION 2: PRACTICAL USE OF EXERCISE

Much of the exercise approach for the management of the thoracic spine is very similar to that for the lumbar spine (Chapter 6) and thus will be referred to rather than repeated. The shoulder complex is
Exercise Therapy in the Management of Musculoskeletal Disorders

Assessment of aerobic capacity

Fitness testing should be included in the assessment as aerobic exercise will be an important part of the programme. Wittink et al. (2000) established the Bruce treadmill test as the most valid for measuring aerobic fitness in patients with chronic low back pain, and it would be logical to use such an approach in testing patients with thoracic spine disorders. However, good practice also demands assessment of respiratory function to gain a clearer knowledge of function of the thorax.

Assessment of endurance

The endurance of the trunk musculature may be assessed using the tests described in Section 2 of Chapter 6.

Assessment of flexibility

The clinician needs to have a clear understanding of the kinematics of the thorax and associated normal movement to be able to identify limitations. It may be necessary to fix the lumbar spine into flexion (Fig. 5.2) to clearly assess the extent of thoracic extension.

Assessment of the patient

Posture

A number of conditions of the thoracic spine are characterized by postural changes in the thoracic spine. These include AS and osteoporosis. Postural changes, particularly those that are a result of altered morphology, will have the result of altering biomechanics in related areas such as the lumbar and cervical spines and the shoulder and hip complexes. A posture grid (Fig. 5.1) may be used to assess posture in side standing and anterior or posterior views which will give indications of kyphotic or scoliotic changes, respectively. Such a tool is a particularly useful as a simple outcome measure where disease progression and further changes may be anticipated.

Figure 5.1 Posture being assessed and measured with a posture grid.

Figure 5.2 The patient’s lumbar spine is fixed into flexion by flexing the hips and knees as the patient’s range of thoracic extension is assessed.
Assessment of movement should be confined, as far as possible, to the thoracic spine so as to achieve a clear picture of motion patterns. In standing, a great deal of side flexion takes place at the lumbar spine and cervical spine (Fig. 5.3). In sitting, the lumbar spine is less mobile and the patient is asked to keep the cervical spine in a neutral position (Fig. 5.4).

As the thorax is a stable unit, movements should be assessed simply with the addition of overpressure by the clinician (Fig. 5.5). Muscles should be assessed for length, particularly groups such as the pectorals and latissimus dorsi, which will contribute to postural changes in the thorax.

The exercise programme

Early phase

The first stage of the programme should be to establish correct posture and enhance postural control. As has been discussed earlier, many patients with thoracic spine pathology will present with hypomobility, which particularly limits extension. It may be necessary to stretch tight muscle groups and introduce mobility exercises to increase thoracic extension before the neutral posture may be achieved. Figure 5.6 shows how a patient can use a gym ball to perform a passive stretch to encourage thoracic extension.

Abdominal bracing should be taught early (see Chapter 6), although it must be ensured that...
thoracic spine position is not compromised. Early motor control exercises may be taught to encourage maintenance of the neutral lumbar position while introducing thoracic spine extension (Fig. 5.7).

Maintenance of a neutral spine position may also be practised with the addition of arm movement. Tightness of muscle groups around the shoulder girdle may be a limiting factor and should be addressed if necessary. Other than stretches that have been suggested so far, simple ROM exercises will address hypomobility. The gymnastic ball (Fig. 5.8) or medical exercise therapy (MET) equipment (Fig. 5.9) will help facilitate dynamic ROM exercises to improve thoracic extension, side flexion and rotation.

Aerobic exercise should be an essential part of this stage with activities such as walking (Nordic or normal) or swimming suitable in this phase (Fig. 5.10). Strengthening activities should not include specific loading in the early phase of the programme and exercises which are aimed at spinal position maintenance will suffice. Proprioceptive work will be informal and again will be an essential part of the spinal position sense work outlined above.

**Intermediate phase**

Postural activities and exercises (Fig. 5.11) may continue in this stage with an emphasis on loading with limb movement while maintaining good thoracic posture. Stretching and ROM exercises will continue to further enhance joint mobility and good spinal positioning and posture. Loading may be introduced with the use of the many exercises described in the lumbar spine programme. MET programmes, notably pulley-based exercises, are particularly useful in the management of the thoracic spine (Fig. 5.12).

![Figure 5.6 Thoracic extension using a gym ball.](image)

(a) (b)

Figure 5.7 In four-point kneeling, the patient finds the neutral pelvis position (a) and is then asked to rock back while keeping the thoracic spine in slight extension and the lumbar spine in neutral (b).
Late phase

The aim of this stage should be to prepare the patient for discharge. The principles described in Chapter 6 should be considered and applied to the thoracic spine. Thus, increased loading and free weights should be added, unstable surfaces introduced, and ROM and aerobic training continued.

Particular emphasis should be placed on developing endurance of the thoracic extensors and the middle and lower trapezius muscles when there are signs of a developing thoracic kyphosis. The exercise demonstrated in Figure 5.13 is particularly useful for this. Aerobic exercise should continue in this phase with the aim to reach guideline levels of 1 hour.
Nordic walking is a particularly suitable aerobic activity in rehabilitation of the thoracic spine as movement of this area is facilitated by the poles.

Postural activity for the thoracic spine. The patient stands against the wall with the spine in a neutral position. The hands slide up the wall and the spine position is maintained.

MET equipment is used to load thoracic rotation.
Functional activities which introduce high and low levels of loading should be incorporated into the regimen to ensure that the patient will be able to manage independently without the risk of re-injury, once they have been discharged. The student should read Chapter 6 for more details about this stage.

Discharge should involve development of a basic and abridged version of the programme followed to this point, which the patient may continue. Chronic diseases such as AS and osteoporosis demand that regular reviews of the exercise regimen are carried out, with alterations made in response to requirements.

CASE STUDIES AND STUDENT QUESTIONS

**Case study 1**

A 17-year-old elite footballer complained of pain and discomfort in the thoracic region of the spine. There was an insidious onset with a gradual increase in discomfort over a number of months. There were no neurological complications but movement was restricted by discomfort and pain at the end of range movement. On examination the discomfort was described as dull rather than sharp and thoracic movements were limited, particularly extension. Postural assessment noted an increased thoracic kyphosis. Palpation was tender on both spinous and transverse processes around T–T10. Radiological investigation demonstrated that the player had Scheuermann’s disease with associated Schmorl’s nodes.

**Management**

Scheuermann’s disease is a common cause of pain in preteens or adolescents and the main aim of management of this athlete should be to manage the pain and prevent progression of the postural deformity that is noted in the disease, i.e. increased thoracic kyphosis. As the patient is an elite footballer, attenuation of activity should be encouraged, with pain being the main guide to participation levels. Complete cessation of activity should not be advised except in severe cases until the pain has settled, at which time, a graduated return is advised. As this patient is already likely to be fit, aerobic activity should be encouraged from the onset of the programme. Postural correction should be addressed initially and spinal ROM exercises that particularly encourage thoracic extension should be included from the start.

Tight muscle groups, particularly the hamstrings and latissimus dorsi should be stretched, along with any others that may be compromising normal thoracic posture. Strengthening may be started as soon as the footballer can achieve a more neutral thoracic posture, with thoracic extension being the primary focus. The footballer may continue to train, provided his symptoms are well controlled, and his technique should be reviewed, with a particular emphasis on addressing postural control during activity. As good
Case study 1—cont’d

postural control is achieved and more mobility in thoracic extension is noted, the goal of the programme is to maintain gains following discharge. Specific exercises should be built into the athlete’s training programme with the assistance of his coach and these will need to be adhered to on a long-term basis. Such exercises should comprise general thoracic ROM exercises, which encourage extension, postural control, particularly of the thoracic extensors, and proprioceptive training in the form of postural control under conditions of moderate loading such as match play. Discharge should take place once the ongoing programme has been established with regular follow-up as hypomobility in the thoracic spine into adulthood is a common manifestation of the disease.

Case study 2

A 30-year-old male teacher presents with insidious onset of low back pain which radiates bilaterally to the sacroiliac joints. The pain, which has a 1-year history is now radiating to the thoracic spine and chest wall. Pain and stiffness are worse in the morning, and relieved by exercise but not by rest. Physical examination shows a flattening of the lumbar lordosis, increased thoracic kyphosis and generalised hypomobility in all spinal movements as well as restricted chest expansion. Radiographic and blood investigations confirm a diagnosis of AS.

Management

The primary aims of management in this patient are to control pain and to relieve stiffness and thus maintain spinal mobility. Pharmacological input is important at an early stage, as pain that is well controlled will allow optimal benefit to be achieved from an exercise programme. The aim of the exercise programme should be to develop a protocol which will be maintained throughout life and will become part of the patient’s everyday routine. ROM exercises should be started early with an aim to increase general joint function and motion, and also to achieve better posture and spine position. Exercises to improve thoracic extension are particularly important and the use of a gymnastic ball (see Section 2) is particularly suitable. All thoracic and lumbar movements should be trained with simple ROM exercises although limited attention should be paid to flexion patterns. It is important to pay attention to respiratory function, and chest expansion exercises as well as appropriate monitoring should be an integral and ongoing part of the programme.

Once an improvement in posture is noted, stability work to increase postural muscle endurance should commence with particular emphasis on lumbar control and thoracic extensor endurance; a gymnastic ball is again particularly suitable. Aerobic exercise should commence at the start of the programme with hydrotherapy showing particular benefits for the AS patient. Proprioceptive work will take the form of postural control, which will be very challenging for such a patient due to gross pathological joint activity. Progression of the programme should be aimed at increasing aerobic activity to 1 hour per day and to introduce some loading. Loading should be minimal in the form of pulleys or wrist and ankle weights, and exercise repetitions should be high to encourage endurance benefits. Loading should be aimed at increasing thoracic extension and rotational strength and trunk flexor patterns should not be emphasised. The patient should be carefully monitored for symptom aggravation and the programme altered accordingly if it is noted. ROM exercises should be continued as a fundamental lifestyle change which will be necessary for this patient. Discharge requires that the patient continues the programme daily to achieve optimal attenuation of symptoms, as the disease is chronic in nature. Best practice demands regular review of the programme. The patient may continue to work as a teacher with good ergonomic practices and inclusion of exercise in his daily routine.
Case study 3

A 12-year-old girl has been referred by an orthopaedic paediatrician for an idiopathic, structural scoliosis as a result of congenital structural abnormalities. The patient has been screened and cleared of the presence of cardiac, respiratory and neuromuscular disease.

Management

Assessment of the patient and radiological investigations will establish the pattern of this patient’s scoliosis and Cobb’s angle, which gives an indication of the severity. Some time should be taken examining available joint ROM, endurance of trunk muscles and levels of activity. The emphasis of an exercise programme will be to improve function within the constraints of deformity. The evidence reviewed earlier in the chapter suggests that a structured exercise programme will help reduce progression of the spinal curvature and improving pulmonary function. The design of the programme will be more complex than a traditional spinal rehabilitation programme. Symmetrical exercises, both in strengthening and stretching, should not be avoided and exercise should be aimed at balancing deformity. All movements should be considered separately and emphasis should be on acquiring more equilibrium. In this patient, thoracic side flexion should emphasise one side more than the other to limit spinal concavity. The same principle should be considered with rotation, and extension should encourage the addition of side flexion away from the concavity of the curve.

Student questions

(1) What are the possible reasons for the limited research regarding the use of exercise in conditions affecting the thoracic spine?
(2) In what ways does the function and movement of the thoracic spine differ from the cervical and lumbar spines?
(3) What are the main reasons for postural changes in the thoracic spine?
(4) Why is aerobic activity important in a thoracic spine rehabilitation programme?
(5) How is respiratory function affected by musculoskeletal changes in the thorax?
(6) Outline the evidence supporting exercise in the management of AS.
(7) What are the common causes of increased thoracic kyphosis?
(8) How do principles of lumbar stability exercise relate to management of the thoracic spine?
(9) How important is proprioceptive exercise in the management of thoracic spine disorder?
(10) How does therapeutic exercise affect the progression of a chronic disease such as AS and osteoporosis?

References


SECTION 1: INTRODUCTION AND BACKGROUND

As many as 80% of all adults experience back pain at some time in their lives. Work disability caused by back pain has risen steadily despite the fact that Western economies are increasingly post-industrial with less heavy labour and more automation (Deyo, 1998). It would therefore appear that there is a positive correlation between decreasing levels of physical activity and low back pain. The purpose of this chapter is to review the evidence for exercise in both management and prevention of onset of low back pain.

Evidence for the use of exercise in the management of low back pain

The frequency of incidence of low back pain in the general population is reflected in the volume of evidence in the area. In many of the studies, however, subjects are grouped into a sample of either acute or chronic, non-specific low back pain. It is well recognised that the symptoms of low back pain are multi-pathological and that to stratify patients into these subgroups is a gross simplification. Many of the studies though are otherwise of sound methodology and provide a strong starting point.

European guidelines on low back pain include analyses of systematic reviews and existing clinical guidelines. Van Tulder et al. (2006) produced a set of guidelines for primary care management of acute non-specific low back pain following a comprehensive analysis of studies and trials that fulfilled an acceptable standard of methodological criteria. Among other recommendations, it was advised that patients with an acute episode of low back pain should avoid bed rest as treatment, stay active and continue normal daily activities if possible. It should be noted that the evidence for inclusion of specific exercises such as strengthening and stretching was not conclusive for acute pain episodes. As patients would be presenting with different pathologies under an umbrella diagnosis of non-specific low back pain, generic exercises may be inappropriate for many conditions. Trials that stratify patients by specific pain presentation patterns may present more meaningful data. It may be concluded that avoiding aggravating activity but continuing to exercise is an important management approach. Other European guidelines compiled by Airaksinen et al. (2006) examined current evidence for...
management of chronic non-specific low back pain. Among other recommendations, supervised exercise therapy was advised within the treatment programme. Treatments commonly adopted by many clinicians, such as electrotherapy and traction, were shown to have a poor evidence base. The authors concluded that there is moderate evidence that exercise therapy is more effective in the reduction of pain and disability than passive treatments.

Hayden et al. (2005) undertook a Cochrane Collaboration review of studies examining treatment of non-specific low back pain. The primary objective of the review was to assess the effectiveness of exercise therapy for reducing pain and disability in adults with non-specific acute, subacute and chronic low back pain compared with no treatment and other conservative treatments. Sixty-one randomised controlled trials met the inclusion criteria: n = 11 for acute; n = 6 for subacute and n = 43 for chronic low back pain. The authors concluded that exercise therapy appears to be slightly effective at decreasing pain and improving function in adults with chronic (longer than 12 weeks) low back pain, particularly in those visiting a health care provider. In adults with subacute (6–12 weeks) low back pain there is some evidence that a graded activity programme improves absenteeism outcomes. For patients with acute (less than 6 weeks) low back pain, exercise therapy is as effective as either no treatment or other conservative treatments. Thus the authors suggest that exercise therapy for low back pain is most effective in the chronic phase. However, this must be considered in the light of the European guidelines, which encourage activity within pain limits in the acute phase (Van Tulder et al., 2006). No comment was made by any of the authors regarding this contradiction although it may be surmised that this suggests that generalised low level aerobic activity is important in the acute phase.

The UK BEAM trial (2004) aimed to measure, for patients consulting their general practitioner (GP) with back pain, the effectiveness of adding the following to general practice management of low back pain: a class-based exercise programme (‘back to fitness’); a package of treatment by a spinal manipulator; or manipulation followed by exercise. The researchers also aimed to establish whether the manipulation package was more or less effective within the private setting or the National Health Service (NHS). Findings demonstrated that the most effective outcome was produced by manipulation followed by exercise and there was no significant difference between manipulation performed in a private and NHS setting. The authors did not identify what the ‘back to fitness’ programme specifically involved although it appears that positive benefits may be achieved even when a generic programme is delivered in a class situation.

A review of randomised controlled trials by Hayden et al. (2006) examined trials of suitable methodological standard which assessed the role of exercise in treatment of acute, subacute and chronic low back pain. The authors concluded that exercise is effective in improving function and reducing pain in patients with chronic low back pain. However, limited response was noted in the cases of acute and subacute pain. The authors also concluded that the most effective strategies are individually designed, supervised and performed regularly and also include conservative therapy.

Pain on movement is a primary reason for limited function in the low back pain population. This is frequently associated with lowered levels of activity and fear avoidance behaviour. Rainville et al. (2004) examined the influence of intense exercise-based physiotherapy on pain anticipated before and induced by physical activities. Subjects were recruited from physiotherapy programmes that used intense group-based exercise programmes as therapy. Anticipated and induced pain was measured by a visual analogue scale during six tests of back flexibility and strength and the Oswestry Low Back Pain Disability Questionnaire scores were also used as outcome measures. Subjects participated in the exercise programme three times per week (2 hours per session) for 6 weeks. The authors found that both anticipated and induced pain with physical activities reduced after the exercise programme. There were also associated improvements with global pain and disability.

Gaskell et al. (2007) examined the effects of a rehabilitation programme for patients with chronic low back pain. A cohort of chronic patients with low back pain (n = 877) completed a programme consisting of nine 2-hour group sessions of therapy, run over 5 weeks. The programme included an hour of exercise and an hour of education and advice. The programme proved to be effective in reducing pain, disability, anxiety and depression levels for people with chronic low back pain. Changes in outcome measures were all statistically significant.
One of the reasons that the topic of low back pain receives widespread general interest is that it is a major cause of acute and chronic disability and work absenteeism. The knock-on effect on the economy is great when measured by disability and sick payments as well as health service funding. It makes sense that treatment for back pain should not just be aimed at returning the patient to work as soon as possible but also should be economically viable on a large scale. Torstensen et al. (1998) examined the efficiency and cost of medical exercise therapy (MET), conventional physiotherapy and self-exercise in chronic low back pain. MET is a progressively graded programme that was developed by Norwegian physiotherapist Oddvar Holten in the early 1960s. Each patient is given their own specific programme which is tailored to their dysfunctions. Repetitions of the exercises are high and designed to improved endurance with additional aerobic exercise such as walking included as part of the programme. The MET programme allows up to five patients to be managed at one time in a specially adapted gymnasium. In a cohort of 208 chronic patient with low back pain, who were randomly assigned to one of the groups, those in the MET group demonstrated the most benefit, as measured by pain, functional activities, return to work and cost-benefit analysis. Although conventional physiotherapy also demonstrated similar benefits, patient satisfaction was highest in the MET group. This presents a useful solution for practitioners in the management of the large groups of patients presenting with chronic low back pain. While allowing a number of patients to be seen at one time, it avoids the generic-type delivery that is often seen in a class-based programme.

One of the challenges facing any patient or clinician managing back pain is that the condition often recurs. While there is a strong argument that many patients are not able to address their risk factors, the effect of introduction of a long-term exercise programme to prevent further episodes requires study. Lifestyle changes which incorporate exercise are well established in cardiac disease although there is a paucity of research in this area when low back pain is considered. Soukup et al. (1999) examined the effect of a combined exercise and education programme (Mensendieck’s method) on the incidence of recurrent episodes of low back pain in patients with the history of the condition and who were currently working. Seventy-seven patients who had completed treatment for a low back pain episode were randomly assigned to either the exercise or control group. The exercise group received 20 group sessions over 13 weeks. At 5 and 12 month follow-up examinations, the patients were assessed for recurrence of pain, sick leave days and functional scores. The authors found that after 12 months, there was a significant reduction in recurrent episodes of low back pain in the exercise group compared with the control group. This was a small study and there is a great need for further longitudinal research in this area.

The studies that have been reviewed above focused on the general role of exercise in the management of acute and chronic low back pain. However, the design of any good rehabilitation programme must include all the components of fitness: aerobic exercise; muscle strength and endurance; range of motion (ROM) or flexibility exercises; proprioceptive and balance training. Despite this, there is a clinically observed reluctance to prescribe exercise for low back pain in this way, and the limited research examining the roles of these different fitness components is reviewed below.

Aerobic exercise

When considering rehabilitation of the patient with low back pain, the concept of aerobic training needs to be considered in two ways: generalised aerobic conditioning and localised endurance training of specific muscle groups, particularly those associated with control of posture. Generalised aerobic training has an effect of many body systems in terms of positive health benefits. However, its role in the rehabilitation of the lumbar spine is frequently overlooked by clinicians.

Chatzitheodorou et al. (2007) examined the efficacy of an aerobic exercise intervention in a pilot study of 25 chronic patient with low back pain. Subjects were stratified into two groups, one which underwent a 12-week, high-intensity aerobic exercise programme and a control group, which received 12 weeks of passive modalities without any form of physical activity. Data analysis identified reduction in pain, disability and psychological strain in subjects in the exercise group and no changes in subjects in the control group. This study was limited by the subject numbers, but this issue merits a larger-scale longitudinal project as the
non-exercise intervention clearly reflects a treatment approach employed by many clinicians. The aerobic exercise approach presents a time-efficient and an economically efficient modality of management. Another study which had significant findings in relation to aerobic exercise and low back pain was carried out by Sculco et al. (2001). A cohort of 35 patients with a history of low back pain was stratified into an aerobic exercise or a non-exercise control group for a 10-week exercise programme. Subjects in the intervention group were prescribed a 10-week home-based aerobic training programme consisting of walking or cycling which they performed four times per week at 60% of maximal heart rate. Subjects in the control group were instructed to continue their normal daily routine and not to participate in any formal exercise programme for the duration of the 10-week study period. A number of outcome measures were assessed and the authors demonstrated that low to moderate aerobic exercise appears to improve mood states and work status, and reduce the need for physiotherapy referrals and pain medication for patient with low back pain under the care of a neurosurgeon. A similar small-scale study by Iversen et al. (2003) assessed the effectiveness of a bicycle endurance programme in older adults with chronic low back pain. Twenty-six subjects were assessed at baseline and at 6 and 12 weeks using standardised questionnaires, physical examination and endurance testing. The intervention required the subjects to exercise three times per week for 12 weeks at a set wattage. At the end of the programme, improvements were demonstrated in physical functioning and mental health and there was a decrease in chronic low back pain symptoms as assessed by a standard set of outcome measures. Despite methodological limitations, this study clearly supports the findings of those discussed previously.

The long-term benefits of aerobic exercise in the management of low back pain have been demonstrated by Mannion et al. (2001). One hundred and forty-eight subjects were randomly assigned to one of three groups: active physiotherapy; muscle reconditioning on training devices or; low impact aerobics. Questionnaires were used to assess pain and disability after therapy and at the 6- and 12-month follow up. All modalities were effective in reducing the intensity and frequency of pain. However, in contrast with the physiotherapy group, the aerobics and devices groups maintained their post-treatment reductions in disability after 12 months' follow-up. The authors concluded that the larger group size and minimal infrastructure required for low-impact aerobics made it less expensive to administer and therefore the most cost-effective method of management.

Long-term management as well as prevention of low back pain depends on recognition of risk factors. Low levels of physical activity and consequent poor aerobic capacity have been noted as established risk factors for low back pain. Hartvigsen and Christensen (2007) carried out a prospective cohort study of 1387 twins over a 2-year period. The objective of the study was to examine associations between physical activity, physical function and the incident of low back pain in an elderly population. The authors found that being engaged in strenuous physical activity at baseline was strongly protective in relation to both having had any low back pain and having had low back pain lasting more than 30 days altogether during the past year at follow-up. Statistically significant dose–response associations between increasing frequency of strenuous physical activity and magnitude of this protective effect were also found. In a 25-year prospective cohort study of 640 school children, Harreby et al. (1997) demonstrated that there was a reduced risk of low back pain, measured as lifetime, 1-year and point prevalence of low back pain, in subjects taking physical exercise during leisure time (at least 3 hours per week) compared with the rest of the cohort.

There is a lack of consensus in the literature on the concept of deconditioning in low back pain, perhaps as a result of methodological difficulties. Most patients presenting with low back pain have no record of previous levels of fitness, i.e. a baseline measure, and studies are usually limited to measurement of changes from that point. Smeets et al. (2006) compared aerobic fitness in patients with chronic low back pain with matched controls. In a study of 108 patients with chronic low back pain it was noted that there was reduced aerobic fitness, especially in males, when compared with the normative population. However, Wittink et al. (2000a) demonstrated that levels of aerobic fitness in patients with chronic low back pain are comparable with those in healthy subjects in a study of 50 patients with chronic low back pain. Further research is required in this area.
There is considerable emphasis on individual muscle training in low back pain rehabilitation. Despite strong counter-arguments for this method of management, many clinicians concentrate on activation of, in particular, deep muscle groups to ‘stabilise’ the lumbar spine. This concept will be discussed later in the chapter. However, Koumantakis et al. (2005a) demonstrated that emphasis on specific re-training of the deep trunk muscles in conjunction with general endurance exercise is of no more benefit than general endurance exercise alone. In this randomised controlled trial, 55 recurrent patient with low back pain were randomised into either a generalised trunk muscle endurance programme enhanced with specific muscle stabilisation exercises or a generalised trunk muscle endurance programme. A series of outcome measures demonstrated equal benefits in both methods and the authors concluded that physical exercise alone and not the exercise type was the key determinant for improvement in this patient group.

**Muscle strength and endurance**

Much of the focus over recent years has focused on rehabilitating the patient with low back pain with specific exercises designed to enhance ‘core stability’. However, this term lacks clarity and has been interpreted in many ways. It has led certain groups of clinicians to concentrate on single muscle groups in rehabilitation, while other groups, particularly those that demonstrate a depth of understanding of spinal biomechanics, would argue that this is not practically possible. This will be discussed further in this section. Stabilising muscles, by definition, have an endurance role although spinal and trunk muscles must also be able to generate power. It is necessary to have an understanding of, and to consider, the different functions of the muscles when rehabilitating the patient with low back pain. Beyond those studies which examine stability, there is little emphasis in the literature on the differing functions of the muscle groups. A problem arises when defining strength and endurance of muscles with some regarding the terms as interchangeable. When strength is regarded as the maximum force that a muscle can exert and endurance refers to the ability to maintain the force over time it would make sense that endurance plays a greater protective role for the lumbar spine (McGill, 1998).

Studies looking at general strength will be considered first.

Slade and Keating (2006) carried out a systematic review of studies examining the role of trunk strengthening exercises for chronic low back pain. Thirteen studies fulfilled the methodological criteria and their findings demonstrated that for chronic low back pain: trunk strengthening is more effective than no exercise for long-term pain; intensive trunk strengthening is more effective than less intensive strengthening in improving function. The authors found that increasing exercise intensity and adding motivation increased treatment benefits. However, they also concluded that trunk strengthening compared with aerobics or McKenzie exercises showed no clear benefit and that it was not clear whether the observed benefits were because of tissue loading or movement repetition. A very clear observation of this review and one which merits caution in its interpretation is the lack of standardisation in the exercise programmes. Many different types of exercise were used for the different muscle groups, with frequency of attendance and number of repetitions varying a great deal between studies. Most studies appeared to include low load training with the mean number of starting repetitions at 29 and the mean number of exercise repetitions at 56. It was not clear why high load and low repetitions were only included in one study. A better planned study highlighted the importance of considering muscle endurance as opposed to strength. Luoto et al. (1995) found that poor static back endurance was a good predictor of risk for low back pain. Confusion in the literature persists with many studies not addressing endurance when strength is considered. The limited number of studies of acceptable standard in this area and the frequent use of this modality in low back pain rehabilitation, warrants more studies in this field of interest.

An area which has been widely researched, particularly in recent years is the concept of spinal stability and associated muscle recruitment patterns in patient with low back pain. Before the research is reviewed, it is necessary to define spine stability, core stability and stabilisation exercise. There are many different viewpoints regarding these terms, but McGill (2002) outlines a logical explanation. McGill states that:

‘achieving stability is not just a matter of targetting a few muscles … Sufficient stability is a
moving target that continually changes as a function of the three dimensional torques needed to support postures. It involves achieving the stiffness needed to endure unexpected loads, preparing for moving quickly, and ensuring sufficient stiffness in any degree of freedom of the joint that may be compromised from injury.’

However, recent years have seen an emphasis in by some clinicians on specific muscle groups, most notably the multifidus and transversus abdominis, in rehabilitation. This is mainly a reflection of studies that noted altered recruitment and activation patterns in these muscles following a low back pain episode (MacDonald et al., 2006; Hyun et al., 2007). Comerford and Mottram (2001) suggest that spinal stability is related to movement dysfunction which can present as a local or global problem. Global presentation can manifest as dysfunction of the recruitment and motor control of the deep segmental stability system resulting in poor control of the neutral joint position. The authors argue that it can also occur globally as imbalance between monoarticular stability muscles and biarticular mobility muscles. Local muscles are characterised by the fact that they are the deepest layer and appear to be biased for low load activity while global muscles are superficial and involve torque production, working at higher loads. This distinction was formalised by Bergmark (1989) and provided a focus for the early discussions on stability. In theory, rehabilitation of low back pain should recognise the role of all muscles and their contribution to stability.

Kavcic et al. (2004) designed a study which aimed to identify the torso muscles that stabilise the spine during different loading conditions and to identify possible mechanisms of function. Ten male university students with no history of back pain took part in the study. Spine kinematics, external forces and 14 channels of torso electromyography (EMG) were recorded for seven stabilisation exercises in order to capture the individual motor control strategies adopted by different people. The results demonstrated that a direction-dependent stabilising role was noticed in the larger, multisegmental muscles, whereas a subtle efficiency to generate stability was observed for the smaller, intersegmental muscles. This clearly supports the theory proposed by Comerford and Mottram. Kavcic et al. (2004) concluded that no single muscle dominated in the enhancement of spine stability and their roles were continually changing, depending on the task. They further argued that effective clinical rehabilitation aimed at enhancing stability requires a programme aimed at improving motor patterns that incorporate many muscles rather than targeting just a few.

Biomechanical theories and findings must, of course, be applied clinically to measure efficacy and ease of practical application. Rackwitz et al. (2006) conducted a systematic review of randomised controlled trials that examined the role of segmental stabilising exercises in low back pain. Seven trials fulfilled the methodological criteria. It was concluded that for acute low back pain, segmental stabilising exercises are equally effective in reducing short-term disability and pain and more effective in reducing long-term recurrence of low back pain than treatment by a GP. For chronic low back pain, segmental stabilising exercises are more effective than GP treatment in the short and the long term and may be as effective as other physiotherapy treatments in reducing disability and pain. A further conclusion, however, was that segmental stabilising exercises are more effective than treatment by a GP but not more effective than other physiotherapy interventions.

Cairns et al. (2006) carried out a randomised controlled trial of spinal stabilisation exercises versus conventional physiotherapy for recurrent low back pain. In a cohort of 68 patients, they showed that, using a standard package of outcome measures, improvement was seen with both treatment packages to a similar degree and that no further benefit was seen following the addition of stability exercises to a conventional physiotherapy protocol. The findings of another randomised controlled trial by Koumantakis et al. (2005b) were similar. This trial examined the role of trunk muscle stabilisation training plus general exercise versus general exercise only in a group of patients with recurrent, non-specific back pain. The results of the study were that a general exercise programme reduced disability in the short term to a greater extent than a stabilisation-enhanced exercise approach. Ferreira et al. (2007) compared the effects of general exercise, motor control exercise or spinal manipulative therapy on a cohort of 240 patients with chronic low back pain. Their results showed that the motor control exercise group had slightly better outcomes than the general exercise group at 8 weeks follow-up as did the spinal manipulative therapy group. However, this result was not
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Despite the fact that ROM exercises are included as a matter of routine in low back pain rehabilitation programmes, there is sparse evidence to support this approach in the literature. ROM is also frequently used not only as an outcome measure but also as an assessment tool in disability screening. Furthermore, ‘spinal flexibility has been shown to have little predictive value for low back pain trouble’ (McGill, 1998).

A justification for including ROM exercises in the rehabilitation of low back pain has followed from the observation of altered movement patterns and ranges in patients with low back pain. Shum et al. (2007) found compensatory movements and altered load-sharing strategies during sit-to-stand and stand-to-sit activities in a low back pain population when compared with controls. McGregor et al. (1995) demonstrated that people with low back pain showed significantly reduced ROM in an antero-posterior direction compared with normal subjects. However, in McGregor et al.’s study of 20 patients with low back pain and 20 matched controls, no significant differences were seen in extension, lateral flexion or rotation. The difficulty in making clinical diagnoses as a result of altered ROM or movement patterns has been noted in a number of studies. Pal et al. (2007) noted that even in healthy individuals, movement patterns, relative contributions and kinematic characteristics of the lumbar spine and hip present conflicting results. A study of lumbar spine and hip motion during flexion and return movement in 20 healthy males confirmed the existence of kinematic and temporal variations between the two regions on movement. They also found that hip-dominant or lumbar-dominant patterns are not the same for all individuals, even in a healthy population.

The importance of ROM to spine health lacks clarity and this has been demonstrated by Poitras et al. (2000). In a study examining the validity of spinal ROM and velocity, it was found that kinematic variables were poor to moderately related to Oswestry questionnaire scores. It was also demonstrated that kinematic variables were also unresponsive to changes in work status and Oswestry questionnaire scores over time. A common clinical approach, particularly when a muscle balance approach is adopted is to consider altered muscle lengths and their effects on posture and ROM. A muscle group which is frequently targeted when low back pain is treated are the hamstrings. Halbertsma et al. (2001) investigated the extensibility and stiffness of the hamstrings in patients with non-specific low back pain. In a study of 20 patients versus 20 controls, it was found that the low back pain group showed a significant restriction in both ROM and extensibility of the hamstrings when compared with the controls. However, the danger of focusing on inclusion of ROM exercises was highlighted by Solomonow et al. (2003), who showed that exposure to prolonged static lumbar flexion both increases the risk of further injury and exacerbates symptoms of low back pain.

Range of motion and flexibility

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Balance and proprioception

The concept of balance and proprioception and its relationship to function in the lumbar spine has generated much interest in recent years. An observation following a number of studies has been that subjects with a history of low back pain demon-
strate repositioning error following specific exercises or postural perturbations. The importance of this finding is that postural control is important for optimal biomechanical positioning, particularly in tasks such as lifting. Education of patients with low back pain is aimed at recognition of risk factors and includes ergonomic advice; poor positioning and postural control will compromise this.

O’Sullivan et al. (2003) examined whether individuals with lumbar segmental instability had a decreased ability to reposition their lumbar spine into a neutral position. Fifteen subjects with lumbar segmental instability were matched with 15 controls. Subjects were assisted into a neutral spine position and asked to independently reproduce this position a number of times. Lumbar repositioning error was significantly greater in subjects with segmental instability than in the control group. The authors concluded that this provided evidence of a deficiency in lumbar proprioceptive awareness among this population. A number of studies have also demonstrated that not only are repositioning deficits noted in the low back pain population when compared to controls but that the percentage error increases when a flexed posture is adopted (Wilson and Granata, 2003; Dolan and Green, 2006). Brumagne et al. (2000) suggest that patients with low back pain have an altered reposition sense than controls, possibly because of altered paraspinal muscle spindle afference and central processing of this afferent input. In a study of 23 patients with low back pain, who were matched with controls, repositioning accuracy was significantly lower in the low back pain group following a lumbar paraspinal muscle vibration protocol. Fatigue was also shown to amplify the error in repositioning in patients with low back pain by Taimela et al. (1999), which is an important consideration when considering design and loading levels in a rehabilitation programme.

A more global view of the effect of low back pain on balance has been examined in a number of studies. Henry et al. (2006) demonstrated decreased limits of stability in response to postural perturbations in subjects with low back pain. A study of 26 patients with low back pain measured sagittal and frontal plane displacement while standing on a force platform which was translated unexpectedly. The low back pain group had reduced and delayed sagittal plane centre of pressure responses compared with the control group. The authors concluded that the low back pain cohort had altered automatic postural co-ordination, both in terms of magnitude and timing of responses, indicating alterations in neuromuscular control. In a similar study, Volpe et al. (2006) also found that patients with low back pain oscillated more than controls in an antero-posterior direction when on an unstable surface. Newcomer et al. (2002) also carried out localised EMG measures of latency, frequency and asymmetry of muscle activation of the erector spinae, rectus abdominis, anterior tibialis and gastrocnemius in a very similar study to those outlined above. They found that significantly more subjects with low back pain had absence of firing of trunk muscles during force plate perturbations than control subjects.

**Summary**

While published studies clearly support the use of exercise both in prevention and management of low back pain, there is a lack of consensus regarding the type and frequency of exercise which is optimal. Although the use of aerobic exercise is quite well defined, trials that have looked at other modes of exercise were vague in their description and stratification of patients. In this case, a common sense approach would be to direct rehabilitation at restoring normal movement and thus function, using the American College of Sports Medicine (ACSM) guidelines for dosage and to include components of fitness as outlined in Chapter 2.

**Lumbar spine injury**

As has been mentioned previously, lumbar spine injury is rarely, if ever confined to one specific tissue. Loading stresses all tissues, albeit to different extents, and it is perhaps more appropriate to discuss injury in terms of the tissue that it affects. The reader is encouraged to examine this area further to learn more regarding specific conditions. The tissues of the lumbar spine may be described as the vertebrae, end plates, disc (anulus and nucleus), neural arch (posterior bony elements) and ligaments (McGill, 2002). Injuries to the different areas are discussed below.
Vertebrae

Fractures to vertebrae occur as a result of direct trauma or as a result of compressive loading. Unstable fractures may of course be catastrophic, resulting in paralysis as a result of spinal cord damage. Specific disease such as osteoporosis presents a major risk factor for vertebral fracture.

Neural arch

Posterior bony elements may be damaged as a result of repeated compressive loading as a result of cyclical flexion–extension cycles. Stress and occult fractures will occur at the pars interarticularis resulting in spondylolysis (unilateral fracture) or spondylolisthesis, which is a bilateral fracture associated with varying degrees of slip of the vertebra.

Disc

Damage may occur in the nucleus and/or the annulus. The annulus and nucleus work together support compressive load when the disc is subjected to bending and compression. Under compression, the nucleus pressurises, applying force to the end plates vertically and the annulus laterally. This causes the annulus fibres to bulge outwards and become tensed. If this pattern is repeated, the nucleus will penetrate the failing annulus leading to disc herniation. There are four degrees of herniation: nuclear herniation; disc protrusion; nuclear extrusion and sequestered nucleus. The disc demonstrates dramatic changes with age, and symptoms associated with these changes are common.

Ligaments

Ligaments of the lumbar spine are well adapted to the loading and cyclical motion requirements demanded of them. However, it has been noted that lumbar ligaments avulse at lower load rates but tear in their mid-substance at higher load rates (Noyes et al., 1994). Ligament damage is frequently associated with high load trauma such as road traffic accidents.

End plates

End plate damage is caused under repeated compressive loading, eventually leading to the formation of Schmorl's nodes (McGill, 2002).

Damage to all or some of the above structures can lead to the development of the number of lumbar syndromes which clinicians will be familiar with: disc disease (acute and degenerative); facet joint dysfunction (acute and degenerative); instabilities including spondylolisthesis; stenosis and other manifestations of degeneration. The reader is encouraged to read further texts to understand the epidemiology and patterns of presentation of each disorder. Co-existence of pathologies is common and good clinical practice encourages the clinician to recognise movement and functional disorder as priority when designing rehabilitation programme, rather than employing a generic treatment approach for a specific disorder.

SECTION 2: PRACTICAL USE OF EXERCISE

Assessment of the patient

It is important that a rehabilitation programme is designed to include a thorough and detailed assessment of the patient. History should not only establish the pattern and nature of the patient's pain but also assess their lifestyle, which is important to establish risk factors. Physical examination should establish postural and movement faults under both low and high load conditions. Examination of movement patterns should always be geared towards considering how exercise can improve movement both functionally and actively.

Assessment of endurance

As it is important to emphasise endurance over strength; simple tests of endurance of the trunk (flexors, extensors and lateral musculature) could include the following (from McGill, 2002).
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Assessment of aerobic capacity

Fitness testing should be included in the assessment as aerobic exercise will be an important part of the programme. Wittink et al. (2000b) established the Bruce treadmill test as the most valid for measuring aerobic fitness in patients with chronic low back pain.

Assessment of motor control

Simple tests may be performed on the patient to assess their ability to maintain their lumbar spine in a neutral position (Fig. 6.4). The neutral lumbar spine position is found when the pelvis is halfway between full anterior tilt (Fig. 6.5) and full posterior tilt (Fig. 6.6). This may then be challenged by asking the patient to move the limbs into different positions. Poor control will result in the inability to maintain the lumbar spine in neutral (Figs 6.7 and 6.8).

Assessment of proprioception

Proprioception should be examined at the initial stage using simple tests such as ability to reproduce

Figure 6.1 Lateral musculature test.

Figure 6.2 Flexor endurance test.

Figure 6.3 Back extensor test.

the upper body moves from the horizontal position.
postural positioning. Tools such as electrogoniometers and EMG will be useful to give some quantitative data at this stage. Electrogoniometers allow accurate measurement of the lumbar spine angles. The patient is placed into a position by the clinician. They are then allowed to move freely and asked to re-create the position (Fig. 6.9).

**Assessment of flexibility**

The important factor to consider when assessing flexibility in the patient with low back pain is the effect of limited ROM of joints around the lumbar spine and their effect on normal lumbar movement.
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Short hamstrings are associated with specific abnormal postural types and will frequently induce early lumbar flexion. A useful test to assess the effect of hamstring length on lumbar spine position places the patient sitting with hips and knees flexed to 90°. He or she is asked to extend the knee slowly. Hamstring tightness will result in posterior tilt of the pelvis (Fig. 6.10).

Hip, thoracic spine and even tightness around muscle groups in the shoulder will alter the biomechanics of the lumbar spine. This may be assessed in standing with the lumbar spine in a neutral position; the patient elevates both arms slowly. If the lumbar spine moves into extension this could be caused by a combination of tight shoulder flexors, limited thoracic spine extension and poor lumbar motor control. Further localised testing is required to establish which muscle groups are affected (Fig. 6.11).

In the modified Thomas test, the patient starts with both hips and knees in flexion. One leg is lowered to allow the hip to go into extension. Tight hip flexors cause the lumbar spine to partly move into extension, resisting the efforts of the contralateral hip to maintain posterior pelvic tilt (Fig. 6.12). These tests are not an exhaustive list and thorough
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postural and motion assessment will give the clinician a better focus for testing specific groups.

Design of an exercise programme

Management of patients with low back pain will frequently include modalities such as manipulation and massage but for the purposes of this text, an exercise-only approach will be described. A generic approach to programme design is strongly discouraged but general principles may be adapted according to the patient’s needs. It is important that concepts are evidence based and consider the components of fitness and the ACSM’s guidelines (see Chapter 2) as well as including stability and proprioceptive work throughout all stages, which are fundamental to success.

McGill (2002) emphasises the importance of training for health as opposed to performance when considering low back pain. This approach stresses the importance of:

- Muscle endurance
- Motor control perfection
- Maintenance of sufficient spine stability in all expected tasks

Strength should not be a targeted goal although strength gains will result. Training for health should also include aerobic fitness and appropriate activity levels. When elite athletes are considered, these principles will still be considered but the spine must be prepared for high stresses and loading.

Application of the principle of specificity will allow a programme of appropriate design, in terms of exercise type and loading, to be formulated.

The exercise programme will be discussed in terms of early, intermediate and late stages of management. Progression through the programme will depend on the patient’s response, according to outcome measures which should be established before the programme is commenced. The programme should be carried out daily for optimum effect. This may not be possible in a clinic situation so it is important that the patients carries out an adapted programme on non clinic days. Ultimately, a lifestyle change is expected when the patient will be expected to carry out a number of components of the exercise programme, if not daily, on a regular basis.

The exercise programme

Early phase

The first stage of any programme should be to correct abnormal movement patterns, posture and to establish postural control under conditions of low load. The patient should be shown and assisted to find the position when their pelvis and spine is in a neutral position. This may be done in different positions such as sitting, standing, lying or four-point kneeling (Fig. 6.13).
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It is common for patients with low back pain to have adopted poor posture, which may be because of a number of reasons including pain, work or sporting demands or genetically determined body type. Education and assistance by the clinician to find a more correct posture is important at this stage. It is likely that stretching or specific muscle groups will be required at this stage to allow the patient to achieve a more normal postural positioning. These muscle groups will have been identified in the assessment procedure and should be targeted early. In patients with low back pain, specific muscle groups demonstrate tightness, in particular, the hamstrings, hip flexors and the muscles of the posterior calf. Stretches appropriate for the patient with low back pain are illustrated in Figure 6.14 and should place particular emphasis on correct lumbar spine and pelvis position while carrying out the stretch.

However, an important point at this stage is that flexibility must not be overemphasised until the spine is stabilised and abnormal movement patterns are corrected. In general, at this stage, flexibility training should be aimed at those muscle groups which prevent the neutral pelvis posture being attained. It is important that movements or stretches which are already overemphasised by the patient are avoided as they may be contributing to the patient’s disorder. For example, a gymnast is frequently hypermobile in lumbar extension so it would be nonsensical to emphasise this movement in rehabilitation if

Figure 6.14 (a) Hamstring stretch. (b) Quadriceps stretch. (c) Adductor stretch. (d) Thoracic extension stretch.
such a patient’s pain was due to overloading in extension.

Once the patient is able to establish neutral position of the spine and improved posture, the muscles which hold the spine in this position must be trained. The first exercise is very simple and the patient is requested to hold this position in sitting, standing and other functional patterns. Such low load training is working on the endurance of the postural muscles as well as proprioception or spinal position sense. Proprioceptive training is enhanced by giving the patient feedback in the form of verbal cues, mirrors, videos, biofeedback or any other technology which has been discussed in Chapter 3. Patients often tire quickly at this stage and this must be expected. Overloading and resulting fatigue is associated with substitution of normal movement or posture to abnormal.

Once the patient is able to adopt and maintain a neutral spine in standing, simple functional movements such as squatting, flexing and extending the lumbar spine and lifting (very small and light) objects may then be introduced (Fig. 6.15). It is common at this stage to observe movement faults with position changes and the clinician must constantly correct these faults. If the patient finds any of the movements too challenging, they may not be ready to progress and control in simple standing and sitting should be reviewed.

At this stage, it is important to consider the role of the abdominal muscles in enhancing spine stability. There has been a great deal of research in this area in recent years and the reader is advised to familiarise themselves with this. McGill (2001) favours the concept of abdominal bracing as opposed to hollowing which is taught by some groups of clinicians. Abdominal hollowing recruits the transversus abdominis whereas bracing co-activates this muscle with the external and internal obliques, offering greater stability. McGill argues that hollowing may be used as a motor control exercise but that it does not enhance stability. Abdominal bracing requires that the abdominal wall is neither sucked in nor pushed out but contracted isometrically. Readers are encouraged to read McGill’s work further to understand the mechanical concepts discussed above. Teaching abdominal bracing may present a challenge to clinicians and they should not hesitate to spend some time with the patient perfecting it (Fig. 6.16). Mental cues such as ‘imagine you are about to be punched in the abdomen’ may be helpful. Demonstrating isometric contractions in other joints may also be useful.

The final component of this phase is to introduce aerobic exercise. Although it may be argued that movement faults may perpetuate when such exercise is added, the patient (unless severely disabled by pain) will probably be undertaking some aerobic exercise already, such as walking. The therapist needs to make a clear clinical judgement in this case and consider whether the addition of aerobic exercise will affect movement which is already poor. If not, simple activity such as walking may be
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throughout the programme as an increase in loading will place stresses on proprioceptive control.

Warm-up

The warm-up should be an opportunity to consolidate normal movement and to ensure that correct motor patterns and spinal positioning is established. Light aerobic exercise to increase the heart rate could include deep knee bends while arm swinging, lunges or step-ups (Fig. 6.17). Each set of movements should be preceded by the patient establishing correct spinal position and maintaining this position throughout the movement.

ROM exercises for the spine should be introduced in the warm-up. It is important not to encourage spinal motion to extremes at this point as good stability has not yet been established. Simple exercises such as ‘humping and hollowing’ (Fig. 6.18), pelvic tilting (Fig. 6.19) and hip hitching (Fig. 6.20) in standing are appropriate.

Stretches may be included to incorporate those muscle groups which were highlighted as significant in initial assessment. Further stretches may be included as appropriate for any programme. As is the theme throughout the programme, stretches must be done with the spine in an optimum position.

Summary of the early phase

- Teach the neutral spine and spinal position sense.
- Correct postural and movement faults.
- Teach abdominal bracing.
- Minimise loading to basic functional tasks.
- Introduce low-level aerobic exercise.

Intermediate phase

This stage of the programme consolidates concepts from the first phase and introduces loading to enhance endurance. At this point it is useful to run the rehabilitation session like a conventional exercise class with a warm-up, aerobic phase and strengthening phase followed by a cool-down. Such a method of delivery works well in hospital and clinical situations and may allow a number of patients to be seen simultaneously. Reinforcing normal movement should be a constant theme introduced. A guideline of 30 minutes per day is the ultimate goal although for the de-trained patient, 10 minutes of walking per day may be a good starting point. The patient should be encouraged to consider postural correction exercises while walking.

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- Correct postural and movement faults.
- Teach abdominal bracing.
- Minimise loading to basic functional tasks.
- Introduce low-level aerobic exercise.

Intermediate phase

This stage of the programme consolidates concepts from the first phase and introduces loading to enhance endurance. At this point it is useful to run the rehabilitation session like a conventional exercise class with a warm-up, aerobic phase and strengthening phase followed by a cool-down. Such a method of delivery works well in hospital and clinical situations and may allow a number of patients to be seen simultaneously. Reinforcing normal movement should be a constant theme introduced. A guideline of 30 minutes per day is the ultimate goal although for the de-trained patient, 10 minutes of walking per day may be a good starting point. The patient should be encouraged to consider postural correction exercises while walking.

Summary of the early phase

- Teach the neutral spine and spinal position sense.
- Correct postural and movement faults.
- Teach abdominal bracing.
- Minimise loading to basic functional tasks.
- Introduce low-level aerobic exercise.

Intermediate phase

This stage of the programme consolidates concepts from the first phase and introduces loading to enhance endurance. At this point it is useful to run the rehabilitation session like a conventional exercise class with a warm-up, aerobic phase and strengthening phase followed by a cool-down. Such a method of delivery works well in hospital and clinical situations and may allow a number of patients to be seen simultaneously. Reinforcing normal movement should be a constant theme introduced. A guideline of 30 minutes per day is the ultimate goal although for the de-trained patient, 10 minutes of walking per day may be a good starting point. The patient should be encouraged to consider postural correction exercises while walking.

Summary of the early phase

- Teach the neutral spine and spinal position sense.
- Correct postural and movement faults.
- Teach abdominal bracing.
- Minimise loading to basic functional tasks.
- Introduce low-level aerobic exercise.
Aerobic phase

Aerobic exercise may be introduced in the form of an exercise which places minimal loading specifically on the low back but is also reproducible for the patient following discharge from the programme. Walking is particularly useful as patients are able to continue this exercise independently. Addition of spinal rotation in activities such as Nordic walking (Fig. 6.21) or using the Nordic ski track makes the activity more interesting and introduces more muscle activity. Target heart rate should be set before the activity begins and a time period of about 20 minutes is useful in a class setting. Out of a class setting, a target of up to 1 hour should be the aim. Swimming is also a useful activity to challenge the aerobic component of the programme but would be more convenient if the whole design of the class was hydrotherapy based. Activities such as rowing machines are particularly unsuitable because of the poor spine position and loading during the activity.

Strengthening phase

The aim of the strengthening phase is to enhance the endurance of the stabilising muscles. McGill (2002) identified the significant stabilisers as:

**Figure 6.18** Humping and hollowing.

**Figure 6.19** Pelvic tilting.

**Figure 6.20** Hip hitching.

**Figure 6.21** Nordic walking.
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The use of a pressure biofeedback unit (PBU) is beneficial to give reinforcement to the patient. The PBU is placed in the lumbar lordosis; the spine is ‘set’ in neutral and the abdomen braced as taught in the early phase. Limb movement is introduced with the arm (Fig. 6.25) or the leg. If good stability is demonstrated, there will be no change in the spine position and thus no change in the reading on the PBU.

Cool-down

The cool-down may comprise walking or low level aerobic activity followed by proprioceptive exercises such as targeted repositioning to encourage good spinal position sense.

- Multifidus and other extensors
- Quadratus lumborum
- The three layers of the abdominal wall.

A simple approach would be to train the muscles of the anterior, posterior and lateral trunk. Assessment established the holding times of the various exercises (see above) and the aim should be to increase the time that the patient is able to hold the correct position of the exercise. Repetitions as well as holding times may be increased as the patient improves. Starting position requires re-establishment of good spinal position at each repetition of the exercise. The side bridge exercise aims to improve endurance of the trunk side flexors. Figure 6.22a is an easy position with Figure 6.22b demonstrating a progression of difficulty.

The trunk curl (Fig. 6.23) aims to work the trunk flexors or muscles of the abdominal wall. The spine is held in neutral with one knee flexed to prevent pelvic rotation (McGill, 2002). It is important that the cervical spine is maintained in a neutral position throughout the exercise and the shoulders are barely raised from the supporting surface. Figure 6.24 illustrates exercises to train the trunk extensors. In four-point kneeling, the patient establishes the neutral spine position and slowly raises one arm or leg. A progression is seen when the patient raises one arm and the leg on the opposite side. The further the arm or leg is extended, the greater the loading as the lever is longer.

Exercises to challenge stability by adding limb movement may be introduced at this stage. The use of a pressure biofeedback unit (PBU) is beneficial to give reinforcement to the patient. The PBU is placed in the lumbar lordosis; the spine is ‘set’ in neutral and the abdomen braced as taught in the early phase. Limb movement is introduced with the arm (Fig. 6.25) or the leg. If good stability is demonstrated, there will be no change in the spine position and thus no change in the reading on the PBU.
challenges. Free weights, pulley weights, gym balls and wobble boards may now be introduced. Rotational movement patterns may be introduced with or without weights. As stressed throughout the text, there must continue to be strong emphasis on correct spinal positioning and control throughout movement. It is well recognised that as loading is increased, control is frequently compromised and abnormal movement patterns are observed. Speed of movement may also be increased but again movement must be observed closely for abnormality. Discharge of the patient should be considered and plans made to incorporate appropriate elements of the programme into the patient's lifestyle. It is likely that there will be a relapse in the patient's condition if recommended activity levels are not met with exercise and localised exercises are not continued. While class design is the same as that described previously, the components of the programme will change in the following ways.

**Aerobic exercise**

The patient should now reach the minimum requirement of 30 minutes of moderately intense exercise on 5 days of the week. The important factor is that this will continue throughout life and will be an activity or activities (variation is encouraged) that the patient may incorporate into their lifestyle such as changing the daily car commute to walking. The rehabilitation programme will only be part of this and may comprise the same exercises as those described above.

**Summary of the intermediate phase**

- Continue to emphasise spinal position sense and good postural control.
- Introduce exercises that challenge endurance of postural muscles.
- Increase aerobic activity.
- Establish a pattern of exercise that the patient will continue throughout life.

**Late or advanced phase**

The advanced phase of rehabilitation will be very similar in design to the previous stages but with a component of increased loading and proprioceptive challenges. Free weights, pulley weights, gym balls and wobble boards may now be introduced. Rotational movement patterns may be introduced with or without weights. As stressed throughout the text, there must continue to be strong emphasis on correct spinal positioning and control throughout movement. It is well recognised that as loading is increased, control is frequently compromised and abnormal movement patterns are observed. Speed of movement may also be increased but again movement must be observed closely for abnormality. Discharge of the patient should be considered and plans made to incorporate appropriate elements of the programme into the patient's lifestyle. It is likely that there will be a relapse in the patient’s condition if recommended activity levels are not met with exercise and localised exercises are not continued. While class design is the same as that described previously, the components of the programme will change in the following ways.

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The patient should now reach the minimum requirement of 30 minutes of moderately intense exercise on 5 days of the week. The important factor is that this will continue throughout life and will be an activity or activities (variation is encouraged) that the patient may incorporate into their lifestyle such as changing the daily car commute to walking. The rehabilitation programme will only be part of this and may comprise the same exercises as those described above.
Of good spinal positioning is challenging in this position and must be monitored by the therapist. The prone bridge (Fig. 6.28) works the trunk flexors to prevent the trunk sagging into extension due to gravity. However, this exercise is a very good example of a general stability exercise that facilitates co-contraction of all trunk musculature.

- **Trunk side flexors**: Two variations of the side bridge frequently seen in Pilates programmes are illustrated in Figure 6.29 and demand endurance activity in the side flexors. Figure 6.30 illustrates trunk side flexion using a pul-
Trunk extensors: In Figure 6.31 the patient is performing trunk extension on an unstable surface (gym ball). In Figure 6.32 the patient is performing extension to a horizontal position.
over a gym bench. The patient may increase loading by extending the arms or placing weights in the hands.

- Adding rotation: The addition of rotation allows more functional patterns to be exercised. In Figure 6.33 the patient rotates and extends the trunk while pulling a pulleyed weight. An extension pattern may be worked if the patient reverses their starting position. Good spinal position sense is important in this case as loading increases with addition of torsion. In standing, the patient may rotate the trunk in a flexion to extension pattern while holding a medicine ball (Fig. 6.34). This is an advanced exercise which places high demands on control and spinal position sense.

Summary of the late phase

- Continue with postural and spinal position training with the introduction of challenges such as unstable supporting surfaces.
- Train endurance in appropriate muscles (as above) with the introduction of loading and rotational activity.

- Continue an aerobic exercise programme so that the patient completes 30 minutes of aerobic activity per day.
- Prepare and adapt the programme so that essential elements will be continued at discharge.

Discharging the patient

Criteria for discharge should have been established with the patient at commencement of the programme. It is important that the patient understands that failure to continue with exercise following discharge places them at increased risk of relapse. It is unrealistic to expect the patient to continue exercise in such an intensive way as that experienced during the rehabilitation programme. However, certain elements including aerobic exercise and endurance training of the trunk muscles will lend particular benefit if continued in the long term. The patient may be able to join a gym or exercise class which will allow them to continue exercising in a social setting.
SECTION 3: CASE STUDIES AND STUDENT QUESTIONS

Case study 1

A 72-year-old man with degenerative disc disease at L3/4 and L4/5 presents with diffuse lower back pain which radiates into the right leg. Pain is eased by walking and aggravated by prolonged sitting and gardening. The patient leads a relatively active lifestyle and is a non-smoker. Examination reveals restriction in all lumbar movements, particularly extension, flattened lumbar lordosis with poor postural control particularly when loading is added. There are no significant neurological signs.

Management

As the pathology causing this patient’s pain is degenerative and, by definition, likely to demonstrate limited improvement, management should be aimed at maximising function which should have a positive effect on pain. Gardening and walking are activities that should be incorporated into the programme as the patient enjoys them. The early stage of the programme should concentrate on achieving a more normal posture in standing and sitting positions. Pelvic tilting, initially in standing should aimed at assisting the patient achieve a neutral spine position as well as increase the lumbar lordosis and increased lumbar extension. If the patient can comfortably achieve a four-point kneeling position, the ‘humping and hollowing’ exercise would help mobilise the lumbar spine, which is likely to be generally hypomobile. Once a more neutral spine position is achieved, abdominal bracing may be introduced and reinforced by practising during everyday activities. Walking may be used as aerobic activity but gait should be assessed to ensure that good spine positioning is maintained. Loading may be added when the patient is able to stabilise the spine during light everyday activity loading. Gardening-type exercises would be ideal for this patient to include activities such as digging, lifting light loads such as garden waste bags in simple patterns and challenging control in a kneeling position, which may add in hip flexion to simulate a weeding position.

It is hoped that normalising and mobilising spinal movements will reduce radicular pain, although many therapists may choose to add in neural tissue mobility exercises. Such exercise type is beyond the scope of this book and readers are encouraged to examine the treatment of radicular pain further. The patient’s discharge programme should encourage everyday aerobic activity combined with basic spinal stability and mobility exercises which fit in well with the patient’s preferred activities.

Case study 2

A 32-year-old sedentary office worker, a smoker, presents with lumbar pain due to an acute disc protrusion at L4/5. Time of presentation is 4 weeks after initial onset and initial referral into the left foot has now cleared resulting in localised pain that is aggravated by lumbar flexion and worse on rising in the morning. Examination reveals pain in early flexion and positive slump and straight leg raise on the left.

Management

This patient has presented for treatment with a number of noted risk factors for low back pain. Poor levels of activity and smoking along with the ergonomic profile of the patient’s occupation must be addressed early if there is to be a successful rehabilitation programme. Smoking cessation will require the aid of an outside intervention such as
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a support group and nicotine replacement therapy to have optimal effect. It is likely that the patient will present with limited ROM in the lumbar spine, particularly in flexion. Simple ROM exercises into all ranges but keeping the motion very small and out of the painful range will encourage normal movement and help to reduce inflammation. Neurodynamic work may be beneficial in management as mentioned previously and the student is encouraged to read further in this area. Spinal position should be trained which may be a particular challenge to this patient as they will probably have adopted poor posture for some time. Simple stretches may be required to allow correct spinal positioning at this stage but care must be taken not to overload the spine motion as pain may be aggravated. Abdominal bracing should be taught early as it is likely that this patient’s lifestyle will mean that he presents with very poor trunk control. Considerable time and effort should be spent at this stage and bracing should be assessed and practised in many different spine positions. An aerobic exercise should be introduced early but should be adapted so that the patient’s pain is not aggravated by the chosen activity. Once good stability in neutral positions has been achieved, some light loading may be introduced and stability may be challenged in positions other than neutral. As the patient will be required to return to a sitting work posture, exercises must also be practised in this position. Although the patient will be advised to avoid prolonged sitting, it is not completely avoidable and good, stable sitting posture which achieves a spinal position which is as close to neutral as possible, will limit damage.

Aerobic exercise should continue with an activity that the patient will carry on following discharge. Postural control during aerobic exercise should be intermittently assessed as such exercise will also be useful for training dynamic stability of the spine. The final stage of the programme should be aimed at producing a regime that the patient will continue following discharge and will induce the lifestyle change that the patient requires for better health. Aerobic exercise should include an activity such as walking or a lunchtime swim which the patient can fit into the working day. Stability and endurance exercise may be more feasible if the patient joins a well designed Pilates programme or has a programme that may be carried out in a social gym. If the patient does not adopt the recommended lifestyle changes then it is likely that the injury will reoccur and this should be stressed on discharge.

Case study 2—cont’d

A 16-year-old elite cricketer who is a bowler presents with an acute onset of right lumbar pain. X-ray reveals spondylolysis at L5/S1.

Management

Cricket bowling is commonly associated with loading in an extension pattern in the lumbar spine with particular stresses noted at the pars interarticularis. The reader is encouraged to study the biomechanics of this activity to understand further. Spondylolysis is a noted injury in cricket, particularly in elite junior players. The ultimate aims of rehabilitation of this patient are to stabilise around the fracture and to minimise loading on return to cricket by altering biomechanics of the bowling technique. Fitness must be maintained as it is likely that the patient will already have good aerobic function. Activities such as swimming or aqua jogging will be appropriate and loading or time spent exercising should be equivalent to the time that the patient will usually spend doing daily aerobic exercise as part of their training. This level should be maintained to discharge. Early rehabilitation will be aimed at achieving stability, particularly around the affected level in the spine. Specific flexibility exercises may
Case study 3—cont’d

be required to achieve good spinal positioning or to address areas of hypomobility such as thoracic extension. Once basic stability has been achieved, loading may be introduced. However, as this patient is an athlete, the programme will require some power work as well as endurance and this should not be introduced until late rehabilitation. Early loading should include patterns which will be used during cricket, in particular, trunk rotation with arms moving from full flexion to extension as in the bowling action. Loading with the trunk in flexion and rotation as is seen in batting should also be included. Pulleys and free weights may be used to achieve these patterns with incremental loading over the progression of the programme. Proprioceptive training is particularly important as return to sport will not only place demands in this area to protect the spine but also to optimise performance.

Late stage rehabilitation should continue aerobic, proprioceptive and endurance training of the spine as described above but should also include power work. Power activities for the trunk could include pulley and free weight activities adding in high loads and speeds or activities such as throwing and catching a medicine ball with the trunk in different positions. A fundamental component of the programme which should be considered on day 1 and beyond discharge is that sporting technique should be analysed with the assistance of the coach. Abnormal movement patterns should be corrected both in sport and everyday activities and it is important that sporting activity is not resumed until patterns are normal. A graduated return to sport should be combined with continuation of the programme to address risk of re-injury. Return of symptoms may necessitate change of cricket activity to fielding rather than bowling until the spine is considered more stable, which may not be achieved until a more mature skeletal status is reached.

Student questions

(1) How does the evidence regarding management of low back pain with exercise differ for acute and chronic low back pain?
(2) What are the common criticisms of many of the exercise and low back pain trials?
(3) Why is aerobic exercise important in a low back pain rehabilitation programme?
(4) Discuss why muscle endurance rather than power is important when considering activity of the trunk muscles.
(5) Define stability and discuss its importance to the lumbar spine.
(6) How does poor proprioception and motor control in the lumbar spine contribute to low back pain?
(7) Why are common exercises such as sit-ups and lumbar extensions inappropriate and sometimes harmful to many patients with low back pain?
(8) Discuss the advantages of a custom-made and delivered exercise programme over a generic programme for patients with low back pain.
(9) Summarise the important concepts of an exercise programme for low back pain in early, intermediate and late stages.
(10) What lifestyle factors are important in long-term prevention or management of low back pain?

References

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SECTION 1: INTRODUCTION AND BACKGROUND

The shoulder is a rather complex joint that allows the ability to perform numerous functional activities with varying combinations of speed, power and precision. A hallmark of the shoulder region is its large freedom of movement, yet poor static stability, given its minimal bony congruency and thin, flexible capsulo-ligamentous structures. All shoulder motion, from simple arm elevation to high-velocity throwing, requires considerable strength and precise interaction of the surrounding musculature to achieve dynamic stabilization. As our understanding of these processes has evolved, so has our approach to shoulder rehabilitation.

Evidence of role of exercise in shoulder rehabilitation

Therapeutic exercise is a well-established component of shoulder rehabilitation. A variety of shoulder exercise and rehabilitation programmes have been shown to be effective in improving function in patients with impingement (Bang and Deyle, 2000; Roy et al., 2008), shoulder pain (Ginn et al., 1997; Ludewig and Borstad, 2003) and adhesive capsulitis (Carette et al., 2003). Studies have also shown shoulder stretching and strengthening exercises to be effective at improving faulty posture (Kluemper et al., 2006) and mechanics (Wang et al., 1999).

The purpose of this chapter is to discuss the role of exercise in the rehabilitation of shoulder injuries and it will provide an overview of exercise principles that address impairments of mobility, strength, dynamic stability and proprioception. A functional exercise progression will be outlined based on these principles and which includes a gradual and full return to daily and recreational activities.

Range of motion and flexibility exercise

Several studies (Ginn et al., 1997; Ludewig and Borstad, 2003; McClure et al., 2004) have attempted to assess the effectiveness of stretching and strengthening programmes in reducing pain and improving function in patients with various shoulder pathologies. The results of the studies suggest that pro-
metrical capsular tightness, where one aspect of the capsule becomes tight and restricted, the humeral head migrates away from the area of restriction.

Specific areas of the glenohumeral joint capsule (with its closely related ligaments) are responsible for limiting physiological motion and checking excessive translation. Knowledge of these biomechanical factors can help the clinician accurately assess the cause of motion restrictions and develop a treatment programme designed to specifically address certain aspects of the joint. The rotator cuff interval, coracohumeral ligament and superior glenohumeral ligament act to limit flexion, extension and external rotation with the arm at 0° of abduction. The middle glenohumeral ligament tightens at the end range of external rotation at approximately 45° of abduction. The three portions of the inferior glenohumeral ligament complex each have independent roles. The anterior portion serves to limit external rotation at 90° of abduction. The middle portion of the inferior glenohumeral ligament complex tightens with end-range abduction and flexion. Finally, the posterior portion checks internal rotation at 90° of abduction. The posterior capsule serves to limit internal rotation from 0° to 45° of abduction (Rockwood et al., 2004).

This information is extremely valuable when assessing the ROM restrictions and can help guide proper stretching and joint mobilization techniques. It is necessary to assess each patient’s available ROM to determine which planes of motion may be limited. For example, a patient who has difficulty performing overhead reaching activities and exhibits adequate external rotation of the glenohumeral joint at 0° and 45° of abduction but limited external rotation at 90° may benefit from joint mobilization and stretching techniques designed to improve mobility of the inferior glenohumeral ligament complex, specifically the anterior band (Fig. 7.1). The information can also help guide exercise interventions aimed at restoring shoulder ROM. By placing stress on structures limiting shoulder ROM, tissue remodeling in ligament, tendon and muscle can be influenced. This can be accomplished with a variety of ROM exercises, capsular and muscular stretches.

**Strengthening exercise**

The efficacy of shoulder strengthening programmes is difficult to evaluate. Several studies (Ginn et al.,
have sought to compare the effectiveness of several exercises for the external rotators, supraspinatus and scapulothoracic musculature. The following sections will discuss each one in detail.

**External rotators**

Several studies have been published to document the EMG activity of the glenohumeral musculature during specific shoulder exercises (Moynes et al., 1986; Blackburn et al., 1990; Greenfield et al., 1990; Kronberg et al., 1990; Bradley and Tibone, 1991; Townsend et al., 1991; Worrall et al., 1992; Ballantyne et al., 1993; McCann et al., 1993; Malanga et al., 1996). Variations in experimental methodology have resulted in conflicting outcomes and controversy in exercise selection.

Exercises in the 90° of abduction position are often incorporated to simulate the position and strain on the shoulder during overhead activities such as throwing. This position produced moderate activity of the external rotators but also increased activity of the deltoid and supraspinatus to stabilise the shoulder. It appears that the amount of infraspinatus and teres minor activity progressively decreases as the shoulder moves into an abducted position, while activity of the supraspinatus and deltoid increases. This may imply that as the arm moves into a position of less shoulder stability, the supraspinatus and deltoid are active to assist in the external rotation movement while providing some degree of glenohumeral stability through muscular contraction.

While standing, external rotation at 90° of abduction may have a functional advantage over 0° of abduction and in the scapular plane due to the close replication of this position in sporting activities, the combination of abduction and external rotation places strain on the shoulder’s capsule, particularly the anterior band of the inferior glenohumeral ligament (O’Brien et al., 1990; Scovazzo et al., 1991). When the arm is not in an abducted position, external rotation places less strain on this portion of the joint capsule. Therefore, although muscle activity was low to moderate during external rotation at 0° of abduction, this rehabilitation exercise may be worthwhile when strain of the inferior glenohumeral ligament is of concern. Side lying may be the most optimal exercise to strengthen the external rotators, based on the highest amount of EMG activity observed during this study.
Supraspinatus and deltoid

Numerous investigations have studied the EMG activity of the supraspinatus during rehabilitation exercises, and controversy exists regarding the optimal exercise to elicit muscle activity. Clinically, many authors have suggested that the empty-can exercise may provoke pain in many patients by encroaching on the soft tissue within the subacromial space during this impingement type manoeuvre. Numerous authors have since compared the empty-can exercise with several other common supraspinatus exercises to determine if exercises that place the shoulder in less of a disadvantageous position elicit similar amounts of supraspinatus activity.

The effect of increased deltoid activity during arm elevation is a concern to rehabilitation specialists, especially when rehabilitating a patient with subacromial impingement or rotator cuff pathology. Morrey et al. (1998) examined the resultant force vectors of the deltoid and supraspinatus during arm elevation at various degrees of motion. Deltoid activity alone exhibited a superiorly orientated force vector from 0° to 90°, and a compressive force on the glenohumeral joint at 120–150°. Conversely, the supraspinatus muscle produced a consistent compressive force throughout the range of elevation. In patients with inefficient subacromial impingement, weak posterior rotator cuff muscles, inefficient dynamic stabilisation, and/or rotator cuff pathology, exercises that produce high levels of deltoid activity may be detrimental due to the amount of superior humeral head migration observed when the rotator cuff does not efficiently compress the humeral head within the glenoid fossa. Therefore, exercises are often chosen to minimise the opportunity for the deltoid to overpower the rotator cuff musculature during arm elevation.

Biomechanically, Poppen and Walker (1978) examined the resultant force vectors of the glenohumeral joint during elevation with the arm position in neutral, internal rotation (‘empty can’ position) and external rotation (‘full can’ position). The authors report that at angles below 90° of abduction, the empty-can position resulted in a superiorly orientated force vector while the full-can position produced a compressive force from 0° to 120°. These results may correlate well with the previously mentioned studies reporting increased deltoid activity, and thus superior humeral head migration, during the empty can exercise.

Therefore, based on the numerous EMG investigations, the full-can exercise may be the best exercise for the supraspinatus due to the moderate amounts of muscle activity with the least amount of pain provocation and surrounding muscle activation.

Subscapularis

The subscapularis provides anterior stabilization and assists the posterior rotator cuff with compression of the humeral head in the glenoid fossa during overhead and throwing activities (Glousman et al., 1988; Scovazzo et al., 1991; Wilk et al., 1997). While many shoulder rehabilitation programmes integrate internal rotation strengthening in the neutral position, recent evidence suggests that this may not be the most effective exercise for selectively strengthening the subscapularis. Several EMG studies have identified exercises and shoulder positions that elicit the most muscle activity and may be important to consider in developing rehabilitation programmes (Decker et al., 2003; Suenaga et al., 2003).

Decker et al. (2003) evaluated EMG data for seven shoulder exercises with 15 healthy subjects in seven muscles including both upper and lower portions of the subscapularis. They found that the push-up with a plus and a diagonal exercise moving from flexion, abduction and external rotation to extension, adduction and internal rotation, consistently elicited the most subscapularis activity in both the upper and lower portions. Furthermore, they found that the upper and lower portions of subscapularis may function independently. Upper subscapularis activity was greater during internal rotation at 90° of abduction while the lower portion was more active at neutral abduction.

Suenaga et al. (2003) examined subscapularis activity during isometric and active internal rotation at 0° and 90° of abduction. Using fine wire EMG, they report subscapularis activity at 12.1% of maximum voluntary contraction (MVC) at 90° of abduction compared to 2.0% at 0° of abduction. In addition, pectoralis major activity was greater than all other internal rotators for active and isometric contractions at 0° abduction. The results of this study suggest that larger muscle groups, such as the pectoralis, latissimus dorsi, and anterior...
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(1992) examined eight muscles, including the upper, middle and lower trapezius, levator scapula, rhomboids, pectoralis minor, and middle and lower serratus anterior, during 16 commonly performed exercises in nine healthy subjects. The authors reported the peak EMG activity for each muscle and noted that the majority of the muscles assisted in more than one scapular function. Based on the results of the study, the authors recommended a core programme of scapular strengthening exercises that included shoulder scaption, prone rowing, push-ups with a plus, and press-ups.

Decker et al. (1999) looked more specifically at the EMG activity of the serratus anterior during eight common scapulohumeral exercises in 20 healthy subjects. The authors selected exercises that are typically performed below 90° of humeral elevation, a range of motion deemed safe for most patients with shoulder pathology. The exercises that elicited the greatest amount of serratus activity included the push-up with a plus, dynamic hug (Fig. 7.2), and a standing serratus anterior punch exercise (Fig. 7.3).

Ekstrom et al. (2003) studied EMG activity of the trapezius and serratus anterior during 10 different exercises in 30 subjects. The authors identified two exercises that yielded the most significant EMG activity of the serratus anterior, are likely have a greater effect on gleno-humeral internal rotation at 0° of abduction.

The aforementioned studies indicate that internal rotation exercises at 90° of abduction may be the most advantageous position to strengthen the subscapularis while minimising contributions from larger muscle groups. Functional exercises such as the diagonal and push-up plus exercises should be considered at the appropriate stage of rehabilitation to strengthen the subscapularis and enhance gleno-humeral stability.

Scapulothoracic musculature

The function of the scapulothoracic joint is critical for normal shoulder function. Several authors have noted that weakness or muscle imbalance of the scapular musculature can lead to altered scapular position and dyskinesis, which may be a factor in shoulder dysfunction such as glenohumeral instability and shoulder impingement (Ludewig and Cook, 2000; Cools et al., 2003; Kibler and McMullen, 2003). The lower scapular stabilisers such as the serratus anterior, rhomboids, and middle and lower trapezius are the most commonly weak or inhibited muscles, and are often targeted in shoulder rehabilitation (Voight and Thomson, 2000).

The EMG activity of the scapulothoracic musculature has also been investigated. Moseley et al. (1992) examined eight muscles, including the upper, middle and lower trapezius, levator scapula, rhomboids, pectoralis minor, and middle and lower serratus anterior, during 16 commonly performed exercises in nine healthy subjects. The authors reported the peak EMG activity for each muscle and noted that the majority of the muscles assisted in more than one scapular function. Based on the results of the study, the authors recommended a core programme of scapular strengthening exercises that included shoulder scaption, prone rowing, push-ups with a plus, and press-ups.

Serratus anterior

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used shoulder strengthening exercises. The authors aimed to determine which exercise optimally recruited the lower trapezius, middle trapezius and serratus anterior with minimal participation of the upper trapezius. Based on the EMG analysis, the following exercises were suggested for high activation of the lower and middle trapezius with low activation of the upper trapezius: side lying external rotation, side lying forward flexion, prone horizontal abduction with external rotation and prone extension.

**Proprioception**

The efficacy of proprioceptive training has received much attention in the orthopaedic community, demonstrating the ability to effectively enhance proprioception after injury and surgery in various joints (Lephart et al., 1997; Mendelsohn et al., 2004; Fu and Hui-Chan, 2005; Risberg et al., 2007; Panics et al., 2008). While the lower extremity has been the subject of the bulk of the research in this area, there have been some studies on proprioception of the shoulder (Lephart et al., 1992; Swanik et al., 2002; Barden et al., 2004) that have shown positive results. In order to train the proprioceptive system, it is important to first understand the static and dynamic functions of shoulder stability and how they relate to shoulder function.

Functional stability of the glenohumeral joint is achieved through the precise interaction of both static and dynamic stabilisers. Due to the anatomical configuration of the glenohumeral joint, static stability is compromised to allow for an increase in functional activities of the upper extremity. This compromise results in an increased demand of the dynamic shoulder stabilisers to control joint arthrokinematics.

**Static stabilisers**

Several passive mechanisms provide static stability of the glenohumeral joint (Wilk et al., 1997). The first mechanism is the osseous articulation between the humeral head and the glenoid fossa. The convex surface of the humeral head is approximately three to four times the size of the concave glenoid fossa, resulting in a significant amount of available activity in the serratus anterior: (1) a diagonal exercise with a combination of shoulder and horizontal flexion, and (2) external rotation and standing shoulder scaption above 120°. EMG activity was greater for both exercises than with traditional straight plane scapular protraction, suggesting that strengthening programmes for serratus anterior should incorporate an element of protraction combined with elevation.

**Lower trapezius**

Exercises designed to strengthen the lower trapezius are often desired in rehabilitation settings. One of the most effective exercises is the prone horizontal abduction with full glenohumeral external rotation. This exercise is often performed at 100–110° of abduction. However, Ekstrom et al. (2003) identified, with EMG analysis, the prone arm raise in line with the fibres of lower trapezius as the most effective exercise to recruit the lower trapezius. Thus it is important to watch the patient perform the exercise with direct visualisation of the scapula to determine the specific angle of lower trapezius insertion.

Cools et al. (2007) investigated the balance ratio of the scapular musculature during 12 commonly
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Involves the subscapularis and the posterior rotator cuff, the infraspinatus and teres minor. The second force couple of the glenohumeral joint involves the deltoid and the entire rotator cuff complex. These forces couples are active throughout the entire range of shoulder motion and serve to provide a dynamic symmetry of joint forces (Wilk et al., 1993).

The role of the surrounding glenohumeral musculature in dynamic stabilisation is multifactorial. The precise interaction of the anterior and posterior rotator cuff musculature as well as the prime movers and the stabilising rotator cuff musculature is vital for normal glenohumeral joint arthrokine-matics. The rotator cuff musculature also provides dynamic stabilisation through blending of the musculotendinous tissue within the shoulder capsule, the second component of dynamic stabilisation (Clark and Harryman, 1992). Therefore, contraction of the rotator cuff produces tension within the joint capsule, centring the humeral head within the glenoid.

The third component to active glenohumeral joint stability is neuromuscular control of the shoulder. Neuromuscular control may be defined as the efferent or motor, output in reaction to afferent, or sensory, input (Lephart et al., 1997; Wilk et al., 1997; Myers and Lephart, 2000). Thus, afferent input is comprised of the ability to detect glenohumeral joint position (proprioception) and motion (kinaesthesia) in space, with subsequent efferent output to produce dynamic joint stabilisation.

The component of neuromuscular control appears to be critical in normal function, and thus drills designed to enhance proprioception, kinaesthesia, and dynamic stabilisation are emphasised when designing rehabilitation programmes. Furthermore, exercises to promote muscular endurance may also assist in preventing abnormal glenohumeral joint translation by minimising muscle fatigue.

Aerobic exercise

It is important to consider aerobic exercises for the general health of any patient with shoulder pathology. After a shoulder injury, patients are generally recommended to remain active with activities such as walking, riding a bike or jogging.
SECTION 2: PRACTICAL USE OF EXERCISE

Functional rehabilitation of the shoulder: Clinical application of dynamic stabilisation

The rehabilitation process for shoulder injuries must include the restoration of ROM, muscular strength, muscular endurance, as well as a gradual restoration of proprioception, dynamic stability and neuromuscular control. As the patient advances, functional or sport-specific drills are emphasised to prepare for a gradual return to activity. Neuromuscular control drills are performed throughout and advanced as the patient progresses to provide continuous challenge to the neuromuscular control system. The following section provides an overview of a functional rehabilitation progression for patients following injury or operative procedure. The programme is divided into four separate phases with specific goals and criteria for advancement for each phase. The use of a criteria-based rehabilitation programme allows for its individualisation for each patient and specific pathology or surgical procedure. Alterations in exercise activities, positioning and rate of progression are based on the type of injury, surgical procedure performed, healing constraints involved and the tissues that are being stressed during rehabilitation.

Acute phase

The acute phase of rehabilitation begins immediately following injury or surgery. The duration of the acute phase is dependent on the healing constraints of the involved pathological tissues. Rehabilitation precautions will vary based on the exact pathology and any postoperative limitations. The initial goals of the acute phase are to diminish pain and inflammation, and progress to include the normalization of motion and muscular balance, and the restoration of baseline proprioceptive and kinaesthetic awareness.

ROM exercises are performed immediately in a restricted ROM, based on the theory that motion assists in the enhancement and organisation of collagen tissue and the stimulation of joint mechanoreceptors, and may assist in the neuromodulation of pain. The rehabilitation programme should allow for progressive applied loads, beginning with gentle passive range of motion. Active-assisted ROM exercises are instructed to the patient including cane or L-Bar (Breg Corporation, Vista, CA, USA) range of motion for flexion, external rotation, and internal rotation (Fig. 7.4). As the patient advances, flexion progresses as tolerated and shoulder rotation ROM is progressed from 0° of abduction to 30° and 45° of abduction. Also, pendulum, and rope and pulley, exercises are used as needed.

Self-capsular stretches may be performed for the anterior, posterior, and inferior glenohumeral joint complex as appropriate. Also, gentle joint mobilization and contract-relax or hold-relax stretching techniques may be performed during the early stages of rehabilitation for pain modulation and to maintain symmetrical capsular mobility.

Strengthening begins with submaximal, pain-free isometrics for shoulder flexion, extension, abduction, external rotation, internal rotation, and elbow flexion. Isometrics are used to retard muscular atrophy and restore voluntary muscular control, while avoiding detrimental shoulder forces. Isometrics should be performed at multiple angles throughout the available range of motion, with particular emphasis on contraction at the end of the currently available range of motion.

Manual rhythmic stabilisation drills are performed for the shoulder internal and external rotators with the arm in the scapular plane at 30° of
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able degrees throughout the available range of motion and notes the accuracy of the patient. Also performed during the acute phase is weight-bearing, or axial compression exercises. Initial exercises are performed below shoulder level, such as weight-bearing on a table while standing. The patient may perform weight shifts in the anterior/posterior and medial/lateral directions. Rhythmic stabilisations may also be performed during weight shifting. As the patient progresses, a medium-sized ball may be placed on the table and weight shifts may be performed on the ball. Weight-bearing exercises are progressed from the table to the quadruped position.

Once the acute pain has subsided, the patient may begin aerobic exercise such as walking, or riding on a stationary bike at low resistance. This can be progressed in intensity and duration according to the patient’s tolerance. Modalities including ice, high-voltage stimulation, ultrasound and non-steroidal anti-inflammatory medications may also be employed as needed to control pain and inflammation.

Intermediate phase

The intermediate phase begins once the patient has regained near-normal passive motion and sufficient balance of strength of the shoulder musculature. Baseline proprioception, kinaesthesia, and dynamic stabilisation are also needed before progressing, as emphasis will now be placed on regaining these sensory modalities throughout the patient’s full ROM, particularly at end range. The goals of the intermediate phase are to enhance functional dynamic stability, re-establish neuromuscular control, restore muscular strength and balance, and to regain and maintain full ROM.

ROM exercises are continued and the athlete is encouraged to perform active-assisted ROM with a cane or L-bar to maintain motion. External and internal ROM may be performed at 90° of abduction. Joint mobilisations and self-capsular stretches are performed as necessary to prevent asymmetrical glenohumeral joint capsular tightness.

Strengthening exercises are advanced to include external and internal rotation with exercise tubing at 0° of abduction and active ROM exercises against gravity. These exercises initially include...
Scapular strengthening and neuromuscular control are also critical to regaining full dynamic stability of the glenohumeral joint. The scapular functions to provide a stable base of support for distal upper extremity movement and serves as a site of attachment for the stabilizing musculature of the shoulder. Thus exercises are performed to enhance scapulothoracic function. Isotonic exercises for the scapulothoracic joint are performed as standing scaption in external rotation (full can) (Fig. 7.6), standing abduction, side lying external rotation, and prone rowing. As strength returns, the program may be advanced to a programme that includes full upper extremity strengthening with emphasis on posterior rotator cuff and scapular strengthening.

Isolated rhythmic stabilisation exercises are performed during the early part of the intermediate phase. Drills performed in the acute phase may be progressed to include stabilisation at end ranges of motion and with the patient’s eyes closed. Proprioceptive neuromuscular facilitation (PNF) patterns are performed in the patient’s available ROM and progressed to include full arcs of motion. Rhythmic stabilisations may be incorporated in various degrees of elevation during the PNF patterns to promote dynamic stabilisation.

Also performed during the intermediate phase is manual resistance to external rotation. By applying manual resistance to specific exercises, the rehabilitation specialist can vary the amount of resistance throughout the range of motion and incorporate concentric and eccentric contractions, as well as rhythmic stabilisations at end range (Fig. 7.7). The application of manual resistance assists in the reinforcement of proper resistance, form, and cadence based on the symptoms of each patient. As the patient regains strength and neuromuscular control, external and internal rotation with tubing may be performed at 90° of abduction (Fig. 7.8). All stabilization drills may be advanced by removing the patient’s visual stimulus.
and quadruped exercises using a towel around the hand, slide board or unstable surface.

Aerobic exercise can be progressed to moderate intensity exercises such as jogging or exercising on a cross-training machine such as an elliptical trainer. The patient may find it more comfortable to start on the elliptical with the arms stabilized, working the legs only. The upper extremities can be gradually incorporated into the exercise according to the patient’s tolerance.

**Advanced phase**

The third phase of a functional rehabilitation programme, the advanced phase, is designed to advance the patient through a series of progressive strengthening and neuromuscular control activities, while preparing the patient to begin a gradual return to full activity. Criteria to enter this phase include minimal pain and tenderness, full ROM, symmetrical capsular mobility, good (4/5 on manual muscle testing) strength and endurance of the upper extremity and scapulothoracic musculature, and sufficient dynamic stabilisation.

Full motion and capsular mobility are maintained through ROM and self-stretching techniques. These include manual stretching and L-bar exercises. Specific emphasis on soft tissue mobility of the posterior musculotendinous structures should be made through exercises such as horizontal adduction stretching while stabilising the scapula (Fig. 7.11).

Strengthening exercises for the entire shoulder complex as well as exercises for the lower extremities and trunk are continued with a gradual increase in resistance. Exercises such as internal and external rotation with exercises tubing at 90° of abduction may be progressed to also incorporate eccentric and higher speed contractions. Aggressive strengthening of the upper body may also be initiated depending on the needs of the individual patient. Common exercises include isotonic weight machine exercises such as bench press, seated row, and latissimus pull downs within a restricted ROM. During bench press and seated row, the patient is instructed to not extend the upper extremities beyond the plane of the body to minimise stress of the shoulder capsule. Latissimus pull downs are performed in front of the head and the patient is instructed to avoid full
extension of the arms to minimise the amount of traction force applied to the upper extremities.

Plyometric activities for the upper extremity may be initiated during this phase as well to train the upper extremity to produce and dissipate forces. Plyometric exercises are initially performed with two-hands. Specific exercises include a chest pass, overhead throw, and alternating side-to-side throw with a 1–2 kg (or 3–5 lb) medicine ball. Two-hand drills are progressed to one-hand drills as tolerated by the athlete, usually between 10 and 14 days following the initiation of two-hand drills. Specific one-hand plyometrics include baseball style throws in the 90/90 position with a 1 kg (or 2 lb) ball (Fig. 7.12) and stationary and semi-circle wall dribbles. Wall dribbles are also beneficial to increase upper extremity endurance while overhead and may be progressed to include dribbles in the 90/90 position.

Axial compression exercises are progressed to include the quadruped and tripled positions. Rhythmic stabilisations of the involved extremity as well as at the core and trunk may be applied. Unstable surfaces, such as tilt boards, foam, large exercise balls, or the Biodex stability system (Biodex Corp., Shirley, NY, USA) may be incorporated to further challenge the patient’s stability system while in the closed chain position (Figs 7.13 and 7.14). Rhythmic oscillations may also be incorporated into the exercise programme through the use several tools such as the Bodyblade (Hymanson Inc., Playa Del Ray, CA, USA), Thera-Band® Resistance Bar (Thera-Band, Akron, OH, USA), or other manufactured or self-made devices. Rhythmic oscillations can be incorporated into exercise tubing and manual resistance exercises to develop stability and muscular endurance in a variety of positions. Oscillations may also be performed during quadruped or tripled exercises using the uninvolved extremity.

Dynamic stabilisation and neuromuscular control drills are progressed to include reactive neuromuscular control drills and functional, sport-specific positions. Concentric and eccentric manual resistance may be applied as the patient performs external rotation with exercise tubing with the arm at 0° of abduction. Rhythmic stabilisations may be
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Bilateral shoulder rotator cuff impingement

These drills are designed to impart a sudden perturbation to the throwing shoulder at near end range to develop the athlete’s ability to dynamically stabilise the shoulder to prevent the shoulder from translating into excessive ranges of motion.

Near the end of the advanced phase, the patient may begin basic sport-specific drills. Various activities such as underweight and overweight ball throwing or swinging for baseball, golf, and tennis players may be performed. Upper extremity aerobic activities such as swimming or rowing can be initiated.

Return to activity phase

Upon the completion of the previously outlined rehabilitation programme and the successful evaluation of the injured shoulder, the patient may begin the final phase of the rehabilitation programme, the return to activity phase. Specific criteria during the clinical exam that needs to be met to begin an interval return to work or sport programme include minimal complaints of pain or tenderness, full ROM, balanced capsular mobility, adequate proprioception, dynamic stabilisation, and neuromuscular control, and full muscular strength and endurance based on an isokinetic examination.

Several authors have advocated an interval return to sport activities (Axe et al., 1996; Ellenbecker and Mattalino, 1997; Axe et al., 2001; Wilk et al., 2001; Reinold et al., 2002). Interval sport programmes are designed to gradually return motion, function and confidence in the upper extremity after injury or surgery by slowly progressing through graduated sport-specific activities. These programmes are intended to gradually return the overhead athletes to full athletic competition as quickly and safely as possible. An athlete is allowed to begin an interval sport programme following a satisfactory clinical examination.

Conclusion

The shoulder joint complex is inherently unstable and must interact with the neuromuscular control included at end range to challenge the patient to stabilise against the force of the tubing as well as the therapist. This exercise may be progressed to the 90/90 position to require the patient to stabilise the shoulder at end range in a more sport-specific position (Fig. 7.15). Also, rhythmic stabilisations may be applied at end range during the 90/90 wall dribble exercise. The patient performs a predetermined number of repetitions before the therapist implies a series of rhythmic stabilisations at external rotation end range. These drills are designed to impart a sudden perturbation to the throwing shoulder at near end range to develop the athlete’s ability to dynamically stabilise the shoulder to prevent the shoulder from translating into excessive ranges of motion.

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system to perform optimally while minimising the risk for injury. Based on a sound understanding of the anatomy and biomechanics of the shoulder joint, comprehensive rehabilitation should include proprioception, dynamic stabilisation, and neuromuscular control drills to establish full range of motion, balanced capsular mobility, and maximal muscular strength and endurance. A functional approach to rehabilitation, using activity-specific exercises, minimises injury risk and ensures a gradual return to activity.

SECTION 3: CASE STUDIES AND STUDENT QUESTIONS

Case study 1

Impingement

A 35-year-old man presents with a complaint of right shoulder pain and stiffness following a weekend of home redecorating and painting 3 weeks ago. During the week he works at a computer for the majority of the day. Examination reveals a forward head posture with increased thoracic kyphosis and protracted, anterior-tilted scapula, superior pain with end range right shoulder flexion, weak and painful right full-can and external rotator strength (4/5) and decreased strength of the scapular retractors and upward rotators (4/5). Flexibility testing reveals decreased length of the pectoral muscles and anterior cervical musculature. Cervical mobility is within normal limits and pain-free.

Management

This patient presents with clinical findings suggestive of impingement syndrome, with symptoms exacerbated by a weekend of intense and repetitive upper extremity activity. The early stage of rehabilitation should include postural retraining with exercise activities to address cervico-thoracic and scapular alignment, stretching of the pectoral muscles, and initiation of basic rotator cuff strengthening. Patient education should focus on proper reach technique to avoid provoking positions/activities. Other modalities such as ice, ultrasound, electrical stimulation or non-steroidal anti-inflammatory may be used for symptom management.

As the acute reactivity calms and full pain-free ROM returns, the patient moves into the intermediate phase of rehabilitation, during which rotator cuff and scapular strengthening is advanced with increased level of resistance and position from neutral to shoulder height and above. Focus is placed on proper postural alignment and scapulohumeral rhythm during each exercise activity. Emphasis is placed on strengthening the external rotators and lower trapezius.

The advanced phase of rehabilitation should focus on strength and control through functional ranges for tasks such as overhead reaching, lifting, pushing and pulling. PNF D2 patterns may be helpful in engaging multiple muscle groups, including supportive trunk musculature. The patient should be observed performing overhead tasks with attention paid to postural alignment and proper scapulohumeral control.

As the patient gradually returns to his normal daily and recreational activities, he should continue a basic exercise regimen to minimise return of symptoms or a re-injury.
Case study 2

Instability

An 18-year-old female cheerleader presents with recurrent anterior glenohumeral subluxations, which limits her ability to participate in cheerleading. She has had three subluxations over the past year. Examination reveals excessive ROM in all directions with multi-directional glenohumeral joint laxity. She is also systemically hypermobile. She has decreased external rotation and flexion strength (4−5/5) and poor scapular stability with scapular winging at rest, which is increased with upper extremity weight-bearing and resisted shoulder testing.

Management

Early treatment of this patient needs to address her issues of rotator cuff and peri-scapular muscle control. Postural education with a focus on activation of middle and lower trapezius to achieve neutral scapular positioning can be initiated in side lying. Stabilization and activation of these muscles can be progressed into manually resisted PNF diagonal patterns. Rhythmic stabilisation exercises for internal/external rotators can be performed with manual resistance in supine with the shoulder in resting position (scapular plane, 30° of abduction). Similarly, rhythmic stabilisation can be performed in elevation (supine 100° of flexion, slight horizontal abduction). An important consideration throughout this patient’s rehab is the strength and control of her core trunk and lower extremities. Initially any strength deficits can be worked on in isolation, but must be integrated with the shoulder in the later stages of treatment.

Once the patient is able to consistently stabilise her scapula and humeral head, resistance can increase to isotonic exercises in standing, side lying and prone. Weight and elastic resistance can be progressed as tolerated. Initial focus of this phase, however, should be on form and control with lower load and higher repetition.

Weight-bearing exercises can also be initiated at this point to further challenge the patient’s stability while recruiting multiple large and small muscle groups around the shoulder and creating axial compression. These exercises should start below shoulder height on a stable surface but need to be progressed to and above shoulder height. Decreasing the stability of the surface and/or adding manual resistance can add further challenge.

The final phase of rehabilitation for this patient needs to prepare her for a return to sports. Strengthening exercises from earlier phases can be progressed in terms of resistance (with decreased repetitions), but they also must be taken through larger ROMs (e.g. PNF shoulder diagonals). The patient should gradually resume individual activities in practice and eventually progress to full participation with other team members.

Case study 3

Proximal humeral fracture

A 72-year-old woman presents with a right proximal humeral fracture following a fall on ice 6 weeks ago. Examination reveals limited active and passive range of motion of the shoulder in all planes and increased kyphotic posture and forward head. She appears guarded with basic mobility tasks using her right upper extremity.

Full shoulder strength testing deferred given fracture status but rotator cuff appears intact (negative drop arm and lag tests).

Management

The patient is referred to physiotherapy, following a period of prolonged immobilization in a sling.
Case study 3—cont’d

During this period the patient performed gentle elbow motion out of the sling to minimize stiffness and frequent ball squeezes to promote circulation.

During the initial phase of rehabilitation and mobilisation the patient is instructed in pendulum exercises and scapular retraction with sternal elevation exercises. Passive ROM exercises are initiated with caution regarding pain and the principles of bony healing, given patient’s age, severity of fracture and location of fracture site. Joint mobilisations are also avoided at this point for the same reason. Flexion, external rotation and internal rotation are the primary motions of focus during this phase.

During the intermittent phase (usually determined by bony healing via X-ray) the focus is shifted to active-assist and active ROM with an emphasis on functional tasks to increase the patient’s confidence and use of the right extremity for activities of daily living. Interventions can range from supine active-assistive exercises (similar to passive exercises) to side lying and standing active motions. Patient position is manipulated to vary the effect of gravity on the arm in order to increase or decrease the challenge to the shoulder musculature. To further improve the functional benefit of these types of exercises, the patient can be given objects or targets to reach and/or grasp towards the limits of her ROM. The use of PNF diagonals can also be helpful in this regard.

During the advanced phase, once good bony healing has occurred, basic rotator cuff and scapular strength is initiated. Attention should be paid to scapular alignment and mechanics to optimise available upper quarter motion. These exercises are begun at the patient’s side and progressed to elevated positions as the patient’s control and tolerance improves. Depending on the extent of pain or weakness, these exercises may need to be progressed from isometric to isotonic exercises. PNF patterns with manual resistance, and eventually band or weight resistance, may also be beneficial.

Student questions

(1) Describe the three components of humerothoracic motion and one specific pathology or impairment that could impact each.

(2) List the capsule-ligamentous structures of the glenohumeral joint and the respective motions that excessive tightness in each would restrict.

(3) Describe an appropriate intervention for tightness in each of the capsular regions of the glenohumeral joint.

(4) Describe factors that would influence clinical decision making around in the intensity of ROM/stretching exercise.

(5) Why is the ‘full-can’ exercise preferable to the ‘empty-can’ exercise?

(6) List exercises most effective in eliciting the external rotators of the shoulder.

(7) List strengthening exercises that optimise a proper balance ratio of the peri-scapular musculature.

(8) List the static and dynamic stabilisers of the shoulder.

(9) Describe important force couples of the shoulder.

(10) Outline goals and treatment progression of an overhead athlete in the return to activity phase of rehabilitation.

References


SECTION 1: INTRODUCTION AND BACKGROUND

It is essential that the elbow and forearm complex, an important link in the upper kinetic chain, functions optimally in order to enable participation in activities of work, sport, leisure and daily living. This region is more commonly afflicted by overuse or insidious injuries of the soft tissues (e.g., tennis elbow, medial ulnar collateral ligament (UCL) instability) than by fractures and dislocations. However, it is noteworthy to consider that the latter can be very debilitating and challenging to rehabilitate.

Restoration of function and participation in activities of daily living following any injury to the elbow and forearm are largely achieved through exercise therapy. The successful application of exercise therapy is reliant upon the selection of specific exercises to bring about adaptations that are commensurate with goals of rehabilitation that have been agreed on by the patient and practitioner. Exercise therapy for the elbow and forearm can be compartmentalised using an outcome-based perspective (schema) into the following categories: (1) exercises geared at improving general aerobic fitness; (2) exercises that aim to restore muscle length and joint range of motion; (3) exercises that aim to improve endurance, strength and power of elbow and forearm muscles; and (4) exercises that seek to normalise elbow and forearm co-ordination and proprioception.

Regardless of the focus of the exercise, there are some fundamental principles that must be followed for effective application of exercise therapy. An initial assessment is mandatory in order to establish baseline measures of performance and to identify specific deficits and impairments that need to be addressed. This requires assessment of local and regional muscle performance as well as global function and work/sport specific skills. For example, optimal assessment of a tennis player may require analysis of the different tennis strokes to identify muscle weakness and/or problems with co-ordination that can be addressed with exercise therapy. Continual assessment must also occur throughout the rehabilitation programme to ensure correct exercise performance and to determine the need for exercise progression or modification. At both the initial and follow-up assessments, it is important to ascertain the phase of healing and degree of severity of the condition in terms of impairments in the neuro-musculoskeletal and sen-
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The elbow is an inherently stable joint due to the congruency of its articulations. The primary restraints of the elbow include the ulnohumeral joint and collateral ligaments, and the secondary restraints include the radial head, flexor pronator origin, common extensor origin and joint capsule (Saati and McKee, 2004). The UCL provides approximately 54% of the elbow’s resistance to valgus forces, followed by the articulation of the radial head with the capitellum and proximal ulna (Morrey and An, 1983; Cook and McKee, 2003).

In order to cover exercise therapy for musculoskeletal conditions of the elbow and forearm complex, it is instructive to discuss a range of disorders from acute traumatic injuries of the bone and ligaments through to overuse injuries of the soft tissues. This chapter will review the epidemiology, aetiology, neuro-musculoskeletal and pain system impairments, and evidence for exercise therapy for fracture and dislocation of the elbow, ligament injuries and tennis elbow. Impairments that relate to these conditions and are relevant to exercise will be highlighted. In brief, the sequelae of the acute management of fracture/dislocations, which requires some period of immobilisation, will require exercises that focus on regaining range of motion and strength. In contrast, overuse/insidious onset injuries will focus less on range of motion and more on somatosensory systems. These factors are critical in planning, implementing and monitoring exercise prescription and progression. All exercises should be pain-free and performed with correct trunk and upper limb alignment. If these criteria are not met, exercises must be adjusted by altering exercise parameters such as the amount of resistance, degree of difficulty and patient position.

Interestingly, as opposed to the spine, there appears to be little emphasis on the benefits of general aerobic exercises for individuals with elbow and forearm conditions. Notwithstanding this, it is important to consider general body fitness (i.e. aerobic, anaerobic) as well as forequarter fitness (i.e., strength, endurance, posture) when managing patients with isolated injuries to the elbow and forearm.

The prescription of exercises for musculoskeletal disorders of the elbow and forearm complex requires the practitioner to be cognisant of salient elbow and forearm anatomy (Fig. 8.1). In brief, the elbow comprises three distinct articulations: the radiocapitellar (radiohumeral), ulnotrochlear (ulnohumeral), and proximal radioulnar joints. The two principal arcs of motion are flexion (135–145°)/extension (0–5°) and supination (85°)/pronation (75°) (Oatis, 2004; Lockard, 2006). In day-to-day function most people only use 30–130° of extension/flexion and 50° pronation/supination; however, athletes often require much more (Morrey et al., 1981; Wilk et al., 1993). The elbow is an inherently stable joint due to the congruency of its articulations. The primary restraints of the elbow include the ulnohumeral joint and collateral ligaments, and the secondary restraints include the radial head, flexor pronator origin, common extensor origin and joint capsule (Saati and McKee, 2004). The UCL provides approximately 54% of the elbow’s resistance to valgus forces, followed by the articulation of the radial head with the capitellum and proximal ulna (Morrey and An, 1983; Cook and McKee, 2003).

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on restoring muscle strength, endurance and power, and retraining co-ordination and proprioception. Thus, this chapter will provide practical guidelines for exercise prescription for post fracture/dislocation of the elbow, ligamentous instability of the elbow and tennis elbow.

**Acute traumatic injuries of bone and ligaments**

The elbow is the second most commonly dislocated joint in adults (Sobel and Nirschl, 1996) and the most commonly dislocated joint in children (Sobel and Nirschl, 1996; O’Driscoll, 2000), with dislocation typically occurring in a posterior or posterolateral direction. Elbow dislocations are most prevalent in sports such as cycling, gymnastics, football and wrestling (Sobel and Nirschl, 1996), and are commonly caused by a fall on the outstretched hand, hyperextension of the elbow, or a combination of valgus, supination and external rotation of the forearm during axial loading (Sheps et al., 2004). The structures involved in an elbow dislocation vary (Sheps et al., 2004) and may include rupture or avulsion of the collateral ligaments, tearing of the capsule or brachialis muscle and fracture of the medial epicondyle (Mehlhoff et al., 1988; Hotchkiss, 1997; O’Driscoll, 2000). Isolated dislocation of the radial head is unlikely, although subluxation of the radial head may present in young children (Sobel and Nirschl, 1996). To optimise outcomes, the specific structures damaged must be taken into consideration when planning rehabilitation.

A radial head fracture is the most common fracture in the elbow (Herbertsson et al., 2005; Bano and Kahlon, 2006). The mechanism of injury for fractures is similar to that for dislocations (e.g. a fall on the outstretched hand with forearm in pronation) (Herbertsson et al., 2005; Bano and Kahlon, 2006). Radial fractures in the presence of an elbow dislocation are often accompanied by a fracture of the coronoid process and damage to the collateral ligaments (Regan and Morrey, 1989). Appropriate management of this injury is essential to avoid chronic instability (Bano and Kahlon, 2006). In adolescents, a valgus stress from a fall or muscle contraction may result in a fracture through the epiphyseal plates of the medial epicondyle. Diagnosis of a fracture is confirmed by radiographs.

Although there is a dearth of studies outlining the best practice approach to managing acute elbow injuries, it is generally agreed that a stable reduction post-dislocation and/or a stable fracture site is best managed conservatively (i.e. casting/bracing), and unstable injuries are best managed with open reduction and internal fixation (Case and Henrikus, 1997; Frankle et al., 1999; Ross et al., 1999; Liow et al., 2002; Saati and McKee, 2004; Sheps et al., 2004; Bano and Kahlon, 2006).

The long-term sequelae of acute traumatic injuries of the elbow include loss of range of motion (particularly extension), decreased force production, recurrent instability, heterotopic ossification, neurovascular problems and chronic pain (Protzman, 1978; Case and Henrikus, 1997; Frankle et al., 1999; Liow et al., 2002; Sheps et al., 2004; Casavant and Hastings, 2006). The degree of loss of motion is related to the duration of elbow immobilisation (Protzman, 1978). Heterotopic ossification in soft tissues is more common following a severe injury with concomitant neural or thermal injuries, and presents with progressive loss of range of motion and/or difficulty in regaining range of motion (Casavant and Hastings, 2006). Although there is a lack of quality clinical trials examining the most appropriate management of heterotopic ossification, there is some evidence to suggest that it is not exacerbated by early movement (Wharton and Morgan, 1970; Stover et al., 1975).

**The evidence for exercise therapy post-dislocation and fracture**

The evidence base for the rehabilitation of elbow dislocations is limited to non-randomised case series and review papers. It suggests that early active/active-assisted range of motion exercises are essential for the restoration of elbow function (Ross et al., 1999) and are associated with good long-term results and low risk of re-injury (Mehlhoff et al., 1988).

An early range of motion protocol is also considered to be optimal for stable fractures that have been managed non-operatively and fractures in which a congruous reduction and stable fixation have been attained. Early active mobilisation is imperative to avoid complications associated with immobilisation, such as pain and loss of motion.
Exercise Therapy in the Management of Musculoskeletal Disorders

Exercise Therapy in the Management of Musculoskeletal Disorders

Joint space (Popovic et al., 2001; Sasaki et al., 2002), joint effusions and loose bodies (Popovic et al., 2001).

The evidence for exercise therapy in unstable elbows

The majority of articles on UCL injuries are clinical commentaries that recommend initial conservative management, followed by surgical intervention if unsuccessful (Field and Savoie, 1998; Hyman et al., 2001; Cain et al., 2003; Safran et al., 2005b; Nassab and Schickendantz, 2006). Rettig et al. (2001) evaluated a conservative rehabilitation programme that involved rest, splinting/bracing (protecting against valgus stress and elbow extension), anti-inflammatory medication, ice, active and passive range of motion exercises for the flexor and pronator muscles, strengthening of the upper extremity muscles and progressive throwing. They found that 42% of athletes were able to return their pre-injury level of competition.

Overuse injuries of elbow ligaments

Injury to the UCL is common in sports that involve repetitive valgus stress to the elbow (Safran and Baillargeon, 2005a; Safran et al., 2005b,c; Nassab and Schickendantz, 2006) (e.g. baseball pitchers due to the large valgus forces incurred when the arm moves from humeral external rotation and elbow flexion to humeral internal rotation and elbow extension during the late cocking and early acceleration phases of throwing) (Callaway et al., 1997; Azar et al., 2000; Cain et al., 2003; Nassab and Schickendantz, 2006). Apart from the UCL, valgus stress may also result in trauma to other structures, such as ulnar nerve, medial head of the triceps, insertion of the wrist flexor and forearm pronator muscles and medial epicondyle (Safran and Baillargeon, 2005a; Safran et al., 2005b,c; Nassab and Schickendantz, 2006). Laxity of the UCL has been shown to alter the articulation between the posteromedial trochlea and olecranon and lead to the development of osteophytes and loose bodies (Ahmad and ElAttrache, 2004a; Ahmad et al., 2004b).

Physical examination of the athlete with an UCL injury typically reveals palpable tenderness approximately 2 cm distal to the medial epicondyle (Safran and Baillargeon, 2005a; Safran et al., 2005c) and a positive valgus stress test (Hyman et al., 2001). Radiography and arthroscopy may also assist in the diagnosis of an UCL injury; but their diagnostic accuracy is questionable in baseball and team handball players, because non-injured elbows may also exhibit significant wider medial elbow

Joint space (Popovic et al., 2001; Sasaki et al., 2002), joint effusions and loose bodies (Popovic et al., 2001).

Tennis elbow

Tennis elbow is largely a clinical diagnosis characterised by pain over the lateral elbow that is typically aggravated by gripping activities. It tends to occur in the dominant upper limb, most commonly in those aged between 40 and 50 years and of either gender, being most prevalent in jobs requiring repetitive manual tasks (as high as 35–64% of all cases) (Kivi, 1982; Dimberg, 1987; Feuerstein et al., 1998). Most importantly, it is one of the most costly of all work-related illnesses (Kivi, 1982; Dimberg, 1987; Feuerstein et al., 1998) and restricts function in all aspects of life.

The nomenclature and underlying pathology of tennis elbow are intertwined and impact on the concepts of treatment (Vicenzino and Wright, 1996; Khan et al., 2002). Tennis elbow has been called lateral epicondylitis, lateral epicondylosis and extensor tendinosis. The term epicondylitis infers inflammation, which is inaccurate in this condition, as a number of studies have found no signs of inflammation (Nirschl and Pettrone, 1979; Regan et al., 1992; Potter et al., 1993; Kraushaar and
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This study showed that the physiotherapy programme was superior to the wait-and-see approach and similar to corticosteroid injections in the short term (6 weeks) (Hay et al., 1999; Smidt et al., 2002). However, an important finding in our study was that over a 12-month period, physiotherapy was responsible for far fewer recurrences, fewer consultations to medical practitioners and increased grip strength compared with corticosteroid injections (Bisset et al., 2006a), a finding consistent with the suggestion of a protective effect of exercise (Pienimaki et al., 1996, 1998). Pienimaki et al. (1996) compared the effects of a graduated progressive exercise programme of strengthening and stretching to ultrasound over 6–8 weeks in 36 patients with chronic tennis elbow that was refractory to many other treatments including physiotherapy and corticosteroid injections. This study reported a statistically significant but small beneficial effect of exercise on resting pain. A recent systematic review of eccentric-only exercise concluded that due to the small number of trials and very large confidence intervals, it was difficult to draw any conclusions on the efficacy of eccentric exercise in tennis elbow (Woodley et al., 2007).

A number of impairments affecting the neuromuscular and sensorimotor systems have been identified in people with tennis elbow including: reduced pain-free gripping capacity; bilateral abnormal wrist posture during these gripping tasks; bilateral deficits in reaction time and speed of movement of the upper limb; and abnormal motor control of the forearm muscles in a tennis backhand stroke (Kelley et al., 1994; Pienimaki et al., 1997a; Bisset et al., 2006b). These deficits and abnormalities can be addressed with specific exercise prescription.

The evidence for exercise in tennis elbow

A number of systematic reviews have identified that studies generally lack high methodological quality and standardised outcomes, which make it difficult to determine the efficacy of exercise (Bisset et al., 2005; Woodley et al., 2007). The literature on exercise in tennis elbow appears to focus on two forms of exercise: a combination of isometric, concentric and eccentric contractions and eccentric-only exercise. Programmes that involve isometric, concentric and eccentric exercises for the forearm muscles are usually accompanied by other physical therapy interventions such as friction massage, manipulation or ultrasound. As such, it is difficult to determine how much of the treatment effects are due solely to exercise. Our recent randomised clinical trial in 198 subjects studied the efficacy of a physiotherapy programme of manual therapy and exercise compared with a corticosteroid injection and a wait-and-see approach (Bisset et al., 2006a).

SECTION 2: PRACTICAL USE OF EXERCISE

Practical guidelines for exercise therapy post-dislocation and fracture

Range of motion and flexibility

Active-assisted range of motion exercises can begin as early as pain and inflammation allow (usually
1–5 days post-reduction/operation). These exercises typically start with elbow flexion/extension through pain-free range of motion with the forearm in neutral supination/pronation. This can often be best achieved in a gravity-eliminated position. For example, elbow flexion can be done in supine and elbow extension can be done in sitting. A general guideline for prescription is 5–10 repetitions every 2–3 hours with progression to 15–20 repetitions hourly. Range of motion exercises for the uninvolved joints of the upper limb should also be performed.

Within the first week, exercises should be progressed to active range of motion against gravity. If the elbow remains unstable or required open-reduction with internal fixation, the patient may be required to exercise within a valgus-restricting brace. In the presence of lateral instability due to associated soft tissue injury, exercises should be performed in forearm pronation to provide maximum stability and avoid excessive load on the radiocapitellar joint (Chinchalkar and Szekeres, 2004; Sheps et al., 2004). When the elbow is stable, active-assisted supination/pronation can be commenced with the elbow positioned in 90° flexion. At approximately 4 weeks, range of motion exercises can be progressed to low load stretches sustained for 20 seconds and repeated 4–5 times (Davila and Johnston-Jones, 2006); however, this should be initiated after strengthening is underway to minimise applying a stretch overload to healing tissue. Proprioceptive neuromuscular facilitation stretching (e.g., hold-relax, contract-relax) can also be used to improve flexibility of muscles at this point.

### Strengthening

The progression of strength training can be divided up into a number of phases based on tissue healing and stability of the elbow joint. Early in the programme, exercises will focus on improving or maintaining strength in adjacent joints (i.e. the shoulder, scapula and wrist) with gradual addition of the exercises at the elbow.

#### Early resolution phase (0–4 weeks)

Shoulder and scapular strengthening, isometric wrist flexion/extension and radial/ulnar deviation can begin within the first 2 weeks. Isometric exercises should be performed at multiple points through available range of motion. Contractions should be pain-free and sub-maximal with slow onset and offset.

#### Consolidation phase (4–8 weeks)

Initially exercises will be isometric with progression to isotonic exercises and gradual addition of load in 0.5–1 kg increments. Submaximal isometric elbow exercises can begin at 3–4 weeks if the elbow is stable or at 4–6 weeks if it is unstable. Once bone healing is deemed adequate (usually around 4–8 weeks), resistive exercises can be commenced. Initial prescription of approximately 1–3 sets of 15–20 repetition maximum (RM) daily will promote endurance adaptations (Table 8.1) while avoiding overload to the injured tissues. Examples of appropriate strengthening exercises for the biceps and triceps muscles are shown in Figures 8.2 and 8.3, respectively. Light throwing activities may also be commenced at approximately 6 weeks in an athlete with a stable medial epicondyle fracture (Davila and Johnston-Jones, 2006).

#### Restoration phase (8–12 weeks)

Exercises can be progressed by increasing resistance and speed to improve strength and power (Table 8.1), and closed kinetic chain exercises, such as wall or floor push-ups (Fig. 8.4) can be introduced. Different types of resistance can be used including free weights (Figs 8.2 and 8.3), pulleys, elastic

<table>
<thead>
<tr>
<th>Desired adaptation (goal)</th>
<th>Prescription: guiding principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance</td>
<td>15–20 RM × 1–3 sets; 30–60 seconds rest between sets</td>
</tr>
<tr>
<td>Strength</td>
<td>3–8 RM × 3–5 sets; 3–5 minutes rest between sets</td>
</tr>
<tr>
<td>Power</td>
<td>1–3 RM × 3–5 sets; 5–8 minutes rest between sets; explosive tempo</td>
</tr>
</tbody>
</table>

RM = repetition maximum.

Bird et al., 2005.
Figure 8.2 Concentric/eccentric contraction of biceps muscle using a free weight. The patient is standing with the elbow extended at her side. The elbow is flexed to full flexion range of motion (mid-position shown) and returned to the starting position.

Figure 8.3 Concentric/eccentric contraction of the triceps muscle using a free weight. The starting position is shown (i.e. the patient is in supine with the shoulder in 90° flexion and the elbow pointing towards the ceiling). The elbow is extended so the arm is vertical and then returned to the starting position.

Figure 8.4 Wall push-ups to strengthen triceps, shoulder and scapular muscles. The patient stands with the hands against the wall shoulder-width apart or slightly wider and elbows near extension. The elbows are flexed and the body approaches the wall (a). To increase the challenge to the sensorimotor system this exercise can be performed on a ball (b) or two rubber discs (c), and to increase the amount of load applied through the upper limb, the feet can moved further way from the wall or the push-up can be performed against the floor.
handholds can also be used during this stage of rehabilitation to improve upper limb endurance.

Work and/or sport-specific phase
Once range of motion and strength are within 10% of the unaffected side, training of sport-specific activities can commence (Davila and Johnston-Jones, 2006). During these exercises, taping or bracing may be used to protect the joint from unexpected stress or overload. Exercises to prepare the individual to return to work should replicate specific work requirements, such as lifting, carrying, pushing, pulling and use of tools.

**Practical guidelines for exercise therapy in unstable elbows**

**Strengthening**
Protection of the UCL is a priority in the initial stages of rehabilitation. This can be achieved with taping or bracing to protect the UCL and elbow from unwanted stress, restricting activities that
apply a valgus strain to the elbow and by avoiding passive elbow motion (Armstrong et al., 2000).

Exercises for the musculoskeletal system should involve muscles that provide medial stability to the elbow joint, such as flexor carpi radialis (Figs 8.7 and 8.8) and pronator teres (Fig. 8.9 and see also 8.12 below), as well as muscles that primarily act at the elbow joint, such as biceps brachii (see Fig. 8.2) and triceps brachii (see Fig. 8.3), and muscles in adjacent areas (i.e. the shoulder, scapula and trunk). Exercises for these muscles may initially be isometric and progression to isotonic with gradual addition of resistance using free weights (see Figs 8.2 and 8.3) or elastic tubing (Figs 8.7-8.9). The amount of resistance used and number of times the exercise is repeated will depend on the goal of the exercise (see Table 8.1) and what the patient is able to perform without producing pain.

Exercises are relatively simple initially, but as the integrity of the ligament and elbow joint improves exercises are progressed to become more complex and achieve concurrent strength, power and sensorimotor adaptations. For example, medicine ball throws (see Fig. 8.5) and high-speed humeral rotations (Fig. 8.10) train strength and power of the upper limb muscles, stability of the scapula and trunk, and proprioception. Eventually the focus turns to function and return to work and/or sport. Exercises to prepare athletes for return to sport may include throwing and tennis strokes (i.e. serving, forehand and backhand) of progressively increased distance and speed and altered predictability. Examples of exercise progressions from simple to
more complex to functional for a throwing athlete are outlined in Table 8.2.

*Proprioception*

In contrast to the considerable evidence from other areas of the body implicating joint position sense deficits (Willems *et al.*, 2002; Bonfim *et al.*, 2003) and muscle reaction time impairments (Konradsen and Ravn, 1991; Bonfim *et al.*, 2003) following ligament injuries, there is a lack of similar evidence following an UCL injury. Not surprisingly then, proprioceptive retaining is commonly lacking from conservative management approaches.

There is evidence to suggest that activation of the wrist and forearm muscles is altered in athletes with UCL injuries, for example reduced activity of the flexor and pronator muscles (Glousman *et al.*, 1992; Hamilton *et al.*, 1996) and increased extensor muscle activity (Glousman *et al.*, 1992) with valgus stress at the elbow during throwing. As these muscles contribute to medial elbow stability (Hamilton *et al.*, 1996), we recommend retraining activation of these muscles.

Exercises for the sensorimotor system should include closed-kinetic chain exercises to increase neural input to the area, joint position sense and muscle reaction time retraining. Closed kinetic chain exercise may simply involve weight-bearing through the affected limb, and difficulty can be increased by altering surface compliance/predictability (i.e. firm surface, foam surface or ball), increasing load (i.e. leaning against a wall, four-point kneeling or a floor push-up position), adding movement (i.e. rolling a ball or performing a push-up) and increasing speed of movement (Fig. 8.4). Joint position sense retraining involves the therapist positioning the athlete’s limb in a certain position (i.e. 70° of elbow flexion) and then the athlete relocating this position independently. This should be performed with the athlete’s eyes closed, and measuring the difference between the target and achieved position can assess accuracy. This retraining can be progressed by altering amount of external input (i.e. supine with the arm on a bed or standing with the arm unsupported), shoulder position and speed of movement.

**Practical guidelines for exercise in tennis elbow**

A graduated progressive exercise programme is essential to resolve symptoms, as well as prevent chronicity and recurrence (Pienimaki *et al.*, 1996; Pienimaki *et al.*, 1998). The key to success is early management of overall load at the involved muscles and tendons. This requires the practitioner to
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related tasks may have to be reduced or modified if painful. Tasks may be modified to reduce load and pain by lifting objects with a less forceful grip, having the forearm supinated rather than pronated and ensuring that the overall posture of the forequarter is such that the forearm extensors are not being used inappropriately (e.g. if the upper limb is held in internal rotation) (Vicenzino, 2003).

Strengthening

The management of tennis elbow can be divided into two phases: the restoration of pain-free muscle performance (i.e. strength and endurance) and the restoration of functional performance. The muscle performance restoration phase involves reduction of pain and improvement of pain-free grip strength to within approximately 80% of the unaffected side. Once pain is absent or difficult to exacerbate, the rehabilitation program focuses on higher order strengthening exercises and functional tasks. The functional restoration phase will improve strength to that of the unaffected side (or >110% if affected side is dominant) and incorporate specific functional activities.

Restoration of pain-free muscle performance
(approximately 6–8 weeks)

Due to the intricately involved pain system in tennis elbow, it is our contention that exercise should be conducted without reproduction of the patient’s pain. Within the confines of this caveat, the goal is to improve strength and endurance of the forearm muscles. The loads recommended to optimally improve strength (i.e., 3–5 sets of 3–8 RM) (Bird et al., 2005) will probably provoke pain in most individuals with tennis elbow, so in the first instance a lower load with a higher number of repetitions is used (i.e. 1–3 sets of 15–20 repetitions). This exercise prescription lends itself to improvements in muscle endurance and size (Bird et al., 2005). The exercises that are usually performed at this stage are for the forearm flexor/extensor (Figs 8.7 and 8.11), supinator/pronator (Figs 8.9 and 8.12) and radial/ulnar deviator (Fig. 8.8) muscles. The exercises should be performed slowly over about 8 seconds for each repetition when the exercise includes both concentric and eccentric contractions. Isometric

Table 8.2 Possible exercises for an UCL injury progressing from early post-injury (i.e. simple) to return to sport (i.e. functional)

<table>
<thead>
<tr>
<th>Simple</th>
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<tbody>
<tr>
<td>Isometric exercises for upper limb muscles</td>
</tr>
<tr>
<td>Isotonic exercises with addition of 20 RM load to improve muscular endurance of upper limb muscles (Figs 8.2, 8.3, 8.7–8.9, 8.11 and 8.12)</td>
</tr>
<tr>
<td>Isotonic exercises with addition of 8 RM load to improve muscular strength of upper limb muscles</td>
</tr>
<tr>
<td>Unloaded exercises for scapular control</td>
</tr>
<tr>
<td>Motor control retraining for stability of the trunk</td>
</tr>
<tr>
<td>Weight-bearing against wall (Fig. 8.4)</td>
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<tr>
<td>Joint position sense retraining</td>
</tr>
<tr>
<td>More complex</td>
</tr>
<tr>
<td>Weight-bearing against wall on ball ± moving ball up and down wall (Fig. 8.4)</td>
</tr>
<tr>
<td>Push-ups on wall/floor ± with hands on unstable surface (i.e. foam, ball, disc) (Fig. 8.4)</td>
</tr>
<tr>
<td>Medicine ball throws (Fig. 8.5)</td>
</tr>
<tr>
<td>Resisted small-range humeral internal and external rotation with elbow at 90° flexion with increasing velocity (Fig. 8.10)</td>
</tr>
<tr>
<td>Functional (throwing example)</td>
</tr>
<tr>
<td>Throwing action with tubing resistance</td>
</tr>
<tr>
<td>Throwing: short distance and slow speed with increasing repetitions</td>
</tr>
<tr>
<td>Throwing: gradual progression of distance and speed</td>
</tr>
<tr>
<td>Throwing: altered predictability of direction</td>
</tr>
</tbody>
</table>

RM = repetition maximum.

balance up the demands of the exercise programme with those outside rehabilitation, such as in the workplace, sport, leisure and activities of daily living. In some cases, loading of the extensor muscles and tendons while gripping during work or
This may initially necessitate a reduction in load to ensure pain-free exercise performance. Throughout this phase of rehabilitation the unaffected forearm should be maximally exercised, as this will afford some adaptation to the affected side (Bonato et al., 1996; Stinear et al., 2001). We strongly believe that regular visits to a physiotherapist at least once a week for the initial 6–8 weeks is essential for a successful outcome. These sessions allow the therapist to check the exercises and evaluate progress (i.e. pain-free grip strength), which facilitates adherence to the exercise programme and allows for programme modifications such as the progression of load and addition of exercises (Vicenzino, 2003).

Restoration of functional performance

The strengthening exercises in this phase of rehabilitation use higher loads to maximise strength gains (Table 8.1). We find that eccentric only protocols are beneficial at this point when there is minimal pain and a reasonable level of extensor muscle strength. When there is no pain and work/sport activities require explosive and ballistic actions, there may be a need to use weekly exercises performed with increased movement speed to address muscular power (Table 8.1). In contrast, some work specific tasks require prolonged isometric gripping under heavy load, such as the need to lift and hold a nail-gun up above the horizontal. Training for these types of tasks requires sustained functional isometric exercises that can be progressed by moving the upper limb into various positions of elevation and adding load. An example is gripping a dynamometer to a designated level of force (e.g. 40% 1RM) and elevating the upper limb against a load using pulleys or resistance tubing. The exercise prescribed and duration of this phase will vary according to the individual’s work or sport requirements.

Flexibility and stretching

As flexibility impairments occur less frequently in tennis elbow than impairments in pain and muscle performance (i.e. strength and endurance), our clinical approach is to prescribe stretching only to those who have reduced extensibility of the forearm muscles and/or decreased elbow and wrist joint motion.
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**Proprioception**

It has previously been identified that people with unilateral tennis elbow have reduced sensorimotor function and abnormally flexed wrist postures during gripping in both the unaffected and affected upper limbs (Kelley et al., 1994; Pienimaki et al., 1997b; Bisset et al., 2006b). These data suggest that wrist posture should be observed during a spontaneous grip test and corrected as necessary to maintain the wrist in slight extension during gripping tasks. In addition, exercises that challenge the sensorimotor system could be included in the programme to improve awareness of wrist posture. Examples of exercises include spontaneously gripping objects and weight-bearing through an exercise ball. These exercises can be progressed by altering the size, texture and density of the objects/ball, performing tasks with the eyes closed and using a weight-scale to control load through the wrist and forearm muscles during weight-bearing.

**Student questions**

1. Identify the key issues in planning and implementing an exercise programme for the elbow and forearm.
2. Once an elbow dislocation is reduced and deemed stable, when should an exercise rehabilitation programme commence?
3. Design an exercise programme for a volleyball player who has undergone reduction of an elbow dislocation and open reduction internal fixation of a medial epicondylar fracture 2 days ago. Include the progression of exercises from the early post-operative period through to return to sport. List the expected timeline and outcome measures that would be used to determine the progression of exercises.
4. Describe exercises that can be used to train the sensorimotor system in a tennis player with an UCL injury. Identify progression of these exercises from the early phase of rehabilitation to return to playing tennis.
5. What exercise prescription would you use if your goal was to improve strength of the flexor carpi radialis muscle? How would you modify this prescription if your goal was to improve endurance?
6. Describe several exercises that can be used to train both the musculoskeletal and sensorimotor systems. Also provide an explanation of your exercise selection.
7. List the likely impairments in a patient with tennis elbow.
8. Describe the role of isometric, concentric and eccentric exercises in the management of tennis elbow.
9. Compare and contrast the application of exercise therapy at the elbow for a dislocation, an instability and tennis elbow.
10. Does aerobic exercise have a role in the management of elbow disorders?

**Conclusion**

This chapter has highlighted the evidence for three major injury types for the elbow and forearm. The three examples cover impairments of the bone, joint, ligament, muscle, sensorimotor and pain systems, and thus serve as a basis on which the reader may approach the treatment of any elbow and forearm condition with exercise therapy. The key to successful exercise therapy resides in a sound clinical assessment to identify the stage of injury/condition, impairments across all involved systems and level of disability, as well as an understanding of possible adaptations following various exercises. The planning, implementation, modification and progression of the exercise programme can then occur on a pragmatic case-by-case basis.

**SECTION 3: STUDENT QUESTIONS**

As this chapter is so condition specific, no case studies have been included and the reader should refer to the text for examples for treating various disorders.

**References**


SECTION 1: INTRODUCTION AND BACKGROUND

The wrist and hand is a complex system of interrelated joints and soft tissues that play a major role in all aspects of activity. Injuries to the wrist and hand are common due to the constant involvement of the hand in most activities of daily living and sporting pursuit. Many of these injuries are a result of trauma, particularly in a physical occupation or sport, but there are a number of overuse conditions which can have a debilitating effect on the patient. There is a tendency to underestimate the importance of injuries to the wrist and hand but even the simplest injury, if not treated correctly, can have a disabling effect on not just sporting activities but activities of daily living.

Evidence for the use of exercise in the rehabilitation of wrist and hand injuries

There is limited evidence that exercise regimens have a positive effect in the rehabilitation of any wrist or hand injury. Theoretically, the use of therapeutic exercise is essential for a number of reasons. Exercises help to prevent contractures, which can cause limitation in some elements of motion. Range of movement exercises should be reintroduced as early as possible to ensure that joint mobility is restored. These movements can be active, active-assisted or passive, depending on the status of the patient. Strengthening exercises will be required later in rehabilitation so the patient can achieve the best functional outcome possible.

In patients following an uncomplicated fracture of the distal radius, a regimen of prescribed home exercises has been shown to be adequate rehabilitation. In contrast, in patients at risk of a poor outcome, individualised physiotherapy has been found to increase the range of flexion and extension of the wrist at 6 months post-injury (Wakefield and McQueen, 2000). A Cochrane review in this area (the effect of rehabilitation following fractures of the distal radius) concluded that there was not enough evidence to establish the effectiveness of rehabilitation interventions in patients with distal fractures of the radius (Handoll et al., 2006). The review included 15 randomised or quasi-randomised trials, involving 746, mainly female and older patients, which evaluated interventions such as active and passive mobilisation exercises, training for activities of daily living and rehabilitation interventions that could be carried out by the patient themselves or in combination with clinicians. Initial
treatment was identified as being conservative, involving plaster cast immobilisation (in all but 27 participants whose fractures were fixed surgically). One trial showed that there was weak evidence of improved hand function with hand therapy in the days after plaster cast removal, and beneficial effects continued for 1 month later. Another trial showed weak evidence of improved hand function in the short term, but not in the longer term (3 months), for early occupational therapy whereas another study showed no difference in outcome between supervised and unsupervised exercises. Four trials examined formal rehabilitation, two trials investigated passive movements, ice or pulsed electromagnetic field (one trial), or whirlpool immersion (one trial). Weak evidence of short-term benefits was found for continuous passive motion (CPM), intermittent pneumatic compression, ultrasound, and also to support better short-term hand function in patients given physiotherapy compared with patients given exercises by surgeons.

Thien et al. (2004) reviewed studies examining rehabilitation of flexor tendon injuries following surgery. Six randomised controlled and quasi-randomised controlled studies were identified, with 464 participants. However the exercise regimens varied and studies included a traditional passive movement regimen, a CPM protocol, early controlled mobilisation using rubber band traction, static and dynamic splinting for the thumb, and controlled passive flexion with active extension and controlled passive mobilisation. The only study that showed a significant effect was that comparing passive mobilisation to CPM, with the CPM regimen having a favourable outcome. However, due to differences in surgical techniques it was difficult to compare interventions. Generally it appears that to regain full function, the majority of tendon injuries should undergo surgical intervention followed by rehabilitation. In the initial stages this should be limited to active-assisted movements and passive movements with no resistance. Tensile loading is gradually increased with some functional movements to re-establish neurological patterns and this is progressed with an emphasis on eccentric loading, plyometric activity, and co-contractions of agonist/antagonist force couples and gradual reintroduction of sporting activities or activities of daily living (Kibler, 1997).

Strength in the hand and wrist is relevant to each individual. The demands of the patient in normal everyday life needs to be known to fully assess the strength requirements in the rehabilitation programme. The benefits of strength training in this area are supported by the results of a study examining the effect of unilateral upper limb strength training on finger pinch force in older men (Keogh et al., 2007). The strength training group exercised twice a week for 6 weeks whereas controls maintained normal activities. The strength training group achieved significantly greater increases in finger pinch force, biceps curl and wrist flexion strength (Keogh et al., 2007). Another recent study compared the effect of an intensive hand exercise programme with a conservative protocol in patients with rheumatoid arthritis (Ronningen and Kjeken, 2008). After 2 and 14 weeks the there were significant differences between the groups in terms of pinch strength (2 weeks) and grip strength (14 weeks) in favour of the intensive exercise programme.

Injuries to the wrist and hand

Fractures, dislocations and ligament injuries

The two most common fractures at the wrist are Colles’ and Smith’s fractures. Both occur at the distal end of the radius. Colles’ fracture occurs as a result of a fall on the outstretched arm and results in the distinctive ‘dinner fork’ deformity. Smith’s fracture can be referred to as a reverse Colles’ fracture and is as a result of a direct blow or fall on a flexed wrist. Fracture reduction is followed by immobilisation in a cast for approximately 6 weeks. It is important that active range of movement exercises are commenced for the shoulder and elbow during the period of immobilisation. Following a period of immobilisation for the wrist, active range of movement exercises should be commenced for all movement patterns with particular attention to extension and supination. Active exercises should be gradually progressed to strengthening exercises, which can be carried out using light hand springs, therapeutic putty, various elastic bands and small hand weights. This is followed by a gradual reintroduction of functional and sporting activities.

Dislocations and ligament injuries are usually treated by splinting the injured finger to the next finger but it is important that a full range of move-
Tendon rupture can occur following a traumatic incident involving undue force through a tendon. The initial symptoms are severe pain and loss of function and these could lead to permanent disability if untreated. Depending on the site and severity of the rupture, treatment could be conservative or surgical. Tendons on the flexor aspect of the hand and wrist have synovial sheaths but extensor tendons do not. The most common cause of tendon ruptures of the wrist and hand are caused by lacerations due to injuries or a forcible impact to the fingers causing a hyperflexion or extension of the digits. These latter injuries are common in sport particularly in cricket, volleyball and basketball. There is often an avulsion fracture where the tendon is pulled off the bone and in these cases surgical intervention may be required to reattach the tendon and bone fragment. There are differences in the rehabilitation protocols for ruptures of extensor tendons and of flexor tendons in the hand and wrist. This is mainly due to the strong pulley system that exists within the flexor tendons. The extensor tendon is more passive in function, but disruption of this tendon can be as debilitating as disruption of the flexor tendons due to the influence these tendons have on the lumbricals and interossei.

Rupture of the flexor digitorum profundus tendon from the distal phalanx may be treated conservatively or with surgery. Splinting is usually in place for 6 weeks and then an active exercise programme is introduced. To minimise the tension on the tendons, flexion exercises are performed with the wrist in extension and extension exercises are performed with the wrist in flexion. Strengthening exercises are not started until there is good active extension of the wrist and the metacarpophalangeal and interphalangeal joints, which usually occurs 8 weeks post-surgery. Strengthening exercises are progressed depending on how well the patient is managing, with the introduction of co-ordination exercises and endurance work.

If the common extensor tendon that inserts into the base of the middle phalanx is damaged, a boutonnière deformity may result. This is a common injury in sport and may be caused by a severe flexion force to the proximal interphalangeal joint (PIP) or direct trauma to the posterior aspect of this joint. A boutonniere injury should be suspected if there is more than 30° extension lag at the PIP joint. Rehabilitation for the common extensor tendon requires immobilisation of the PIP joint in full...
symptomatic (Piazzini et al., 2007), but when the symptoms have reduced, an active exercise programme may be reintroduced. Surgery to relieve the compression on the median nerve may be considered in extreme cases.

Joint diseases

Osteoarthritis is a common disease that can either be a primary condition or follow a pre-existing condition. As a primary condition, the most common area in the hand and wrist for osteoarthritis to manifest is the first carpometacarpal joint of the thumb. Osteoarthritis of this joint is typified by pain at the base of the thumb, especially when gripping an object. Osteoarthritis is more common in women than men, especially over the age of 45–50 years of age. Conservative management includes splinting, gentle moist heat, usually administered by wax baths, and gentle exercises.

Secondary osteoarthritis can develop in any area of the wrist or hand following a previous injury, particularly fractures in which a joint or joint surface is involved. It is a progressive degenerative condition and is exacerbated with use. It is very common following injuries to the scaphoid and in extreme conditions it can lead to degeneration of the joint between the scaphoid and radius, and consequently lunate and capitate, which will ultimately result in a collapse of the wrist. Support may be offered to the joint through splinting, and gentle non-resisted exercises will help maintain some range of movement.

Rheumatoid arthritis and juvenile arthritis are conditions that affect the whole of the body, but can cause particular problems in the upper limb, wrist and hand. Treatment and rehabilitation will help relieve symptoms to a certain degree and help minimise disability. The repeated inflammatory episodes of various joints of the body can cause substantial damage to the soft tissues and extra-articular structures. This can result in pain, stiffness, joint instability and ultimate deformity, including ulnar deviation of the metacarpophalangeal joints, boutonnière deformity and swan-neck deformity. Joint laxity, weakness of the muscles and loss of range of movement will lead to major dysfunction of the hand and wrist, making even the simplest tasks in everyday living almost impossible to perform.
Interventions for this disease include stabilisation, to allow better function of the wrist and hand by utilising the muscles of the forearm, controlling the inflammatory process and protecting the joints. Some patients present with stiff and immobile joints due to scarring following inflammatory episodes or surgery and these patients require sustained exercise therapy. Patients may also present with joint laxity following surgery that may require splinting for long periods.

Active exercises should be used to maintain joint range followed by isometric strengthening exercises. Resisted exercises should be undertaken with extreme caution due to the inflammatory nature of the disease. There are many pieces of adaptive equipment that can be introduced and which will reduce the stresses of everyday living for the patient with rheumatoid arthritis. Avoidance of repetitive actions and patient education are paramount for improvement in symptoms.

SECTION 2: PRACTICAL USE OF EXERCISE

Assessment of the wrist and hand

The most important aspect of any rehabilitation programme involving the wrist and hand is to restore full function to the movements of the fingers and thumb. The ability to manipulate various objects and the application of dexterity and range of uses that humankind is capable of set us aside from all other creatures. Prehensile or gripping activities have been described in various ways over the years but essentially they are all variations of the power grip (Fig. 9.1), precision grip (Fig. 9.2) and the hook grip.

In the power grip all the fingers and thumb are flexed around the object with the thumb controlling the movement if any is required. The purpose of this grip is to hold an object firmly, so that it can be worked on by the other hand or wielded as a tool or weapon. The precision grip uses very fine, small movements of the digits. The object is grasped between the ends of the fingers and thumb or just the thumb and index finger. The manipulation or positioning of the object is carried out at the wrist or in particularly fine work the lumbricals and interossei of the hand. The hook grip is used to pull or suspend objects. It may sometimes be used as a power grip when carrying out activities such as climbing, where it is used to suspend or elevate the body. The thumb may or may not be used as the fingers are flexed into the palm as far as the dimensions of the object allow. These movements should be fully assessed by the clinician prior to design of a programme.
Assessment of the strength of the hand and wrist should include both isometric and dynamic tests. These tests should include the lumbricals and interossei and all other movements of the wrist hand and digits. The initial tests should be single joint movements such as flexion, extension radial and ulna deviation of the wrist (Figs 9.3–9.5). The more complex patterns involving multiple joints should follow if the initial tests are comparable with the opposite side.

Movements of the hand and wrist in all planes should be tested first actively and then passively. It is important to establish which is the dominant side, as this may have some bearing on the results. It is vital to note the position of the fingers when testing mobility as the long tendons cross over many joints, and if the fingers are flexed movement in the wrist may be restricted.

**Exercise management of the wrist and hand**

*The early phase – passive exercises/mobilisation*

In the initial stages of rehabilitation of the wrist and hand passive movements can be introduced to re-establish full mobility. Passive movements involve the therapist manipulating specific joints, while the patient tries to relax and takes no active part. With many wrist problems there is a loss of supination and pronation at the distal radioulnar joint. To regain full range of active movement it is essential that these movements are re-established. To mobilise the distal radioulnar joint the forearm can be
in either a prone or supine position. The therapist places one hand around the radial head and the other around the head of the ulna.

To make the patient more comfortable when mobilising the wrist joint a pad can be placed under the distal forearm and the hand placed over the edge of the treatment couch or table. With the patients' forearm in pronation and the wrist in neutral, the therapist should secure the lower end of the forearm around the radial and ulnar styloids with one hand and place the other hand over the carpal bones. A longitudinal distraction force should be applied by the second hand; this force can either be sustained or oscillatory.

To increase either radial or ulna deviation the forearm is placed with either the radial or the ulnar side uppermost, depending on the area that needs to be mobilised. For an increase in ulnar deviation the forearm is placed radial side up with the wrist in neutral, with the stabilising hand over the radial and ulna styloids and the mobilising hand over the carpals. A downward force is applied by the mobilising hand. For radial deviation, the ulna is uppermost and the same directional force is applied.

To increase flexion or extension of the wrist, the forearm is placed in pronation with the wrist in neutral. The therapist stabilises the forearm by grasping the radial and ulnar styloids and mobilises the wrist by placing the other hand over the carpal bones. To increase flexion, an antero-posterior (AP) force is applied parallel to the wrist joint. To increase extension, a postero-anterior (PA) force is applied in the same manner.

The carpal joints can be mobilised on an individual basis if required, but it is important to understand the shape of the bones involved and their relationship with their neighbours to ensure that the correct force is applied in the most appropriate direction. To mobilise the individual carpal joints the therapist uses a pinch grasp on a pronated hand; one hand stabilises while the other hand carries out the mobilising technique.

The proximal row of carpal bones has a convex shape that fits in to the radius and ulna, which are both concave. To increase flexion in the radiocarpal joint a posterior force is applied to the radius, and to increase extension an anterior force is applied. The ulnocarpal joint is further complicated by the presence of a articular cartilaginous disc between the distal radioulnar joint and also between the ulnar medial part of the lunate, and the triquetral if the hand is adducted. The disc can block free movement if disrupted. The ulnocarpal joint can be mobilised by applying an anterior force that will help to mobilise the disc. The scaphoid is convex compared with the concave shape of the trapezium and trapezoid thereby to increase flexion the scaphoid should be fixed and an AP glide of the trapezium and trapezoid should be carried out. To increase extension an AP glide of the scaphoid on the distal carpals is carried out. Mobilisation of other carpal bones is similar, by securing one carpal bone with a stabilising thumb and finger and then mobilising the joint with the other thumb and finger using either an AP or PA glide.

Techniques to mobilise carpometacarpal and metacarpophalangeal joints are similar to those previously described; in addition, traction forces can be applied to the joints and this is particularly effective when treating the first carpometacarpal joint for increasing opposition and rotation movements.

When passive range has been re-established active exercises can be recommenced. It is important that active movements are recommenced as soon as possible as they have advantages over purely passive movements. Exercises to improve active flexion of the wrist and hand are shown in Figure 9.6.

**Intermediate stage – strengthening exercises**

When normal joint range and function have been restored, progressive strengthening exercises can be gradually introduced. These can be commenced with static or isometric contractions and then progressed to active or dynamic exercises that include concentric eccentric and isotonic contractions. A strengthening programme should commence with specific exercises for particular joints and progress onto exercises that involve the kinetic chain for the whole of the upper limb. If possible, functional patterns of movement should be followed. It is important that both the interossei and the lumbricals (Fig. 9.7) are included in any strengthening protocols particularly following any type of immobilisation.
Resisted exercises can be performed manually, using the clinician or self administered for a home exercise programme. Pieces of equipment that can be used for resisted work include: therapeutic putty of various densities denoted by a variety of colours, elastic bands and hand springs and small dumbbells. However, it is essential that a full range of movement is completed, which is not always possible with putty, hand springs or dumbbells. Figures 9.8–9.13 illustrate different strengthening exercises using a range of equipment.

Grip strength exercises are essential to restore normal function of the wrist and hand. These exercises can be carried out using ball of various sizes and different densities of therapeutic putty. Elastic bands around the fingers are useful and offer a good...
The Wrist and Hand

made in normal everyday life, particularly in employment or sporting activities. The functional exercise programme should incorporate as many normal activities as possible to re-establish functional movement patterns at the correct speed and stress levels that will be encountered in normal life.

Plyometric and proprioceptive exercises for the wrist and hand are the same as those used for the elbow and shoulder. Many other plyometric and proprioceptive exercises can be introduced using a

Late or functional stage

Functional exercises for the hand and wrist will differ greatly between patients due to the demands

Figure 9.8  Concentric strengthening of wrist flexors.

Figure 9.9  Eccentric strengthening of wrist flexors.

Figure 9.10  Strengthening of wrist flexors against resistance.

Figure 9.11  Strengthening of wrist extensors against resistance.
Proprioception exercises include various gripping actions of various sized objects and throwing and catching balls of different weights and sizes. Practising precision grips with different sized objects will also promote an increase in proprioceptive abilities.

**SECTION 3: CASE STUDIES AND STUDENT QUESTIONS**

**Case study 1**

A 70-year-old woman fell on her outstretched right hand and sustained a fracture of the distal end of the radius and ulna.

**Management**

The patient’s forearm was immobilised with plaster of Paris and she was encouraged to move her fingers and flex her elbow as much as she could during immobilisation. Following 6 weeks of immobilisation, passive, active and active-assisted exercises were commenced. This included passive movements to mobilise the carpus and first carpometacarpal joint. When full range of movement had been achieved gentle strengthening exercises were introduced using therapeutic putty and elastic bands.
Case study 2

A young cricket player caught a ball, which forced a hyperextension of a distal interphalangeal joint.

Management

On examination it was found that the patient had a ‘Mallet finger’ deformity, suggesting a rupture of the long extensor tendon and which was confirmed on magnetic resonance imaging (MRI). Open reduction was carried out and a splint applied post-surgery. The hand was kept in the splint for 6 weeks, at which point the splint was removed and the tendon was tested to evaluate whether it could maintain extension of the distal phalanx. This was not the case, therefore the splint was reapplied and checked every 5 days. When the tendon was able to maintain extension, active exercises were commenced. The splint was reapplied between sessions. It was important for the therapist to check for an extensor lag of the distal phalanx at every session. At week 10, gentle progressive exercises were started using therapeutic putty and elastic bands. At this point the splint was disregarded, and at 16 weeks, full sporting activities were recommenced.

Case study 3

A 50-year-old diabetic man noticed a thickening on the palm of the left hand, and his little finger was starting to flex into his palm.

Management

On examination it was found that the patient was developing Dupuytren’s contracture. A stretching programme was implemented to try to ease the situation but after a period of time, when the fifth digit was flexing into the palm and the fourth digit was beginning to follow, it was decided that a Z-plasty should be carried out to elongate the palmer fascia and release the contracture. Following surgery, a splint was applied but passive and active exercises were initiated as soon as the patient could tolerate and the wound was checked regularly to ensure that scarring was minimal and scar mobility was maximised, particularly as the patient was a diabetic and wound healing could have been compromised. Success of this surgery may depend on correct splinting and exercise therapy. Hand function was restored as soon as possible but during this time it was noticed that the other hand was developing a thickening and the same procedure had to be repeated on the other hand, which was not unexpected.

Student questions

(1) What are the common complications following fractures of the wrist?
(2) How quickly is an exercise rehabilitation programme reintroduced for flexor tendon ruptures?
(3) What is the most common carpal bone to sustain a fracture and why?
(4) How can plyometric exercises be undertaken for the wrist and hand?
(5) What movements are possible at the first carpometacarpal joint?
(6) Describe an exercise protocol for a patient with rheumatoid arthritis.
(7) Describe a progressive exercise programme for tendinopathy of the wrist.
(8) What is the common cause of carpal tunnel syndrome?
(9) What is the primary site for osteoarthritis in the wrist and hand?
(10) What is the common cause of inter-carpal instabilities.
References


SECTION 1: INTRODUCTION AND BACKGROUND

While hip and pelvic girdle pain are not as common as low back pain, the incidence of hip osteoarthritis (OA) or pelvic girdle pain (PGP) does increase with age and in pregnancy (Felson et al., 2000; Van De Pol et al., 2007). The purpose of this chapter is to review exercise approaches to these two closely related regions.

Evidence of exercise efficacy in the management of hip pain

Specific evidence for the role of exercise in hip disorders is surprisingly scarce. Often the hip and knee are considered together with the assumption that if exercise is beneficial for the knee then the same will apply to the hip. As an example, a recent document published by the Osteoarthritis Research Society International group provided evidence-based, consensus-driven recommendations for the management of hip and knee OA (Zhang et al., 2008). The following recommendations specific to exercise were made:

- ‘Patients with symptomatic hip and knee OA may benefit from referral to a physical therapist for evaluation and instruction in appropriate exercises to reduce pain and improve functional capacity’.
- ‘Patients with hip and knee OA should be encouraged to undertake, and continue to undertake, regular aerobic, muscle strengthening and range of motion exercises. For patients with symptomatic hip OA, exercises in water can be effective’.

Both of these recommendations are primarily based on randomised controlled trials (RCTs) of the knee. Apart from two RCTs (Stener-Victorin et al., 2004; Cochrane et al., 2005) supporting hydrotherapy, the evidence supporting exercise in hip OA is based largely on expert clinical opinion (Roddy et al., 2005).

However, several studies do support the efficacy of exercise in managing hip OA. Both hip (37%) and knee (59%) OA subjects were included in an RCT, which looked at muscle strengthening and stretching, general mobility and co-ordination plus advice on adaptation of activities of daily living (van Baar et al., 1998). The content, intensity and frequency of treatment were tailored to the patient’s needs. A medium reduction in pain (a comparison of visual analogue scale (VAS) scores of each week
with the previous week) and a small reduction in observed disability (composite score of time taken and quality of performance of functional tasks) was found (van Baar et al., 1998). In a later follow-up, these beneficial effects were shown to decline and by 6 months had disappeared, indicating the need for long-term patient compliance with exercise programmes (van Baar et al., 2001).

In another study, exercise therapy was compared with manual therapy (Hoeksma et al., 2004). The exercise therapy was based on the protocols designed by van Baar et al. (1998) and the manual therapy included muscle stretching, traction, manipulation and promotion of physical activity including walking, cycling and swimming. The main outcome measure was the patient's perceived improvement on a six-point scale (ranging from 'much worse' to 'complete recovery'). Using this measure, 81% of the manual therapy group and 50% of the exercise therapy group reported an improvement. These improvements persisted at the 29-week follow-up. The authors concluded that there was support for the beneficial effects of manual therapy although both groups improved in the study (Hoeksma et al., 2004).

Most recently a group of community-dwelling patients with hip (11% control group, 5% treatment group) and knee OA were treated with a twice-weekly, 6-week period of hydrotherapy (Hinman et al., 2007). The intervention consisted of progressive exercises in functional weight-bearing tasks under direct supervision from a physiotherapist. The primary outcome measures were subject-perceived changes in pain and physical function rated on a five-point Likert scale (4 or 5 indicating improvement). The treatment group reported a 72% improvement in pain (compared with 17% in the control group) and 75% improvement in physical function (compared with 17% in the control group). These benefits were maintained for 6 weeks after the completion of the programme with 84% of participants continuing to exercise independently. However, as the majority of subjects in both groups had knee OA the results of this study are most applicable to this condition. There is no evidence for conditions other than hip OA.

**Aerobic exercise**

There is no specific evidence on the effect of aerobic exercise and hip disease. However, an RCT which examined the effects of hydrotherapy on hip and knee OA found a reduction in pain and an increase in physical function utilising a programme which included an aerobic exercise component (Cochrane et al., 2005). Several studies in subjects with knee OA suggest that aerobic walking programmes lead to a reduction in pain and disability (Kovar et al., 1992; Talbot et al., 2003). This would suggest that similar benefits would occur in subjects with hip OA.

**Muscle strength and endurance**

A large-scale review of exercise and OA bemoans the 'almost complete absence of published data' on the effects of structured exercise and hip OA (Vignon et al., 2006). As strengthening exercises have benefits for subjects with knee OA (see Chapter 11) one is left to extrapolate that similar effects probably occur in subjects with hip OA. One major study investigating the benefits of exercise (including strengthening) in people with hip OA has shown a reduction in pain and disability (van Baar et al., 1998). A recent case series also includes a description of strengthening of the hip abductors and external rotators as routine in all subjects (MacDonald et al., 2006). Although this is encouraging, further evidence is required.

Another alternative is to review published data on muscle weakness associated with hip OA. This provides a rationale for targeting certain muscle groups although the presence of muscle impairment does not imply cause and effect with hip OA. A weakness of the hip abductors, flexors and adductors (tested with a dynamometer) was found in 27 men (average age 56) with hip OA when compared with healthy controls (Arokoski et al., 2002). Hip extension strength was not different between groups but was weaker on the side of the more affected hip in the hip OA group. There was also a reduction in cross-sectional area (measured with magnetic resonance imaging (MRI)) of the pelvic and thigh muscles in the more severely affected hip compared with the better hip.

More recently, a study investigating predominantly older women (mean age 67) with unilateral hip OA identified weakness (compared with the unaffected limb) in the hip extensors, flexors, abductors, adductors and knee extensors (Rasch et al., 2007). This study also identified a reduced
suggests balance can be improved in subjects with hip OA but due to the multi-modal treatment it is not possible to identify the relative importance of specific interventions. The lack of a control group makes it impossible to know if the hip OA group had impaired balance at the start of the programme.

Common injuries/conditions

Hip OA

Hip OA is a common disorder characterised by loss of articular cartilage and new bone formation (Sokoloff, 1969). The incidence of hip OA increases with age (Felson et al., 2000) but genetic and systemic factors (e.g. obesity) are also part of its aetiology (Dieppe and Lohmander, 2005). Occupations involving carrying heavy loads, exposure to vibration, repeated stair climbing or jumping (e.g. farmers and miners) increase the risk of developing hip OA (Vignon et al., 2006). Clinically, there is a loss of joint range of motion, with internal rotation loss most closely linked to with radiographic hip OA (Birrell et al., 2001).

Femoro-acetabular impingement

Femoro-acetabular impingement is characterised by a contact between the head and neck of the femur with the acetabular rim and is associated with abnormalities of the proximal femur and the acetabulum (Beck et al., 2005). One commonly described variety of impingement is cam impingement, where an aspherical femoral head is jammed into the acetabulum during normal ranges of flexion, leading to chondral damage and labral tears (Lavigne et al., 2004). The other common variety is pincer impingement, where there is contact between the acetabular rim and the femoral head neck junction due to acetabular over-coverage (Lavigne et al., 2004). It is proposed that femoro-acetabular impingements are a common cause of early hip OA.

Instability/dislocation

Although the hip is considered to be an inherently stable joint, the concept of hip instability is gaining momentum. Several clinical syndromes have been
described that have as their basis an excessive anterior translation of the femoral head during hip motion (Sahrmann, 2002). Atraumatic instability is thought to occur as a result of repetitive hip rotation with axial loading (Shindle et al., 2006). This leads to capsular stretching and labral injury with subsequent micro-instability. Such a process may occur in athletes such as figure skaters, soccer players, ballet dancers and gymnasts. The hip may also dislocate (e.g. dash-board injury in motor vehicle accident) or subluxate (e.g. fall on a flexed hip and knee playing football), commonly in a posterior direction (Shindle et al., 2006).

Labral tears
Tears of the acetabular labrum are increasingly recognised with the anterior labrum most commonly affected (McCarthy et al., 2001). The labrum has sensory nerve endings in the superficial layers, making it a source of pain (Kim and Azuma, 1995). It may be damaged by any of the conditions described above as well as trauma. The labrum is continuous with chondral cartilage and thus labral tears are commonly associated with chondral defects (McCarthy et al., 2001).

Trochanteric bursitis
This commonly used term is best renamed ‘greater trochanteric pain syndrome’ as recent evidence has failed to find bursal inflammation in subjects with lateral trochanteric pain (Silva et al., 2008). Instead this condition is likely to be a combination of gluteus medius and minimus tears or insertional tendinopathy (Kong et al., 2007). It is more common in older females and is more likely in the presence of low back pain and knee OA (Segal et al., 2007).

Evidence of exercise efficacy in the management of pelvic girdle pain
Dysfunctions of the pelvis are common in pregnancy, with PGP a common feature in 7–25% of women (Wu et al., 2004; Van De Pol et al., 2007). There is a body of evidence which has examined exercise in the management of PGP. A systematic review of physiotherapy treatments for pregnancy-related low back pain and PGP failed to find evidence of positive effect (Stuge et al., 2003). The authors identified two high-quality trials (Nilsson-Wikmar et al., 1998; Mens et al., 2000) which failed to find a difference in pain intensity and functional status between exercise and control groups.

One of these studies (Mens et al., 2000) utilised an exercise approach, based on the concept of diagonal slings linking the gluteus maximus, latissimus dorsi and the oblique abdominals in stabilising the sacroiliac joint. Attachment of these muscles via the posterior layer of thoraco-lumbar fascia provides compressive forces across the sacroiliac joint, which has been termed force closure (Pool-Goudzwaard et al., 1998). This approach was compared with two control groups. One group did not do any exercises and the other exercised the longitudinal muscles (rectus abdominis, erector spinae and quadratus lumborum). All subjects were approximately 4 months post partum and were treated for 8 weeks. While the diagonal sling proposition is attractive, the results of the study did not show a difference between the groups in terms of pain and perceived improvement (Mens et al., 2000). One possible reason was that in the study design the exercises were given to patients on a videotape, which did not allow for individual modification. Approximately 25% of the treatment group experienced an increase in symptoms from the exercises (Mens et al., 2000), particularly longer lever exercises targeting the gluteus maximus.

Stuge et al. (2004) published a study on the physiotherapy management of PGP after their systematic review, in which each subject was examined individually and a programme most appropriate to the individual was formulated and supervised throughout. In this study, both groups received other physiotherapy modalities as appropriate (mobilisation, massage, heat, etc.) but the treatment group performed exercises based on the diagonal sling approach and also utilised specific stabilising exercises (Stuge et al., 2004). The control group received instruction on strengthening and stretching exercises but no specific stabilising exercises. The intervention period was 20 weeks with approximately 11 treatments in this time. Both groups commenced treatment approximately 10 weeks post partum. Subjects undergoing the specific stabilising programme had lower pain intensity, disability and
a higher quality of life than the control group (Stuge et al., 2004).

The specific stabilising exercises were low load contractions of the transversus abdominis with co-activation of the multifidus. Other authors have demonstrated that muscles such as the erector spinae, gluteus maximus and biceps femoris also increase sacroiliac joint stiffness and help in force closure (van Wingerden et al., 2004). Thus, it would appear that exercise approaches for persons with PGP should include training for the transverse abdominal wall, pelvic floor, multifidus and gluteus maximus.

However, it would be a mistake to assume that stabilisation exercises are a necessary requirement in the management of all PGP disorders. Recently O’Sullivan (O’Sullivan and Beales, 2007b,c) has argued that appropriate management of subjects with PGP is dependent on subclassifying subjects into groups. Mechanical PGP (as opposed to inflammatory) subjects may present with disorders of inadequate or excessive force closure. The two groups can be identified by, among other things, their different responses to compression. Subjects with reduced force closure are helped with external compression (e.g. the active straight leg raise test) whereas in subjects with excessive force closure, their condition is aggravated by these procedures. Thus, in some cases it may be necessary to embark on a muscle relaxation or stretching programme (O’Sullivan and Beales, 2007b).

### Aerobic exercise

No trials have examined the specific effects of aerobic exercise on PGP. Given the positive effects in subjects with low back pain (see Chapter 6) one may expect a similarly beneficial effect in PGP.

### Muscle strength and endurance

The preceding section on evidence of PGP exercise programmes has reviewed two studies where the diagonal sling and specific stabilising muscles have been targeted. The subjects in both of these studies were post partum.

Several other studies have investigated exercises designed to improve pelvic girdle support in subjects pre partum. One study compared three groups that received information or home exercise or supervised exercise (Nilsson-Wikmar et al., 2005). The supervised exercises targeted the gluteals, latisimus dorsi and abdominals whereas the home exercise group performed movements of the arms and legs in sitting, standing and four-point kneeling while maintaining the pelvis in a stable position. Pain and function in all groups improved post partum with no evidence that either of the exercise groups were superior to the information group. It was concluded that perhaps exercise needs to be more specific for the transversus abdominis or may not be effective until after delivery (Nilsson-Wikmar et al., 2005). Stabilising exercises (transversus abdominis and pelvic floor contractions) were found to reduce PGP pain in pre-partum women more effectively than standard intervention (education and unsupervised home exercise programme) (Elden et al., 2005).

Two other studies examined the effects of pre-partum exercises on the resolution of PGP post partum. One compared an intervention which included information, advice on posture and activities of daily living, and exercises (stretching and stabilising but not described in the text) with a control group with PGP who did not receive treatment (Haugland et al., 2006). Four sessions were delivered to small groups once per week for four weeks during weeks 18–32 of gestation. At 6 and 12 months post partum there was no difference in pain levels between the groups. These findings were consistent with another study in which the recovery from PGP post partum was not influenced by either specific stabilising exercises or acupuncture as additions to standard treatment administered between gestational weeks 12 and 31 (Elden et al., 2008).

### Range of motion and flexibility

None of the studies have specifically addressed the benefits of this type of exercise although several studies have included stretching in the exercise programme (Stuge et al., 2004; Nilsson-Wikmar et al., 2005; Haugland et al., 2006).

### Balance and proprioception

Exercises of this type have not been investigated in subjects with PGP.
Common pelvic conditions/injuries

Inflammatory arthritis
The sacroiliac joint may be affected by spondyloarthropathies such as ankylosing spondylitis, which is a progressive inflammatory disorder. Clinical features include back pain and progressive stiffness of the spine (Dakwar et al., 2008).

Mechanically induced PGP disorders
A recent paper attempted to develop a logical pragmatic approach to identifying mechanically induced PGP (O’Sullivan and Beales, 2007b). This was done in order to bypass the often complicated and confusing clinical models that had previously formed the basis for treatment. Using this approach mechanical PGP disorders can be subdivided into two main groups as described below.

- **Reduced force closure**: The underlying dysfunction in this group is increased strain on sensitive and lax ligamentous tissue in the sacroiliac joint in association with a reduced ability of the central nervous system to provide appropriate muscle support, i.e. reduced force closure. This is commonly present post partum (O’Sullivan and Beales, 2007b). This group will typically respond well to stabilising exercises.

- **Increased force closure**: In this group the pain is due to excessive sustained loading of sensitive structures in the sacroiliac joint by the surrounding muscles i.e.: increased force closure. In this group, PGP is often aggravated by performing stabilising exercises (O’Sullivan and Beales, 2007b).

SECTION 2A: PRACTICAL USE OF EXERCISE AROUND THE HIP

Prior to commencing any exercise programme the physiotherapist must have assessed the patient and identified specific dysfunctions in the neuromuscular system. The following exercise approaches are necessarily general and all patients must have a programme tailored to their specific needs.

Aerobic exercise
As has been noted in Section 1, there is limited evidence that aerobic exercise is beneficial in subjects with hip OA. However, the reader should review Chapter 11, which identifies aerobic exercise as of benefit to subjects with knee OA. A simple graded walking or swimming programme may provide good benefits to patients with hip OA.

An example of a walking programme (modified from Ettinger et al., 1997) is given in Table 10.1.

Note: Care should be taken to ensure an optimal gait pattern. This may require use of walking aids such as a stick or walking poles (Fig. 10.1).

Strengthening exercise
As a general rule the exercises should replicate the function which will be required. For example, the gluteals are required to work in their inner range during stance phase of gait. Thus exercises should be performed in this functional range (Sullivan et al., 1982).

Early phase
In order to encourage a beneficial co-activation of the surrounding hip muscles to optimise support of the joint an early-stage exercise is to ask the patient to gently draw the hip into the socket. This may be done in supine crook lying (Fig. 10.2) and may be facilitated by asking the patient to resist a gentle long axis distraction. Once learned, this action may be incorporated prior to the commencement of other exercises.

Gluteus medius is retrained in side lying with an external rotation of the hip (Fig. 10.3). The emphasis is on hip motion without motion in the pelvis and low back. Adjusting the degree of hip flexion may be required to ensure the activation is of gluteus medius rather than TFL. Emphasis is on maintaining an inner range hold for up to 10 seconds, provided the patient has sufficient endurance. The number of repetitions is again determined by the patient’s ability.

Both gluteus maximus and gluteus medius contraction may be facilitated by inner range hip exten-
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around the joint, improving muscular contraction (Dee, 1969; Kisner and Colby, 1996).

Open chain hip extension in prone is best performed after the previous exercise when the muscle is likely to be optimally facilitated. Focus initially would be on maintaining an inner range hold (Fig. 10.5).

Hip external rotation may also be retrained in sitting with Thera-Band® resistance (Fig. 10.6). A neutral spine position is essential to the optimal

Table 10.1 Walking programme for hip osteoarthritis

<table>
<thead>
<tr>
<th>Week</th>
<th>Frequency</th>
<th>Duration</th>
<th>Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>2 days per week</td>
<td>25 min</td>
<td>Warm up 5 min (slow walking, arm circles, trunk rotation, shoulder and chest stretches, and side stretch) Walk 15 min (ideally 50% of max heart rate) Warm down (slow walking and three flexibility exercises: a shoulder stretch, hamstring stretch, and lower back stretch)</td>
</tr>
<tr>
<td>Week 2</td>
<td>3 days per week</td>
<td>25 min</td>
<td>As per week 1</td>
</tr>
<tr>
<td>Week 3</td>
<td>3 days per week</td>
<td>30 min</td>
<td>Increase walk to 20 min</td>
</tr>
<tr>
<td>Week 4</td>
<td>3 days per week</td>
<td>40 min</td>
<td>Increase walk to 30 min</td>
</tr>
<tr>
<td>Week 5</td>
<td>3 days per week</td>
<td>50 min</td>
<td>Increase walk to 40 min</td>
</tr>
<tr>
<td>Week 6+</td>
<td>3 days per week</td>
<td>60 min</td>
<td>Increase walk to 50 min</td>
</tr>
</tbody>
</table>

Figure 10.1 An older adult walking with a single stick to minimise limp.

Figure 10.2 Manual facilitation of co-activation of hip muscles to draw the hip into the socket. The therapist is applying a gentle longitudinal distraction along the line of the femur while the patient resists this action.
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Initially require a conscious pre-activation of the stance limb gluteals.

Later phase

Performance of this exercise. It is proposed that in addition to gluteus medius, iliopsoas is also active in this exercise (Johnston et al., 1999).

It is important to include retraining of gluteus medius function in standing early in a rehabilitation programme. Initially this may involve optimising the standing posture (specific to the individual patient) and training them to maintain pelvic alignment in the frontal plane while they lift their contralateral limb onto a step (Fig. 10.7). This may initially require a conscious pre-activation of the stance limb gluteals.

Later phase

Higher-level gluteus medius exercise is done by performing hip abduction with an extended knee (Fig. 10.8). The hip must not drift into flexion or internal...
The Hip and Pelvic Complex

on a step. The stance limb gluteus medius then eccentrically lowers and concentrically raises the contralateral pelvis (Fig. 10.9). The patient must be aware not to rely on the contralateral trunk lateral flexors (quadratus lumborum) to dominate in this exercise. Use of a mirror may help to reinforce the rotation to avoid TFL dominating the abduction synergy. Rehabilitation should target inner range holds initially but may also include through range repetitions.

Standing gluteus medius activity can be progressed by having the patient stand with one foot on a step. The stance limb gluteus medius then eccentrically lowers and concentrically raises the contralateral pelvis (Fig. 10.9). The patient must be aware not to rely on the contralateral trunk lateral flexors (quadratus lumborum) to dominate in this exercise. Use of a mirror may help to reinforce the
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There is no specific published evidence that stretching exercises are useful when dealing with hip correct movement pattern. This may be progressed by standing on a step with the contralateral limb unsupported. The stance limb abductors then control the lowering and raising of the contralateral pelvis (Fig. 10.10). Depending on the specific dysfunction present in the patient it may be necessary to practise maintaining control of the pelvic position during gait, e.g. stance phase of gait. This may be enhanced by use of a mirror.

Higher-level gluteus maximus function should include double leg squats where instruction of correct technique is important. It is optimal for the patient to keep the anterior knee over the middle of the arch of the foot during the squat (Fig. 10.11). During the return to the upright position the patient must initiate the movement from the pelvis and not the thorax. Bridging exercises are also good to challenge gluteus maximus function to a higher level.

It may also be important to modify standing postures to optimise gluteus medius and maximus function. For example, patients who tend to slouch and stand excessively onto one limb are instructed to limit the amount of hip adduction by maintaining gluteus medius tone (Fig. 10.12). Similarly, people who stand with excessive lumbar extension may need to incorporate gluteus maximus activity to maintain a more neutral position of the pelvis relative to the lumbar spine.

Range of motion and flexibility exercises

There is no specific published evidence that stretching exercises are useful when dealing with hip
In order to sustain the beneficial effects of treatment it is important that the patient continues with the programme after a treatment phase. An important way to achieve this is to incorporate exercises into functional tasks that the patient performs regularly. Exercise training should simulate the functional tasks (Pisters et al., 2007) or aim simply to alter movement patterns during the functional tasks so that the appropriate muscles are recruited or stretched.

SECTION 2B: PRACTICAL USE OF EXERCISE AROUND THE PELVIS

This section provides a brief outline of the use of exercise around the pelvis. The specific exercises are outlined elsewhere in this text. Again it is critical to assess each patient to design a programme specifically tailored to their needs.

Summary

In order to sustain the beneficial effects of treatment it is important that the patient continues with the programme after a treatment phase. An important way to achieve this is to incorporate exercises into functional tasks that the patient performs regularly. Exercise training should simulate the functional tasks (Pisters et al., 2007) or aim simply to alter movement patterns during the functional tasks so that the appropriate muscles are recruited or stretched.

Proprioceptive and balance training

There is no published evidence on this form of training. It may be that in some cases basic balance training may be a useful means of generally facilitating muscles around the hip prior to strengthening exercises. A progression from maintaining static positions (Fig. 10.14a tandem stance) to more dynamic situations (Fig. 10.14b standing on one leg with contralateral leg swings) to advanced situations (e.g. standing on one leg with contralateral leg swings and eyes closed).
Aerobic exercise

Several studies have indicated that general aerobic activity is beneficial in the management of low back pain (see Chapter 6). There is every reason to believe that a carefully structured aerobic exercise programme would have a similar benefit for patients with PGP.

Any aerobic exercise should take into account the ability to transfer load through the pelvis. Given that in many patients the pain is likely to be aggravated by the excessive impact forces associated with walking and running, the pool may be more appropriate. It is also wise to avoid activities with emphasis on twisting and rapid direction changes (e.g., tennis, squash, netball) until muscle strength and pain are both improved. An example of a low-impact pool session programme is given in Table 10.2.

Strengthening exercise

As seen in Section 1 the evidence suggests that patients with PGP due to reduced force closure will respond well to exercise targeting the transverse abdominal wall, the pelvic floor, multifidus and gluteus maximus. A strengthening programme for the hip musculature would follow the same progressions as outlined in Section 2A. A programme to improve lumbo-pelvic muscle function is described in Chapter 6 on the lumbar spine.

In most cases, the success of any exercise programme hinges on the patient being able to incorporate muscle support into functional situations such as standing and walking. As has been described in Section 2A this may require activation of the gluteals and the transverse abdominal wall muscles to maintain an optimal alignment between the pelvis and the lumbar spine (Fig. 10.15). Neglecting this important aspect of exercise therapy will lead to disappointing results.

Range of motion and stretching exercises

There is no specific evidence regarding stretching and the management of PGP. One study showing...
improvement in PGP with exercises included stretching of the buttock, hip flexors and quadriceps in the programme, based on an individual assessment of the patient (Stuge et al., 2004). Stretches of these muscle groups are described in Section 2A. It is likely that patients with PGP related to excessive force closure may respond better to stretching exercises of muscles identified as being overactive.

**Proprioception exercises**

There is no documented evidence to support this form of training in patients with PGP. However, it may be relevant to re-educate patients and increase their awareness of trunk and pelvis body position to improve sitting and standing postures. The use of a mirror to optimise this is recommended.
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SECTION 3: CASE STUDIES AND STUDENT QUESTIONS

Case study 1

A 68-year-old woman presents with 4 years of left groin pain and stiffness gradually becoming more noticeable. An X-ray shows degenerative changes in the hip joint with a loss of superior joint space. Her main functional problems are stiffness after prolonged sitting and in the morning. She also is unable to walk or stand for more than an hour before experiencing significant groin discomfort. Examination reveals a loss of internal rotation, flexion and extension. During left stance phase of gait her left hip is kept in slight adduction the pelvis shifts to the left. She has weakness of the gluteus medius and maximus and an overactive TFL.

Management

This woman has a mild superior form of hip OA. Her functional problems are standing and walking, and treatment is focused on improving these issues. Manual therapy (a longitudinal distraction) is used early to improve movement, reduce pain and give an associated improvement in muscle activation. Gentle massage and stretching of the left TFL is also done before starting on the exercise approach. Early exercise treatment is based on improving the function of the gluteus medius. This is done in side lying with a pillow between knees and externally rotating the hip. With manual guidance of the motion, the patient is able to activate the gluteus medius without domination of the TFL. She can hold this position for only 2–3 seconds and after four repetitions she is fatigued. Following this, the patient practises standing on the left leg with the right leg on a step. In this position the patient maintains the pelvis in a neutral position in the frontal plane (i.e. avoids stance limb hip adduction) using the gluteus medius and not the TFL. This position does not feel normal to the patient and a mirror is an important tool to improve her awareness of the
The Hip and Pelvic Complex

A 28-year-old delivery driver presents with 6 months of right groin pain following an incident in standing when he was forced into lumbar hyperextension with his pelvis fixed. He initially had low back pain, which later settled, and is now troubled by groin pain on walking (as the right hip extends) and prolonged standing. On examination he stands in a sway back posture with increased passive hip extension. He has poor abdominal and gluteal tone bilaterally, worse on the right side and his gluteus maximus activation and strength are poor. His range of hip extension is excessive, psoas is lengthened and weak. Passive accessory glides indicate increased anterior range of motion. An MRI of the hip is normal.

Management

This man has clinical signs of instability which fit in with the mechanism of injury of hip hyperextension. Because his pain is aggravated by standing the initial focus of treatment is to improve the position of passive hip extension in which he habitually stands. This is done by doing posterior pelvic tilts in supine which activate the abdominals and gluteus maximus. This is immediately incorporated into standing with feedback to bring the pelvis back under the trunk. A mirror is required to illustrate this to him and he immediately feels more comfortable in this position. To manage the pain with walking, he is given a squat exercise in standing and a prone hip extension exercise to improve gluteal activation.

Once this programme has been started he is also instructed on maintaining a better neutral spine posture in sitting. He practises moving in and out of this position when driving. This encourages activation of psoas. To further activate this muscle hip external rotation with Thera-Band® resistance in a neutral spine sitting posture is also added. The patient also finds that his pain on walking can be reduced if he tries to keep his pelvis under his trunk. This leads to better recruitment of the abdominals and gluteals (and probably the psoas also). Two months later his pain is absent in standing and his walking is much improved provided that he does not over-stride. He is happy with his progress and elects to self-manage his condition with a continuation of his exercise programme.
Case study 3

A 34-year-old woman presents with right groin pain 6 weeks after the birth of her third child. She noted increased low back discomfort in the last 8 weeks of her pregnancy. This settled but she was anxious to return to activity post partum and as she increased walking volume the groin pain developed 3 weeks post partum. It is also noticeable at night when she rolls over in bed and when she gets out of a chair. On examination she weight-bears more on the right leg and tends to favour this leg on rising from the chair. She has tenderness on palpation through the right adductor longus belly and insertion on the pubic ramus. She has a positive active straight leg raise when lifting the left leg which reproduces her right groin pain. Compression of the sacroiliac joint completely relieves the pain. She has poor gluteal tone and activation bilaterally and stands in a passive sway extension of the lumbar spine and hip.

Management

This patient has adductor pain due to inadequate attempts to provide force closure to the sacroiliac joint. This has been aggravated by attempts to increase activity too soon after birth. She is instructed on transversus abdominis and pelvic floor exercises in supine. She is quickly able to perform this accurately. On the first day she is also given a posterior tilt exercise in supine. In standing she controls her passive lumbar extension by repositioning her pelvis under the trunk. She is quickly able to do this as well. Finally, she is given a squat exercise focusing on equal weight-bearing. She is instructed on pacing her walking so that she is not exceeding her capabilities.

Two weeks later she reports that she is significantly better. The only time she notices any groin pain is if she tries to walk too fast. She has minimal tenderness in the adductor longus and her active straight leg raise is no longer positive. Her abdominal exercises are progressed to include unilateral leg lifts in supine while maintaining a neutral spine position. She is instructed to increase the volume of the squat exercise. She also is asked to include walking up a mild incline near her home as a means of getting good gluteal recruitment. After another 2 weeks she is very happy, with minimal pain, and is able to exercise more without exacerbation of her symptoms.

Student questions

(1) On what is the evidence base for exercise in the management of hip disorders largely based?
(2) Do the beneficial effects of hip exercise in clinical studies persist once the programme has finished?
(3) What is the evidence comparing exercise and manual therapy in managing hip pain and improving function?
(4) Which muscles are most likely to be adversely affected by hip pain and pathology?
(5) What is one possible reason why the study of the effects of exercise of the diagonal sling muscles failed to show a positive effect on the management of PGP?
(6) Which muscles have been identified to play a key role in providing force closure to the sacroiliac joint?
(7) Is there evidence that exercise in pre partum women can influence the recovery from PGP in women?
(8) Do all people with PGP require stability training?
(9) Why is it important to retrain the gluteus medius and maximus in the inner range?
(10) Which group of patients with PGP is likely to respond better to stretching exercises?

References


O’Sullivan, P. and Beales, D. (2007c) Diagnosis and classification of pelvic girdle pain disorders, Part 2: Illustration of


SECTION 1: INTRODUCTION AND BACKGROUND

The knee joint is one of the most commonly injured joints in both the working and the sporting environment. It is made susceptible to injury because of the shape of the bony surfaces and the two long lever arms, created by the femur and tibia. Its stability is provided by the soft tissues surrounding the joint. Even though the joint is technically unstable it takes tremendous force, more than three times the body weight (Chen and Black, 1980), to disrupt the surrounding soft tissue. The patellofemoral joint is integral to the correct functioning of the knee joint. It acts as a modified pulley system to lengthen the lever arm of the quadriceps mechanism.

Evidence for the use of exercise in the rehabilitation of knee injuries

The use of exercise for the rehabilitation of knee injuries has been well illustrated in the literature for numerous conditions and injuries, both acute and chronic. Fransen et al. (2001) carried out a systematic review of the use of exercise therapy for osteoarthritis (OA) of the knee. Seventeen randomised controlled trials (RCTs) were identified, which included 2562 patients. The studies looked at the effectiveness of an exercise programme in relation to self-reported pain and increases in physical function. There was a mixture of exercise protocols on both a group and individual basis. The overall conclusions were that therapeutic exercise demonstrates a beneficial effect on pain and physical function for people with symptomatic OA of the knee joint and that group therapy was as effective as individual therapy. Van Baar et al. (1999) also conducted a systematic review examining the effectiveness of exercise therapy in patients with OA of the hip or knee. They concluded that there was evidence to support the use of therapeutic exercise in the management of hip or knee OA. In an RCT of 83 patients with OA of the knee, Deyle et al. (2000) demonstrated that manual physiotherapy combined with an exercise programme (which included: stretches and range of motion (ROM) exercises; riding a stationary bike; muscle strengthening exercise) decreased pain and stiffness and increased the distance walked in 6 minutes and was associated with less surgery. A frequent mode of delivery of an exercise programme is through hydrotherapy which has a number of benefits, particularly in the management of the more disabled patient. Silva et al.
(2008) examined the effect of a hydrotherapy exercise programme versus a conventional land-based exercise regimen for management of patients with OA of the knee. This RCT of 64 subjects concluded that although both water- and land-based exercises reduced knee pain and increased knee function, hydrotherapy was superior in relieving pain during and after walking. Further evidence in support of aquatic exercise in the management of knee (and hip) OA came from a systematic review of six trials (800 subjects) by Bartels et al. (2007). Although there were methodological limitations in a number of trials, the authors concluded that aquatic exercise has a beneficial effect in the short term for patients with OA of the hip or knee.

There are a number of studies on exercise protocols for anterior cruciate ligament (ACL) rehabilitation, pre and post surgical reconstruction, although some show methodological limitations. Trees et al. (2005) carried out a systematic review of treatment of isolated ACL injuries. They reviewed nine trials consisting of 391 participants. Two trials examined conservative treatment and the remainder examined exercise programmes, post surgery. The outcome measures for all these studies were return to work and return to pre-injury activity levels measured at 6 and 12 months. The general conclusions of this review were that even though active exercise is an accepted part of treatment of ACL injuries, there were no significant differences between the various exercise routines.

Trees et al. (2007) carried out a systematic review of the exercise regimes of ACL injuries in combination with meniscal and collateral ligament injury which is more frequent than isolated injuries. Six studies were identified, involving 343 participants. One study was conservative and all the rest followed reconstruction surgery. The outcome measures were the same as in the previous review. Again all the studies involved exercise of various types from isometric to isotonic work, joint mobility, balance and proprioception. Some of the studies compared supervised with home-based programmes or accelerated versus non-accelerated programmes. The general conclusions were similar to the previous review in that there were no significant differences between exercise regimens. These reviews demonstrate that although exercise shows efficacy in the management of ACL injury, there is a requirement for further research, with well-controlled randomised studies, and consensus on suitable outcome measures and surveillance periods. More specifically, there is a need to identify the exercise mode that is the most effective.

Compared with the number of studies on rehabilitation of the ACL, there is less evidence regarding the role of exercise in posterior cruciate ligament (PCL) rehabilitation, which probably reflects the number of cases seen in practice. Peccin et al. (2005), in a review of treatment of the PCL, identified 286 studies that involved use of exercise in the rehabilitation process but none of these trials were randomised or even quasi-randomised. The problem for researchers when carrying out randomised trials for both ACL and PCL rehabilitation is that exercise therapy is traditionally a fundamental part of any rehabilitation programme for both these injuries. It is therefore unlikely that a trial would compare an exercise versus a non-exercise control group due to ethical considerations. It is also difficult to compare different types of exercise programme because many exercises are multifunctional, particularly as soon as weight-bearing begins, e.g. the squat can be used for strengthening, proprioception, balance and in some circumstances range of movement of the knee.

In summary, there are a number of studies which demonstrate the efficacy of general exercise in the management of knee pain related to specific conditions, notably OA and cruciate ligament injury. However, the lack of clear description of the exercise mode and methodological limitations in published studies warrant further work in this area.

**Aerobic exercise**

One of the difficulties in examining the effect of aerobic exercise in the management of disorders of the knee is the absence of trials investigating aerobic activity only. Many of the studies outlined above combined aerobic exercise with other activities such as muscle strengthening and ROM exercises. Ettinger et al. (1997) stratified patients with knee OA into an aerobic exercise group or resistance exercise group as part of an RCT. They found that both groups had modest improvements in a number of outcome measures including measures of disability, physical performance and pain. This suggests that aerobic exercise is important in the management of OA of the knee. Rogind et al. (1998) examined the effects of a ‘physical training’ programme...
on patients with OA of the knee, demonstrating beneficial effects, even in those with severe OA.

In a number of joints discussed throughout this book, poor levels of physical activity and thus aerobic fitness have been cited as a risk factor for onset, associated disability and pain in musculoskeletal disorders. A number of studies have produced similar findings in disorders of the knee. Manninen et al. (2001) examined the association between physical exercise and the risk of severe knee OA requiring arthroplasty. Their results showed that the risk of severe knee OA decreased with increasing cumulative hours of recreational physical exercise. The effect of exercise on levels of disability associated with knee OA was examined by Pennix et al. (2001). The study concluded that aerobic and resistance exercise may reduce levels of disability in older people with knee OA. Similarly, Dias et al. (2003) and Evcik and Sonel (2002) also found that an exercise and walking protocol had a positive effect on the quality of life of elderly individuals with knee OA. Thus, while it is unclear how activity levels are related to onset of knee OA, evidence suggests that the inclusion of aerobic exercise is needed for optimal management.

On the contrary, a number of recent studies have noted an increased risk of knee OA and musculoskeletal disorders of the knee in general with high levels of physical activity, particularly in sports such as soccer (Drawer and Fuller, 2001). These studies must be considered with caution as they examine the effects of high-intensity exercise, often with the inclusion of contact injury. Intensity of aerobic exercise in the management of OA of the knee was investigated by Brosseau et al. (2003), who analysed a number of trials in the area, and concluded that both high- and low-intensity aerobic exercise are equally effective in improving a number of outcome measures in subjects with OA knee. The analysis also concluded that programmes with higher-intensity exercise components had a greater drop-out rate, indicating that low-intensity aerobic exercise may be the safest and most successful type of programme. The type of exercise prescribed in these studies was primarily stationary cycling, presumably chosen as it loads the knee joint less than a weight-bearing activity. The biomechanics of this activity, however, should be considered with caution. Neptune and Kautz (2000) examined the effects of backward and forward pedalling on a stationary bike to establish the relative loading of the knee joint complex. It was found that backward pedalling offers reduced tibiofemoral compressive loads for knee disorders such as meniscus damage and OA but higher patellofemoral joint loads. The authors recommended that backward pedalling should not be prescribed for patients with disorders of the patellofemoral joint or after ACL injury or reconstruction.

Thus there appears to be clear evidence for the benefits of aerobic exercise in the management of disorders of the knee although there is a requirement for further trials considering aerobic activity as a sole intervention. While evidence suggests that high levels of activity may increase risk of injury, it should be noted that this research was conducted on a specific group of patients who also exposed the knee joint to extreme loading as a result of contact injury. Further, there is evidence to the contrary that low levels of activity may predispose individuals to a higher level of disability associated with OA of the knee.

### Balance and proprioception

The role of proprioception in the function of the knee joint complex has received growing attention in recent years. This is a result of studies which have noted proprioceptive deficits following injury or deficits associated with pathology. While it is unclear if the proprioceptive deficits precede or are as a result of disorders of the joint, proprioceptive training has been adopted as an integral part of knee rehabilitation. Baker, V., et al. (2002) found abnormal knee joint proprioception in individuals with patellofemoral pain syndrome while Bonfim et al. (2003) and Reider et al. (2003) noted similar deficits in patients with ACL impairments (lesions and following reconstruction). The role of proprioception in knee OA is less clear with conflicting evidence in the literature. Koralewicz and Engh (2000), Pai et al. (1997) and Hassan et al. (2001) all found evidence of proprioceptive deficits in individuals with knee OA when compared with controls. However, Bayramoglu et al. (2007) found that in 50 patients with bilateral knee OA, repositioning error was not affected in those with a mild-to-moderate form of the disease. Reasons for altered joint position sense, particularly in OA, have not been clearly established yet. Pain has been cited as a factor in proprioceptive deficits although there is
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Included passive joint movements, muscle stretching and soft-tissue mobilisation as well as ‘ROM exercises for the knee’ in an 8-week programme for knee OA. However, strengthening exercises for the hip and knee were also included as part of the intervention. While the programme was concluded to be successful with a significant number of subjects reporting a ‘decrease in stiffness in the knee’, this measure is likely to be a subjective report as measurement of knee joint ROM was not carried out in any part of the trial.

ROM exercises are routinely used by many clinicians, as most knee disorders, particularly those which are degenerative in nature, present with decreased ROM. While many clinicians would support the efficacy of this approach, there is a requirement for more research to endorse this clinical application.

Muscle strength and endurance

Muscle strengthening exercise is a core component of rehabilitation of knee disorders for most practitioners. This is likely to be a reflection of the fact that muscle weakness surrounding the joint, particularly of the quadriceps, has been found to be both a risk factor and a common finding in conditions such as OA (Slemenda et al., 1997; Lewek et al., 2004). A number of studies have focused on this single component of rehabilitation, particularly in the treatment of knee osteoarthritis. Baker, K.R., et al. (2001) examined the efficacy of home-based progressive strength training in adults with knee OA. A combination of functional exercises such as squats and resistance exercises with ankle weights were performed by patients three times per week for 4 months. The researchers’ findings showed that high-intensity, home-based strength training can produce substantial improvements in strength, pain, physical function and quality of life in patients with knee OA. In a similarly designed trial, O’Reilly et al. (1999) showed that a home exercise programme, which consisted of strengthening exercise for the quadriceps, significantly improved self-reported knee pain and function in patients with knee OA.

There is debate regarding the optimal mode of exercise in the management of knee disorders, particularly of OA. Jan et al. (2008) examined the relative effects of high versus low load resistance
strength training in patients with knee OA resulting in significant improvements in pain, function, walking time and muscle torque for both modes. The effects of high resistance strength training were larger than that of low load training although this finding was not statistically significant. Cheing et al. (2002) found that a 4-week programme of simple isometric exercise was effective in reducing knee pain in those with OA. Eyigor (2004) investigated the efficacy of isokinetic and progressive resistance exercise in 40 patients with knee OA, and found that both modes of exercise reduced pain and relieved function, with no statistically significant differences between the two programmes. As a simple progressive resistance programme is cheaper and more easily performed by the patient than isokinetic exercises it presents a viable option in the management of knee OA. This mode of training is supported by the findings of Sevick et al. (2000), who examined the cost-effectiveness of aerobic and resistance exercise in seniors with knee OA. In a study including 439 patients with OA of the knee, they found that resistance training was more economically efficient than aerobic exercise in improving physical function.

Research in recent years has been directed at analysis of strengthening protocols for the management of specific pathologies, notably patellar tendinopathy and ACL deficiency. Visnes and Bahr (2007) performed a critical review of the role of eccentric training as treatment for patellar tendinopathy. Following analysis of seven studies, the authors concluded that most studies suggest that eccentric strength training with the inclusion of an incline board provides the best outcome in management of this condition. However, no specific protocol demonstrated superiority over any other. Heintjes et al. (2003) performed a systematic review of exercise therapy for patellofemoral pain syndrome (PFPS). Twelve studies were identified (nine RCTs and three concurrent controlled trials). Three studies compared a group receiving exercises against groups that did not. One group underwent a programme of eccentric exercises, another group underwent a programme of static open chain exercises along with isokinetic exercises and the final group used a brace that provided progressive resistive resistance during activities of daily living. All the other studies compared one exercise protocol with another, and of which five studies compared open kinetic chain (OKC) with closed kinetic chain (CKC) exercises. Of the three studies that compared exercise groups with non-exercise groups, all trials found that there was an improvement in pain levels but little change in functional capacity. Of the studies comparing OKC with CKC exercises both were said to be significantly effective but no method was more successful. This conclusion was supported by Herrington and Al-Sherhi (2007) and Witvrouw et al. (2004), who showed significant improvements in clinical outcomes with both open and closed kinetic chain exercises both in the short and in the long term. O’Sullivan (2005) went further, stating that to achieve the most successful recruitment of the vastus medialis obliquus (VMO) during the rehabilitation of PFPS, both open and closed kinetic chain exercises should be carried out. Cowan et al. (2002) showed that by applying a specific progressive rehabilitation programme, the motor control of the VMO could be altered in relation to the vastus lateralis, leading to a positive outcome. However, Syme et al. (2008) demonstrated similar results with the use of either VMO selective training or general quadriceps strengthening only and suggested that clinicians should not over focus on selective activation before progressing rehabilitation.

However, in a more recent study, Fredberg et al. (2008) examined the effect of prophylactic eccentric training in asymptomatic soccer players with ultrasonographic abnormalities in Achilles and patellar tendons. The findings were that a stretching and eccentric programme reduced the risk of abnormal ultrasound findings but had no effect on reducing injury risk. However, it was also shown that in asymptomatic players with abnormal ultrasound findings, the exercise protocol increased injury risk. As this study examined both eccentric exercise and stretching, it was not possible to come to a clear conclusion regarding eccentric exercise and injury risk, suggesting that there is still a requirement for more research in this area.

There has been a great deal of debate about the efficacy of open versus closed kinetic chain work for knee ligament injuries. CKC exercises are considered to be safer as they are thought produce less shear factors across the joint. The major problem with CKC exercises is that even though they are less stressful to the ACL they put more pressure on the patellofemoral joint. It therefore makes it difficult to treat a patient with multiple pathologies. Tagesson et al. (2008) examined the role of closed
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In any rehabilitation programme. The ACL is commonly injured in sporting activities which involve rapid twisting and turning. The ligament is most commonly injured when an excessive valgus force is applied to an extended knee joint, when the foot is planted on the floor creating a lateral rotation of the femur on the tibia. This movement regularly occurs in multidirectional sports such as football or rugby where an athlete rapidly changes direction. The injury can occur with or without contact from another person.

An ACL rupture may be partial or complete. Occasionally a patient may present after a number of incidents that result in small tears, which lead on to the final insult that completed the total rupture. An acute total ACL rupture is characterised by severe pain and varying degrees of haemarthrosis, and the patient may complain of instability. There may be a loss of extension and a positive Lachman’s and anterior drawer test, but these may be difficult to perform due to spasm in the hamstrings. Management may be conservative or surgical depending on the age of the patient and their degree of activity, sporting or otherwise.

Management following repair of an ACL depends on the method of surgery used. If other structures had been damaged in conjunction with the ACL they would be allowed to heal before a repair was attempted. Rehabilitation can either be delayed or accelerated depending on the type of surgery used, the preferences of the surgeon, other associated injuries and the expectations of the patient. In an accelerated programme if there were no problems, full contact sporting activities may be reintroduced after approximately 6 months.

PCL injuries are far less frequent than ACL injuries and usually occur following forceful hyperextension or a fall on a flexed knee. Following rupture, reconstruction of the PCL is performed far less frequently than for the ACL and usually only if other structures are involved. A PCL-deficient knee is less likely to have problems with instability, and conservative management is most common with an emphasis on quadriceps strengthening and proprioception exercises with introduction of co-contraction exercises when the signs of inflammation have diminished.

The MCL can be damaged if a direct blow occurs to the outside of the joint as in a tackle or indirectly if a player, wearing a studded boot, plants his foot in soft ground and twists, creating a rotational

Disorders of the knee joint complex

Ligament sprains

The ligaments surrounding the knee are considered to be passive stabilisers of the joint and disruption can lead to instability. The ligaments of the knee can be divided into two distinct groups, the intra-articular group or central pivot, consisting of the anterior and posterior cruciate ligaments and the extra-articular or peripheral group. Knee ligaments are commonly injured in the sporting environment but can be easily damaged in a non-sporting incident such as a fall or a road traffic collision. The cruciate ligaments provide joint stability in all planes of movement in collaboration with the peripheral musculoskeletal structures. If the joint is put under a valgus force with external rotation the ACL and medial collateral ligament (MCL) prevent anterior translation of the tibia. The close association of all these soft tissues and their collaboration in providing stability of the knee joint explain why these structures are rarely injured in isolation and also why these relationships need to be considered in any rehabilitation programme. The ACL is commonly injured in sporting activities which involve rapid twisting and turning. The ligament is most commonly injured when an excessive valgus force is applied to an extended knee joint, when the foot is planted on the floor creating a lateral rotation of the femur on the tibia. This movement regularly occurs in multidirectional sports such as football or rugby where an athlete rapidly changes direction. The injury can occur with or without contact from another person.

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The MCL can be damaged if a direct blow occurs to the outside of the joint as in a tackle or indirectly if a player, wearing a studded boot, plants his foot in soft ground and twists, creating a rotational
force about the joint. If a direct force is applied to the outside of the joint, with the knee slightly flexed, in a weight-bearing position, it causes an external rotation of the tibia in relation to the femur, which can cause damage to the MCL. This can occur in isolation, or more usually in combination with the medial meniscus and if the force exceeds the physiological limits the ACL may become involved. In extreme situations the PCL may become compromised. This results in global instability of the joint. The lateral collateral ligament is less commonly damaged than the MCL and often in isolation, although if the force is severe enough associated damage may occur to the lateral meniscus or either cruciate ligament. It is usually damaged following a direct varus force to the knee with some hyperextension.

**Meniscus injuries**

Injuries to the menisci of the knee rarely occur in isolation and are less common than injuries to ligaments and problems with the patellofemoral joint. When isolated tears do occur they are usually degenerative in nature and are sustained by the older rather than the younger generation. Acute meniscal tears usually involve other soft tissue structures. Meniscal injuries can occur following a number of different mechanisms including rotational and translational forces as well as overuse or degeneration.

Damage to the medial meniscus is more common than the lateral meniscus by a ratio of approximately 10:1. Approximately 80% of injuries to the medial meniscus are associated with damage to other soft tissue structures of the knee particularly the MCL and ACL due to their common attachments. Symptoms of meniscal tears are often characterised by ‘locking’ or ‘clicking’ of the knee joint, as a portion or flap of meniscus becomes impinged in between the femoral condyles and tibial plateau, when the joint is moved into extension or sometimes flexion. The patient also often reports that the knee ‘gives way’ and feels unstable. There may be a small effusion and tenderness along the joint line with McMurray’s and Appley’s compression tests often positive. If the effusion is aspirated and blood is present it would usually indicate ligament involvement. A posterior horn tear would produce pain on full squatting.

**Osteoarthritis of the knee**

OA of the knee often produces significant pain that worsens on weight-bearing and consequently leads to an increase in functional disability. It is characterised by morning stiffness, diminished joint range and crepitus on movement. If inflammation is present, it is localised to the joint involved. The medial compartment of the knee is more likely to be affected than the lateral compartment, which can ultimately lead to a varus deformity, joint laxity and muscle weakness, particularly of the quadriceps. The cause of the laxity may be multifactorial and can be due to a combination of soft tissue pathology, primary laxity of the ligaments and capsule, previous injury or degeneration of the articular cartilage and bone, which would result in a loss of joint space.

Gait patterns can become compromised with a loss of knee flexion during weight-bearing that increases the load on the articular cartilage. To compensate for the laxity or weakness around the knee joint, the patient will often demonstrate a reflex stiffening of the joint with associated co-contractions of the quadriceps and hamstrings, which increases the pressure inside the joint. A combination of increased internal pressures and increased load on the articular cartilage can increase the risk of cartilage destruction.

**Anterior knee pain**

Anterior knee pain is an umbrella term for a number of conditions that affect the patellofemoral joint. Sometimes it is difficult to differentiate between the separate conditions and it is not uncommon to have multiple pathologies. These include PFPS, patella tendinopathy, bursitis and plicae syndrome.

**Patellofemoral pain syndrome**

PFPS is common in all groups within the active and sedentary population with a high incidence in the adolescent population. There are a number of factors which have been attributed to the cause of PFPS, both static and dynamic including biomechanical and muscle weakness/imbalance factors. The most common are listed in Table 11.1. The differences in symptoms between PFPS and patellar tendinopathy are sometimes very slight and these
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able to injury but especially the muscles that cross both the hip and knee, which include the hamstrings and rectus femoris. Sartorius, which even though is not part of the quadriceps group, falls into the same category as rectus femoris. Care must be taken with the diagnosis to differentiate between inter- and intra-muscular haematomas as the treatment protocols are different in the initial stages (Table 11.2). In the case of an intra-muscular haematoma blood is trapped within the sheath and becomes a ‘space-occupying lesion’. In severe cases, this may require surgical decompression.

Myositis ossificans is a rare complication which occurs when the haematoma calcifies. This may occur with disruption of the periosteum at the time of the injury or with too aggressive rehabilitation following an intramuscular haematoma. Injuries often result from previous injury if rehabilitation has been inadequate.

Muscle injuries

The muscles around the knee joint that provide dynamic stabilisation of the joint are essentially the hamstrings and quadriceps. Both groups are vulner-

### Table 11.1 Clinical signs of patellofemoral pain syndrome (PFPS) and patellar tendinopathy (PT)

<table>
<thead>
<tr>
<th>Clinical signs</th>
<th>PFPS</th>
<th>PT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Painful activity</td>
<td>Running, stairs, eccentric work</td>
<td>Jumping, landing</td>
</tr>
<tr>
<td>Site of pain, tenderness</td>
<td>Diffuse at the patella, may not be palpable</td>
<td>Localised, inferior pole patella, length of tendon</td>
</tr>
<tr>
<td>Crepitus</td>
<td>In severe cases at patella</td>
<td>In tendon</td>
</tr>
<tr>
<td>Giving way</td>
<td>Yes, due to pain, quadriceps weakness</td>
<td>Not usual</td>
</tr>
<tr>
<td>Effusion</td>
<td>At patella in severe cases</td>
<td>At tendon in severe cases</td>
</tr>
<tr>
<td>Range of motion</td>
<td>↓ in severe cases</td>
<td>normal</td>
</tr>
<tr>
<td>Patella mobility</td>
<td>↓ medial glide due to tight lateral retinaculum</td>
<td>normal</td>
</tr>
<tr>
<td>Vastus medialis obliquus</td>
<td>Wasted; vastus medialis obliquus/vastus lateralis imbalance</td>
<td>General quads wasting.</td>
</tr>
<tr>
<td>Effect of activity</td>
<td>↑ pain with ↑ activity</td>
<td>Initial pain ↓ with activity, ↑ when stopped.</td>
</tr>
<tr>
<td>Pseudo locking</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Adapted from Houghum (2005).

sometimes occur at the same time. The clinical signs are shown in Table 11.1.

### Table 11.2 Differentiating between intra- and inter-muscular haematomas

<table>
<thead>
<tr>
<th>Intra-muscular haematoma</th>
<th>Inter-muscular haematoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area inflamed</td>
<td>Not noticeably inflamed</td>
</tr>
<tr>
<td>Loss of power and stretch</td>
<td>Loss of power but not stretch</td>
</tr>
<tr>
<td>No bruising visible due to encapsulation in muscle sheath</td>
<td>Bruising visible below injury site 24–48 hours after injury</td>
</tr>
<tr>
<td>Joint range limited and returns slowly due to pain and internal pressure</td>
<td>Joint range returns quickly</td>
</tr>
<tr>
<td>Internal pressure high due to blood encapsulated within muscle sheath</td>
<td>Internal pressure low due to blood loss via ruptured sheath</td>
</tr>
</tbody>
</table>

Quadriceps

These muscles are commonly injured in sport, particularly in all codes of football. Common causes of strains and tears include fatigue, poor flexibility,
and sudden contraction of the muscle, which may occur while jumping or with a sudden change in direction. Other contributory factors may be muscle imbalance; particularly an abnormal quadriceps:hamstring ratio (usually hamstrings have 60–80% power of quadriceps). Tears are characterised by sudden pain in the front of the thigh and signs of inflammation, and a defect may be palpable. Surgery is rarely indicated even in the most severe cases.

**The hamstrings**

The hamstring muscles are a common site of injury in the active population, not just in sporting activities. The hamstring muscles are important trunk stabilisers in posture and also extend the hip and flex the knee when walking and running. Hamstring tears are usually the result of overload of the muscle fibres, particularly during an eccentric contraction. Symptoms are similar to those of quadriceps tears with pain in the posterior aspect of the thigh. Any posterior thigh pain must be investigated thoroughly as it may be neural rather than muscular in nature. This is particularly important in children who rarely suffer from hamstring tears, even those in elite sports. Posterior thigh pain in children is usually a consequence of a growth spurt and with neural stretches will settle quickly, unlike true hamstring tears, which can take a number of weeks to settle.

### SECTION 2: PRACTICAL USE OF EXERCISE

When planning a rehabilitation programme for the knee joint it is helpful to consider both primary and secondary issues. The primary issues deal with the specific problem that has affected the knee joint, such as the damage to the joint or soft tissue surrounding and supporting it, and the secondary factors, which are the areas affected as a consequence of the primary problem and could include increased or decreased stability of the joint, loss of range, decreased muscular power, endurance and strength, reduced proprioception and co-ordination difficulty in activities of daily living. To identify the primary and secondary factors surrounding a knee injury a comprehensive assessment must be carried out.

Rehabilitation protocols of the knee joint have been developed with specific pathologies in mind so the programmes outlined below reflect this. However, it must be noted that the general principles described may be used in management of many presentations of knee pain. Further, it should be considered that knee pain is commonly caused by a number of structures simultaneously and while a working diagnosis may be given, the protocols should be a guideline rather than a generic approach to management.

The pathologies which will be considered here are: OA of the knee, patellar tendinopathy, PFPS, ACL injury, and meniscal and ligament injury.

### Osteoarthritis of the knee joint

As osteoarthritis is a degenerative disorder with no known cure other than joint replacement, the management of this condition aims to use exercise to reduce pain and improve joint function.

### Aerobic exercise

**Early phase**

Brosseau *et al.* (2003) confirmed that ‘both high and low intensity aerobic exercise were equally effective at improving a patient’s functional status, gait, pain and aerobic capacity for people with OA of the knee’. The ultimate aim of the programme should be to allow the patient to reach the activity as recommended in the American College of Sports Medicine (ACSM) guidelines, although early goals will focus on improving general function. The choice of activity will depend on the ability of the patient to perform the activity within limits of pain and the activity should not aggravate the condition. Many patients will find that weight-bearing activity aggravates their symptoms so non-weight-bearing activity should be the exercise of choice in the early stage of rehabilitation. Hydrotherapy is an excellent option in patients with OA of the knee as the lower limb is de-loaded by the buoyancy of the water. Also the water provides resistance that will allow the
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heart rate to be raised more easily in fitter individuals. Use of a buoyancy vest will allow the patient to perform walking and running patterns with the lower limb, which will be the precursor to improving these functions on the land. Use of a static bicycle for cycling is another appropriate option. In the early stage of rehabilitation, the height of the saddle should be set so that the patient’s knee is moving through a movement range that is comfortable as this may be limited by pain; this may mean that the saddle is high to begin with but should be gradually lowered throughout rehabilitation to try to improve the range, see Figure 11.1 (a: early phase; and b: late phase). If high-intensity training is chosen, the patient should exercise at 70% heart rate reserve (HRR) and for low intensity, 40% HRR should be selected. Choice of exercise intensity will depend on factors such as the cardio-respiratory health of the patient and will be decided following appropriate assessment of the patient.

Late phase
The choice of late-stage aerobic activity should reflect the specific functional requirements of the patient. A walking programme should be commenced as soon as possible with the ultimate aim to achieve 1 hour of this activity on most days of the week. Simple walking programmes have demonstrated efficacy in management of OA of the knee (Evcik and Sonel, 2002). Patients may benefit from a Nordic walking approach (see Chapter 2), as the walking poles give them extra support. All patients should progress to walking without any support and move from a stable surface (smooth pavements) to less regular surfaces such as a field or sandy beach. The footwear of choice should be training shoes to correct foot biomechanics and attenuate shock. The patient should be told that the walking programme should be continued following discharge and, as far as possible, incorporated into daily life.

Range of motion and flexibility exercises
As mentioned above, the nature of OA of the knee means that exercise therapy is likely to be ineffective in restoring full ROM to the joint. Therefore, the aim of ROM exercises should be to achieve a ROM that facilitates better function according to the demands of the patient’s lifestyle.

Early phase
Pain may limit ROM in the early stage of rehabilitation and the aim should be to avoid aggravating the condition. Active-assisted exercise may be beneficial and a good example was outlined above, using a static exercise bicycle. There should be no tension on the wheels and if the therapist manually starts

Figure 11.1 (a) Cycling with a high saddle. (b) Cycling with a low saddle to encourage knee flexion.
ity in the patellofemoral joint and it may be necessary for the clinician or patient to mobilise the patella in all directions while in a relaxed, long sitting position. Use of a padded rope in a prone position may allow the patient to facilitate their own knee flexion (Fig. 11.3).

The addition of passive ROM exercises may be appropriate in the early phase of rehabilitation, particularly to the patellofemoral joint and these may be particularly useful to improve joint range when active and active-assisted exercise are no longer as effective (Fig. 11.4).

Stretches of muscles that cross the knee joint should be incorporated into the ROM programme and will be done most effectively following aerobic

Figure 11.2  Use of a sliding board to ease heel sliding and facilitate knee flexion.

Figure 11.3  Use of a padded rope around the ankle to facilitate knee flexion.

(a)  (b) Passive knee flexion. (b) Passive knee extension.
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Late phase
Progression of proprioceptive exercise will take place at the same time as partial weight-bearing (PWB) strengthening exercise. PWB exercises are classified as CKC exercises where multi-joint, multi-muscle actions are reinforced. These exercises enhance proprioception and kinaesthetic awareness, balance, equilibrium and co-ordination and weight-bearing control. Specific movement patterns can be introduced that will replicate patterns of movement which will be used by the patient when the process of rehabilitation is complete. Static balance exercises can be commenced, and there are a number of ways to progress proprioception training of the knee, using various exteroceptors – which are the five senses. Progression of proprioception is affected by the type of base, i.e. whether it is rigid or soft, the height of the base from the floor, which can be altered by lowering the support surface from which the body has to raise, therefore the exercise could be started initially from a high chair to a chair, a stool and then a bench. As the base becomes smaller, the proprioceptive demands are greater. The size of the base can be changed by starting with a wide foot position, gradually bringing the feet together and ultimately standing on the injured leg alone. Adding superimposed movements such as bouncing a ball against a wall while standing on one leg. will challenge balance further.

Muscle strength and endurance exercise
Slemenda et al. (1997) found that quadriceps weakness was a significant finding in patients with OA of the knee and for many clinicians, restoring strength in this muscle group is the starting point in any rehabilitation programme. Further, Baker, K.R., et al. (2001) emphasised the importance of strength training in the management of OA of the knee by demonstrating that ‘high intensity, home based strength training can produce substantial improvements in strength, pain, physical function and quality of life in patients with knee OA’.

Early phase
Exercises to maintain strength in the musculature around the knee joint can be carried out from a
Figure 11.5  (a) Hamstring stretches. (b) Quadriceps stretches. (c) Adductor stretches. (d) Abductor stretches. (e) Calf stretches.
very early stage in any knee injury in the form of isometric exercises. Isometric exercises can be carried out if the joint is immobilised or if there is insufficient dynamic strength or too much discomfort in the area to allow active joint movement. For OA of the knee, isometric contraction of the quadriceps group in a long-sitting position, followed by straight leg raises (Fig. 11.11) of various derivatives are the usual starting point in strengthening exercises. A high degree of tension can be produced in the muscle but no active movement is produced at the joint itself. Position of the patient is important to ensure that they do not use trick movements to lift the leg off the surface. The loading of the exercise can be increased by placing an ankle weight in situ and repeating the movement.

While Jan et al. (2008) demonstrated that both high and low load resistance training improved clinical effects in patients with knee OA, the emphasis in the early stage of rehabilitation is usually to improve the endurance of the muscles to enhance basic function. For this reason, high repetitions with no or minimal load or alternatively, sustained contractions should be carried out at this stage. The patient may then progress to isotonic exercise, loading the knee joint through its movement range with particular emphasis on the quadriceps, and also addressing other muscle groups that demonstrated deficits at initial assessment. Ankle weights, pullies or isokinetic resistance machines may be used to provide resistance. Suggested exercises include knee extension, knee flexion, hip extension, hip adduction and hip abduction. Baker, K.R., et al. (2001) suggest that two sets of 12 repetitions should be performed three times a week for each exercise, increasing the weights according to the patient’s progress.
Late phase

While some of the strengthening exercises outlined above may constitute the late stage by virtue of their progression, the emphasis at this stage should be on functional exercise. Weight-bearing exercise such as lunges and squats allow CKC patterns to be used, which facilitates co-contraction of a number of muscle groups. Exercises such as rising to standing from a sitting position are very functional and resistance may be increased by holding a weight at the chest (Fig. 11.12). Step-ups on to a low bench may be progressed by increasing the height of the bench or placing a weighted back pack on the patient. Lunges may be progressed by asking the patient to hold a weight, although the therapist should observe the patient carefully for biomechanical faults because a high level of proprioception is required in such an exercise.

The components of the late phase of strength training depend on the stage of OA. Patients with moderate and severe disease may only be able to
Previous treatment focused on the management of the condition as an inflammatory process but recent studies have negated this theory. For the purpose of management of this condition, it will not be divided into the different exercise components as in OA (above) but will be described as a rehabilitation protocol derived from analysis and review of research to date. Visnes and Bahr (2007) concluded from a review of the management of patellar tendinopathy that eccentric training has a positive effect on the injury although individual protocols varied, with no clear definition of which was most effective. Further, they suggested that a clinical approach will also use factors such as warm-up and stretching, which are not analysed in many studies. The protocol described below is adapted from Jonsson and Alfredson (2005).

**Early phase**

While the main component of treatment is the eccentric exercise programme, full assessment of the patient should establish deficits in flexibility, aerobic fitness and proprioception of the knee joint and surrounding structure. While this injury is frequently seen in competitive athletes, aerobic fitness may still be an issue as it must be maintained during a period of rehabilitation. Purdam et al. (2004) stated that subjects were not allowed to take part in their normal sporting activity during the first 8

**Patellar tendinopathy**

Great advances in the management of patellar tendinopathy have been seen in recent years with the introduction of eccentric exercise protocols.

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**Figure 11.10** Use of an electrogoniometer to train joint repositioning.

**Figure 11.11** Straight leg raise.

**Figure 11.12** Sitting to standing holding a weight.
weeks of the eccentric protocol trial. Weight-bearing programmes may not be appropriate in the early stage, so stationary cycling is a good choice of activity, although backwards pedalling should be avoided due to increased load on the patellofemoral joint. Flexibility of the hamstrings (Fig. 11.5a) and quadriceps (Fig. 11.5b) in particular should be addressed with inclusion of stretches to other groups indicated following assessment. The aerobic exercise and stretching component may precede the eccentric training protocol as a warm-up, although the aim should not be to exercise to any level of fatigue, meaning that an aerobic programme may also be carried out separately to a level required by the more competitive athlete. Following the warm-up, the protocol is as follows.

A starting position is standing with the trunk upright on a 25° incline board with the entire body weight on the injured leg (Fig. 11.13a). The knee is then slowly flexed to 70° (Fig. 11.13b). To return to the starting position, the other leg is used to push back up to avoid concentric activity. The patient should be informed that the activity may cause muscle soreness initially and will be painful in the tendon during exercise. The exercise is repeated 15 times, twice a day, 7 days a week.

Late and functional phase

The programme is carried out for a period of 12 weeks. After the first 4 weeks, the patient may progress the aerobic component to slow jogging on flat ground, increase the intensity of cycling or add in swimming (Purdam et al., 2004), provided that these activities do not increase the pain. The eccentric programme should be carried out as above but weight should be added in the form of a loaded backpack on the patient. Weights should be added when the patient no longer finds the exercise painful, to a load that re-creates the pain. The proprioceptive component of the programme will be monitored by the therapist, who must ensure correct biomechanics during all activities of the programme, in particular, ensuring that the patient squats to the correct angle, using an electrogoniometer if necessary.

After 8 weeks, the patient should be allowed to make a graduated return to normal activity while completing the final stage of the programme ensuring that appropriate stretching protocols are adhered to. Functional exercises such as walking can be progressed to fast walking then jogging, half pace running, three-quarters pace running, and then sprinting, forwards, backwards and sideways. This should be done initially in straight lines, then multi-directional work can be introduced, including rotational work, which will involve shearing and compressive forces. Finally, the joint should be taken through sudden acceleration and deceleration manoeuvres to ensure there is functional stability. Jumping and landing can be introduced, initially with two feet and progressing to one.
There is some emerging evidence that eccentric training and stretching may have a prophylactic effect on recurrence or onset of ultrasonographic changes in the patellar tendon (Fredberg et al., 2008), although further work is required to establish a direct link with injury risk. However, it may be appropriate to include eccentric training as a regular warm-up exercise in patients who are at risk of injury following discharge from treatment.

Patellofemoral pain syndrome

Exercise has been the mainstay of treatment for PFPS, particularly with the introduction by McConnell (1996) of a specific programme that targets patellar tracking and timing of the vastus muscle group. While McConnell placed emphasis on patellar taping to correct tracking in her original research, there is a need for further studies to establish its efficacy (Vagan and Hunt, 2008); and recent research has even suggested that taping may inhibit contraction of the VMO (Ng and Wong, 2009). For this reason, taping is not included in the programme described below but the clinician must make an informed decision on its use according to available evidence as it is still widely used clinically.

The programme outlined below is based on that described by Crossley et al., (2002) and will not be formally separated into components of fitness as for OA.

**Early phase**

The emphasis of exercise in the early stage of rehabilitation should be correction of timing and intensity of VMO contraction relative to the vastus lateralis (VL). Stretches to appropriate muscle and soft tissues aim to correct the patellar position and allow normal biomechanics of the lower limb. As the position of the whole of the lower kinetic chain will influence patellar position, initial assessment of lower limb biomechanics should be comprehensive, including assessment of dynamic function.

Maintenance or achieving aerobic fitness may be challenging in the management of a patient with PFPS, as many forms of activity will be limited by pain. While there have been no studies examining cardiovascular fitness and its relationship to PFPS, maintenance of minimal activity levels should be addressed. Activities such as stationary cycling may be chosen. However, the seat should be high so that the knee joint moves through a small ROM, ensuring that the hip does not medially or laterally rotate, and that the patella is directed over the second toe during the cycling motion of the leg. The foot should also face straight ahead in the pedal. There should be no loading on the crank and backwards pedalling should be avoided.

Stretches should be applied to any tissue which is hypomobile at initial assessment. In particular, Crossley et al. (2002) recommend:

- Mediolateral (glide and tilt) mobilisation of the patella (stretching of the lateral retinaculum) (Fig. 11.14a)
- Hamstring muscle stretches in sitting (Fig. 11.14b)
- Anterior hip structures stretch with the subject in prone with hip externally rotated and the hip and knee flexed (Fig. 11.14c).

Three repetitions of each stretch with a 30-second hold is recommended. McConnell (1996) suggests that isometric quads exercise should be taught early, placing emphasis on VMO activity. Addition of adduction of the thigh (placing a ball between the patient’s knees and asking them to squeeze while contracting the quads) will help facilitate the VMO. Crossley et al. then recommend:

- Isometric VMO contractions in sitting with knee at 90° flexion
- Squats to 40° knee flexion combined with isometric gluteal contractions (Fig. 11.15).

(Four sets of 10 repetitions each.)

- Isometric hip abduction against the wall while standing.

(Four sets of 15-second hold.)

All the above exercises should be carried out twice daily.

**Late and functional phase**

Crossley et al. (2002) specify that the above programme should be carried out for 2 weeks. After that, the knee joint may be moved through more
challenging motion patterns with the introduction of gravitational loading. Aerobic exercise should be increased progressing to walking on a flat surface. If orthoses are prescribed by a podiatrist, these should be worn at all times to optimise lower limb biomechanics. Provided that the vastus group is functioning well, this may be progressed to jogging in straight lines. Crossley et al. recommend the following exercise for the last 4 weeks of the programme.

- Step-downs – slow lowering of unaffected leg, standing on affected leg with a 10 cm step (three sets of five repetitions progressing to three sets of 10 repetitions) (Fig. 11.16)
- Isometric hip abduction while standing (4 sets of 30 second hold) (Fig. 11.17).

The height of the step may be increased to 20 cm provided that the patient is able to complete the activity correctly and without pain. The stretches described in the early phase should be continued. Proprioceptive work will be done throughout this programme as a high level of control is required to complete the exercises correctly and constant feedback should be given to the patient to reinforce correct movement patterns.

The patient will be allowed a graduated return to activity on completion of the programme but must maintain flexibility of soft tissues. Athletes
It should be noted that some authors suggest that over-emphasis on selective VMO timing may not be necessary and that exercises which simply exercise the quadriceps group in general may be adequate (Syme et al., 2008).

Anterior cruciate ligament injury

It is common for both the medial meniscus and the MCL to be injured at the same time as the ACL, although the rehabilitation programme described below should address deficits noted in both combined and ACL injury only. A systematic review of studies by Trees et al. (2007) suggests that while exercise is efficacious in the management of ACL injury (both surgically and post-operative) it was not possible to conclude which mode of exercise or programme produces the best results. However, a review by Wright et al. (2008) concluded that early weight-bearing and early ROM exercises are safe and that CKC exercises are beneficial in the first 6 weeks.

The exercise programme outlined below is based on the results of the review by Trees et al. (2007) and adaptation of the programme designed by Tagesson et al. (2008). Tagesson et al. describe the distinct phases of an ACL rehabilitation programme as:

- Phase 1 (weeks 1–4) – protection.
- Phase 2 (weeks 5–8) – early strength training.
- Phase 3 (weeks 9–12) – intensive strength training.
- Phase 4 (weeks 13–16) – intensive strength training and return to sports.

**Phase 1 (weeks 1–4) – protection**

The aims of this phase are to increase ROM of the knee joint, improve gait patterns, improve proprioception of the knee, improve or maintain aerobic fitness and to improve muscle function. This stage may constitute the immediate post-operative phase or the initial stage of a conservative programme. Standard approaches such as anti-inflammatory medication and cryotherapy may be necessary at this stage to reduce swelling.
Muscle strength and endurance exercise

Static quadriceps contractions should be carried out on an hourly basis at this stage if possible, progressing to a straight leg raise as soon as possible. These exercises are progressed to squatting exercises, which can be combined with proprioceptive function. A two-legged squat leaning back against a gym ball against a wall is a good CKC exercise to improve muscle function of both the hamstring and quadriceps muscles (Fig. 11.20). Slow step-ups on to a low step and small lunges to the front and side are appropriate at this stage.
Proprioception and balance exercise
All exercises described above incorporate proprioceptive function as the patient must work to ensure correct movement patterns are maintained. However, specific proprioceptive exercise may be introduced, such as standing on an unstable surface, progressing to small squats (Fig. 11.21).

Phase 2 (weeks 5–8) – early strength training
At this stage, the patient should have full ROM and normal gait and the aims of this phase are to increase loading in strength training and to continue to improve function.

Aerobic exercise
The patient may start activities such as a stepper machine or increase the resistance on an exercise bicycle. Walking may be increased in tempo, progressing to very light jogging, particularly if the patient is returning to a sport that involves running.

ROM exercise
As the patient should have full ROM at this stage, the emphasis should be on stretching of appropriate muscle groups to maintain full ROM. These muscle groups will include the hamstring and quadriceps muscle groups in particular. Stretching will be most effective following the aerobic exercise of the programme.

Muscle strength and endurance exercise
This is the most important component of the phase and will see the introduction of a variety of exercise. A combination of both open and closed chain exercise will add variety as both will enhance different functions of the muscle. Lunges may now be loaded with a weight on the shoulders ensuring correct biomechanics at all times. Squats may be progressed by loading in a shoulder press machine and performing on one leg. Other resisted movements which should be included are hip abduction, hip adduction, hip extension, heel raise, leg curl and seated knee extension (avoiding shearing on the tibia). Tagesson et al. (2008) suggest that load at this stage should be at 50–60% of 1 RM (repetition maximum), with three sets of 10 repetitions of the exercise performed three times a week. A combination of free weights and machine weights is useful but the additional proprioceptive challenge that free weights provide will be beneficial at this stage.

Proprioception and balance exercise
Once the patient is competent at performing a few of the resisted exercises with free weights, some of them may be performed (with care and reduced loading) on unstable surfaces such as wobble boards. Single leg squats on trampolines and wobble boards are also appropriate exercises.

Phase 3 (weeks 9–12) – intensive strength training
The aim of this phase is to introduce more functional exercise and to increase strength.

Aerobic exercise
The patient may continue with static cycling and the step machine, but may also include exercise that is appropriate to allow them to return to their particular sport. Jogging may now increase and progress to running. Running should initially take
place on a flat surface, in straight lines but should quickly proceed to up and down a hill, diagonal patterns and directional changes, and running on uneven surfaces.

ROM exercise
As the patient should have very good ROM, the emphasis of this phase should be as above, to maintain the ROM with a good stretching regimen for appropriate muscle groups.

Muscle strength and endurance exercise
All exercises included in phase 2 should be continued in phase 3 with an increase in loading. Again, the exercises are performed 10 times in three sets and repeated three times a week.

Proprioception and balance exercise
Exercise can be continued in this phase with wobble boards and trampolines as for the previous phase. Running in between cones or hopping over a line on the floor will introduce more dynamic proprioceptive activity.

Phase 4 (weeks 13–16) – intensive strength training and return to sports
The aim of this phase is to increase strength, coordination and to introduce functional activity to allow the patient to return to sport or work.

Aerobic exercise
Running may increase with changes in tempo. Turns and agility drills should be introduced. Acceleration and deceleration activities should be included over various distances. Sports specific activity may be included. For example, if the patient is a footballer, ball skills will be an important component of the programme at this stage. The patient should be reaching optimal fitness by the end of this phase.

ROM exercise
As full ROM should have been achieved in the early phase of the programme, the emphasis is on maintenance. Particular attention should be applied to ROM of the patellofemoral joint, ensuring that movement is normal before discharge, particularly if the graft site was the patella tendon.

Muscle strength and endurance exercise
The exercises shown above (phase 2) may be continued with the load at 80% of 1RM, increasing this load by 10% at week 15. Plyometric activity is an important addition to this stage of the programme. Jump training will fulfil this requirement, to the front and side and over objects to challenge the proprioceptive system as well (Fig. 11.22). Vertical jumps, landing on a soft surface will increase the challenge of the activity. Hopping between the rungs of a ladder placed on the ground will require a high level of control and is suitable for the late stage of functional rehabilitation.

Proprioception and balance exercise
Exercise carried out in the previous phases should be continued but the greatest proprioceptive challenge in this phase will be seen in the plyometric drills and introduction of agility drills in the late stage of functional rehabilitation.

The emphasis on return to sport should be to maintain the health of the knee and avoid further injury to the same knee (after conservative place on a flat surface, in straight lines but should quickly proceed to up and down a hill, diagonal patterns and directional changes, and running on uneven surfaces.
SECTION 3: CASE STUDIES AND STUDENT QUESTIONS

**Case study 1**

A 60-year-old postman presents with diffuse pain in his right knee which is aching in nature, painful on rising in the morning, and aggravated by sitting for more than 20 minutes with the knee flexed. Walking in training shoes at a moderate pace eases the pain within 10 minutes. Investigations show that he has early OA, both in the tibiofemoral and patellofemoral joints.

**Management**

As this patient has presented with a degenerative disorder, the aim of the treatment will not be to achieve complete resolution of symptoms but rather to improve pain and function. As this patient is already active as part of his occupation, a functional approach should be adopted in his rehabilitation. Aerobic exercise will consist of his daily walking activity, ensuring that he is wearing good footwear to optimise lower limb biomechanics. Limitations in ROM will be addressed with a programme to stretch muscle groups which cross the knee joint and activities such as heel slides and full knee extension exercises in a long sitting position. If the patellofemoral joint is hypomobile, passive mobility exercises may should be performed by the therapist. Specific strengthening exercises may incorporate proprioceptive training, by performing squats in standing, progressing to standing on an unstable surface. Single leg squats will progress the exercise, performed slowly and ensuring that the knee is well positioned over the second toe. Step-ups and step-downs may be performed, gradually increasing the depth of the step. However, as the patellofemoral joint is involved, step-downs may be painful and should be avoided if this is the case. The number of repetitions of the strengthening exercises should be high as they are only loaded by body weight and the aim is to improve the endurance of the musculature. The patient should be discharged with advice to continue daily walking and ROM exercises if possible, and strengthening exercises three times a week if possible. Regular review of this patient is necessary to monitor any progression of the OA.

**Case study 2**

An 18-year-old man, who is a semi-professional footballer, sustained an injury to his right knee during a game. He went in for a block tackle and felt pain on the medial aspect of his right knee. There was no immediate swelling or locking but there was pain on weight-bearing. There was no evidence of a fracture. The following day the knee was swollen, hot and painful. A diagnosis of a severe grade 2 medial ligament sprain was made.

**Management**

The knee was iced on a regular basis and placed in a rigid brace for weight-bearing. The brace was...
left *in situ* for 6 weeks but removed regularly for non-weight-bearing mobility and strengthening exercises. During the period that the brace is *in situ*, it is very important that this patient’s aerobic fitness is maintained with non-weight-bearing activity such as cycling, and the uninjured leg may be used to pedal alone in the first phase of rehabilitation. Careful ROM exercises will aim to achieved full flexion and extension from an early stage in an unloaded position with full extension avoided for the first 2–4 weeks. Proprioceptive activity could be carried out in the early stage using an electrogoniometer to practise repositioning of the knee.

Between the second and fourth week, the crutches may be removed and the patient may progress to full weight-bearing. Isometric quadriceps exercise and straight leg raise exercises will aim to restore muscle function. After the fourth week, ROM exercise should aim to achieve full range, and strengthening exercise may now become weight-bearing without loading (squats and lunges) progressing to loaded exercises (leg press, hamstring curls and knee extension). Squats may be performed on an unstable surface to enhance proprioception. At 6 weeks the brace should be removed with care, provided good control of the knee joint is demonstrated. Exercises may be now more functional with the introduction of fast walking, progressing to running, initially in straight lines and then multi-directional. Strengthening exercises should continue as above with loading increased until the patient’s injured knee has 80–90% of the strength of the unaffected knee, depending on which is dominant. When the patient can run comfortably, ball work may be commenced and a gradual reintegration of football training undertaken until full fitness had been achieved.

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**Case study 2—cont’d**

A 45-year-old man, who is training for a marathon, presents with anterior knee pain which is intermittent in nature but is aggravated by descending stairs and sitting at his desk for more than 20 minutes. He is not able to run for more than 10 minutes as he cannot continue because of pain. Examination reveals genu valgum and pes planus and it is noted that his running shoes are deformed and 8 years old.

**Management**

A working diagnosis of PFPS was given to this patient. A podiatric referral was organised at initial appointment and a pair of orthoses prescribed. The first phase of rehabilitation addressed hypomobility of soft tissue with particular emphasis on stretching the hamstrings, quadriceps, iliotibial band and tensor fascia lata. The patella was mobilised to improve lateral tilt and to improve mobility in the lateral retinaculum. As taping the patella did not change any symptoms, it was not used in this case. Initial strengthening exercise consisted of isometric quads contraction, with particular emphasis on VMO activity. This is progressed to squats to 40° in standing and isometric hip abduction against a wall. Positioning of the knee over the second was monitored and the position of the medial arch of the foot was corrected. Aerobic fitness was maintained with aqua jogging on a daily basis. After 2 weeks, this patient was allowed to start walking, increasing his tempo to a light jog, monitoring position of the knees, hips and feet. He wore his orthoses in a new pair of running shoes which were designed to specifically address his foot pronation. The therapist regularly monitored his VMO activity while walking and jogging to ensure that normal activity was demonstrated. ROM exercises were carried out as above. Squat exercises were progressed to step-downs, introducing some loading at a later stage. At the final stage of the rehabilitation the patient was allowed to increase the distance of a run, progressing to an increased tempo and running on a hilly terrain and changing direction. At discharge, he was advised that all stretches and the VMO programme should be continued and that he should regularly renew his running shoes with specific advice from a podiatrist.
Student questions

(1) A football player has suffered a second-degree tear of his hamstring muscles. Describe the:
- Pre-stretching routine
- Exact stretching routine used
- Post-stretching routine.

(2) Describe your rehabilitation programme for a non-active woman with a sedentary occupation who has OA of the knee.

(3) Discuss an exercise programme for a third-degree MCL sprain of the knee sustained by a young car mechanic, in the intermediate stage of rehabilitation.

(4) Why is proprioception so important in knee rehabilitation?

(5) Demonstrate five non-weight-bearing exercises you might use in the treatment of a repaired medial meniscus.

(6) Discuss the factors that are important in the progression in proprioception training for a knee injury.

(7) What are the differences in a quadriceps muscle with an intra-muscular and an inter-muscular haematoma? How would the treatment approach differ?

(8) Describe the progressions of strength training for a knee ligament injury.

(9) What benefits are there in aerobic training for a retired school teacher who has OA of the knee?

(10) A rugby player is referred to you 8 weeks after an injury to his MCL to his right knee for your opinion on his fitness to resume match play. What are your considerations?

References


Exercise Therapy in the Management of Musculoskeletal Disorders


SECTION 1: INTRODUCTION AND BACKGROUND

The treatment of the foot and ankle complex is multifactorial, requiring the clinician to use many treatment approaches for the successful management of both acute and chronic injuries. However, the emphasis in this chapter is on basic exercise rehabilitation of the foot and ankle, although it is important that the therapist considers all the other variables which affect the foot and ankle complex.

Evidence for the use of exercise in the rehabilitation of foot and ankle injuries

Evidence which supports treatment interventions to the foot and ankle is limited overall, and there has been a large emphasis in the research on the ankle and rearfoot complex, with little on the midfoot and forefoot. Much of the research has focused on a small number of conditions, notably anterior talofibular ligament (ATFL) sprain.

Handoll et al. (2001) conducted a review of research under the Cochrane Collaboration. Studies which examined various interventions for the prevention of ankle ligament injuries were included. Although a large number of studies that were included in the review had methodological limitations, some conclusions were drawn. Co-ordination training using ankle discs in those with a prior history of ankle sprain demonstrated a decreased risk of ankle sprain in the intervention group compared with controls in a number of studies. Some evidence was also presented indicating that a supervised physiotherapy programme that emphasised balance reduced risk of re-injury when compared with controls. The review found good evidence for the use of external ankle supports to prevent ligament injuries of the ankle but concluded that further research was needed to be conclusive regarding exercise therapy.

A more recent Cochrane review conducted by Kerkhoffs et al. (2007) examined surgical versus conservative treatment for acute injuries of the lateral ligament complex of the ankle in adults. Of the 20 trials that were included, the authors suggested that all had methodological flaws that could have affected their results and the overall conclusion was that there was not enough evidence to say if surgery or conservative treatment, including exercise therapy, was the optimal treatment for ankle sprains. De Fries et al. (2006) reviewed studies which examined interventions, including exercise therapy, for treating chronic ankle instability. Again, methodological flaws were highlighted in many studies and the authors were unable to conclude if any specific intervention was optimal for
treating ankle instability. However, it was found that following surgical construction, early functional rehabilitation, or exercise therapy was superior to immobilisation regarding time to return to work and sports. Zoch et al. (2003) reviewed studies that examined rehabilitation of ligamentous ankle injuries, concluding that a combination of isokinetic strength training with proprioceptive training shortens rehabilitation and serves as a secondary prophylaxis.

Karatosun et al. (2008) compared intra-articular injection therapy to exercise therapy in the management of osteoarthritis of the ankle and found that both provided functional improvement, although the authors concluded that larger trials were necessary to compare individual efficacies more accurately. Van der Wees et al. (2006) conducted a review of trials which examined the effectiveness of exercise therapy and manual mobilisation in acute ankle sprain and found that exercise therapy was effective in reducing the risk of recurrent sprains and functional instability although the effects of manual mobilisation were limited to having an (initial) effect on dorsiflexion range of motion (ROM).

More recently, Loudon et al. (2008) reviewed studies which examined the effectiveness of active exercise as an intervention for functional ankle instability. Results were positive for the inclusion of exercise therapy in management of ankle instability and the authors concluded that conservative treatment interventions including balance, proprioceptive and muscle strengthening exercise were effective in decreasing ‘giving way’ episodes, improving balance stability and improving function. Thus, while there is some clear evidence for the positive benefits of exercise in the management of ankle ligament sprain and some evidence in the management of ankle OA, there is a demand for further trials which are of robust methodology to support this approach.

Aerobic exercise

There is little evidence to support the use of aerobic exercise in the treatment of foot and ankle dysfunction and the author was unable to source any trials which examined the role of an aerobic exercise programme specifically for foot and ankle disorders. However, Willems et al. (2005a) showed that poor cardio-respiratory endurance was a risk factor for inversion ankle sprain in a study of male subjects and Tyler et al. (2006) showed that a high body mass index, which is frequently related to poor cardio-respiratory endurance, was also a risk factor for the same injury. Valderrabano et al. (2006) showed that patients who were more ‘sports active’ showed better functional results following total ankle replacement compared with patients who were inactive. Although Xu et al. (2004) showed that tai chi had a significant effect on improving proprioception in the ankle, it is unclear if such exercise involves aerobic conditioning. Hubley-Kozey et al. (1995) evaluated the effects of a general exercise programme on the passive ROM of the lower limb joints including the ankle in elderly women. The programme included aerobic exercise, stretching and muscular strength and endurance exercise and the authors found that ROM improved in all joints lower limb joints following the programme. As there was a stretching component to the programme it is therefore unclear if the aerobic exercise contributed to the improvements.

Part of the reason for lack of research may be related to the difficulties of loading the cardio-respiratory system when the foot and ankle are dysfunctional, leaving limited options such as swimming and non-weight-bearing programmes for aerobic exercise. However, those studies which examined the role of aerobic exercise in the management of multi-joint osteoarthritis should be considered at this point and have been discussed in earlier chapters.

Muscle strength and endurance

For many clinicians, the early focus of rehabilitation of any foot or ankle disorders will be muscle strengthening exercise. Hartsell and Spaulding (1999) showed that chronic ankle instability and muscle weakness do co-exist and Willems et al. (2005a) identified decreased dorsiflexion strength as a risk factor for ankle inversion sprain. Konradsen et al. (1998) showed that eversion strength is reduced (compared with the non-injured joint) 3 weeks following acute ankle inversion injuries and Munn et al. (2003) found that eccentric inversion strength was reduced in ankle instability. Despite these findings, there is a paucity of research into strengthening exercise as rehabilitation following ankle joint injury.

Much of the focus of strengthening exercise in the management of foot and ankle disorders has been
on rehabilitation of Achilles tendinopathy. Alfredson et al. (1998) were one of the first groups to prospectively study the effect of a 12-week, heavy load, eccentric calf muscle training programme on individuals with chronic Achilles tendinopathy compared with a control group that received conventional treatment during the same period of time (rest, non-steroidal anti-inflammatory drugs (NSAIDs), orthoses, physiotherapy and ‘ordinary’ training programmes). While the control group showed no improvement in symptoms, the subjects in the intervention group were all able to return to full function (running) following the programme. While this was a moderately small study with some methodological flaws, similar findings were presented by Mafi et al. (2001) with a similar intervention and the overall clinical outcome was much better for eccentric calf training that a concentric programme (Niesen-Vertommen et al., 1992; Mafi et al., 2001). Alfredson et al. (2008) suggested that eccentric exercise involves muscle activation combined with muscle-tendon unit lengthening and it is likely to affect the dampening characteristics of the calf muscle and change the type 1 collagen production and tendon volume, which will increase the tendon tensile strength over time.

In further support of an eccentric strengthening protocol, Kingma et al. (2007) conducted a systematic review of studies with such a programme in management of Achilles tendinopathy. The authors concluded that although further studies are warranted, results to date are promising and support eccentric overload training in the management of Achilles tendinopathy. More recently, similar findings were presented in a systematic review by Magnussen et al. (2009), who analysed 16 quality trials, which concluded that eccentric exercises have the most evidence of effectiveness in the management of mid-portion Achilles tendinopathy.

Many of the studies on strengthening exercise and the foot and ankle have also looked at proprioceptive training and will be discussed in the following sections.

**Range of motion and flexibility**

Restoring full range of movement to the ankle and foot is essential for the correct movement patterns and biomechanical alignment of the foot and ankle. This can be done using joint mobilisation techniques, tissue massage and stretching or ROM exercises. Willems et al. (2005a) found that lack of ankle dorsiflexion was a strong predictor of ankle injury, stating that poor dorsiflexion is associated with 2.5 times the risk of injury. If there was excessive dorsiflexion, and a hypermobile ankle, the risk increased to eight times. However, Willems et al. (2005b) found that a greater ROM, in this case in the first metatarsophalangeal (MTP) joint, was a risk factor for ankle inversion sprain in females. Beedle and Mann (2007) determined that the optimal stretch to increase ROM at the ankle joint was a static stretch following a warm-up, which was superior to ballistic stretching following a warm-up.

There is a lack of consensus regarding the immobilisation of acute ankle inversion injuries. Boyce et al. (2005) advocated a return to immobilisation, but on a temporary basis and recommended the use of an ankle brace for grade 2 and 3 lateral ligament sprains. Immobilisation was shown to result in significant improvement in ankle joint range of movement at both 10 days and 1 month, when compared with an elastic support.

Flanigan et al. (2007) examined the effect of plantar fascia stretching on plantar fascia pain. Previous studies had demonstrated that specific stretching of the plantar fascia was superior to standard weight-bearing Achilles tendon stretching exercises and had a significant effect in reducing pain and functional limitations in subjects with chronic plantar fasciitis (Digiovanni et al. 2006). Flanigan et al. (2007) concluded that a stretch which included both MTP and ankle joint dorsiflexion was superior to ankle joint or MTP joint alone, having positive effects in the management of plantar fasciitis.

**Balance and proprioception**

Recent research has placed great emphasis on functional control of the foot and ankle in rehabilitation and the influence of proprioceptive exercise has received focus in a number of studies. The single leg stand test is probably the most useful clinical test in identifying proprioceptive and/or balance dysfunction following foot and ankle disorders.

Trojan and McKeag (2006) state that the single leg balance test is a reliable and valid test for predicting ankle sprains and that the association between a poor single leg stand test and ankle sprain is significant. Javed et al. (1999) demonstrated longer reaction time in the peroneus longus muscles of patients who presented with chronic or
acute functional instability when compared with controls. Further, they examined the effects of either surgical stabilisation or proprioceptive exercise on peroneal reaction time and found that only the exercise group showed improvement.

Evidence from a number of studies supports the use of wobble boards to improve proprioception in the ankle following inversion injuries (Clark and Burden, 2005). Clark and Burden (2005) noted a significant decrease in muscle onset latency and a significant improvement of their perception of functional instability when a group followed a 4-week wobble board training programme for 10 minutes, three times per week. However, there has been a recent trend among clinicians not to use wobble boards as they are not considered a functional exercise, and it is thought that it is better to focus on a land-based functional programme instead. Delahunt (2007) noted that subjects who have functional instability in the ankle, exhibit feed-forward control deficits to the peroneus longus during dynamic activities. Delahunt suggests that rehabilitation strategies should include exercises that produce sudden unexpected changes in joint movement, as this will facilitate unconscious joint stabilization. The need to rehabilitate the feed-forward mechanism suggests that the use of wobble boards, foam blocks, foam rollers and trampolines will all aid in the rehabilitation of the functionally unstable ankle, as it will produce sudden unexpected change.

A number of studies have noted that introduction of a balance training programme is effective in reducing the risk of ankle sprains. McHugh et al. (2007) showed that including a balance training intervention in training for high school football players reduced the incidence of non-contact ankle sprains; Mohammadi (2007) found similar results with the same kind of intervention in soccer players. McGuine and Keene (2006) showed that a balance training programme reduced the risk of ankle sprains in high school athletes. Schweizer et al. (2005) attempted to include variation in balance and co-ordination demands by examining stability and co-ordination in the ankles of rock climbers compared with soccer players. The authors suggested that rock climbing demands slow, well-controlled movements of the foot and ankle with the tibiotalar and subtalar joints in varying positions. The study found that the rock climbers exhibited significantly better results in stabilometry testing and greater maximum strength in the ankle when compared with the soccer players. It was concluded that a rock climbing type of exercise may be of value in the treatment of ankle instability.

Thus although the evidence supporting the use of exercise in the management of foot and ankle disorders is limited in some areas, there is clear support for the use of certain protocols, particularly in the areas of strengthening and proprioception. Such exercises will be discussed practically in Section 2.

Common conditions

Ankle inversion injury

Often an ankle inversion injury is thought to be the same as a lateral ligament sprain; however, this is not always the case. An ankle inversion injury may affect multiple structures beyond the lateral ligament and can cause problems such as a fracture at the fibular head, an osteochondral fracture of the dome of the talus or subluxation of the peroneal tendons – all of which can be very subtle and difficult to diagnose. The patient may present with symptoms very similar to a straightforward lateral ligament sprain. It is essential that the therapist diagnoses the ankle dysfunction correctly and bears in mind the other possible diagnoses. For the purposes of this chapter, a lateral ligament sprain will be discussed, and it is important to remember that an inadequately rehabilitated ankle will lead to prolonged symptoms, a high risk of recurrence and reduced function.

A lateral ligament injury is usually caused by a plantar flexion/inversion movement, and the most commonly injured portion is the ATFL. Depending on the severity of the injury (grades 1–3 ligament sprain), the person may need to stop their activity immediately, or can continue with limitations. The swelling may be immediate or may develop within a few hours. In a grade 1 tear, there is no ligament laxity; in a grade 2 tear there is some ligament laxity but a firm end point and in a grade 3, there is gross laxity with a complete ligament rupture and no end point when testing. Often grade 3 injuries are the least painful, but it is important to get the diagnosis correct as this will dictate the rate of recovery and also the rate of rehabilitation. The management principles for all three grades are the same: control swelling; reduce pain ± immobilisa-
tion with a brace, taping or crutches; restore range of movement; restore muscle strength; proprioceptive exercises, and implement a functional sports or work specific programme.

Ankle sprains account for 20% of all sports injuries (Price et al., 2004). Disability from ankle sprains can be severe with 40% of the population having dysfunction that persists for as long as 6 months after the injury (Gerber et al., 1998) and athletes with multiple ankle sprains have significantly reduced proprioception and kinaesthetic awareness (Garn and Newton, 1998). Ankle sprains are the most common injury with an incidence rate of 80% in athletic populations and a recurrence rate of 73% (Yeung et al., 1994). The successful rehabilitation of ankle injuries is crucial in preventing high recurrence rates. Those at risk of an ankle inversion injury include those with mobile foot type, a more pronated foot, a longer total foot contact time, lateral pressure in the forefoot at push off phase in the gait cycle and those with delayed knee flexion (Willems et al., 2005a). Willems et al. (2005b) advocate that the therapist attends to gait patterns and addresses foot biomechanics to prevent inversion injuries. Proprioception is disturbed after an ankle sprain (Hartsell, 2000), thus highlighting the importance of adequate rehabilitation. Often rehabilitation is combined with ankle bracing or taping, as this has been shown to reduce the incidence of re-spraining (Surve et al., 1994).

Chronic pain following an ankle inversion injury may be due to a number of factors including: lateral or deltoid ligament instability; impingement lesion; osteochondral lesion of the talus; syndesmotic instability; or fracture.

**Pes Planus, plantar fasciitis and hallux valgus**

Pes planus (flat feet) and pain in the region of the plantar fascia (plantar fasciitis or fasciosis) are often seen together, so are being discussed together rather than as separate entities for the purposes of this chapter. Clinically, it is very common to see one condition with the other. The plantar fascia is the major stabiliser of the longitudinal arch, particularly during the mid stance phase of the gait cycle. Pes planus, whether rigid or flexible can lead to injury. The navicular is dropped and the longitudinal arch remains pronated during the gait cycle, which can cause torsion of the plantar fascia and the Achilles' tendon. The author's experience is that planus must be treated if there is a varus or valgus dysfunction at the subtalar joint causing poor biomechanics; this is particularly important in the childhood/adolescent population. If the patient has a stable subtalar joint, but is genetically flat footed, they would appear to have a low risk or predisposition to injury. Overuse injuries are associated with excessive pronation and it is important to fully rehabilitate not only the long and short intrinsic foot muscles, but also soleus, gastrocnemius and tibialis posterior, as these are likely to absorb shock and reduce the impact on the plantar fascia and midfoot region (O’Connor and Hamill, 2003).

Plantar fasciitis is thought to be due to irritation of the proximal plantar fascia with or without a history of trauma. Pain typically presents under the plantar heel and is worse on weight-bearing although may ease with exercise. There is usually tenderness at the proximal plantar fascia. Magnetic resonance imaging (MRI) may be useful in distinguishing from a stress fracture. Optimal treatment requires a stretching programme for the gastrocnemius, soleus, plantar fascia, orthoses, NSAIDs and in worse cases, surgery (Berkson et al., 2007).

Hallux valgus of the first MTP joint is also known as a bunion, and can have a genetic or biomechanical cause or a combination of both. A hallux valgus diagnosis is given when there is 10° valgus or greater at the first MTP joint, and it is usually associated with a pes planus. This causes the forces at the toe off phase of the gait cycle to pass through the medial aspect of the first ray, thus pushing the ray even further across. Rehabilitation of the foot and ankle may prevent the progression of this condition, but there is a need for further research in this area, particularly in the adolescent population.

**Achilles’ tendinopathy**

Achilles’ tendinopathies involve pain in the region of the Achilles’ tendon. They can be extremely chronic and difficult to treat and can be very frustrating for the patient, both athlete and non-athlete alike. Until recently it was assumed that overuse of the tendon caused inflammation and thus pain, requiring regular use of NSAIDs. However, more recent research has demonstrated
that the pain of tendinopathy may be due to unidentified biochemical factors that activate peritendinous nociceptors without inflammation. Pathological studies have shown that Achilles' tendinopathy is a degenerative process with an absence of inflammatory cells (Smith and Sands, 2007).

Achilles' tendon functions eccentrically to lower the heel to the ground when landing from a jump and it works hard when walking and running uphill. It is usually a chronic overuse injury, of insidious onset, with no specific event to trigger it. However, on further questioning of the patient, it generally becomes obvious that it is associated with excessive stress and either slow or sudden overload on the Achilles' tendon, which can be caused by poor and excessive training methods, poor biomechanics of the lower limb and in particular foot pronation, a change in footwear or training programmes, poor balance within the training programme, which can lead to joint and muscle imbalances causing weakness and lack of flexibility not only of the calf but also of the lumbo-pelvic region and leg. The pain can be both in the mid section of the Achilles tendon and can also be at its insertion into the calcaneum. The latter is much harder to treat and takes a lot longer to settle, so the patient should be aware of the different prognosis, and it is important that the therapist diagnoses it correctly. Tendinopathy frequently occurs in the mid-substance of the tendon in the area of hypovascularity. Patients will complain of pain when rising from a resting position. Examination reveals thickening of the mid-substance of the tendon with local tenderness. Optimal rehabilitation requires exercise therapy and biomechanical considerations. As it is now known that this disorder is not defined by inflammation, traditional anti-inflammatory approaches, such as NSAIDs, should be avoided. The greatest advance in the management of this condition over the past 20 years has been in the use of eccentric exercise therapy with a number of quality trials demonstrating its efficacy (Rees et al., 2009). The evidence for use of eccentric exercise is strong for the management of mid portion Achilles' tendinopathy but less robust in the management of insertional Achilles' tendinopathy although recent work has demonstrated increased efficacy of eccentric exercise in insertional pathology when the exercise does not move beyond plantigrade (Jonsson et al., 2008). Section 2 outlines practical implementation of the eccentric exercise programme.

**SECTION 2: PRACTICAL USE OF EXERCISE**

The evidence supporting the use of exercise therapy in the management of foot and ankle disorders is very condition specific and so this chapter will discuss rehabilitation with reference to chosen pathologies or disorders.

**Ankle inversion injury**

**Early rehabilitation**

**Aerobic exercise**

The primary concern when prescribing aerobic exercise following an inversion injury is the stability of the ankle. In the acute stage, single leg cycling with the unaffected leg will allow the cardiovascular system to be challenged without compromising the affected joint. The patient may then progress to cycling with the affected leg with the clinician ensuring that the ankle is maintained in a close packed, dorsiflexed position by keeping the heel rather than the toe at the front of the pedal. Swimming is also suitable, particularly front and back crawl. Breast stroke may be tried with the ankle in dorsiflexion, although avoid the ‘whip kick’ in as this can be painful. If the ankle is too painful with any leg kicking movement, the patient may put a float between the legs and concentrate on arm movement only.

**ROM and flexibility**

A programme that includes range of movement exercises and alphabet drawing with the foot is suitable to rehabilitate ROM. Progress the programme to weight transfer and knee bending in standing with support, and gait re-education focusing on heel strike, foot flat and toe off. The patient may not be able to weight-bear more than 25% of their body weight at this stage onto the affected leg, but they should slowly try to progress their percentage body weight onto this leg until they can do a single leg stand with comfort.

See Figures 12.1 and 12.2 for progression of dorsiflexion from non-weight-bearing to weight-bearing. See Figure 12.3 for plantar flexion home
exercise progression in standing and sitting. It is important that full ROM in all directions are restored to the ankle, particularly dorsiflexion, as this is the movement required not only for gait, but also for the stairs and landing from jumps.

After an ankle inversion injury, the patient often loses the ability to dorsiflex the ankle, and with that, the gastrocnemius and soleus muscles tighten. It is very important to start a flexibility programme early for the calf muscles and to identify the other muscle groups that may also be tight, particularly the peroneals, as these are often overstretched during the injury and subsequently have increased tone and spasm at rest.

It is possible to start the calf stretches in long sitting using a belt, if the patient is unable to weight-bear, if there is too much pain or if there are positive neurodynamics in the form of a straight leg raise. Maintain a straight leg for the gastrocnemius, and a bent knee for the soleus, while using the belt to dorsiflex the foot and try the exercise in both long sitting (Fig. 12.1) or in a straight leg raise position with knee extension or flexion in supine (Fig. 12.4). It is important that a clinical reasoning approach is used in prescription of every exercise. There is no point in prioritising the exercise in the straight leg raise position if neurodynamic tests are abnormal.

There are many different ways to stretch the calf muscles but the most common way to stretch the gastrocnemius is to start on a flat surface and then progress to a book or a slope (Fig. 12.5) and note the different foot positions available. Starting with the foot in a central position will give a general calf stretch; turning the foot medially can give a more lateral gastrocnemius stretch (Fig. 12.6) and turning the foot laterally (Fig. 12.7) can give a more medial head stretch. It is important to ‘chase’ the
stretch – the patient focuses on the tightest and most restricting position. It is also important that the patient does not roll the foot in, and maintains an optimal arch profile by keeping the knee moving over the third metatarsal. If the patient cannot do this, the clinician can place a book along the longitudinal arch to stop it collapsing inwards. They can progress the stretch in standing by asking the patient to stand with both feet on an incline board, aiming to keep the legs straight while moving the pelvis forwards (Fig. 12.8).

To focus the stretch on soleus, perform the stretch as for gastrocnemius (above), but flex the knee, ensuring that the knee moves over the third metatarsal. This can be progressed to a bilateral soleus squat ensuring that both heels remain on the ground and that the knees move forward over the feet ensuring ankle dorsiflexion (Fig. 12.9).

Muscle strength and endurance

There is much crossover between the exercises for muscle strengthening and proprioception/co-ordination. The outline and divisions of this chapter are more for academic reasons, but it is important to bear in mind, that if a patient is doing a single leg stand on toes for balance, they are also doing a concentric strengthening exercise for the gastrocnemius/soleus complex. To turn the same exercise into a strengthening exercise will mean that the patient repeats a heel lift and lower 20–30 times rather than a sustained hold of 30–60 seconds for balance.

Start with the basic isotonic exercises using Thera-Band® or free weights and do the entire ankle movements with both knee flexion and knee extension (Fig. 12.10). If isotonic exercises are too
Figure 12.5  Stretch to the gastrocnemius using a block.

Figure 12.6  Lateral gastrocnemius stretch with the foot turned medially.

Figure 12.7  Medial gastrocnemius stretch with the foot turned laterally.

Figure 12.8  Stretch on an incline board.

Figure 12.9  Bilateral soleus squat.
Figure 12.10  (a) Resisted plantar flexion in knee extension. (b) Resisted dorsiflexion in knee extension. (c) Resisted dorsiflexion in knee flexion. (d) Resisted plantar flexion in knee flexion. (e) Resisted eversion in knee flexion. (f) Resisted inversion in knee flexion.
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painful, start with basic isometrics, where the patient pushes against their other foot for resistance (Fig. 12.11).

Progress the subject to a weight-bearing programme as quickly as possible, and always consider the kinetic chain when doing these exercises. Ensure that there is excellent control around the hip and trunk, and that the patient is not compensating by dipping the pelvis/hip or flexing the trunk forwards. The progression of the rehabilitation will depend on the presenting patient and their functional demands or sport.

Start with the basic step-up and step-down (Fig. 12.12) or step-over (Fig. 12.13). This exercise covers many issues. It helps regain dorsiflexion, but more importantly, it works the gluteus medius and pelvic stabilisers. Ensure that the patient can start to hop, and include multi-directional tasks and add resistance as needed (Fig. 12.14). As the patient progresses, start to increase both the distance and the height. Adapt the hopping patterns to suit the patient’s needs and design as many hopping patterns as possible. This may include focusing on sideways or backwards hopping more than forwards. Include the trampette – double foot jump, single foot jump, and jumping on and off (Fig. 12.15).

Progress the jumping activity, by asking the patient to jump forwards, backwards and sideways
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Progress the single leg stand in flat foot position to standing on toes on two feet and one foot with straight legs and then onto toes on two feet and one foot with a bent knee (Fig. 12.20). It is important that the patient keeps the heels high as they bend over an object of varying heights on two feet and one foot (Figs 12.16 and 12.17). Include skipping, shuttle runs (forwards, backwards, and sideways) and figure-of-eights forwards and backwards.

Proprioception

The basic approach to restoring balance is to start the patient standing on one leg. (See Fig. 12.18 for the correct technique.) Refer to Figure 12.19 for a poor technique and excessive weight transference. Although this may be difficult to see in the figure, ‘Trendelenburg’s’ or ‘compensatory Trendelenburg’s’ are very common clinical presentations. If the patient is having difficulties with weight transference and has a large pelvic shift, start in standing, with a narrow base of support, and start with a heel lift, progressing on to a heel and toe lift. Progress the exercise by widening the stance.

Progress the single leg stand exercise with knee flexion on the standing leg. Ensure that, again the patient does not cheat by dipping the pelvis/hip and the only body part to change position is the knee, and that continues to track out over the third metatarsal. If the knee rolls inwards and falls over the first, this will have a pronatory effect on the longitudinal arch and will reduce the work of the intrinsic muscles.

Figure 12.15 (a) Trampette jumps. (b) Single foot trampette jumps.

Figure 12.16 Single hop forwards and backwards.

Figure 12.17 Single hop forwards and backwards.
Figure 12.17  Double hop sideways.

Figure 12.18  Correct technique for single leg stand.

Figure 12.19  (a) Poor one leg standing technique with (b) ‘compensatory Trendelenburg’.
the knee and that the knee continues to move out over the third metatarsal. If the patient can comfortably do these exercises, they can then try to perform them with their eyes closed, and then throwing a ball. The clinician can then progress all the above exercises to the wobble board, foam block and foam roller (Fig. 12.20c). The progression of the patient will depend on many things including their motivation to continue with exercise, their functional ability and prognosis, and also their sporting level.

Functional and late rehabilitation

Functional exercises as outlined above (hopping, jumping, shuttle runs) should be applied when the patient is pain free, has full ROM and good muscle strength and proprioception. It is important to remember that inadequate rehabilitation and early return to sport will increase the chances of re-injury, so it is essential that the patient completes a functional programme and the sooner the clinician can commence this, the more successful will be the rehabilitation. Re-train the movement patterns rather than just focusing on the individual muscles at this stage, and ensure that all the variables of functional training are considered, including load progression, range of movement, base of support, speed and, most importantly, multi-directional activity, by including exercises that challenge the sagittal, transverse and frontal planes. Include squats, dips and plyometric exercises that use different arm positions and different directions to not
only challenge the ankle joint but also the whole kinetic chain (Fig. 12.21).

**Planus and plantar fasciosis and hallux valgus**

**Rehabilitation**

**Aerobic exercise**

All the aerobic exercises described above for ankle inversion injury are appropriate for the management of plantar fasciosis. Activities which are not fully weight-bearing such as rowing are suitable and weight-bearing activities which do not promote constant pronation may be tried. In general, pain is a good indicator of an inappropriate exercise. If the patient has been prescribed orthoses they should be worn during the activity and the prescribing clinician should constantly monitor biomechanics of the foot and ankle, correcting as appropriate.

**ROM and flexibility**

Start by reducing the pain in the plantar fascia region; this can be done by massaging the sole of the foot and the calf muscles, and also by giving a home exercise of massage or trigger pointing on a spiky ball and progress to a golf ball as able. Progress the massage treatment to massage of the calf muscles in standing, which will create a wind-up effect of the myofascia and can give very good release of the muscles restricting the normal movement. The therapist must restore full range of movement to the ankle (as outlined earlier), but must also correct the hallux valgus and restore full MTP extension. This can be done in standing (Fig. 12.22a) as well as in sitting (Fig. 12.22b), but the patient must ensure that they abduct the toe before extending it, and ensure that they fixate the MTP joint before extending the hallux.

It is also very important to restore normal movement and function to the toes. Toes, when challenged, can be almost as dexterous as fingers. The effect of a rigid foot, may not only lead to pain, but it may also reduce the shock absorbing capabilities of both the foot and the lower leg. The foot strengthening programme, for both the foot intrinsics and extrinsics can be trained quite easily with the following exercises.

**The toe spread (Fig. 12.23)**

See if the patient is able to spread their toes (in the same way as they can spread their fingers) and use the interossei muscles without moving the heel or lifting the foot. A progression of this exercise is to...
then ‘toe spread and dome’. In this exercise, the patient uses the short intrinsics muscles, and it is important that they do not curl the toes, but still have a slight ‘doming effect’ where the arch lifts up.

The towel exercise (Fig. 12.24)

This exercise involves the long toe flexors and also helps with the arch lift and requires the patient to spread the toes, placing them on the towel and then scrunching the towel up, until they have managed to pull the whole towel in without moving the heel. A progression of this exercise is to place the towel on a carpet rather than a wooden floor to add more resistance, or place a weight on the towel. Finally, the patient should pick up objects using all the toe flexors, e.g. pencils, markers, buttons, marbles. Ensure that they do not cheat by just using their big toe.

It is also important to include some stretches of not only the calf muscles, as previously demonstrated, but also of the plantar fascia. This can be difficult for the individual who cannot get enough MTP extension, and if that is the case, they may need to do the stretch while keeping the first MTP free. Ensure that the arch profile is maintained throughout the stretch.

Muscle strength and endurance

There are also some specific foot strengthening exercises that should be included. Include walking on toes with the heels kept high and a straight leg to work the gastrocnemius. Repeat with a bent knee, ‘the soleus walk’, both of which will help to control the rearfoot. Walking on the heels (Fig. 12.25) will help use the tibialis anterior to control the arch position. With this exercise, ensure that the
Achilles’ tendinopathy

The main aim of treatment is to restore the ankle range of movement, particularly dorsiflexion, lengthen the calf muscles as outlined previously, and start the patient on an eccentric training programme for the gastrocnemius and soleus. Management of this condition should be based on a symptom-related approach.

Aerobic exercise

Aerobic exercise will generally be non-weight-bearing in the acute phase of Achilles tendinopathy. Aerobic exercise described in the management of ankle inversion injury is appropriate. Progression to weight-bearing activities should be with caution and as pain allows and low impact exercise should be prescribed. Late stage of rehabilitation should encourage activities such as plyometrics, skipping and bouncing on a trampette to challenge the tissues of the Achilles’ tendon.

Range of motion and flexibility

The exercise programme described to address ROM in the management of plantar fasciosis, as described above, should be applied in the rehabilitation of Achilles’ tendinopathy.

Muscle strength and endurance

The programme should commence with the patient performing heel drops over the edge of a step, with both a straight leg and a bent knee (Fig. 12.27). Start without any weight and then gradually increase the patient’s load by performing the heel drops with a backpack filled with weights on their shoulders. Again the weight can be gradually increased, as can the repetitions. Alfredson et al. (1998) recommend three sets of 15 repetitions, performed twice a day, 7 days a week. This programme should be maintained for 12 weeks. The patient must ensure that they do not load the affected calf concentrically as they move into plantar flexion but must use their non-affected leg to push themselves back up. The patient should be
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It is very important to address the orthoses issue, ensuring that the patient not only has orthoses that they will wear, but that will also give enough rear- and midfoot control and will act as good shock absorbers. Advice on footwear is essential; ensure that the footwear has a good heel counter, which helps control the calcaneum and also has good shock absorbency. Often clinicians recommend excellent training shoes, with good shock attenuation, and then suggest that the patient wear a rigid orthotic device, which will counteract any shock absorbency benefits of the shoes. It is important that the clinician understands the kind of shoe and device required and for what effect.

Proprioception

As discussed previously, it is important to include a good proprioceptive programme, see the above exercises, including Figure 12.20, and ensure that the end-range rehabilitation plan includes functional exercises such as uphill walking and walking downstairs. Step-down exercise will work the calf muscles eccentrically and will also work the hip and leg muscles.

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SECTION 3: CASE STUDIES AND STUDENT QUESTIONS

Case study 1

A 32-year-old female presents to the clinician with an acute right ankle inversion injury 3 days after inverting her ankle while wearing high heels. She attended the accident and emergency room, was X-rayed and was given a Tubigrip and crutches and told that she had no fracture but to weight-bear as able. She has been applying the PRICEM (protection, rest, ice compression, elevation, medication) principles since injury, and complains of lateral ankle pain, ‘tightness’ in the forefoot and...
Case study 1—cont’d

marked spasm/pain in the peroneus muscles and, just today, a feeling of tightness in the calf. Assessment reveals marked swelling and discoloration of the lateral ankle and forefoot; marked pain with palpation over the fibula head, all the lateral ankle structures, particularly the ATFL, and muscle spasm and pain in the peroneus muscles. ROM is reduced and painful in all directions – 30° plantar flexion, –10° dorsiflexion, 5° inversion, 5° eversion. Ankle strength cannot be assessed accurately due to pain and lack of movement. Instability tests suggest a grade 2 ATFL sprain. She is afraid to weight-bear on the ankle not only because of pain but also because of the fear that her ankle may ‘give way’.

Management

The emphasis in the early stage of management of this patient should be to reduce swelling and pain to allow an increase in function. If the pain is severe, the ankle should be initially immobilised in a brace and the patient should use crutches. At this stage, gait should be re-educated progressing from partial weight-bearing with the crutches to fully weight-bearing as pain allows. Early exercise will include a balance programme comprising weight transference with or without crutches. Soft tissue work on the peroneus muscles, gastrocnemius and soleus muscles may enhance recovery. Active ROM exercise of the ankle may be performed and repeated in a straight leg raise position if neurodynamic tests are positive. ROM exercise may be performed passively with accessory movements added with particular attention to the inferior tibiofibular joint. Aerobic exercise at this stage could include swimming with a kickboard or one leg cycling. Strengthening exercise at this stage would be fulfilled by the performance of the balance programme.

The middle to late phase of rehabilitation requires a progression to functional activities. Single leg stand with knee flexion and extension should be performed as well as ‘toe stands’ to enhance proprioceptive and build strength. Stair climbing and gait activities with an emphasis on good pelvis control are good functional activities. The patient should perform ROM exercises in functional positions such as squatting in standing. The final stage of rehabilitation should include a full functional programme such as plyometrics and trampette work which includes all components of fitness. The emphasis at this stage is to include multi-directional activities. Taping may provide a psychological and proprioceptive aid in the final stage of management.

Case study 2

A 14-year-old girl, who is a competitive dancer, complains of right heel and arch pain since 8 weeks. Her dance teacher tells her that she has flat feet and that she is not lifting her heels high enough when she dances. The dancer feels that her dancing has deteriorated over the past several months, as she cannot jump as high as she used to, and she now has to really use her arms when she jumps to achieve height. Her mother states that she dances four times a week and that she has noticed that her daughter has become ‘heavier on her feet’ and has had quite a significant recent growth spurt.

Clinical examination reveals a right early hallux valgus, approximately 10°, bilateral rearfoot varus and compensatory pronation bilaterally. She also has very weak foot intrinsic muscles and is unable to toe spread or dorsiflex in standing (heel walk). She is able to stand on one foot with the eyes open, but is poor with the eyes closed and is unable to stand on her toes on two feet or one foot without significant pronation and heel drop. She has a very poor jump, with little power coming from her calf muscles or her core.

There is a loss of end-range ankle dorsiflexion, MTP 1 extension is 40° with a poor movement
**Case study 2—cont’d**

Pattern and the right hip has lost end of range external rotation. Palpation shows marked tenderness of the right plantar fascia at the calcaneum and also along the longitudinal arch with multiple trigger points in the deep intrinsics.

Management

The aim of management of this patient is to take a global approach, i.e. to address foot dysfunction as well as performance issues. The working diagnosis of this patient is plantar fasciosis. Rehabilitation should commence with ROM activities to include intensive stretching of the plantar fascia, gastrocnemius and soleus, as well as mobilisation of the first MTP joint. Soft tissue work such as massage with the muscle in a stretched position may aid progress. The intrinsic foot programme (described in text above) should commence early and other issues to correct biomechanics should be addressed at an early stage. Proprioception work in the early stage for this patient should include toe standing on one leg demonstrating good control of the whole limb and the ability to prevent the rearfoot from dropping. The middle to late stage of rehabilitation should progress to jumping and trampette work, teaching the patient to jump correctly by controlling from the hip. This patient should be encouraged to jump with hands behind her back to facilitate lift with the lower limb and good ‘core’ activity. Jumping and trampette work will challenge the proprioceptive, aerobic and strengthening systems. The patient may be further helped by prescription of correct functional foot orthoses or corrective taping.

**Case study 3**

A 40-year-old male office worker, who plays tennis once per week and likes to walk daily to and from work, complains of pain in the midportion of his right Achilles’ tendon. The pain has been gradually worsening over the past 3 months, and it is particularly stiff first thing in the morning getting out of bed. This stiffness tends to last 10–15 minutes and eases as the patient gets moving. He likes to walk, and has pain at the beginning of the walk, which eases as the walk progresses, but if he overdoes it, the pain will return and he will start to limp. The pain can then last the rest of the day and evening, although eases with the application of a heat pack. He also notices pain walking downstairs. The patient states that he always wears soft slip on leather shoes, and has not changed his running shoes for about 5 years. He also used to wear orthoses, but found that they were too cumbersome and did not fit into his work footwear, so he stopped wearing them about 3 years ago.

Clinical findings show marked tightness in the right soleus and gastrocnemius, with the patient unable to dorsiflex the right ankle more than 5° in standing, without marked compensatory pronation. The patient is able to do a single leg heel raise without pain, but five single leg hops on the spot provoke his pain, while two hops forwards provoke the pain. There is marked tenderness of Achilles’, both with the squeeze test of the tendon and with direct postero-anterior pressure on the tendon.

Management

In the early stage of rehabilitation of this patient, aerobic activities may be continued within the confines of pain. If weight-bearing exercise is painful then non-weight-bearing exercise such as swimming may be acceptable. ROM exercise early in management should emphasise recovery of full ankle dorsiflexion and first MTP ROM. Gait re-education should emphasise, in particular, good heel strike and mid stance. The eccentric
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Student questions

(1) Design three functional exercises for a painter who complains of Achilles’ pain each time he goes up and down the ladder.
(2) What are your goals for the first three days after an acute ankle inversion?
(3) Describe three different ways to stretch the gastrocnemius.
(4) Develop two new proprioceptive exercises for the elite level gymnast.
(5) Why would you give a patient a concentric Achilles’ programme as against the recommended eccentric programme?
(6) List the benefits of good footwear.
(7) Why do therapists use wobble boards to train proprioception, a wobble board is not considered a functional exercise? What is the neurophysiological benefit to training on unstable surfaces?
(8) Develop a strengthening programme for the foot with a tibialis posterior tendinopathy.
(9) When would it be appropriate to select a rigid orthotic device for a patient?
(10) Design two new home exercises to improve ankle plantar flexion.

References


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Musculoskeletal Disorders in the Developing Child

Juliette Hussey and Mandy Johnson

Physical activity in children – health benefits and guidelines

Health benefits of physical activity in childhood

There are a number of health benefits of physical activity, many of which have been discussed in previous chapters. The benefits of regular activity in early adulthood were first investigated in the Harvard Alumni Health Study where activity levels in 16,396 men aged 35–74 years were investigated. An inverse dose relationship between physical activity and all-cause mortality was found (Paffenbarger et al., 1986).

Other studies (Morris et al., 1966; Lee et al., 1999; Bucksch, 2005) have added further to the evidence for the health benefits of regular activity in adults. The evidence for the effects of physical activity on morbidity and mortality in children is not available at present. The paucity of evidence may in part be due to a lack of studies that have reached a conclusion, or studies that have not been of sufficient length to examine such a relationship. Currently there are a number of population studies investigating the prevalence of cardiovascular disease risk factors in children and adolescents; these include the Bogalusa Heart Study, the Amsterdam Growth and Health Longitudinal Study, the Northern Ireland Young Hearts Project, the Cardiovascular Risk in Young Finns Study and the European Youth Heart Study (EYHS). While end points have not been reached in these studies they have highlighted the importance of physical activity and fitness in the prevention of cardiovascular risk factors. These and other related studies have produced considerable evidence for the benefits of activity and fitness on insulin sensitivity (Raitakari et al., 1994b; Schmitz et al., 2002), blood lipid profiles (Suter and Hawes, 1993; Raitakari et al., 1994a), flow mediated dilation of the brachial artery (Abbott, 2002) and multiple risk factors including the metabolic syndrome (Bouziotas et al., 2004; Brage et al., 2004; Ribeiro et al., 2004).

Physical activity guidelines in children

Young children tend to be active if given sufficient opportunity and space. The activity they engage in tends to be short bursts of intense activity interspersed with less intense periods. Unlike adults, children tend not to engage in long periods of sus-
tained activity. As the child gets older he or she commences engaging in more sustained periods of activity generally associated with sport or walking/cycling as a means of transport.

Activity guidelines for children have changed over the last number of years. Physical activity guidelines for children were first presented by the American College of Sports Medicine (ACSM) in 1998. The guidelines were based on those of adults and the recommendation was that children should achieve 20–30 minutes of vigorous activity per day. The general ACSM guidelines for physical activity were that adults should accumulate at least 30 minutes of moderate intensity activity on most, and preferably all days of the week (ACSM, 1990). In 1994 the International Consensus Conference on Physical Activity Guidelines for Adolescents recommended that ‘all adolescents are physically active daily, or nearly every day, as part of play, games, sports, work, transportation, recreation, physical education, or planned exercise, in the context of family, school and community activities’ and that ‘adolescents engage in three or more sessions per week of activities that last 20 minutes or more at a time that require moderate to vigorous levels of exertion (Sallis and Patrick, 1994). More recently in the USA, an expert panel was set up by the Divisions of Nutrition and Physical Activity and Adolescent and School Health of the Centers for Disease Control and Prevention to review and evaluate the evidence on the influence of physical activity on several health and behavioural outcomes in children aged 6–18 years, and to develop evidence-based recommendations (Strong et al., 2005). A total of 850 articles were reviewed, and the areas included adiposity, cardiovascular health, asthma, mental health, injury associated with physical activity and musculoskeletal health. Most of the intervention studies reviewed included supervised programmes of 30–45 minutes of moderate to vigorous activity on 3–5 days per week. The panel recommended that ‘school aged youth should participate in 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate, enjoyable, and involves a variety of activities’.

The strength of the evidence base for the exercise recommendations by Strong et al. (2005) could be questioned. It could be argued that a minimum of 60 minutes of moderate to vigorous activity per day is too low, given that, in a study on 7–10 year old children, while almost all achieved such a level, yet a percentage were overweight (20.7% of boys and 20.2% of girls) (Hussey et al., 2007). Similar findings were those of a EYHS study where among children aged 9 years, 97.4% of boys and 97.6% of girls were meeting the recommendations, and again a number were overweight (Riddoch et al., 2004). The idea that there is a need for both genders to have a higher level of physical activity is supported by Andersen et al. (2006), who found a higher level of activity was needed to prevent clustering of cardiovascular disease risk factors. In addition to a higher level of activity required for children it has also been proposed that boys need to do more activity for a given level of body composition. Tudor-Locke et al. (2004) recommended different amounts of activity for boys and girls based on data on activity levels collected by pedometer and cut off points for normal weight and overweight/obesity. The selected cut-off points for 6–12 year old children would equate to approximately 120 minutes of activity per day for girls and 150 minutes per day for boys. Therefore it may be that requirements for boys and girls not only need to be higher but need to be different, due to inherent physiological or behavioural differences in the genders.

To the authors’ knowledge, there are no long-term longitudinal studies on activity and bone health in children, but there have been a number of studies that have investigated activity over a few years and retrospective studies that have compared adult bone health with activity performed as a child. Both exercise and nutrition are independently recognised as factors essential for optimal bone health during growth. Regular weight-bearing exercise is well recognised as important in bone mineral content and bone mineral density during childhood and growth.

The ASCM recommends that to augment bone mineral accrual in children and adolescents they should engage in impact activities (gymnastics, plyometrics and jumping) and moderate intensity resistance training. Participation in sports that involve running and jumping (soccer, basketball) is likely to be of benefit. The intensity should be high in terms of bone loading forces but resistance training should be <60% of 1 RM (repetition maximum). The frequency should be at least 3 days per week and the duration 10–20 minutes.

In a review on the evidence in this area Daly (2007) concludes that the structural response of
defin ed until after birth. Bone tissue is different again as all three processes of hyperplasia, hypertrophy and accretion occur in bone growth, which can continue into late teens or early twenties. Maturation occurs in all the various body systems, skeletal, sexual, physiological, neurological, and morphological, etc., but the timing of the process differs with each body system (Malina et al., 2004a). The maturation of the neurological system occurs around the age of 7 years, sexual maturation or the ability to reproduce usually occurs in early teenage years, with girls approximately 2 years ahead of boys. Skeletal maturation is said to have occurred when full skeletal ossification has taken place, and also occurs earlier in girls.

Monitoring and measuring growth

The measurement of growth is termed anthropometry and is used in various ways in both clinical practice and the sporting environment to monitor the development of children. The monitoring of children’s growth is well established in paediatric health care, as poor or slow growth can be due to, among other things, poor nutrition, social or economic status or various genetic and/or hormonal deficiencies (Hall, 2000; Hermanussen et al., 2001; Cole et al., 2002). Regular monitoring of growth can often pre-empt problems and can be carried out at a specific chronological age and compared with population reference standards usually in the form of growth charts. Measurements can be taken at one moment in time and compared with the charts but that will only give the information of whether the child at that particular time is small or tall, which if only taken once is clinically meaningless (Zeferino et al., 2003). Usually, measurements are taken at set points over a period of time giving longitudinal data and growth velocity or tempo (Cole et al., 2002). It is accepted that children grow at irregular rates at different chronological ages, which can lead to difficulties in interpreting the results in a meaningful way. Height and weight are the two most commonly used measures to monitor growth, with weight more relevant in infancy and height more relevant after infancy (Cole et al., 2002).

Growth and maturation

During childhood and adolescence there is considerable growth in terms of height and weight, and growth spurts can result in changes in the ratios of muscle strength to limb length and in stress on the related soft tissues. Limb growth affects the muscle forces that are required for movement and growth also affects the strength of the tendon, apophysis, ligaments and bone (Hawkins and Metheny, 2001). Muscles and tendons have to lengthen with a growth spurt but if they do not hypertrophy until after the growth spurt, then the increased mass of the limb will require the muscle to generate a greater percentage of their maximum force to produce a movement. This increased force may lead to increased stress on the tendons.

Different types of tissues grow at different rates and at some point go through a process of hyperplasia (an increase in cell number), hypertrophy (an increase in cell size) and accretion (an increase in intercellular substance). Hyperplasia usually occurs before birth whereas hypertrophy occurs after birth, but this does depend on the tissue type (Malina et al., 2004a; Stratton et al., 2004). Neural tissue is essentially defined at the pre-natal stage of development but the amount of muscle tissue is not defined until after birth. Bone tissue is different again as all three processes of hyperplasia, hypertrophy and accretion occur in bone growth, which can continue into late teens or early twenties. Maturation occurs in all the various body systems, skeletal, sexual, physiological, neurological, and morphological, etc., but the timing of the process differs with each body system (Malina et al., 2004a). The maturation of the neurological system occurs around the age of 7 years, sexual maturation or the ability to reproduce usually occurs in early teenage years, with girls approximately 2 years ahead of boys. Skeletal maturation is said to have occurred when full skeletal ossification has taken place, and also occurs earlier in girls.

Monitoring and measuring growth

The measurement of growth is termed anthropometry and is used in various ways in both clinical practice and the sporting environment to monitor the development of children. The monitoring of children’s growth is well established in paediatric health care, as poor or slow growth can be due to, among other things, poor nutrition, social or economic status or various genetic and/or hormonal deficiencies (Hall, 2000; Hermanussen et al., 2001; Cole et al., 2002). Regular monitoring of growth can often pre-empt problems and can be carried out at a specific chronological age and compared with population reference standards usually in the form of growth charts. Measurements can be taken at one moment in time and compared with the charts but that will only give the information of whether the child at that particular time is small or tall, which if only taken once is clinically meaningless (Zeferino et al., 2003). Usually, measurements are taken at set points over a period of time giving longitudinal data and growth velocity or tempo (Cole et al., 2002). It is accepted that children grow at irregular rates at different chronological ages, which can lead to difficulties in interpreting the results in a meaningful way. Height and weight are the two most commonly used measures to monitor growth, with weight more relevant in infancy and height more relevant after infancy (Cole et al., 2002).

Growth charts are used to monitor the changes that take place longitudinally in a child and were first developed for British children in the early
sixties by J.M. Tanner and R.H. Whitehouse, and these charts (in a modified form) are still used along with Freeman charts and the Buckler-Tanner charts (Wright et al., 2002). Different countries use reference data collected from their own national populations which makes it very difficult to compare studies across countries due to the differences in ethnic groups. These differences in ethnicity are beginning to create problems in countries with growing ethnic minorities as the growth charts used for a specific population are not representative of these different groups (Cole et al., 2002). In most sporting environments growth is monitored usually by regular measurements of height and weight.

The adolescent growth spurt

During adolescence there is a sudden increase in the velocity of growth, which is called ‘the adolescent growth spurt’. During this time there is an increase in the growth rate that peaks and then gradually slows down until full maturity is reached. The adolescent growth spurt is used in sport to identify the stage of maturation that has been reached by the athlete and whether they are early, normal or late developers as compared with others in the same age group. The onset of the adolescent growth spurt is highly individual and occurs at different chronological and skeletal ages. The adolescent growth spurt in girls occurs at approximately 9–10 years of age and can continue until 14–16 years of age; in boys it commences approximately 2 years later and does not finish until 18 years of age and in some cases even later (Malina et al., 2004a). The adolescent growth spurt has been identified as a particularly vulnerable stage in a young athlete’s development. There appears to be an increase in the rate of injury during this time including the risk of fracture. This is thought to be due to the rapid skeletal growth with a delay in bone mineralisation in the cortical bone (Blimkie et al., 1993).

The age of onset of puberty can occur between 8 and 19 years (Baxter-Jones et al., 1995). The assessment of the biological status of young elite performers is becoming more critical as the demands for success grow. Chronological age is a poor indicator of biological status (Mirdwald et al., 2002) and it has been shown that physical performance can depend on the stage of biological maturity and development that has been reached (Katzmarzyk et al., 1997; Jones et al., 2000). This information is needed by coaches so they may plan sessions to apply the correct training loads in boys of the same chronological age who are at various levels of physiological development and therefore have different performance abilities. Differences in maturity and development can be as much as 3–4 years for boys of the same chronological age (Hägg and Taranger, 1991; Beunen et al., 1992; Iuliano-Burns et al., 2001). This difference often results in the early maturing boys being in an advantageous position for performance purposes (Malina et al., 2000, 2004b) and often means that late-maturing boys are deselected, even though research has shown that ultimately the late-maturing boys will catch up in all dimensions when they reach adulthood (Philippaerts et al., 2006).

Peak height velocity

When the adolescent growth spurt occurs the rate of the change in height accelerates and then gradually decelerates. Peak height velocity (PHV) is a somatic biological maturity indicator and records the moment of maximum velocity of growth during adolescence. PHV has been used in number of studies as a non-invasive method of assessing the maturation status of players and athletes (Hägg and Taranger, 1991; Beunen et al., 1992; Malina, 1994; Philippaerts et al., 2006). PHV normally precedes all other peak velocities for other tissue growth and the point of time at which this occurs is highly individual and there can be considerable variation among children (Iuliano-Burns et al., 2001). PHV will occur on average between 11.3 and 12.2 years of age in girls and 13.3 and 14.1 years of age in boys (Malina, 1994) with the average PHV occurring up to 2 years earlier in girls than it does in boys (Hägg et al., 1991; Iuliano-Burns et al., 2001). PHV can only be determined in a longitudinal study in which regular height measures are taken and then plotted to determine the growth velocity over time.

Methods of establishing maturity

There are a number of non-invasive methods used to assess maturation. Various maturity indicators can be used including the development of sexual characteristics or morphological age although some
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training sessions, and many injuries are of a minor nature which may not be reported.

Generally, overuse injuries in children include tendon injury and traction apophysitis, stress fractures, bursitis, and joint disorders. They arise due to highly repetitive activities. Children are vulnerable as their apophyseal growth plates are active and even minor injuries to tendons or growth plates should lead to restriction in activity until the symptoms resolve. Many studies have described the important part that growth and development play in overuse injuries in youth athletes (Krivickas and Feinberg, 1996; Marsh and Daigneault, 1999; Oeppen and Jaramillo, 2003). All these studies acknowledge the fact that longitudinal growth of bone is the primary event and the surrounding soft tissue of joint tendons, ligaments, tendons and muscles elongate as a secondary response. In the short term, this results in an increased tension in the surrounding soft tissues which leads to relative inflexibility and muscle imbalance and consequently weakness. This leaves the athlete vulnerable to injury particularly during repetitive overload which occurs during regular training (Micheli and Klein 1991; Krivickas, 1997; Di Fiori, 1999; Oeppen and Jaramillo, 2003). Biomechanical imbalances are due to the speed of growth in the skeletal tissue compared with the period of time it takes for the surrounding soft tissues to adapt (Marsh and Daigneault, 1999; Hawkins and Metheny, 2001; Oeppen and Jaramillo, 2003).

Prevention strategies include improving flexibility, strength and general fitness in addition to matching children by size rather than chronological age, adherence to the rules, improved playing conditions and the compulsory wearing of protective clothing implements such as shin pads (Schmidt-Olsen et al., 1985; Drawer and Fuller, 2002; Olsen et al., 2004).

In the immature athlete, muscle and tendon strains and ligament sprains are not as common as in fully mature athletes because the soft tissue tends to be stronger than the bone to which it is attached. The resulting injury therefore, is usually an avulsion of the muscle, ligament or tendon from its bony attachment (Bruns and Maffulli, 2000). Overuse injuries, in youth athletes are usually reported by the player when he or she is no longer able to train comfortably rather than when the symptoms are first felt. All types of injury, if incorrectly treated, can have ramifications in the future with regards to

Musculoskeletal disorders in children

Movement is an essential part of learning for the child. The most common musculoskeletal problems in children are due to trauma, and fractures of the upper limbs are more common than those of the lower limbs. Children engaged in sporting activities are susceptible to overuse injuries for a number of reasons. At a competitive level, children will be engaged in regular competitive training as well as weekly competition. Many of these injuries can be prevented by incorporating specific techniques into

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the players’ balance and proprioception abilities being affected (Emery, 2003).

Specific musculoskeletal disorders in children

The conditions described below are specific to children although management of these conditions should involve application of the same exercise principles described for each joint in the appropriate preceding chapters.

Traction apophysitis conditions

Osgood–Schlatter’s syndrome is a traction apophysitis of the tibial tubercle due to repeated stress on the secondary ossification centre of the tibial tuberosity. This condition presents in growing children usually between 8 and 12 years in girls and between 12 and 15 years in boys. The symptoms include pain, swelling and tenderness over the tibial tuberosity. On X-ray, changes seen include irregularity of the apophysis with separation from the tibial tuberosity in the early stages and fragmentation in the later stages (Gholve et al., 2007). The tibial tubercle is the site of insertion of the quadriceps tendon and activities involving strong contractions of the quadriceps, e.g. football, running and basketball are associated with this injury. In adolescents this area is a growth plate and repeated vigorous activity causes traction on the growth plate, which leads to the inflammation and pain. As the tubercle is pulled forward by the quadriceps, contracting bone forms behind and the tubercle can become very prominent. This may in turn lead to pain when kneeling. The condition settles once the growth plate fuses to the tibia. Treatment is aimed at reducing the pain and swelling. Ice packs will provide pain relief, and non-steroidal anti-inflammatories may be recommended. A knee brace may help to reduce strain on the tibial tubercle. Generally symptoms disappear after the growth spurt is complete and only in rare cases is there a need for surgical management such tibial tubercleplasty (Weiss et al., 2007).

Sever’s disease affects the calcaneal attachment of the gastrocnemius/soleus musculature (Kaeding and Whitehead, 1998). Other traction apophysitis include the elbow region which may be seen in baseball players or more rarely in those playing racquet sports (Blohm et al., 1999). For both of these conditions, maintenance of joint range of motion (ROM), strength and proprioception should be emphasised, within limits of pain, for the patient. The preceding chapters on the knee and ankle should be reviewed for specific detail.

Scheuermann’s disease

Scheuermann’s disease is an osteochondrosis of the spine that mainly occurs in adolescents, usually boys, in their last 2–3 years of growth. It is a disturbance in the normal growth of the vertebral epiphyseal ring (Williams, 1979). If the compressive forces in the spine are sufficient it may cause a wedge deformity in the vertebral body causing a kyphosis of the thoracic spine and an associated increase in lumbar lordosis. Small disc herniations in the vertebral end plate called Schmorl’s nodes are sometimes identified on X-ray. The condition often remains asymptomatic but can become painful after activity. Treatment would usually consist of moderation of activities to minimise repetitive flexion and extension movements of the spine but with an active exercise programme. See Chapters 5 and 6, which discuss exercise in the thoracic and lumbar spine areas, for specific details of appropriate exercise.

Spondylolysis and spondylolisthesis

The conditions of spondylolysis and spondylolisthesis are commonly found in adolescent athletes (Standaert et al., 2000; Gregory et al., 2004; Iwamoto et al., 2004). Both conditions are described as stress fractures of the pars interarticularis of the lumbar spine. Spondylolysis is when there is a fracture on only one side of the spine; spondylolisthesis is when the stress fractures are bilateral (Standaert et al., 2000; Gregory et al., 2004; Iwamoto et al., 2004). The most common cause of spondylolysis in the immature athlete seems to be repetitive loading of the lumbar spine which creates a stress reaction (Gregory et al., 2004). It can be both symptomatic and asymptomatic, which is only established on routine radiographs (Standaert et al., 2000). The treatment is more commonly conservative, with spontaneous healing occurring in 87.5% of all cases of spondylolysis. (Iwamoto et al., 2004). Spondylolisthesis is more complex because with a bilateral fracture there may be some spinal instabil-
ity and spinal fusion surgery is not uncommon (Iwamoto et al., 2004). Soler and Calderón (2000) state that spondylolysis is as common in adolescent athletes as a ‘lumbar sprain’ and that it is said to be 3–4 times more common in athletes than in the general adolescent population. Low back sprains and strains are said to be very common in athletes (Keene, 1983). Rehabilitation would include a stability programme discussed in Chapter 6 on the lumbar spine.

Stress fractures can be commonly experienced in other areas in the adolescent athlete including the foot, tibia and fibula (Oeppen and Jaramillo, 2003), and less commonly – but not unusual – in the tarsal bones and clavicle.

Slipped upper femoral epiphysis
A slipped upper femoral epiphysis (SUFE) is where the growth plate at the upper end of the femur is weakened and the head of the femur moves downwards and backwards, thus affecting the movements at the hip joint. The exact cause is unknown and early diagnosis is important. The child complains of pain in the groin, hip, thigh or knee and has limited movement in the hip joint. The child may walk with a limp and there may be slight shortening of the affected leg. Treatment depends on the severity and is guided by X-rays and scans. Surgery may be required to stabilise the hip. Metal screws are inserted into the head of the femur and removed once the growth plate has closed. Post operatively the child will be non-weight-bearing for about 6 weeks.

Perthes’ disease
Perthes’ disease is a condition characterised by a loss (temporary) of blood supply to the hip. The area around the head of the femur becomes inflamed. It is usually seen in children between 4 and 10 years of age and is five times more common in boys. Symptoms generally commence with a limp and pain, which may be intermittent over a few months. Pain is brought on by movements of the hip and relieved by rest. Diagnosis is confirmed with X-rays. Treatment may be conservative or surgical. Anti-inflammatory medication is used to reduce the inflammation around the joint. Stretching exercises are prescribed to increase range of movement and the particular focus is on hip abduction and rotation. The child may require crutches for mobilisation. Casts may be used to maintain the hip in a good position (abduction). Surgical treatment realigns the head of the femur within the acetabulum and the alignment is maintained with screws and plates. The child is kept in a plaster cast for 6–8 weeks post operatively.

In both these conditions, when surgery is required, the general principles of exercise therapy in management of hip pathologies should be applied in post-operative rehabilitation. The reader is referred to Chapter 10 for details.

Scoliosis
Scoliosis is a curvature of the spine in the lateral plane accompanied by rotation. The muscles on the side of the convexity are at a mechanical disadvantage. Scoliosis can be idiopathic or as the result of a neuromuscular condition such as Duchenne’s muscular dystrophy, spina bifida or cerebral palsy. Treatment aims at reducing or halting the progression of the deformity by splinting or surgery. In terms of exercise the focus should be on maintaining mobility in the spine and overall musculoskeletal system and a level of fitness. Swimming is recommended to maintain fitness, muscle strength and respiratory function. Prescription of exercise should refer to the principles discussed in Chapters 4–6, which discuss the spine.

General considerations in the exercise management of children
The ability to physically perform at any stage is reflected in a child’s progress in growth, maturity and development. A potential exists in all children that follow normal developmental pathways, to learn basic performance skills and movement patterns, which become refined with practice and repetition to form a basic movement framework used in any sport.

The peak bone mass that develops during childhood is an important risk factor in osteoporosis. In children who are physically active higher bone mass is seen (Slemendra et al., 1991). Therefore it is important that clinicians encourage and promote health-enhancing physical activity from an early
age. As clinicians are involved in the ongoing management of children with disorders affecting mobility it is essential that weight-bearing activities are encouraged to optimise bone mass. In children with specific paediatric conditions, exercise management may need to be modified to meet particular requirements associated with their overall management. In children with cystic fibrosis, exercise will improve mucociliary clearance, strengthen respiratory muscles and improve bone density, whereas for children with muscular dystrophy the aim may be to increase muscle strength and endurance and thereby prolong the time the child is ambulant. In those with spina bifida the primary aim will be upper limb strength and control of body mass and maximising aerobic power. Specific exercise programmes may need to be devised taking into account the limitations associated with movement in the child with neuromuscular disorders.

References


Musculoskeletal Disorders in the Cardiac and Respiratory Patient

Juliette Hussey

Introduction

The aim of this chapter is to highlight the range of musculoskeletal disorders associated with respiratory and cardiac disease, so the musculoskeletal abnormalities associated with conditions such as chronic obstructive pulmonary disease (COPD), asthma, cystic fibrosis and heart failure will be considered. In addition, the musculoskeletal changes that the patient may experience after cardiac or thoracic surgery will be presented. The evidence for the management of these conditions with exercise therapy will be discussed. Comprehensive details of both cardiac and pulmonary rehabilitation may be found in a previous publication by the authors (Gormley and Hussey, 2005) and will not be discussed in detail in this chapter.

COPD is characterised by airflow limitation. It is progressive and is associated with cough, sputum production and shortness of breath (Global Strategy for the Diagnosis, Management and Prevention of COPD, Global Initiative for Chronic Obstructive Lung Disease (GOLD), 2007) and diagnosis is confirmed by spirometry. Exercise capacity is gradually decreased in these patients due to the associated dyspnoea. One of the goals of pulmonary rehabilitation is to address this limitation. Asthma is an inflammatory disorder of the airways with airway obstruction that is reversible either spontaneously or with treatment (British Thoracic Society (BTS), 2001). Symptoms include wheeze, shortness of breath and cough. The symptoms may be provoked by a number of triggers including exercise. The paradoxical relationship with exercise is that exercise induces broncho-constriction in many asthmatic people, but exercise is recommended as part of the overall management of the condition. Cystic fibrosis is a disorder of the exocrine glands and is characterised by excessive mucus secretion. Exercise is recognised as an important part of the management of this condition due to its beneficial effects on mucociliary clearance, lung function, aerobic capacity and bone health.

Musculoskeletal disorders in respiratory disease

Limitations in physical functioning in patient with respiratory disease

Patients with respiratory disease face a number of musculoskeletal problems. These include: postural abnormalities, muscle wasting and dysfunction,
both in patients with mild and severe disease (BTS, 2001). Pulmonary rehabilitation includes practical exercise classes and education of exercise training, secretion clearance techniques, nutritional support, smoking cessation and advice on breathing control. Musculoskeletal assessment in these patients should include observation of posture, measurements of joint range of motion, muscle activity and strength. It should also include documentation of any pain on rest or movement. Questioning about the use of long-term steroids is required in patients with chronic respiratory disease, as this treatment may lead to reduced bone density. Chapters 5 and 7–9, which discuss exercise in the management of the thoracic spine and upper limb conditions, should be consulted for practical examples of appropriate exercises.

**Range of movement and respiratory disease**

The range of movement in the spine and shoulder girdle needs to be evaluated prior to specific exercise prescription in the patient with respiratory disease. Posture in sitting needs to be examined; typical abnormalities in patients with cystic fibrosis include forward head posture, tight suboccipital and cervical extensors, scapulae the abducted and protracted, an increase thoracic kyphosis and a reduced lumbar lordosis. The range of movement in the thoracic region is dependent on the movement at the apophyseal, costovertebral, costotransverse joints and ribs, and the length of the intercostals, pectoralis and latissimus dorsi. A thoracic kyphosis may be the result of limited range in the upper thoracic spine. Thoracic rotation and lateral flexion occur in the mid-thoracic spine and any restriction here or shortening of the latissimus dorsi or teres major will limit the range of shoulder elevation. The range of rotation in the glenohumeral joint may also be affected by the tightness in the anterior and posterior shoulder capsule and related muscles. Shoulder movements and scapulohumeral rhythm need to be observed.

**Muscle function and respiratory disease**

Both peripheral muscle strength and respiratory muscle strength are affected in patients with respi-
Respiratory muscle function may be affected by a number of factors including hypoxia, hypercapnia, acidemia and malnutrition (Tobin, 1988). The combination of steroids, decreased exercise tolerance and chronic inflammation may lead to respiratory muscle weakness. Function may also be affected by biomechanical changes associated with hyperinflation of the lungs, which leads to flattening of the diaphragm so it is at a disadvantageous position in terms of the length tension curve.

In addition to the respiratory muscles, the peripheral muscles are also affected with generally a greater decrease in the strength of the lower limb muscles (a decrease of 20–30% in quadriceps strength has been reported) and relative preservation of upper limb strength (Decramer et al., 1994; Gosselink et al., 1996). Within the upper limbs, proximal muscle strength has been found to be more impaired than distal strength in patients with stable COPD (Gosselink et al., 2000). Structural and biochemical abnormalities have been found along with a reduction in the percentage of type I muscle fibres. Metabolic abnormalities are probably due to hypoxaemia and inactivity. Lactic acidosis occurs at lower work rates in COPD patients when compared with controls and this is associated with impaired exercise tolerance.

Muscle function in patients with respiratory disease may also be limited by disease, malnutrition, inflammatory markers, low levels of sex hormones, or prolonged use of systemic corticosteroids. Malnutrition may contribute to the muscle wasting and the patient with COPD may experience weight loss and an associated decrease in fat-free mass. Nutritional supplementation for 3 months was found to have a positive effect on maximal skeletal muscle strength (respiratory muscles and handgrip) in addition to body weight, mid-arm circumference and triceps skinfold thickness (Efthimiou et al., 1988) in patients with COPD who received supplemental oral nutrition compared with controls. Respiratory muscle strength and hand grip strength improved alongside nutritional status.

Many respiratory conditions are associated with systemic inflammation (Gan et al., 2004). Yende et al. (2006) examined the association between inflammatory markers and ventilatory limitation, muscle strength and exercise capacity in elderly patients, both with and without obstructive lung disease. Those with obstructive lung disease had lower quadriceps strength, lower maximum inspiratory pressure, higher systemic interleukin-6 levels and higher C-reactive protein levels than those who had normal lung function measures. Higher systemic levels of interleukin-6 were found to be associated with reduced forced expiratory volume in 1 second (FEV₁), quadriceps strength and exercise capacity.

Reduced levels of growth hormone and testosterone may contribute to muscle wasting. Van Vliet et al. (2005) compared circulating levels of hormones of the pituitary-gonadotrophic axis of men with COPD and age matched controls. The relationship between muscle force, exercise tolerance, inflammatory markers and hypogonadism was also explored. The hormonal differences were significantly higher for follicle-stimulating hormone and luteinising hormone, and lower testosterone in subjects with COPD. Low testosterone was significantly related to quadriceps weakness (r = 0.48) and C-reactive protein (r = −0.39) but not to exercise tolerance as measured by the 6-minute walk test.

Many patients with chronic respiratory disease will have a combination of these factors, all of which contribute to the decrease in muscle strength and have to be considered in exercise management.

**Bone health and respiratory disease**

Patients with obstructive lung disease have many risk factors that can predispose them to low bone density. In those with severe disease, the risk of osteoporosis increases as patients become more immobile, malnourished and more dependent on drug therapy. Sin et al. (2003) analysed data from the Third National Health and Nutrition Examination Survey and found that airflow obstruction was associated with increased odds of osteoporosis compared with those without airflow obstruction (odds ratio (OR) 1.9; 95% CI 1.4 to 2.5). Those with severe airflow obstruction were at an increased risk (OR 2.4; 95% CI 1.3 to 4.4). The authors concluded by highlighting the need for bone mineral density (BMD) evaluation in these patients to inform related management. Treatment of emphysema by lung volume reduction surgery has been found to result in an improvement in BMD (Mineo et al., 2005). The increase in BMD correlated with residual volume, diffusing capacity of the lung for carbon monoxide and fat-free mass, suggesting that the improvement was related to improved respiration and nutritional status.
Oral glucocorticoids are frequently used in asthma. Inhaled glucocorticosteroids are used in asthma to reduce symptoms and theoretically should have low systemic effects but even in those on low-dose inhaled corticosteroids, BMD has been found to be lower than controls (El et al., 2005). In this latter study on 45 female subjects, no correlation was found between disease duration, inhaled steroid treatment duration, cumulative inhaled dose and BMD measurements.

In subjects with cystic fibrosis, osteopenia and osteoporosis are seen and may be related to factors such as malnutrition and chronic use of corticosteroids (Hardin et al., 2001). Total body bone mineral content in children with cystic fibrosis has been found to be significantly less than in age- and gender-matched controls (Hardin et al., 2001). In children with non-cystic fibrosis bronchiectasis, osteopenia has been found to be more common compared with controls (Guran et al., 2008). The risk increased with age but BMD was not related to the severity of lung disease, calcium intake or steroid use.

**Exercise management of patients with respiratory disease**

The exercise component of the pulmonary rehabilitation programme generally comprises aerobic, strength and flexibility exercises. Either continuous or interval aerobic training in the form of walking or cycling is a key component and is carried into the home programme. Extremity conditioning exercises are used to improve maximum oxygen uptake, strength, endurance and co-ordination (Ries, 1994; Siebens 1996). The type of exercise indicated is of low resistance and high repetition which can be tolerated by the patient.

Patients are assessed prior to commencing rehabilitation and an individual training programme is devised. Patients may need postural correction with the goal of obtaining a position so that the spine, pelvis and shoulder girdle are in a neutral position to permit optimal muscle function. The management of joint restriction includes the use of passive mobilisations followed by exercises. Upper limb flexion and spinal extension may be performed with breathing exercises. In sitting the patient can perform extension and rotation with assistance if required to gain an increase in range. Home exercises need to be explained and the use of a mirror may help provide visual feedback to the patient.

Typical exercises to increase range of movement in the cervical and thoracic spine and shoulder joint include active-assisted rotation for the cervical and thoracic spine with the patient sitting on a chair, active thoracic spine lateral flexion with the patient in standing, and passive stretch of the anterior shoulder muscles. Figures 14.1–14.4 show examples of exercises that are performed in pulmonary rehabilitation and which benefit the musculoskeletal system. Exercises to maintain range of movement, in particular, in the shoulder and thoracic regions are included as part of the warm-up and exercise session. Examples of these are shoulder circles in each direction, trunk rotation and flexion and push-ups with hands against the wall at shoulder height.

Muscle strengthening as part of rehabilitation for patients with COPD is recommended. In addition to lower limb exercises, upper extremity training is also recommended to help performance in daily activities. Subjects with reduced exercise capacity who experience less ventilatory limitation to exercise and more reduced respiratory and peripheral muscle strength have been found to be more likely to respond well to exercise training (Troosters et al., 2001). At this stage there is insufficient evidence to advocate high-intensity exercise and there is a
need for studies to investigate the results of varying intensities of exercise. Low-intensity peripheral muscle conditioning, in the form of 10 different exercises, each performed for 30 seconds, has been shown to be well tolerated and led to improved muscle performance in patients with COPD (Clark et al., 1996).

The effects of inspiratory muscle training have been extensively studied with varying results. However, an 8-week programme of high-intensity inspiratory muscle training resulted in a significant increase in inspiratory muscle function, increased thickness of the diaphragm, improved lung volumes and work capacity in subjects with cystic fibrosis (Enright et al., 2004) and healthy subjects, at 80% of maximal effort (Enright et al., 2006). A Cochrane systematic review by Ram et al. (2008) identified five randomised controlled trials in which respiratory muscle training was investigated. The pooled results showed a significant effect of inspiratory muscle training.

**Cardiac disease and musculoskeletal dysfunction**

**Limitations in physical functioning in patients after cardiac surgery and in those with cardiac disease**

The causes of musculoskeletal problems post cardiac surgery may be the result of sternal retraction, positioning of the patient during the surgery (which lasts a number of hours), cannulation of the internal jugular vein and the relative devascularisation of the sternum due to harvesting of the internal mammary artery (El-Ansary et al., 2000). Retracting the sternum involves the eversion of the upper ribs and this may be one explanation for pain in the anterior chest wall and thoracic joint dysfunction. The results of the alterations in the chest wall can be seen for at least 3 months post operatively, with
pulmonary function demonstrating a restrictive pattern (Kristjansdottir et al., 2004). After cardiac surgery involving a median sternotomy there may be limitation of movement in the shoulder girdle and upper back as well as pain over wound sites (LaPier and Schenk, 2002). The pain may be due to direct surgical trauma, and swollen and inflamed areas may lead to mid or lower cervical root irritation causing referred pain to the scapula or upper limb. Posture may also be affected and a flexed posture with forward head position may lead to shortening of some muscles and lengthening of others.

In post-thoracotomy or -sternotomy patients, passive movements of the shoulder joint may be limited as the patient may hold the upper limb immobile due to fear of pain. In the weeks following surgery the patient may be limited in forward bending or backward extension due to approximation of the incisional area or stretching of the area. Exercises prescribed need to considered in light of overall activity recommendations for patients and gradually increased. Despite current management aimed at regaining range of movement in the immediate post-operative period, a number of patients (approximately 30%) will develop musculoskeletal complications that affect comfort and/or function after cardiac surgery (Stiller et al., 1997). Complications after harvesting the radial artery are rare other than persistent cutaneous paraesthesia in a small percentage of patients (Budillon et al., 2003). In patients on long-term ventilation, restrictions in joint range may occur, and where possible, passive or assisted movements of the upper and lower limbs should be performed.

Cardiac rehabilitation is part of the overall management of patients post surgery and/or stenting, and in more recent years is prescribed for those with heart failure. In patients with heart failure there appear to be peripheral muscle changes with exercise training. Muscle mass and endurance are decreased in patients with heart failure, and on biopsy a decrease in type 1 fibres with an increase in type 11b fibres is seen (Sullivan et al., 1988). Patients with heart failure have been found to have lower BMD than age-matched controls (Kenny et al., 2006) and therefore interventions to increase physical activity are important in their management. Heart failure in elderly patients is often accompanied by other co-morbidities such as musculoskeletal problems, cerebrovascular disease and respiratory disease, and such may influence function and activity (Lien et al., 2002). The presence of osteoarthritis needs to be taken into account when rehabilitating these patients as heart failure may be exacerbated by the use of over-the-counter non-steroidal anti-inflammatory drugs (Page and Henry, 2000; Van der Wel et al., 2007).

Heart failure is associated with changes in muscle mass, cellular structure, energy metabolism and blood flow. These are associated with decreased exercise capacity and are improved with exercise training (Warburton et al., 2007).

Exercise management of musculoskeletal conditions in patients with cardiac disease

Cardiac rehabilitation has been defined as ‘the sum of activity required to ensure cardiac patients the best possible physical, mental and social conditions so that they may by their own efforts regain as normal as possible a place in the community and lead a normal life’ (WHO, 1993). Exercise is a major component of all phases of cardiac rehabilitation. It commences with walking in phase 1 and 2 and is increased to circuits in phase 3 in outpatient, exercise-based cardiac rehabilitation generally for 8–12 weeks. Patients are then expected to continue incorporating exercise into daily life (phase 4). The exercise components are aerobic-type activities and resistance training is generally reserved for low- to moderate-risk cardiac patients. Patients with cardiac disease may have other co-morbidities that may affect their ability to exercise.

In patients early post cardiac surgery, exercises need to be performed to prevent the risk of the patient developing a frozen shoulder (Tucker et al., 1996). The scapula can be moved with the patient in side lying and active upper limb exercises encouraged. While Stiller et al. (1997) found that routine range of movement exercises did not lead to a change in the incidence of musculoskeletal problems at 8–10 weeks post operatively, upper limb and trunk exercises are advised to help anterior chest wall discomfort (El-Ansary et al., 2000) and stretching exercises when the sternum is stable.
If a patient has osteoarthritis in any of the lower limb joints this will interfere with exercise performance. Therefore, the physiotherapist needs to address the limitations to movement including pain and may need to prescribe more non-weight-bearing exercise so that the patient may experience the benefits associated with exercise rehabilitation. Weight loss may also help in symptoms of osteoarthritis and facilitate exercise uptake.

Patients with heart failure have also been found to benefit from exercise rehabilitation and specifically muscle strengthening. A 12-week quadriceps resistance training programme in New York Heart Association (NYHA) class III patients led to improvements in muscle strength (P<0.01), exercise capacity (P<0.01), clinical status (P<0.01) and quality of life (P<0.05) (Jankowska et al., 2008). The training programme was performed three times per week and consisted of resistance exercises of several exercise circuits of 10 repeated quadriceps resistance exercises. The weight lifted commenced at 35% of maximal weight. Bartlo (2007) analysed data from a number of trials on aerobic and strength training in subjects with congestive heart failure. Aerobic exercise was found to have a significant beneficial effect on dyspnoea, work capacity and ventricular function (P<0.01) and strength training increased muscle strength (P<0.05) and endurance (P<0.001) and left ventricular function (P<0.01).

In conclusion, while the exercise management of patients with cardiac or pulmonary disease focuses on increasing aerobic capacity it is important for the physiotherapist to recognise the limitations to exercise and pain, and limitation of movement that may result from musculoskeletal concerns.

References


Musculoskeletal Disorders in Obesity
Grace O’Malley

Introduction

A positive relationship exists between musculoskeletal fitness and general health status. Previous research has demonstrated impairments of the musculoskeletal system in individuals who are overweight, and to date, it is unknown whether these impairments occur as a consequence of obesity or whether they independently impart an increased risk of weight gain. In the USA between 1988 and 2004 the level of functional impairment associated with obesity increased and a greater burden of disability may be seen in the obese population of the future (Alley and Chang, 2007). In adults, osteoarthritis is the condition best documented to be associated with obesity; however recent research describes other musculoskeletal disorders. Common disorders that may present to physiotherapists working with overweight and obese individuals include: disorders of the lower limb such as foot pain; osteoarthritis of the knee (Felson et al., 1988); recurrent ankle injury (Timm et al., 2005); low back pain (Leboeuf-Yde et al., 2005) and slipped upper femoral epiphyses (Loder, 1996). Musculoskeletal disorders in the upper body of overweight individuals include: neck pain, headaches, rotator cuff tendinitis (Werner et al., 2005), frozen shoulder, peripheral nerve entrapment (Descatha et al., 2004) and diabetes-related disorders.

Pain and discomfort can act as barriers to physical activity, and physiotherapists and other health clinicians can help improve the health and functional independence of obese individuals by reducing pain and discomfort. The positive relationship between musculoskeletal fitness (MSF) and weight status is mediated by physical activity, as those individuals with high levels of physical activity are seen to have better musculoskeletal health (Huang and Malina, 2002). Physiotherapists have vast experience in the rehabilitation of individuals with multiple pathologies and are very often the key professionals to motivate change, improve attitude and build self-efficacy. As such, when an individual who is obese presents to a therapist with musculoskeletal complaints, efforts to improve the global health of the client should be made, and might furthermore, be considered not only ethical but also part of the duty of care.

In an effort to individualize the management of overweight and obesity, the physiotherapist must first be able to assess the degree of overweight, second examine the general physical condition of the individual and third, in agreement with the

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patient, define goal-oriented methods of improving the functional independence and quality of life of the client.

Musculoskeletal assessment

In assessing the general health of an overweight client, the physiotherapist should complete a global examination of musculoskeletal fitness. This examination should include measures for joint range of movement and muscle flexibility, muscle strength and endurance, standing balance, pain, posture and gait. Collecting accurate measures for joint range of movement can be a challenge due to the difficulty in identifying bony landmarks and as such, the use of functional measures may be more appropriate.

In addition to assessment of the musculoskeletal system, the physiotherapist should detail the client’s medical history, the level of overweight with which the client presents and the level of both physical activity and sedentary pursuits in which the patient engages. Body composition can be assessed by measuring height, weight, waist circumference and by calculating the body mass index (BMI; weight (kg)/height (cm)^2). Subjective measures of physical activity such as the Baeke Questionnaire, the International Physical Activity Questionnaire or a 7-day activity recall can be useful in clinical practice. Similarly, time spent in sedentary activity can be calculated by summing the number of hours spent using a computer, playing video games and watching television.

Furthermore, assessing cardio-respiratory fitness is useful to gain a greater understanding of the general fitness of the patient and can provide a reliable client-specific outcome measure. In many cases medical clearance may be required prior to testing cardio-respiratory fitness, however, measures such as a 10-m walk test, the 6-minute walk test or a shuttle test can be used in appropriate clients. Regardless of the age of the client, a holistic assessment will enhance the therapist’s understanding of the impairments associated with the client’s health status, which will in turn, guide him/her on how best to reduce limitations to activity and enhance participation.

During a musculoskeletal examination, the therapist should be aware that palpation and provocative testing can be difficult to complete due to excess subcutaneous tissue and the inertia of the client’s body segments. As such, the manual handling risk associated with certain tests should be considered.

Physical effects associated with obesity

Clinically, limitations of the physical system are easily observed in the overweight population and recently, research has begun to describe these. In addition, many overweight individuals will present with diabetes mellitus as a co-morbidity and this condition is independently associated with musculoskeletal symptoms.

Impaired joint range of movement and flexibility

Bony structure determines the primary degree of joint freedom of movement and is influenced by the extensibility of soft tissue structures. Range of movement parameters are commonly used in clinical practice and have been utilised as indicators and predictors of physical function (Koman et al., 2000). Overweight and obese individuals may present with a reduction in joint range of motion (ROM). This may be due to increased subcutaneous adipose tissue blocking joint excursion, localised oedema, abnormal bony torsion or decreased muscle length. Regardless of the underlying cause, it can be assumed that limited joint ROM may lead to subsequent reductions in flexibility and suboptimal postural alignment. Reduced muscle flexibility is commonly associated with musculoskeletal conditions (Hertling and Kessler, 1996) and may predict the presence of musculoskeletal symptoms in adulthood (Mikkelsson et al., 2006). Research suggests that those who are physically active have better muscle flexibility than those who are not (Huang and Malina, 2002).

Increased body weight has been shown to be inversely associated with lower limb range of motion and impaired hip ROM is described as a risk factor in recurrent non-specific low back pain (LBP) (Jones et al., 2005). In a cyclical process, it is hypothesised that poor hip mobility increases spinal strain leading to LBP which, in turn can lead to reduced levels of physical activity, thus possibly increasing the BMI and subsequently increasing the strain on spinal structures.
Reduced ankle dorsiflexion ROM and the resultant equinus gait pattern has been observed to cause abnormal pronation of the subtalar joint, which may increase stress on the plantar fascia (Hill, 1995). Furthermore, both obesity and excessive subtalar pronation have been highlighted as risk factors for the development of chronic plantar heel pain and repetitive strain injuries (Irving et al., 2007).

Tight quadriceps and hamstrings may increase compression of the patellofemoral joint, causing pain (Hertling and Kessler, 1996), and reduced hamstring and quadriceps length has been described in obese persons. Impaired hamstring length can affect pelvic tilt, drawing the pelvis posteriorly (Józwiak et al., 1997). Thus, hamstring tightness may affect posture, gait and low back discomfort, and evidence suggests that impaired hamstring flexibility is a risk factor for LBP in both adults (Esola et al., 1996) and adolescents (Salminen et al., 1992; Sjolie, 2004).

**Oedema**

Many obese clients have underlying conditions that may induce joint and soft-tissue swelling. The therapist should be aware of conditions such as lymphoedema and lipidaemia (a disorder of abnormal fat deposition) to ensure appropriate management for affected patients. Lymph drainage requires intermittent changes in local pressure from exercise and movement and as such, sedentary overweight individuals may develop dermatological symptoms (Garcia, 2002). Lymphoedema results from accumulation of protein-rich lymph in tissues and is caused by inadequate lymph drainage. Conservative management is initially recommended, such as lymphatic massage therapy, limb mobility exercises, use of compression garments and limb elevation (Weston and Clay, 2007). The clinician should bear in mind that local tissue swelling post injury may be difficult to appreciate secondary to the large bulk of adipose tissue surrounding the joints.

**Impaired balance and postural stability**

Balance is described as the ability of the body to maintain a centre of gravity over its base of support with minimal sway and maximal steadiness. Factors that have been shown to influence balance include: age (Colledge et al., 1994), physical activity level (Hahn et al., 1999), previous lower limb injury (Emery et al., 2005) and height and weight (Odenrick and Sandstedt, 1984). Balance may be reduced in overweight clients due to muscle weakness, limited range of movement and low levels of physical activity. Research has shown that increased body weight is correlated with an anterior displacement of the centre of mass, which places obese individuals closer to their boundaries of stability and at greater risk of falling when exposed to daily postural stress (Hue et al., 2007). Weight loss in the obese cohort has proven to incur significant improvements in balance capabilities (Teasdale et al., 2007).

Furthermore, limited joint range influences standing balance (Lowes et al., 2004). Reduced knee and ankle range of movement can increase postural sway (Potter et al., 1990) and also impede the implementation of the ankle strategy for postural adjustment (Mecagni et al., 2000). Reductions in joint range of movement can also affect standing balance through the alteration of muscle length/tension curves, leading to inefficient gait and stance (Damiano et al., 2001).

Appropriate measures of balance should be chosen depending on the patient’s age and general physical condition. Standardised tests such as the Berg balance scale, the timed up and go and timed single leg stance tests are useful; however, at all times the clinician should use the tests with caution, particularly if the client is morbidly obese or has a significant fear of falling.

**Reduced muscle and bone strength**

Muscle strength is an integral part of physical fitness and relates to the ability of a muscle to generate force at a given speed. Inadequate muscular strength can predispose individuals to an increased risk of musculoskeletal fatigue and injury (Riddiford-Harland et al., 2006). Impaired muscle strength is commonly due to advanced ageing, systemic illness, degenerative disease, injury and obesity (Miyatake et al., 2000). A positive relationship exists between muscle strength and physical activity (Neder et al., 1999) and a negative relationship has been observed between strength and obesity (Riddiford-Harland et al., 2006).

It is thought that in overweight individuals, the dampening and decelerating capability of lower
limb musculature is impaired secondary to muscle weakness and the resistance offered by the body's weight, thus increasing the rate of joint loading (Mikesky et al., 2000). Functional tasks such as rising from a chair have been shown to be adversely affected by obesity (Riddiford-Harland et al., 2006). In addition, weakness of muscles such as the gluteals and posterior tibialis (which eccentrically control during the stance phase of gait) may also lead to hyperpronation and associated injury (Cornwall and McPoil, 2000). In order to improve postural muscle co-ordination and enhance balance capacity, strengthening of ankle dorsiflexors, ankle plantar flexors and both hip and knee extensors should be encouraged (Lowes et al., 2004).

It is uncertain to date as to what role reduced muscle strength plays in the development of musculoskeletal impairments. It is clear, however, that reduced muscle strength in children impairs the development of bone strength, and that inadequate bone strength at the peak growth stage may increase the risk of sustaining fractures (Goulding et al., 2000b). Strong developing muscle has a positive effect on the accrual of bone mass both in puberty and in adolescence (Gustavsson et al., 2003). Engaging in physical exercise incurs loading forces upon bone by exercising muscle, which in turn, increases bone mineral content and density.

In the physically active obese child, greater body mass requires larger muscle force to move the body in space and as such will lead to greater bone strength (Slemenda et al., 1997). However, inactive obese children with weaker muscles can have a reduction in bone strength and thus may become osteopenic, increasing the risk of fracture. In addition, studies of inactive overweight children have suggested that high BMI, adiposity and associated low bone density increase the risk of fracture when members of this group sustain a traumatic fall (Goulding et al., 1998, 2000a; Molgaard et al., 1998).

In the morbidly obese, it is evident that there is bone loss and increased skeletal fragility following weight loss. More significant increases in bone fragility are seen where weight is lost during a relatively short period of time, such as 3–4 months (Van Loan et al., 1998; Fogelholm et al., 2001), whereas moderate weight loss over a longer period (6 months) results in little or no bone loss (Ramsdale and Bassey, 1994; Shapses et al., 2001). Similarly, dramatic weight loss such as that induced by the roux-en-Y gastric bypass and gastric banding is also associated with significant bone resorption and loss (Berarducci, 2007; Carrasco et al., 2009). Efforts should be made to ensure that weight loss interventions aim to minimise bone loss by including aerobic and resistance-training protocols.

Finally, particular attention should be given to weight loss initiatives targeting elderly people, as the health benefits of weight loss in this cohort are uncertain. Weight loss in this cohort may accelerate the loss of muscle mass which, correlates negatively with functional capacity for independent living. The co-existence of reduced lean mass and increased fat mass is defined by ‘sarcopenic obesity’, and characterises a group of individuals with high risk of functional impairment (Miller and Wolfe, 2008).

**Altered biomechanics and gait**

In adults, links have been made between obesity and musculoskeletal conditions such as osteoarthritis and chronic back pain (Visscher and Seidell, 2001). Knee osteoarthritis is more common in overweight individuals, especially women, with external knee adduction moments cited as the most important load factors in generating articular injury (Hurwitz et al., 1998; Sharma et al., 1998). A recent study investigating risk factors for lumbar disc degeneration found that there was a strong association (95% CI 1.3 to 14.3) between disc degeneration at follow-up and persistent overweight, classified as BMI ≥25 kg/m² at age 25 and 40–45 years (Liuke et al., 2005). A causal link between obesity and low back pain is yet to be described, as epidemiological studies report contradictory results (Leboeuf-Yde et al., 2005; Lee et al., 2005).

Recent work has described greater ground reaction forces and knee-joint loading in those who are obese compared with those who are not (Browning and Kram, 2007). Furthermore, Messier et al. (2005) reported that for every pound of weight lost, there is resultant four-fold reduction in the load exerted on the knee for each step taken during daily activities.

Regarding gait, individuals who are obese may present with a shorter stride length and slower cadence, and spend more time in stance phase and...
Musculoskeletal Disorders in Obesity

**Diabetes mellitus**

Diabetes mellitus is a chronic metabolic condition with associated microvascular and macrovascular complications. Physical activity is recommended as a cornerstone in the management of diabetes mellitus and can both aid glycaemic control and decrease the risk of diabetic complications. Diabetic individuals have a greater incidence of musculoskeletal conditions such as reflex sympathetic dystrophy/chronic regional pain syndrome type 1, frozen shoulder, limited small-joint (hands and feet) mobility, Dupuytren's contractures, carpal tunnel syndrome, flexor tenosynovitis, neuropathic joints (Charcot's), diabetic amyotrophy and diffuse idiopathic skeletal hyperostosis (Smith et al., 2003).

When treating this cohort the therapist should advise and educate on correct footwear and appropriate management of blisters. In some cases, the use of silica gel or air mid-soles may be indicated in an effort to protect feet and prevent blisters. During the rehabilitative phase of musculoskeletal conditions, the patient should be advised to avoid Valsalva-like manoeuvres due to the risk of vitreous haemorrhage. Similarly, the therapist should work closely with patients in whom physical activity is prescribed to avoid hypoglycaemic episodes and to ensure that any exercise undertaken is well planned and safe.

**Limitations in rehabilitation of the obese patient**

The main aim of intervention should be to improve the general function of the client. However, the obese client may present with factors that may limit the effectiveness of a therapeutic approach. The client may be restricted by a plethora of both intrinsic and extrinsic barriers depending on his/her age and such barriers should be considered prior to and throughout treatment. Adequate attention should be given to the importance of goal setting and motivational techniques to optimise treatment.

Extrinsic barriers to the rehabilitation of musculoskeletal complaints in individuals who are obese include: a lack of time; a lack of information; a lack of support by employers and or family members (particularly parents, where paediatric clients are
double support in walking (Lai et al., 2008). It is possible that individuals who are obese may adjust the characteristics of their gait (such as walking speed) in order to reduce ground reaction forces and moments about the knee joint. This point should be considered when prescribing walking to clients, as the cardiovascular benefits derived from walking at brisk speeds may be attenuated by the slower speeds required to avoid musculoskeletal discomfort. As such, if a cardiovascular benefit is not anticipated from the self-selected natural walking speed of the client, non-weight-bearing activities may be more appropriate, particularly in the management of severely obese clients. Few authors have investigated the effect of obesity on gait but preliminary results (Gushue et al., 2005) propose that overweight children have altered knee joint kinematics during walking due to higher peak knee adduction moments (73–100% higher than normal weight children). The authors propose that gait adaptation may increase medial compartment loading of the lower limbs, and contribute to the development of varus/valgus deformities and osteoarthritic wear and tear.

**Musculoskeletal pain**

Cross-sectional investigation reports that those who are obese are more likely to report musculoskeletal pain and that the severity of pain reported increases with the level of obesity (Hitt et al., 2007). The most commonly reported sites of pain include the back, the feet and the knees (Shiri et al., 2008; Stovitz et al., 2008) and individuals with a BMI >35 have been shown to be at a greater risk of pain (Rohrer et al., 2008). Tukker et al. (2008) reported a dose response relationship between the degree of overweight and the presence of osteoarthritis, pain and disability. These authors also reported that approximately 25% of health problems of the lower limb were attributable to overweight and obesity. It would be prudent for therapists working with those who are obese, to investigate the presence of pain and discomfort and to determine where possible, the underlying cause for these complaints in order to establish an optimal treatment plan. In addition, it is recommended that pain be addressed as it is cited as a barrier to the physical activity required for health enhancement (Mauro et al., 2008).
Finally, certain manual therapy techniques may not be appropriate, given the inertia of the client’s body segments and may pose a manual handling risk. In such cases, alternative treatment procedures may need to be considered such as the use of belts or hydrotherapy for manual therapy treatments.

Rehabilitation exercises for the overweight client

In order to rehabilitate a client who is overweight, certain modifications to therapeutic exercises may be necessary. Modifications may prove to be safer to the client and may reduce the manual handling risk to the therapist. The therapist should be aware of any assistance the client may require in getting down to the floor and may need to recommend the use of a chair/bench to aid a safe transition. Such transitions should be practised with therapist supervision until the client is confident and safe.

Figure 15.1a illustrates a modified quadriceps stretch whereby the client gets into a kneeling position (using a chair for assistance if needed) and then with ankles and knees together begins to gradually sit back on the heels with the ankles in plantar flexion (Fig. 15.1b). The client may use his or her upper limbs to ease into this position and should be encouraged to press the knees into the floor.

Figure 15.2a depicts the starting position for a seated hamstring stretch whereby the client sits with his or her back flat against a wall, the knees extended, the upper limbs outstretched with the scapulae set against the rib cage and the toes pointing to the ceiling. The client is instructed to bend forward at the pelvis to the point that he or she feels the hamstrings stretch and should keep the back and knees straight at all times (Fig. 15.2b).

Figure 15.3 illustrates a modified calf stretch whereby the client leans into a wall with the toes pointing forward and flexing forward on the front leg. The forefoot is prevented from rolling in by placing the edge of a book under the first metatarsal and the calf of the back leg is stretched by keeping the knee straight throughout the stretch.

Figure 15.4 illustrates a modified adductor stretch whereby the client sits with his or her back against the wall with the hips in 90° flexion. The client then flexes the knee and externally rotates the hip by placing the foot against the inner aspect of
Figure 15.1 (a) A modified quadriceps stretch whereby the client gets into a kneeling position. (b) With ankles and knees together begins to gradually sit back on the heels with the ankles in plantar flexion.

Figure 15.2 (a) The starting position for a seated hamstring stretch. (b) The client is instructed to bend forward at the pelvis to the point that he or she feels the hamstrings stretch and should keep the back and knees straight at all times.

the opposite thigh. The adductors are stretched by gently leaning and pushing the knee down to the floor.

Core stability work can aid in the management of back pain in this client cohort. Core stability training should commence with effective contractions of the abdominal wall and the therapist should be aware that excess abdominal tissue may make palpating the contractions difficult. The therapist might choose to use easy to understand instructions in order to stimulate contractions. Such instructions might include asking the client to concentrate on preventing him or herself from going to the toilet by contracting the pelvic floor musculature. These exercises can then be progressed by contracting the abdominals while maintaining a balanced posture sitting on a ball (Fig. 15.5), while kneeling on a pillow (Fig. 15.6) and by getting into a modified four-point position (Fig. 15.7) and slowly extending one of the hips (Fig. 15.8).

Balance exercises can be used to improve postural stability and might include: toe walking; heel walking; single leg standing with the eyes open and closed; double leg standing; and single leg standing
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**Figure 15.3** A modified calf stretch.

**Figure 15.4** A modified adductor stretch.

**Figure 15.5** Contracting abdominals while maintaining a balanced posture sitting on a ball.

**Figure 15.6** Contracting abdominals while maintaining a balanced posture while kneeling on a pillow.
on a cushion or pillow with the eyes open and closed (Fig. 15.9).

References


Introduction

Evolution has optimised bone structure, shape and mass to reflect its various functions: mechanical support and leverage for the musculoskeletal system; protection of vital organ systems; mineral storage and homeostasis; and within the marrow, lipid storage and haematopoiesis (Currey, 2003). Osteoporosis is one of the most significant bone disorders the therapist will encounter in modern practice. Diagnosis of osteoporosis is based on the combination of clinical risk factor assessment and bone mineral density measurement by a special low-dose X-ray technique (dual energy X-ray absorptiometry (DXA)). Treatment of established osteoporosis is complex, and has three main aspects: adequate nutrition, appropriate drug therapy and mechanical loading through exercise.

Exercise plays a role in preventive strategies in childhood and adolescence, maintenance of bone mass through adult years and interventions to slow age-related bone loss in later life. In addition exercise programs can be used to correct posture, improve balance, increase strength and coordination, with an overall effect to reduce falls. The therapist should take note that exercise without attention to diet or without appropriate drug therapy may be ineffective, those who over-exercise can develop osteoporosis, and finally that in severe osteoporosis certain types of exercise are dangerous and cannot be recommended.

Bone structure

The skeleton comprises some 206 individual bones adapted in shape and size for functions of protection, weight-bearing and movement. Bones consist of a dense outer cortical shell and a more porous inner trabecular network of struts and plates. The ratio of cortical to trabecular bone varies in different parts of the skeleton. Long bones such as the humerus and femur are over 75% cortical bone whereas vertebrae consist of up to 75% trabecular bone; and external and internal structure can be adapted at different sites in the skeleton according to the local mechanical function and loading that has to be endured (Currey, 2003).

Trabecular bone is light, only 15–25% of volume is calcified tissue the remainder being occupied by bone marrow, blood vessels and connective tissue. The large trabecular bone surface area provides...
70–85% of the interface between the skeleton and soft tissues for cellular metabolic activities (Keaveny and Yeh, 2002). In the proximal and distal ends of long bones trabeculae effectively redistribute forces and bending moments to the cortical shell of the mid-shaft. In vertebral bodies, trabeculae distribute axial compressive forces throughout the entire network. The type of cellular structure formed, as well as thickness and connectivity of the struts and plates are key determinants of trabecular bone strength (Gibson and Ashby, 1997).

Cortical bone in contrast has a more solid form, making it highly resistant to bending and twisting forces and able to withstand very high loads (usually only in one predominant direction). Sudden loads applied in unusual directions can lead to fracture (Martin and Burr, 1989). The mass of bone making up the cortical shell and the distance of the cortical shell mass away from the neutral axis determine the cortical bone strength; or more simply, the strength of cortical bone is determined by both bone quantity, amount of mineralisation, and by geometrical properties of shape and structure (Frost, 1997).

Osteoporosis affects both cortical and trabecular bone but trabecular bone is affected to a much greater degree due to its higher surface area for unbalanced remodelling. Sites in the skeleton with a high proportion of trabecular bone such as the distal radius, the proximal femur and the vertebrae are therefore more prone to the effects of osteoporosis.

**Bone ultra-structure**

At an ultra-structural level both cortical and trabecular bone are made up of layers or lamellae. Within lamellae, collagen fibres are aligned along the lines of the predominant stresses encountered during everyday activity, and this accounts for bone’s anisotropic properties (Turner et al., 1995). In trabecular bone, two to three lamellae form the interconnected rods and plates. In cortical bone, two to three sheets of circumferential lamellae make up outer smooth surfaces; deep to this are the osteons or ‘Haversian’ systems, three to five layers of concentrically arranged lamellae with central canals containing blood vessels and nerves. Interstitial lamellae, consisting of partially remodelled osteons, fill in gaps between the osteons and circumferential layers (Khan et al., 2001).

**Bone matrix**

Bone matrix comprises an organic phase (20–25%), a mineral phase (70%), and a small amount (5%) of water (Sommerfeldt and Rubin, 2001). The organic phase conveys strength, flexibility and toughness and is mainly type I collagen fibres, non-collagenous proteins, proteoglycans, glycoprotein, osteocalcin and osteonectin. The mineral phase consists of crystals of calcium phosphate hydroxides, known as hydroxyapatite, which gives bone its hardness and stiffness. When formed *ex vivo*, the non-organic crystalline structure of these components is brittle but when combined with the organic phase the resultant composite material has a much greater hardness, strength and resilience to load (Khan et al., 2001). Smaller breakdown products of collagen, osteocalcin and osteonectin, can be measured in the blood and thus are useful as clinical markers of bone turnover.

**Bone surfaces**

All bone surfaces, both inner and outer, are covered with bone-lining cells in a thin continuous layer (Currey, 2003). The outer lining membrane, the periosteum, also has fibrous and vascular layers. The inner lining layer on trabecular bone surfaces and lining channels for blood vessels is known as the endosteum. A single layer of osteoprogenitor cells is found here and it represents the primary source of cells for new bone formation during modelling, remodelling and repair.

**Bone cells**

Bone cells are derived from pluripotent stem cells of the bone marrow. Numerous factors influence differentiation, subsequent development and roles in bone modelling and remodelling. Bone cells are of three types, bone-resorbing cells (osteoclasts), bone-forming cells (osteoblasts) and the predominant cell type (osteocytes, >90%). The first two cell types are found on bone surfaces whereas osteocytes form a network within bone.

**Osteoclasts**

Osteoclasts are large, multinucleate cells derived from macrophage precursor cells in the blood, and
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have a resorptive function to remove bone matrix. Like macrophages, when signalled they have the capability to migrate into areas of damage for repair. Their ruffled borders attach to damaged bone surfaces in large lacunae on trabecular surfaces and in the cutting cones of basic remodelling units in cortical bone (Figs 16.1 and 16.2). They release enzymes, breaking down mineral and protein components of the matrix; acid secretions break collagen linkages with hydroxyapatite crystals, and collagenase and cathepsin further break down the protein elements. Activated osteoclasts can reabsorb bone at a rate of approximately 200,000 μm³ per day; which is far in excess of the maximum osteoid production and mineralisation rate of bone-forming osteoblasts.

Osteocytes

Osteocytes are mature osteoblasts that have been enclosed within bone matrix during growth and remodelling. Embedded within bone, their fine cytoplasmic extensions form a communicating network via small channels (canaliculi) in the bone matrix with neighbouring osteocytes and cells lining surface layers (Khan et al., 2001, Currey, 2003). Mechanical loading of bone has been shown to produce fluid shear stresses, which deform and in some cases damage this canalicul network. Damage and shear stress of the osteocyte network is purported to initiate and then modulate bone repair and remodelling mechanisms (Frost, 1987).

Bone development and ageing

The skeleton first appears as a cartilaginous template at 6 weeks of embryonic life; subsequent min-
Osteoporosis

Those genetically endowed with bones of greater width, thickness and of higher density due to accrual of greater bone mass during development have stronger bones and are less likely to have osteoporosis in later life.

Bone remodelling

Bone is a ‘smart material’ unlike inert materials such as concrete, because it possesses an adaptive mechanism which allows it to alter both its geometric (shape, length and width) and material properties (strength, stiffness and toughness) when exposed to varying mechanical stimuli. This process is called remodelling and is a dynamic biological balancing act of destruction and renewal, whereby approximately 10% of old bone is replaced by new bone each year. Normally remodelling activity is coupled so that no net bone loss occurs but with ageing the process becomes progressively unbalanced, ultimately leading to osteoporosis (Khan et al., 2001).
In cortical bone remodelling (Fig. 16.1), osteoclasts core out small tunnels or ‘cutting cones’ which move through bone at approximately 50 μm per day (Kanis, 1994). The space left by tunnelling osteoclasts, the resorption cavity, is then closed in layers by following osteoblasts, and as the layers of osteoid mineralise and new lamellae are formed, the osteoblasts become entrapped and become osteocytes. Successive lamellae are formed as osteoblasts add more and more layers in the ‘closing cone’ until the space is refilled, toward the central canal. The co-ordinated movement of the cutting and closing cones of the bone multicellular unit (BMU) through cortical bone has the effect to remove any small cracks within osteonal cortical structure which occur during normal everyday loading. In trabecular bone remodelling (Fig. 16.2) a similar process occurs on the surface of the struts and plates of trabecular bone. Firstly, osteoclasts gouge out old or damaged bone, and in reversal zones, the following osteoblasts fill in the grooves and indentations left behind.

In terms of localised structural adaptation, remodelling enables bone to adapt osteonal and trabecular structure to changes in directions and magnitude of predominating forces on the bone (Fig. 16.4). Resorption takes about 10 days and refilling with osteoid and mineralisation (reversal) can take 2–4 months (Currey, 2003). One of the short-term negative effects of remodelling is reduced bone mass, reduced trabecular thickness, reduced connectivity and ultimately decreased strength. In the normal healthy skeleton, however, this is soon rebalanced by refilling but in osteoporosis this is a different matter.

**Remodelling and osteoporosis**

In osteoporosis the resorption in cortical and trabecular remodelling becomes unmatched by slower incomplete refilling. In trabecular bone, the struts and plates become thinner or disappear. Some trabecular bone may get thicker and thus stronger in one direction but lose strength in other directions due to loss of connectivity with loss of interconnecting struts. In cortical bone resorption cavities remain unfilled giving rise to areas of excess poros-
Aetiology

Genetic and environmental factors result in development of smaller bones, with fewer thinner trabeculae, thinner cortices and less accrual of bone mass during growth. Ageing leads to disordered remodelling; with advancing age over-dominance of resorptive activity leads to greater removal of older damaged bone unmatched by osteoblastic reversal. The result is a net loss of bone mass; thinner, less connected trabecular bone; and increased porosity in thinner cortical bone. Oestrogen withdrawal in females and hypogonadism in males will cause osteoporosis if it occurs at any age, but more usually gonadal insufficiency accelerates age-related remodelling failure in later life after the menopause in females. Hyperparathyroidism, secondary to calcium malabsorption, at any age in either sex, can also lead to decreased mineralisation (Kanis, 1994; Cummings and Melton III, 2002; Seeman, 2002).

In the elderly low trauma fractures must also be distinguished from ‘pathological fracture’ due to multiple myeloma or secondary metastatic deposits from tumours of the breast, thyroid and prostate. Many forget that osteoporosis can also affect younger patients. Patients with early gonadal failure, on high-dose steroid regimens for autoimmune or chronic inflammatory conditions, and post cancer chemotherapy are all at risk. Patients with nutritional deficiency due to anorexia nervosa, malabsorption syndromes due to coeliac disease or post abdominal surgery are also at risk of early osteoporosis (Seeman, 2002). In the elderly low trauma fractures must also be distinguished from ‘pathological fracture’ due to multiple myeloma or secondary metastatic deposits from tumours of the breast, thyroid and prostate. Many forget that osteoporosis can also affect younger patients.

Clinical presentation

Clinically osteoporosis should be suspected, when patients present with a low trauma fracture at a typical site: wrist, hip or spine, or if there are early signs of vertebral collapse on X-ray during the...
investigation of back pain. The clinical complications of osteoporosis depend on the site of the fracture although only vertebral and hip fractures result in an excess mortality (Cummings and Melton III, 2002). In the vertebral column pain, disability and spinal deformity are the main secondary problems. The most serious complications arise with hip fracture; up to 50% of patients will suffer permanent disability, and between 10–20% will die within 3 months to a year usually due to complications of prolonged immobility (Cummings and Melton III, 2002; Goldsby et al., 2003; Kanis et al., 2003).

Obviously the latter situation represents the clinical end point for osteoporosis, and it is far more preferable to detect those at risk earlier. Therefore, elderly patients with a strong family history of osteoporosis or early menopause, or younger patients with a history of steroid treatment, chemotherapy or any chronic disease and disability preventing normal biomechanical loading, should be investigated. Low bodyweight individuals, those with eating disorders and low body weight athletes, people on unusual diets, vegans and vegetarians, both male and female may be at risk and should also be investigated.

**Investigation**

In elderly patients presenting with bone pain or deformity, the medical practitioner must obtain a thorough history and perform an examination and investigations to rule out primary and secondary bone tumours; and, metabolic and endocrine disorders affecting bone. In the majority of patients this will entail, in addition to risk factor identification an estimate of bone quantity using DXA. The degree of attenuation of a dual beam of photons is correlated to bone mineral content and when divided by projected area of the site of interest an area density for the bone of interest is calculated. Thus DXA scans are two-dimensional images and it must be remembered that the density is not a true volumetric density but an area density. However, despite this and other errors introduced by non-uniformity of surrounding soft tissues, DXA-derived bone mineral density still remains the gold standard of clinical diagnosis in osteoporosis (Kanis, 2002).

The therapist should ensure that the patient has had a standard scan protocol in a centre specialising in osteoporosis. This usually assesses L1–L4 vertebral, and both the left and right hip. However other regions such as the distal radius and even whole body scans can be done depending on the type of scanner device and protocols used. DXA scans report estimated area (EA, cm²), bone mineral content (BMC, g), and area density (BMD, g.cm⁻²) for regions of interest in a standard protocol of scans.

The measured BMD value is then compared with a database of mean values for the standard population. Due to racial variation in bone density these standard population databases may be different for people from different parts of the world. Scan results when compared with the same age and gender norms are referred to as ‘Z scores’. However, it is more usual to compare measured values with a set of standard values typical of peak bone mass in young adults (age 20–30 years); this is known as the ‘T score’ (Cummings *et al.*, 2002).

In DXA terms normal bone density is then a T score of +1 to −1 SD around the mean, a difference of −1 to −2.5 SD from the mean is defined as osteopenia, and a T score of −2.5 SD or below is defined as osteoporosis (WHO Study Group, 1994; Kanis and Glüer, 2000). Severe osteoporosis is defined as the same ‘T’ score criteria as previously described plus an osteoporotic-related fracture (Kanis, 2002).

The relevance of this is that longitudinal research has shown that fracture risk approximately doubles for every one standard deviation below mean T score. However it should be noted that any fragility fracture at any typical site also defines osteoporosis, even in the absence of low BMD from the DXA scan. It should also be noted that overall fracture risk in individual patients is determined only after a full evaluation of risk factors outlined above in conjunction with the DXA scan results. Ideally management should be prescribed by medical specialists working in osteoporosis clinics with experience in evaluation, diagnosis, investigation and treatment of the condition. Table 16.1 summarises the risk factors which may be implicated in early osteoporosis and DXA diagnostic criteria, and the associated diseases and their treatments.

**Treatment and prevention of osteoporosis**

The treatment and prevention of osteoporosis can been likened to the repair of a ‘three-legged stool’.
Osteoporosis

In a younger fit population with normal bone status high impact targeted bone loading exercises are recommended. At the opposite extreme in the frail elderly, exercise aims to maintain mobility and increase neuromuscular co-ordination to prevent falls. Targeted bone loading in this group can cause fractures.

Prevention is better than cure and strategies here aim for attainment of optimal peak bone mass by early adulthood by focusing on targeted bone loading exercise programmes and adequate nutrition in childhood and adolescence. Further prevention strategies through adult life can build bone and slow bone loss, however, they do not have the same magnitude of effect as that seen with

Over-attention to repair of one or even two legs of the stool can still result in failure, because if the third leg fails the stool will fall (Marcus, 1996). Treatment of osteopenia and osteoporosis has to consider all three main areas: adequate diet, appropriate drug therapy depending on grading and extent of osteoporosis, and appropriate skeletal mechanical loading by exercise.

The common drug therapies for osteoporosis include hormone replacement therapy, antiresorptive medications, and recently developed bone-building medications. Nutritional advice should aim to promote adequate energy and protein intake, and according to age and gender adequate amounts of calcium and vitamin D should be present in the diet. Exercise prescription should be appropriate to age, level of mobility and bone status. In a younger fitter population with normal bone status high impact targeted bone loading exercises are recommended. At the opposite extreme in the frail elderly, exercise aims to maintain mobility and increase neuromuscular co-ordination to prevent falls. Targeted bone loading in this group can cause fractures.

Prevention is better than cure and strategies here aim for attainment of optimal peak bone mass by early adulthood by focusing on targeted bone loading exercise programmes and adequate nutrition in childhood and adolescence. Further prevention strategies through adult life can build bone and slow bone loss, however, they do not have the same magnitude of effect as that seen with

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<th>Drug therapies</th>
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<td>Corticosteroids</td>
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<td>Smoking alcohol</td>
<td>Hyperparathyroidism Gonadal failure</td>
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<td><strong>DEXA diagnostic criteria</strong> Osteopenia: T score −1 to −2.5</td>
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<td></td>
<td>Severe osteoporosis: low trauma fracture + any of above T scores</td>
</tr>
<tr>
<td>Acidic diet</td>
<td>Rheumatoid arthritis</td>
<td></td>
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bone-loading exercise programmes in childhood and adolescence.

**Nutritional factors**

Growth, development and maintenance of bone structure requires adequate protein intake to provide the necessary amino acid building blocks for collagen synthesis and adequate intake of calcium, and its co-factor in metabolism vitamin D₃, to form the mineral component hydroxyapatite. Growth, repair and remodelling also require energy, therefore adequate calorific intake is also required to maintain bone tissue integrity. Inadequate protein, mineral, vitamin D and low calorie intake for whatever reason will ultimately lead to poor bone quality and no exercise programme can create strong healthy bones without proper nutrition. An example of poor nutritional practice associated with over-exercise occurs in the ‘female athletic triad’ – a clinical syndrome seen in gymnasts, ballet dancers and long-distance runners that is characterised by eating disorder, amenorrhoea and osteoporosis.

In the growing skeletons of children and adolescents, adequate amounts of calcium and vitamin D₃ are essential for the attainment of greater peak bone mass in early adulthood. Adolescent girls and boys require up to 1200 mg of calcium a day during the growth spurt. However, the need for calcium and vitamin D in adults and elderly populations is often underestimated. Recommended female daily allowances (RDA) for calcium and vitamin D₃, for use in conjunction with an exercise programme are shown in Table 16.2.

**Practical guidelines**

Most adults with normal bone density or mild osteopenia should take 500 ml of full fat milk or one of the newer milk products fortified with extra calcium and vitamin D once a day. In established osteoporosis milk intake would have to double to 1 litre of milk a day. For many this is impractical, therefore increasing intake of calcium-rich dairy produce plus a calcium and Vitamin D supplement once daily are usually required instead. Patients should be discouraged from following very strict vegetarian and vegan diets, or from fad diets with excessive protein intake and the excessive intake of acidic carbonated drinks.

**Drug therapies**

It is important for the therapist to be aware of the common drug regimens for osteoporosis; although widely prescribed, many have side effects and if recognised must be reported to the prescribing doctor. Drug treatment should be tailored to the individual patient, taking into account other illnesses and possible interactions with other medications.

In early or pre-menopause, some women with osteoporosis may be prescribed hormone replacement therapy in the form of oestrogen. Oestrogen has been shown to prevent fractures, prevent bone loss and increase calcium absorption. However, due to a slightly increased risk of female cancers, newer selective oestrogen receptor modulator (SERM) medications have been developed. SERMs such as raloxifene have the same actions on bone as oestrogen without the increased risk of uterine and breast cancers. Calcitonin and the bisphosphonate group of drugs are the other commonly prescribed anti-resorptive medications for osteoporosis. Calcitonin is taken as a nasal spray and may be especially useful in the case of bone pain from vertebral collapse. The bisphosphonate group of drugs, alendronate, etidronate and risendronate, are very effective drugs but are particularly tricky to administer. They have to be taken in the morning on an empty
stomach, and the patient must stand in the upright position and be well hydrated. Gastrointestinal upset is common and although these are very effective anti-resorptive drugs, many patients cannot tolerate their side effects. Newer injectable forms are now coming on the market with extremely long half-lives, which could potentially mean an injection once or twice a year rather than daily oral medication.

The last group of bone-building drugs, parathyroid hormone (PTH) and strontium ranelate, should only be prescribed in patients with severe osteoporosis. Timing and dosage especially of PTH therapy depends on initial serum PTH level and other factors in the patient history. PTH may actively stimulate new bone formation or bone resorption depending on timing and dosage and should therefore is only be prescribed in specialist osteoporosis clinics (Delmas, 2002).

**Exercise and bone health**

The evidence for the use of exercise in the management of osteoporosis comes from three areas: epidemiological studies on fracture rates from countries with different lifestyles; studies comparing bone density of athletes with inactive populations; and animal studies of bone remodelling. There is also an accumulating body of evidence from intervention studies looking at change in bone mass and fracture incidence with varying exercise programmes and in different age groups.

Comparative studies of fracture incidence in Europe, Africa and Asia have shown that even after adjustment for age-related decline in bone health, there was still an excess of osteoporosis-related fractures in those countries with more Western, urbanised sedentary lifestyles (Mosekilde, 1995). Studies on fracture incidence within Europe have suggested that effects of postmenopausal oestrogen insufficiency in females and decreasing testosterone levels with ageing in males may have been overemphasised and lifestyle and genetic factors may be more important in the development of osteoporosis (Kanis, 1993). Based on these findings Kanis has recommended habitual exercise as way of protecting the population from the effects of osteoporosis.

Studies on the bone density of athletes have shown significantly higher density in the impact loaded forearms of gymnasts when compared with runners, and higher bone density in the lumbar spine and hips of runners than that of non-impact loaded swimmers (Kannus et al., 1996; Frost, 1997). Biological mechanostat theory suggests that prerequisite stresses and strain levels are required to activate bone modelling BMUs to maintain bone health (Frost, 1988). Essentially, strain levels of greater than 1500–3000 microstrain are purported to induce bone modelling processes and increase bone mass, cortical thickness and cross-sectional area; but much lower strain levels, 100–300 microstrain, are all that are required to decrease activation frequency of mechanically controlled bone remodelling and thus preserve bone. However, below this level, ~100 microstrain, there is increased activation of BMUs, loss of bone mass and thus any unloaded structures will disappear. At a cellular level, therefore, exercise could theoretically prevent bone loss in two ways: first, high strains could stimulate bone modelling, i.e. new bone formation, and, second, intermediate level strains could inhibit the mismatched remodelling processes causing osteoporosis.

**General recommendations**

Basic training theory suggests that, given the correct exercise mode, progressive overload in training by manipulation of FITT (*frequency/intensity/time/type*) with adequate time for repair or recovery will result in adaptation (Kannus et al., 1996; Turner and Robling, 2005). It has also been shown that lack of force through the skeleton due to prolonged immobility due to enforced bed rest, or in zero gravity due to space flight will result in loss of bone mineral, the *disuse* principle of training.

Unfortunately many studies involving exercise and bone density do not consider basic physiological training principles. When evaluating training or exercise studies purporting to have an effect on BMD, one must also consider the basic principles of training listed below.

- **Specificity:** The major impact of the activity should be at the site where BMD is being measured as the response to loading appears to be a localized effect.
- **Overload:** To effect change in bone mass, the training stimulus must exceed the normal loading.
Exercise Therapy in the Management of Musculoskeletal Disorders

- **Reversibility**: The positive effect of a training programme on bone will be lost if the programme is discontinued.
- **Initial values**: Those with the lowest levels of BMD have a greater capacity for percentage improvement in training studies; those with average or above average bone mass have the least.
- **Diminishing returns**: Each person has an individual biological ceiling that determines the extent of a possible training effect. As this ceiling is approached, gains in bone mass will slow and eventually plateau.

**Targeted bone loading**

In terms of specificity, exercise can be divided into activity which is good for overall general health and that which is good for bone health. Swimming, cycling and may benefit general cardiovascular health but have little if any impact on bone mass accrual or prevention of bone loss and therefore bone strength. The concept of targeted bone loading is used to describe exercise which specifically stimulates bone modelling or inhibits bone remodelling processes and thus improves bone strength. For targeted bone loading, exercise must be weight-bearing and mechanical stress on the bone must be greater than those normally experienced by the skeleton during everyday activities (specificity and overload principles).

The way in which the force is applied to the skeleton also makes a difference. Jumps off a raised platform 0.3m of the ground 20–30 times three times per day with total exercise duration less than 30 minutes/day, is more effective than a 2-hour walk or bike ride. Forces generated during the gait cycle of walking and running are attenuated as one moves up the skeleton and by the time forces reach the axial skeleton there is little substantive loading of the vertebral column (site specificity). In terms of practical exercise advice, walking and running will only benefit the bones of the lower limb, and other forms of loading need to be used to target the spine.

Exercise programmes to improve or maintain bone health should continue throughout life, and whenever clinically appropriate should involve targeted bone loading, that is, an exercise mode which specifically exposes bone to loading at stresses and strains in excess to that encountered in everyday activities. Only in this situation will the training stimulus be great enough to produce adaptation. Exercise for osteoporosis can be thought of in three main areas according to chronological age:

1. Optimum accrual of bone mass in childhood and adolescence
2. Prevention of bone loss through adulthood

**Optimum bone accrual in childhood and adolescence**

Childhood and adolescence is an especially important time to improve bone mass through exercise (Khan et al., 2000; Janz et al., 2004; Forwood et al., 2006). Achievement of a higher peak bone mass by age 26–30 years means that later age-related decline in bone quantity starts from higher peak values and takes longer to reach fracture thresholds (Fig. 16.3).

In terms of training principles and targeted loading, regular short duration and high intensity physical exercise in childhood especially at or slightly before the pubescent growth spurt can significantly increase accrual of a greater bone mass by the third decade (Kannus et al., 1996). It goes without saying that inactivity such as television, computer video games and vehicular transport for short journeys should be limited.

Exercise in young children should be weight-bearing, provided there are no contraindications to high impact, but most importantly the emphasis should be on fun. McKay and co-workers from Canada have developed simple exercise programmes, such as ‘bounce the bell’ and ‘leaping lizards’, to study effects of exercise on bone health in primary school children (McKay et al., 2005). For example, the leaping lizards programme involves competitive team drills of running, jumps and turns performed over a short course marked by cones at 2.5m intervals. The team that picks up all cones in the quickest time is the winner! Exercise duration is approximately 15 minutes (time) and the races can be performed on a daily basis (frequency). The therapist can adapt this simple routine and vary speed and length (intensity) of the course,
and change running to hopping, galloping or bunny hops (type) etc. to ensure progressive overload.

In adolescents (<18 years) and younger adults (<28 years) the key to increasing bone mass accrual is again to encourage short duration, high-impact weight-bearing exercise. In this group, organised classes such as step aerobics and dance, or running, are more appropriate. In all younger age groups simply advocating any weight-bearing activity, such as fast walking and sporting activity of any type for at least 30 minutes per day, may be just as effective.

Prevention of bone loss through adulthood

In adults (30–50 years) small but significant differences in bone density have been shown between exercising groups and controls. Exercise modes in these studies include jogging, supervised or unsupervised weight-training, high-impact jumps or steps incorporated into an aerobics exercises. Results of these studies show only small gains, 1–2% increase or no change in bone density at the hip and spine in comparison with controls. The best results seem to be with high-impact jumping programmes (Bassey and Ramsdale, 1995).

Increasing bone mass over and above that seen in a healthy active population can probably only be achieved by resistance training. Several studies have shown that bone density at certain sites can be predicted by overall muscle strength in that general area of muscle attachment. Increases in BMD due to strength training programmes are site specific, and the magnitude of response is again governed by FITT principles in modulation of progressive overload. If resistance programmes are stopped, muscle strength and BMD will be lost, i.e. the disuse principle. A combination of a step-based aerobic programme, and gym exercises incorporating body resistance and weights, 12 exercises, 3 sets, 15 repetitions (weight depending on 1 or 3 RM (repetitions maximum)) has been shown to be effective programme in preventing decline and/or further developing bone mass in this group (Friedlander et al., 1995). It should also be re-emphasised here that over-exercise in young adults can suppress levels of gonadal hormones, and result in low bone density.

Slowing age-related bone loss and prevention of falls in older people

Although weight-bearing exercises, such as aerobics and strengthening exercises are all useful for increasing BMD in the spine and walking can increase BMD in the hip (Bonauiti et al., 2002), it is important to determine bone status before exercise prescription. Exercise programmes for older people with normal density can focus on short duration, high-impact programmes. However, vigorous activity in those with established osteoporosis is potentially dangerous as it may cause further wedge fractures of the spine and as exercise in older people has not been shown to improve bone density, it cannot be recommended (Forwood and Larson, 2000). In particular exercise with sudden stop starts and or twisting movements, involving sudden abdominal flexion or impact loading should be avoided. In very frail elderly people with low bone density, exercise programmes should focus on improving muscle strength for mobility and balance, improving quality of life and preventing falls. Exercises that enhance posture, such as back extension exercises in a seated position or seated back and scapula extension against a wall can counteract anterior wedging in the spine.

Exercise programmes for osteoporosis: key information sources

There is now a vast resource of information with regard to exercise in individual patients with osteoporosis or for those who just want to improve their bone health. There are many fact sheets available giving general lifestyle advice on exercise and nutrition at all ages from reputable sources e.g. the Medicine and Science for Women in Sport Group of Sports Medicine Australia (2008; www.sma.org.au). The National Osteoporosis Society (2008) in the UK (www.nos.org.uk) has also produced two useful booklets, Exercise and Bone Health and Exercise and Osteoporosis, which contain exercise advice to prevent osteoporosis and exercise advice for those patients with established osteoporosis. For the therapist, Forwood and Larson (2000) have outlined safe exercise
guidelines for those with established osteoporosis, in a series of postural exercises for frail elderly people. For a synopsis of the current research in the area of bone health and physical activity consult Khort et al. (2004). Physical Activity and Bone Health covers exercise and osteoporosis in its entirety with a variety of programmes to maximise bone mass accrual in childhood and adolescence, strengthen bone in adulthood and in the elderly, plus effective exercise programmes to slow age-related bone loss and prevent falls (Khan et al., 2001).

It must be stressed that those in at risk groups for osteoporosis or osteopenia should always have an assessment of bone health in a specialist medical osteoporosis clinic prior to any exercise advice or programme. In addition it should be appreciated that the prescription of exercise alone in the absence of adequate nutrition and in certain cases without a pharmacological intervention will be largely ineffective and in certain cases may put the patient at serious risk of a fragility fracture.

Summary

In the treatment of osteoporosis, exercise can be employed as a primary prevention strategy in childhood and adolescence to maximise accrual of bone mineral by early adulthood. In the adult years, exercise is necessary to prevent or decelerate bone loss due to natural ageing processes, and, especially in urbanised societies, to counteract the negative aspects of a sedentary lifestyle. In the early adult years, targeted exercise programmes and resistance training are required to improve bone strength above normal levels. In later years, exercise may slow the rates of bone loss and additionally by maintaining mobility, balance, and muscle strength, and prevent the falls which can cause fracture of more fragile bones. In patients with established osteoporosis the therapist needs to work closely with allied health professionals in the provision of individually tailored, safe, and well-monitored exercise programmes. The therapist must also be mindful of the hazards of exercise prescription in patients with severe osteoporosis, as not all exercise is beneficial and some exercises are dangerous for fragile bones.

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