0	Nothing at all	How you feel sitting or simply standing
1		
2	Weak	
3	Moderate	Exercise goal: How you feel when you exercise
4		
5	Strong	How you feel when you really push yourself
6		
7	Very strong	
8		
9		
10	Extremely strong	
•	All-out effort	You're unable to go on

Figure 2.13 The rating of perceived exertion (RPE) scale.

contracts eccentrically. At full stretch (Phase II), there is a transition between eccentric and concentric contraction. This is termed the amortization or coupling phase and should be keep brief to prevent dissipation of the energy stored within the eccentric phase. Phase III is a rapid concentric contraction, causing the subject to move in the opposite direction. Effects are achieved in both the contractile and inert structures of the muscle.

Key point

The *stretch–shortening cycle* (SSC) consists of three phases. An eccentric lengthening (Phase I), a transition phase (Phase II) and a rapid concentric contraction (Phase III).

The rapid stretch of the muscle stimulates a stretch reflex, which in turn generates greater tension within the lengthening muscle fibres. In addition to increased tension, the release of stored energy within the elastic components of the muscle makes the concentric contraction greater than it would be in isolation. Increased tension will in turn stimulate Golgi tendon organ (GTO) activity, inhibiting excitation of the contracting muscle. Desensitization of the GTO has been suggested as a possible mechanism by which plyometrics allows greater force production.

The use of muscle contraction involving acceleration in the concentric phase and deceleration in the eccentric phase more closely matches the normal function seen in sport, and therefore has advantages in terms of training specificity. However, the rapid movements involved are not suitable in early-stage training as they can be relatively uncontrolled.

Several neuromuscular adaptations have been proposed for the effect of plyometric exercise (Table 2.16), and exercise of this type has been shown to significantly increase peak power output (Potteiger 1999). Comparing plyometric exercises with their non-power equivalents demonstrates the advantages of this training. A plyometric jump compared to a deep knee-bend action, used 22 per cent less energy, produced 9 per cent more work and was 40 per cent more efficient (Lees and Graham-Smith 1996), while a rebound bench press compared to a standard lift gives 30 per cent more work, allowing the subject to lift 5.4 per cent greater weight.

Practical considerations of plyometric training

Plyometric exercise is only effective when the concentric contraction occurs immediately following the pre-stretch cycle. If there is a pause in the transition phase, some of the benefits are lost as elastic energy is wasted, and the effect of the stretch reflex is altered. The ability to recover the stored elastic energy within the tissues depends on the time period between concentric and eccentric activity (coupling time). The stored elastic energy of the leg extensor muscles has a half-life of 4 seconds (Lees and Graham-Smith 1996), and the coupling time in plyometric exercise has been measured at average periods of 23 ms. Providing the coupling time remains at these levels, nearly all the stored elastic energy can be utilized.

Table 2.16 Proposed neuromuscular adaptations to plyometric training

Increased inhibition of antagonist muscles
Better co-contraction of synergistic muscles
Inhibition of neural protective mechanisms
Increased motor neuron excitability

Source: Potteiger, J.A. (1999) Muscle power and fiber characteristics following 8 weeks of plyometric training. *Journal of Strength and Conditioning Research*, 13 (3), 275–279. With permission.

Injury considerations in plyometrics

This type of training is intense, and should only be used after a thorough warm-up, and usually at the end of an exercise programme. To perform plyometrics, the subject needs a good strength base, and his proprioceptive activity should be tested using single-leg standing and single-leg half squats (eyes closed, position maintained for 30 seconds) before training commences. Any loss in proprioception may cause the subject to fall as fatigue sets in. Safety considerations, including proper clothing and footwear and a firm non-slip sports surface, are essential.

Compression forces present in plyometrics have the potential for injury. Spinal shrinkage has been measured at 1.75 mm after 25 repetitions of a drop jump from a height of 1.0 m so this type of exercise is not suitable for individuals with a history of lower back pain of discal origin. In normal walking, deceleration forces have been measured at 3 g (three times earth's normal gravity), while in a drop jump from a height of 0.4 m the deceleration has been measured at 23 g (Lees and Graham-Smith 1996). This type of force acting on the lower limb makes plyometrics unsuitable for those with a history of arthritis in the joints of the lower limb or spine.

Key point

Plyometrics is an advanced, intense form of exercise, not suitable for the beginner. Safety considerations are essential throughout.

Three types of exercises are normally used: in-place, short response and long response (Table 2.17). In-place activities include such things as standing jumps, drop jumps and hopping. Short-response actions are those such as the standing broad jump, the standing triple jump and box jumps. Long-response movements include bounding, hopping and repeated hurdle jumps.

Although plyometric activity is primarily used for lower-limb training, is does have an important place for the upper limb and trunk. Overhead throwing actions using a medicine ball, and throwing and catching from a bent-knee sit-up position, are examples of this.

Resistance may be added to increase the overload on the working muscles as the plyometric activity is used. Vertical jumps may be performed using

Table 2.17 Plyometric exercises

Exercise type	Movement	Description
In-place	▶ Standing jumps	Jumping and landing on the same spot, to emphasize the vertical component of the jump
	▶ Drop jumps	Use gravity and body weight to increase resistance and emphasize eccentric component of movement
	▶ Hopping	Straight, zig-zag or rotatory hopping on the same spot
Short response	▶ Standing broad jump	Emphasizes horizontal component of jump
	▶ Standing triple jump	Combines several jumps and hops over a distance
	▶ Box jumps	Jump over an object to emphasize both vertical and horizontal component of jump
Long response	▶ Bounding	Greater horizontal range than others. Single/double/alternate legs
	▶ Hopping	Repeated combinations of straight/zig-zag/rotatory hopping
	▶ Repeated hurdle jumps	Horizontal and vertical jump component for endurance

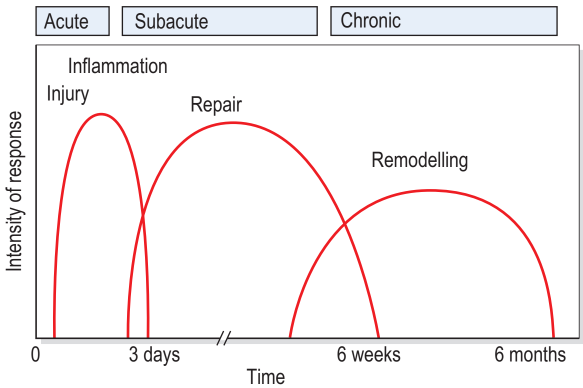

Figure 1.1 Timescale for healing. From Oakes, B.W. (1992) The classification of injuries and mechanisms of injury, repair and healing. In *Textbook of Science and Medicine in Sport* (eds J. Bloomfield, P.A. Fricker and K.D. Fitch). Blackwell Scientific Publications, Melbourne. With permission.

the inflammatory process has restarted due to disruption or persistent irritation of the healing tissues. The total healing process occurs over a continuum, shown in Fig. 1.1.

> **Keypoint**
> Treatment must be adapted to the stages of healing, which are injury, inflammation, repair and remodelling.

Injury

This stage represents the tissue effects at the time of injury, before the inflammatory process is activated. With tissue damage, chemical and mechanical changes are seen. Local blood vessels are disrupted causing a cessation in oxygen to the cells they perfused. These cells die and their lysosome membranes disintegrate, releasing the hydrolysing enzymes the lysosomes contained. The release of these enzymes has a twofold effect. First they begin to break down the dead cells themselves, and second, they release histamines and kinins which have an effect on both the live cells nearby and the local blood capillary network.

The disruption of the blood vessels which caused cell death also causes local bleeding (extravasated blood). More vascular tissue such as muscle will bleed more than less vascular tissue such as ligament. On average, bleeding following soft tissue injury stops within four to six hours (Watson 2016). The red blood cells break down, leaving cellular debris and free haemoglobin. The blood platelets release the enzyme thrombin, which changes fibrinogen into fibrin. The fibrin in turn is deposited as a meshwork around the area (a process known as walling off). The dead cells intertwine in the meshwork, forming a blood clot. This network contains the damaged area.

The changes occurring at injury are affected by age. Intramuscular bleeding, and therefore haemorrhage formation, is more profuse in individuals over 30 years of age. The amount of bleeding which occurs will be partially dependent on the vascularity of the injured tissues. A fitter individual is likely to have muscle tissue which is more highly vascularized, and therefore greater bleeding will occur with muscle injury. In addition, exercise itself will affect gross tissue responses. Muscle blood flow is greatly increased through dilatation of the capillary bed, and again bleeding subsequent to injury will be greater.

> **Keypoint**
> The tissues of an active individual are more highly vascularized than those of an inactive subject. The subject's tissues will therefore bleed more during injury, and bruising will be more noticeable.

Inflammation

The next phase in the healing sequence is that of inflammation, summarized in Fig. 1.2. This may last from ten minutes to several days, depending on the amount of tissue damage which has occurred, but generally reaches its peak by one to three days.

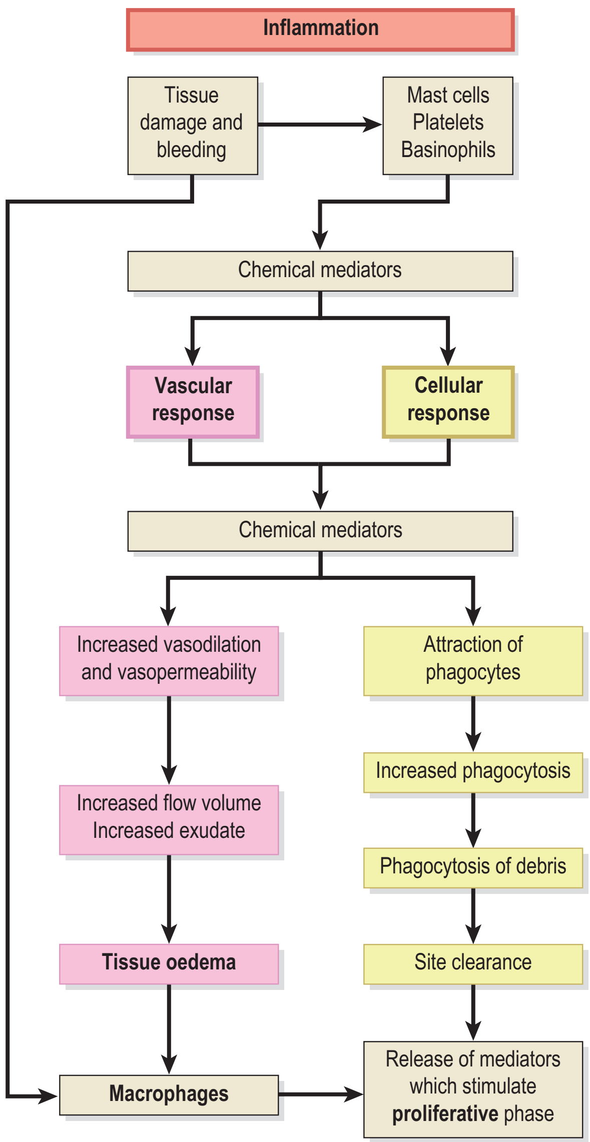

Figure 1.2 Inflammatory elements.

Vascular and chemical cascades occur in parallel to drive the inflammatory process.

> **Definition:**
> A *chemical cascade* (signalling cascade) is a series of chemical reactions. As one reaches its completion, it triggers the next in a type of 'chain reaction'.

The inflammatory response to soft tissue injury is much the same regardless of the nature of the injuring agent or the location of the injury itself. Inflammation is not simply a feature of soft tissue injuries, but also occurs when the body is infected, in immune reactions and with infarction. Some of the characteristics of the inflammatory response seen with soft tissue injury may be viewed as excessive and better suited to dealing with infection than healing injury.

The cardinal signs of inflammation are heat (*calor*), redness (*rubor*), swelling (*tumor*) and pain (*dolor*). These in turn give rise to the so-called fifth sign of inflammation: disturbance of function of the affected tissues (*functio laesa*).

> **Keypoint**
> Inflammation is often seen as undesirable. However, inflammation is the first stage of healing and so is a vital step on the road to recovery. The aim should be to prevent excessive inflammation and move the subject on through the phases of healing towards eventual full function.

Heat and redness

Heat and redness take a number of hours to develop, and are due to the opening of local blood capillaries and the resultant increased blood flow. Chemical and mechanical changes, initiated by injury, are responsible for the changes in blood flow.

Chemically, a number of substances act as mediators in the inflammatory process. The amines, including histamine and 5-hydroxytryptamine (5-HT or serotonin) are released from mast cells, red blood cells and platelets in the damaged capillaries and cause vessel dilatation and increased permeability. Kinins (physiologically active polypeptides) cause an increase in vascular permeability and stimulate the contraction of smooth muscle. They are found normally in an inactive state as kininogens. These in turn are activated by the enzyme plasmin, and degraded by kininases.

The initial vasodilatation is maintained by prostaglandins. These are one of the arachidonic acid derivatives, formed from cell membrane phospholipids when cell damage occurs, and released when the kinin system is activated. The drugs aspirin and indometacin act to inhibit this change – hence their use as anti-inflammatory agents in sports and soft tissue injury treatment (see Treatment Note 1.1). The prostaglandins E1 and E2 will stimulate nociceptors and also promote vasodilatation, blood-vessel permeability and lymph flow.

The complement system, consisting of a number of serum proteins circulating in an inactive form, is activated and has a direct effect on the cell membrane as well as helping to maintain vasodilatation. Various complement products are involved, and these are activated in sequence. Finally, polymorphs produce leukotrienes, which are themselves derived from arachidonic acid, help the kinins maintain vessel permeability.

Treatment note 1.1 Medication used in soft tissue injury

Although inflammation is an essential part of the healing process, sometimes it can be excessive. Anti-inflammatory treatments are designed to limit inflammation and interfere with the chemical processes described above. Two groups of drugs are generally used in the treatment of soft tissue injuries in this respect: corticosteroids and non-steroidal anti-inflammatory drugs (NSAIDS). Analgesics are used to limit pain, and may be used in isolation or together with anti-inflammatories.

Non-steroidal anti-inflammatory drugs

NSAIDS have both anti-inflammatory and pain relieving (analgesic) properties, causing both local (peripheral) and mild central effects. They inhibit the cyclo-oxygenase (COX) system, which has an important function in the cascade of chemicals driving the inflammatory process (see above) and works to block the production of prostaglandin. Two types are generally used, COX-1 and COX-2. As COX-1 also has an important function on the gastric mucosa, COX-1 inhibitors can lead to gastritis, and with long-term usage ulceration. COX-2 inhibitors have fewer effects on the gastric mucosa and so are better tolerated, but can increase the risk of thrombosis. NSAIDS are also available as creams and patches which can be used for superficial injury such as muscle injuries, contusions, and knee arthritis. Drugs such as *aspirin*, *Volterol*, *Brufen* and *Naprosyn* are common oral NSAIDS.

NSAIDS can inhibit protein synthesis and affect satellite cell activity, detrimentally changing muscle repair (see Chapter 2). They may alter collagen formation and fibroblast proliferation, so long-term usage should generally be avoided. In addition, tenocyte action during tendon repair may be negatively affected, but pain reduced (Pollock 2017). The role of prostaglandins in bone repair is also a potential concern with NSAID usage, as osteoblast activity may be impaired, delaying callus maturation in bone (Wheeler and Batt 2005).

Targeting pain

Painkillers (analgesics) work on the peripheral or central nervous systems. Drugs such as *paracetamol* have painkilling (analgesic) and fever-reducing (antipyretic) effects, but do not generally reduce inflammation. This type of drug works by blocking a type of cell membrane receptor called a cannabinoid receptor, which drugs such as cannabis work on. *Codeine*, *morphine* and *ketamine* are more powerful painkillers and are opiates. They may be taken alone or combined with paracetamol. Opiate drugs are generally derived from the opium poppy or its synthetic equivalent (one of which is heroin) and are the first four weeks of training, are neurogenic in nature, the mismatch in movement patterns could detrimentally affect the subject's performance (Palmitier et al. 1991).

A common open-chain movement used in knee training is the seated leg-extension exercise (Fig. 2.14a). The muscles primarily responsible for this action are the quadriceps. Contrast this to the closed-chain movement of the squat (Fig. 2.14b). When the leg extends to raise the body from the squatting position, the hamstrings extend the hip and assist in knee extension as the foot is stabilized. This co-contraction (co-activation) greatly reduces the anterior shear forces acting on the knee, and is of particular importance in the rehabilitation of anterior cruciate ligament (ACL) repairs.

Figure 2.14 Open- and closed-chain movements.

Source: a) Leg extension – example of an open-chain movement b) Squat with barbell – example of a closed-chain movement.

Several additional differences exist between open- (single joint or 'isolation') and closed-chain (multi-joint or 'general') exercises in resistance training. In an open-chain action, movement occurs mainly distal to the joint axis, whereas with a closed-chain action, motion is both proximal and distal to the joint. An open-chain action, when performed slowly, primarily emphasizes concentric work, but a closed-chain movement brings a more balanced action of concentric, eccentric and isometric contractions into play.

Open-chain actions, when performed rapidly (punching and kicking for example), are often *ballistic* in nature. Here, muscles begin the movement and end it, but the middle part of the action also uses momentum of the moving limb. The limb is literally thrown into the action. This requires large acceleration and deceleration forces at the beginning and end of the action, and the muscle work involved is very subtly coordinated. During the final stages of rehabilitation especially, the type of coordination required for ballistic actions is important to retrain. Ballistic actions are used functionally in sport, but less obviously in day-to-day actions. For example, a rhythmic gardening activity is ballistic in nature, as is swinging a child in her mother's arms.

Definition

A *Ballistic action* is high velocity, with rapid acceleration and deceleration. The EMG pattern is triphasic, showing activity in the agonist, then antagonist, and finally agonist muscles once more.

Implications for rehabilitation

The evidence on mixtures of sets, repetitions and types of muscle work indicates that no single combination yields optimal gains for everyone. In early rehabilitation, where range of motion is severely limited, isometric exercise is useful.

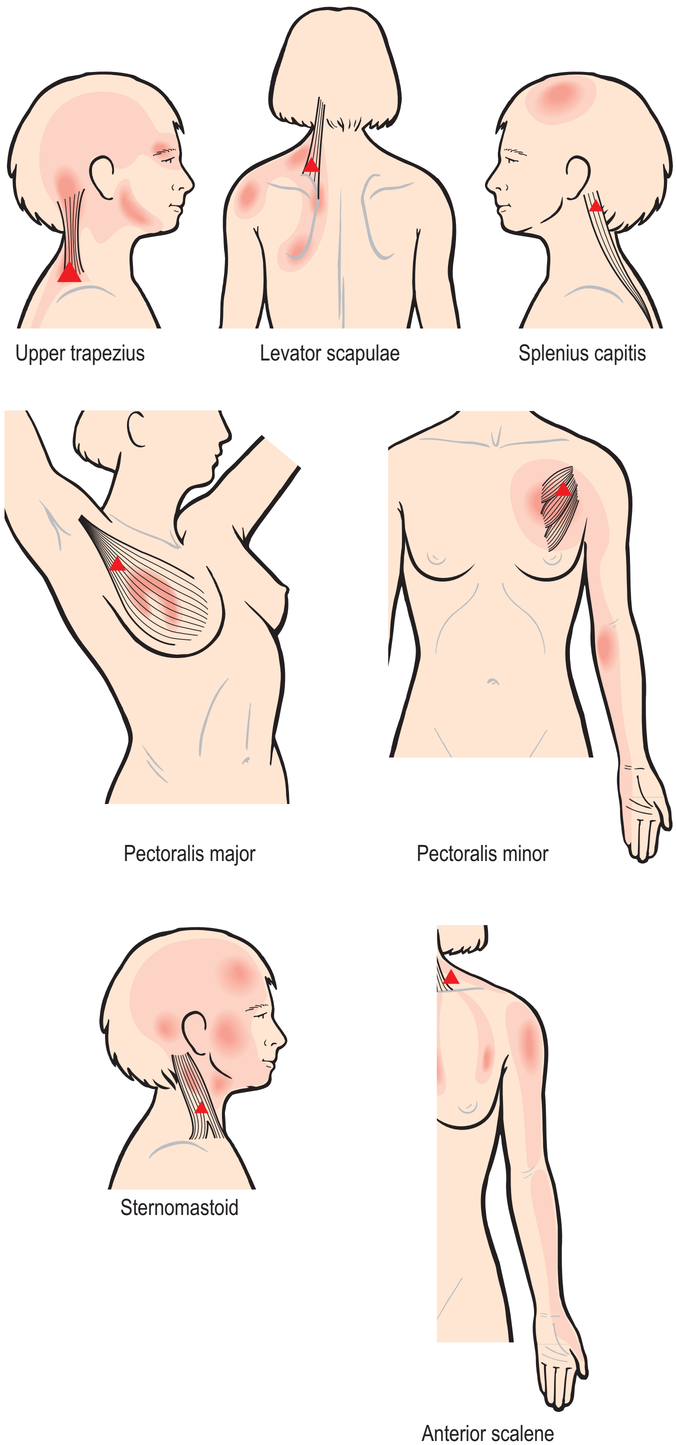

Figure 2.22 Trigger points within hyperactive upper limb muscles. From Petty and Moore (2001), with permission.

Figure 3.11 The Nordic hamstring exercise (NHE). (A) Start position in high kneeling with the ankles fixed. (B) NHE using Swiss ball. (C) Bent-knee back extension in NHE position.

the subject placing their hands on a swiss ball and rolling it away from themselves (Fig. 3.11C).

From the same starting position, a bent-knee back extension action may be performed, pulling from the hip and keeping the spine straight to begin. This action targets the hamstring higher up into the buttock, using an active pelvic tilt. It may be combined with or used separately from the traditional eccentric only version.

Deadlift variations

The straight-leg (Romanian) *deadlift* uses a fixed-leg position, either with the legs straight (knees locked) or slightly bent (knees soft). The action is to keep the spine straight and lift the body from the hip. Initially, bodyweight alone is used (arms behind the tail or behind the head), but resistance may be added from a barbell, kettlebell or dumb-bells (Fig. 3.12). As an alternative, the *arabesque* may be viewed as a single-leg version of the straight-leg deadlift. The leg to be trained stays with the foot on the floor (leg vertical) and the other leg lifts (leg horizontal) (Fig. 3.13A). There are a number of versions of this action. In yoga this is one of the warrior poses, and the final position is with the lifted leg, trunk and arms horizontal to emphasize balance. This action may be performed standing on one leg with the arms lifted above the head. The movement is to keep the lifting leg, trunk and arms rigid and tip forwards into a 'T' position (Fig. 3.13B). The hands may be placed on

Figure 3.12 Deadlift actions using barbell.

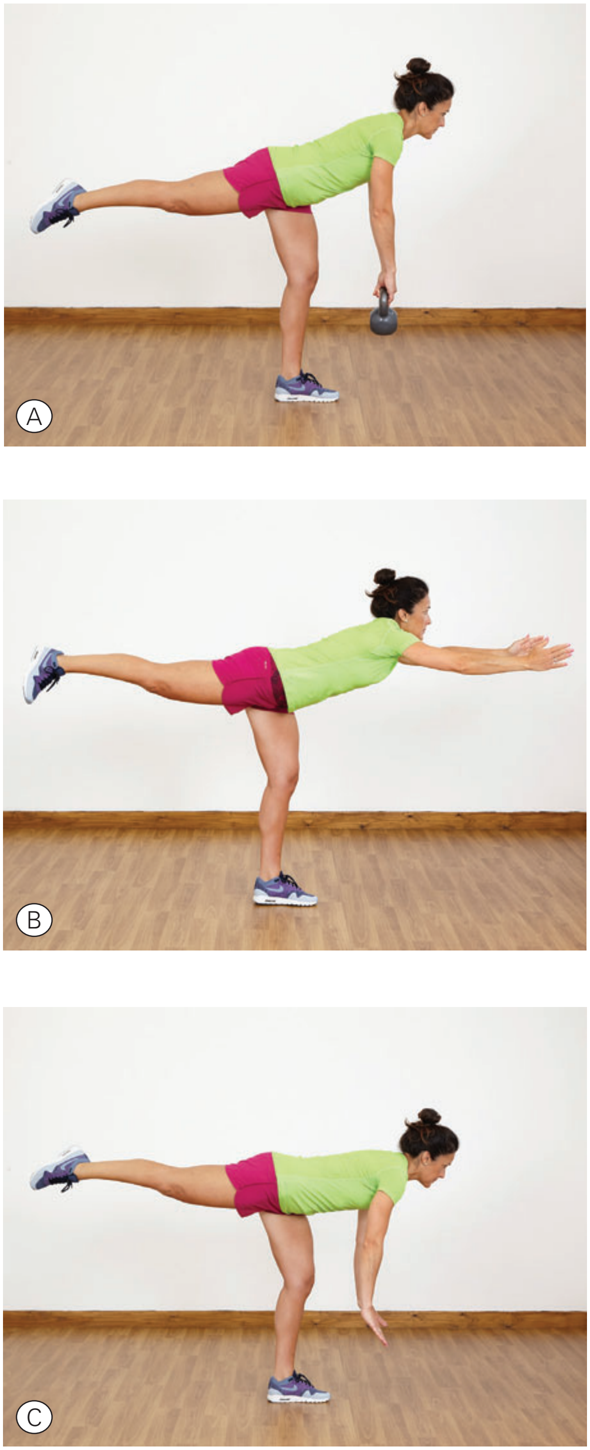

Figure 3.13 Single-leg actions. (A) Arabesque using kettlebell. (B) Warrior 3. (C) Diver.

a wall for balance. The diver is the same action, but the arms reach downwards to touch a stool or gym bench and then the body is moved back to the starting position focusing on repetitions and strength (Fig. 3.13C).

Bridge type movements

Bridging actions use the hip extensors and spine extensors from a supine lying position. For the slide board leg curl the subject lies on their back with their foot on a slide board – a piece of shiny paper on a carpet, cloth on a wooden floor, or the seat of a rowing machine. The action is to slide the foot out from a bent-knee position to straight leg and return. Single-leg or bilateral-leg action may be used (Fig. 3.14A).

The high bridge (gym ball bridge) is performed from a crook (hook) lying position, with one heel on a bench or chair, or for an unstable surface a gym ball. The action is to press the heel down to dig into the bench and lift the hips upwards. Again, unilateral or bilateral actions may both be used. Where the unilateral action is used, the pelvis must be kept level, not allowing the hip on the non-active side to trail. This action may be modified into the eccentric leg curl on a gym ball. The action now is to press the heels into the gym ball to lift the pelvis and to straighten the legs and then lower the trunk (eccentric only) or to straighten the legs and then bend them again (eccentric-concentric) (Fig. 3.14B).

The loaded bridge may be performed with the shoulders on a gym bench and the knees bent. A weight disc is placed on the lap, or a barbell is placed over the pelvis with the bar (padded) level with the top of the pelvis. The action is to lift the pelvis into a bridge position, finishing with the thigh horizontal. The foot must press directly downwards (hip extension) rather than outwards (knee extension).

Deceleration drops

Deceleration drills involve dropping into a bent hip and knee (squat) position, either unilaterally