Abdominal muscle training in sport

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This paper evaluates several abdominal exercises, and highlights factors which are important for their safe prescription and effective use. The function of the abdominal muscles and hip flexors is considered, and the importance of the infra-umbilical portion of the rectus abdominis is emphasized. The effects of flexion on the lumbar spine are outlined. The trunk curl, sit-up, and straight leg raise are analysed, together with modifications of these exercises. The effect of foot fixation and hip flexion during the performance of the sit-up is discussed. The sit-up performed with foot fixation, and the bilateral straight leg raise can compound hip muscle imbalance, and both hyperextend and hyperflex the lumbar spine and are therefore not recommended. The importance of muscular control of pelvic tilt is considered with reference to muscle imbalance around the pelvis. It is recommended that a musculoskeletal assessment should be performed before prescribing abdominal exercises. Exercise therapy to re-educate control of pelvic tilt is described. Intra-abdominal pressure, and the effects of abdominal exercise on this mechanism, and lumbar stabilization are examined. The importance of training specificity is stressed.

Keywords: Exercise, abdominal muscles, lumbar spine, muscle imbalance, injury

Many adults begin an exercise programme with the aim of reducing their 'spare tyre', and athletes often feel that a strong 'mid-section' is important. These two factors make abdominal strengthening exercises tremendously popular for fitness training and sport.

Although adequate muscle tone in this area is important, abdominal exercises can be dangerous to the spine if performed incorrectly. Therefore, this paper will review several commonly used abdominal exercises, and highlight factors which are important for their safe prescription and effective use.

Abdominal muscles

The anterior abdominal wall consists of four major muscles, the rectus abdominis, external oblique, internal oblique, and transversus abdominis. The iliopsoas must also be considered because of its important effect on the lumbar spine during trunk exercise. The muscles are illustrated in *Figure 1.*

The rectus abdominis will flex the trunk by approximating the pelvis and ribcage. The supra-umbilical portion is emphasized by trunk flexion,

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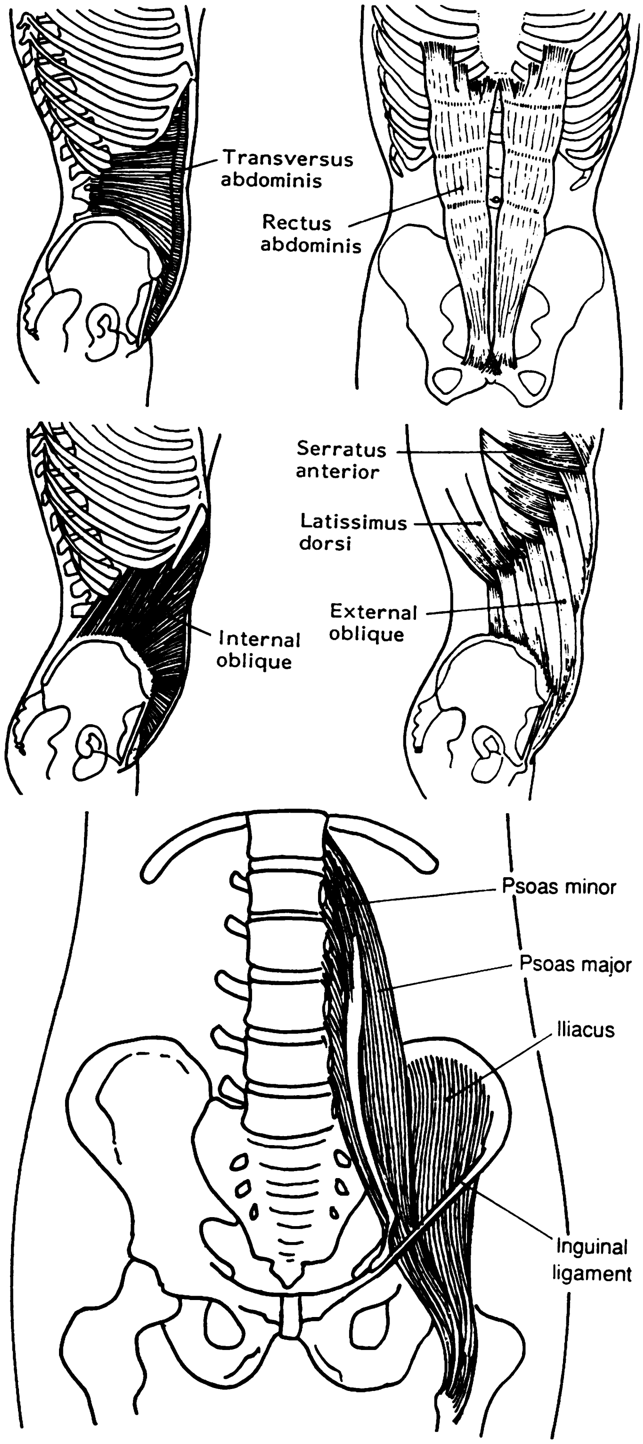

Figure 1. The anterior abdominal wall. Reproduced with the permission of the publishers from: Oliver J, Middleditch A. *Functional Anatomy of the Spine.* Oxford, UK: Butterworth-Heinemann, 1991

while activity in the infraumbilical portion may be greater in posterior pelvic tilting[1]. The oblique abdominals work harder in twisting actions, the external oblique rotating the trunk to the opposite side, while the internal oblique rotates it to the same side. Thus, in right trunk rotation the right internal and left external obliques are active.

The internal oblique and transversus have an important function in protecting the inguinal canal. They are continuously active in standing[2], and this activity is increased during straining and expulsive actions. The transversus abdominis is thought not to participate greatly in trunk movements[3]. However, through its attachment to the thoracolumbar fascia it can exert an antiflexion effect on the lumbar spine[4], a particularly important role in lifting.

The function of the iliopsoas is mainly hip flexion, with slight adduction. It will tilt the pelvis anteriorly, holding it in this position if tight and increasing the lumbar lordosis. When the femur is fixed, the iliopsoas will pull the lumbar spine forwards, flexing it and rotating it to the opposite side, the rotation action being most noticeable at the L3 level[5].

Effects of flexion on the lumbar spine

Lumbar flexion is limited by both contractile and inert structures. The spinal extensors will control flexion from the vertical body position by eccentric action. However, they will only limit movement if they are excessively tight, or if a flexion action is so rapid that a stretch reflex is stimulated.

Of the inert structures on the posterior lumbar spine, the facet joints and spinal discs limit flexion more than the spinal ligaments[6]. The greatest resistance to flexion is provided by the apposing facet joints[7]. Facet joint movement in the lumbar spine on flexion is a combination of forward rotation and forward translation. The translation movement is limited by the facet joint, with the anterior component taking the horizontally imposed stress[8]. As these areas receive the highest pressures[9] they are particularly vulnerable to degenerative changes[3].

Rapid, full change, flexion exercises on the lumbar spine are not recommended as they can stress the posterior structures excessively and may ultimately lead to hypermobility and facet degeneration.

During flexion the intervertebral disc is compressed anteriorly causing the anterior annular fibres to bulge. The posterior annular fibres are stretched, placing them under tension. The discal nucleus is thought to move posteriorly with flexion[10, 11].

Intradiscal pressure within the lumbar spine varies tremendously with general alterations in posture, and variation is equally marked between the various sit-up procedures. If the pressure at the L3 disc for a 70-kg standing subject is said to be 100%, supine lying reduces this pressure to 25%[12]. The pressure variations increase dramatically as soon as the lumbar spine is flexed, with the sitting posture increasing intradiscal pressure to 140%. The sit-up action from crook lying increases intradiscal pressure to 210%. Interestingly, the bilateral straight leg raise, although placing considerable stress on the lumbar spine, increases intradiscal pressure to only 150%[13], possibly because the lumbar spine itself does not flex.

As well as intradiscal pressure variations, general lumbar compression and shear forces have been shown to alter considerably during the performance of different sit-up exercises. Reductions of 18% for compressive forces and 97% in shear forces were shown by Johnson and Reid[14] using computer simulation during the performance of a sit-up exercise with the knees and hips flexed to 90° (bench curl-up).

Kinesiological analysis of abdominal exercises

The term 'sit-up' is used to describe an action where the athlete moves from a supine lying to a sitting position by performing hip flexion without lumbar flexion (*Figure 2*). The term 'trunk-curl' (*Figure 3*) is used to describe flexion of the trunk, without hip flexion. Where an exercise involves both movements, the term 'curled trunk sit-up' will be used.

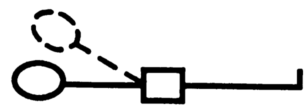

Figure 2. The sit-up

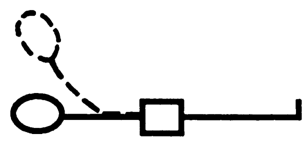

Figure 3. The trunk curl

Trunk curl

At the beginning of this exercise, as soon as the head lifts from the ground, activity is seen in the rectus abdominis[15], and as a consequence the rib cage is depressed anteriorly. This initial period of muscle activity emphasizes the supraumbilical portion of the rectus, the infraumbilical portion and the internal oblique contracting later[1]. As the internal oblique contracts, it pulls on the lower ribs, causing the ribs to flare out and so increase the infrasternal angle.

Fixation of the pelvis is provided by the hip flexors, especially iliacus through its attachment to the pelvic rim. The strong pull of the hip flexors is partially counteracted by the pull of the lateral fibres of the external oblique which tend to tilt the pelvis posteriorly. Action of the external oblique, if powerful enough, will compress the ribs and reduce the infrasternal angle once more[1].

If during the execution of the trunk curl exercise, the trunk is rotated, by pulling the right shoulder towards the left leg for example (trunk curl with twist, *Figure 4*), extra stress is imposed on the oblique abdominals.

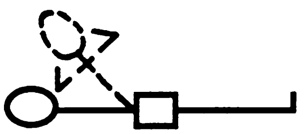

Figure 4. The trunk curl with twist

Sit-up

Often, the initial movement in a rapid sit-up is a momentary posterior tilting of the pelvis by action of the hip extensors. This will pre-stretch the hip flexors, giving them a mechanical advantage before hip flexion occurs. During this phase the abdominal muscles work eccentrically[16]. Later, the abdominals work isometrically to fix the pelvis and provide a stable base for the hip flexors to pull on.

The trunk is lifted from the ground by concentric action of the hip flexors, working on the stationary femur. Only if the trunk is flexed (curled trunk sit-up) do the abdominal muscles act as primary or secondary movers. During the pure sit-up, the abdominal action felt by the athlete is mainly through action of these muscles as fixators.

However, with subjects in poor physical condition, the abdominal muscles may be too weak to fix the pelvis. In this case, the iliopsoas can pull the lumbar spine into dangerous hyperextension.

Effects of foot fixation

If the sit-up action is attempted from the supine lying position, there is a tendency for the legs to lift up from the supporting surface. This occurs because the legs constitute roughly one-third of the bodyweight and the trunk two-thirds, the lighter body part obviously lifting first. However, if the feet are fixed, the hip flexors can now pull powerfully without causing the legs to lift.

In addition, the act of foot fixation itself may facilitate the iliopsoas[17]. Foot fixation requires the subject to pull against the fixation point by active dorsiflexion. This process stimulates the gait pattern at heel contact, increasing activity in the tibialis anterior, quadriceps and iliopsoas, a pattern known as flexor synergy[18].

As with the standard sit-up, when the feet are fixed the action of the iliopsoas is to hyperextend the lumbar spine (*Figure 5*). However, the increased activity seen in the iliopsoas through foot fixation will cause greater hyperextension, and therefore an increased likelihood of injury to the lumbar spine.

Effects of knee and hip flexion

Bending the knees and hips to alter the starting position of a sit-up or trunk curl (*Figure 6*) will affect both the passive and active actions of the hip flexors, and the biomechanics of the lumbar spine. In the supine starting position, the iliopsoas is partially stretched and so able to exert its greatest active tension. As the muscle is shortened by flexing the hips and knees, tension produced by the iliopsoas on contraction will reduce. With 45°-hip flexion tension development is 70–80% of its maximum, while with the hips and knees flexed to 90° this figure reduces to between 40 and 50%[14].

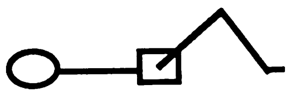

Figure 6. Bent knee sit-up

However, passive tension developed by the iliopsoas due to elastic recoil must also be considered. If the hips are flexed, the iliopsoas will not be fully stretched, and will not be able to limit passively the posterior tilt of the pelvis. Instead, to fix the pelvis and provide a stable base for the abdominals to pull on, the hip flexors will contract earlier in the sit-up action. This contraction, although occurring earlier, will be of reduced intensity[15] due to the length–tension relationship of the muscle[19].

When performing a sit-up in any starting position, contraction of the iliopsoas may place stress on the lumbar spine in severely deconditioned subjects. To reduce iliopsoas activity to a minimum, active hip flexion should be eliminated and the trunk curl exercise chosen.

Straight leg raising

The bilateral straight leg raise (*Figure 7*) has been shown to create only slight activity in the upper rectus abdominis, although the lower rectus abdominis contributes a greater proportion of the total abdominal work than with the sit-up[20]. The rectus works isometrically to fix the pelvis against the strong pull of the iliopsoas[21]. The force of contraction of the iliopsoas is at a maximum when the lever arm of the leg is greatest, near the horizontal, and reduces as the leg is lifted towards the vertical.

In subjects with weaker abdominals, the pelvis will tilt and the lumbar spine hyperextend (*Figure 8*). This forced hyperextension will dramatically increase stress on the facet joints, in the lumbar spine

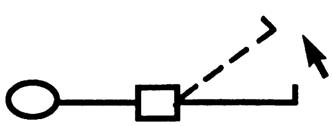

Figure 7. Bilateral straight leg raise

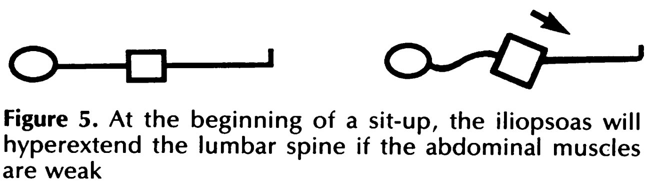

Figure 5. At the beginning of a sit-up, the iliopsoas will hyperextend the lumbar spine if the abdominal muscles are weak

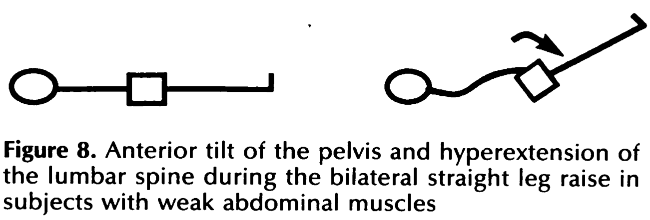

Figure 8. Anterior tilt of the pelvis and hyperextension of the lumbar spine during the bilateral straight leg raise in subjects with weak abdominal muscles

particularly. The movement is likely to be limited by impaction of the inferior articular processes of the facet joints on the laminae of the vertebrae below, or in some cases by contact between the spinous processes[8]. Where this action occurs rapidly, damage may result to the facet joint structures. Once contact has occurred between the facet and the lamina, further loading will cause axial rotation of the superior vertebra[22]. The superior vertebra pivots, causing the inferior articular process to move backwards, overstretching the joint capsule. In some cases the joint capsule may become trapped between the inferior articular process and the lamina, and eventual erosion of the laminal periosteum may occur[3].

Modification of straight leg raising

As none of the abdominal muscles actually crosses the hip, they are not prime movers of the straight leg raising movement. However, the action is an important one as it emphasizes the pelvic stabilizing function of the infraumbilical portion of the rectus abdominis, a body area frequently neglected during training. It is common to find athletes who can perform sit-ups easily, but who are unable to demonstrate a bilateral straight leg raise while keeping the back flat on the ground.

Two exercises serve as modifications of the bilateral straight leg raise to reduce the stress on the lumbar spine. The first movement is leg lowering (*Figure 9*). For this exercise the subject lies supine with the hips flexed to 90° but the knees extended. From this position, the legs are lowered by eccentric action of the hip flexors to a point where the pelvis begins to tilt. Immediately this occurs, the legs are brought up again to 90° hip flexion. The advantage of this exercise over the standard straight leg raise is one of changing leverage. With the standard leg raising action, the subject starts from a point of maximum leverage on the leg, forcing the hip flexors and abdominals to work maximally straight away. With leg lowering, the starting position is one of minimum leverage as the legs are held vertically. As the legs are lowered away from the vertical, leverage increases but the subject is able to control the descent of the legs and avoid the position of maximal leverage which would cause the spine to hyperextend. In cases where subjects find the leg lowering difficult to control, the knees should be bent, to reduce leverage on the leg. Alternatively the subject can perform the exercise close to a wall, so their legs cannot be lowered fully (*Figure 10*).

The leg lowering movement is sometimes combined with a trunk curl (the 'V' sit-up). However, this action must be performed as a controlled movement,

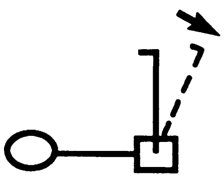

Figure 9. Leg lowering

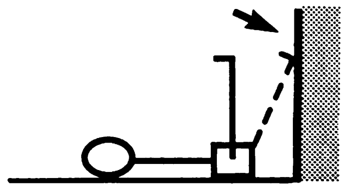

Figure 10. Use of wall to provide relaxation stop in leg lowering

with the leg staying close to the vertical position to limit leverage Rapid flexion of both the spine and hips from a supine lying position in an attempt to touch the toes (salmon snap exercise) can be extremely dangerous. The momentum involved by two heavy body parts moving at speed can cause trauma to the lumbar spine or abdominal musculature, especially in untrained subjects. Combined hip and trunk exercises should only be considered for athletes who already have well developed abdominal muscles.

The second modification of the straight leg raise is the bench lying pelvic raise (*Figure 11*). Here, the subject starts the action in bench lying and maintains 90° hip and knee flexion throughout the movement. The arms are held by the sides to give counterforce and aid general stability. The action is to flex the lumbar spine, keeping the legs relatively inactive, and lift the buttocks from the bench. Although the lumbar spine is flexed as with the trunk curl, the movement occurs from 'below upwards' with the L5–S1 joint moving first followed by flexion of each successively higher lumbar segment. The reverse movement (above downwards) is seen with trunk curling actions[23].

Performing the actions from a wallbar hanging position (*Figures 12, 13, 14*) places the trunk vertically, reducing the leverage forces on the lumbar spine considerably, and providing traction. Initially, the

Figure 11. Bench lying pelvic raise

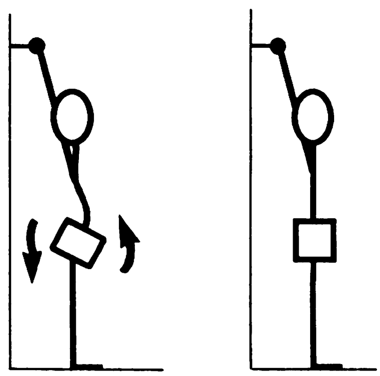

Figure 12. Wallbar hanging, pelvic tilt

athlete is required to hold a neutral pelvic position, preventing anterior tilt of the pelvis, and being encouraged to 'press the small of the back into the wallbars' (*Figure 12*). The action is then progressed to one of hip and knee flexion, bringing the bent knees up to a point where 90° hip flexion is achieved, but still keeping the lumbar spine in contact with the wallbars (*Figure 13*). The final progression is to stop knee and hip movement, and flex the lumbar spine to lift the back away from the support of the wallbars (*Figure 14*). This action, although working the abdominals hard, will also strengthen and possibly tighten the hip flexors.

Muscular control of pelvic tilt

Anteroposterior tilting of the pelvis on the femoral heads will change the lumbar lordosis, and is an important factor in the prevention and management of posturally related back pain[23, 24]. Pelvic tilt is largely controlled by the abdominal, hip, and spinal muscles. These will affect the pelvic position either actively through contraction, or passively through tightness.

The pelvis can be thought of as a 'seesaw' balanced on the hip joints (*Figure 15*). Anterior (forward) tilting of the pelvis occurs when the anterior part of the pelvis drops downwards, and posterior (backward) tilting is the reverse action, with the anterior pelvis moving upwards. Anterior tilting will increase the lumbar lordosis and commonly is a result of weakness in the abdominal muscles and tightness in the iliopsoas. Posterior tilting reduces the lordosis and commonly is seen in sitting, especially with the legs straight. In this case tightness of the hamstrings pulls the posterior aspect of the pelvis down.

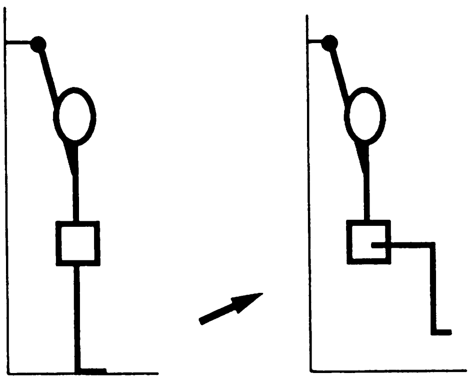

Figure 13. Wallbar hanging, knee raise

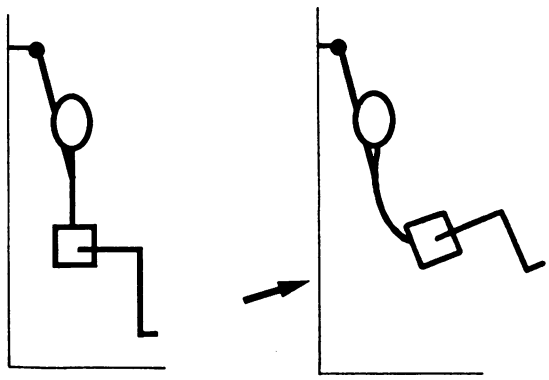

Figure 14. Wallbar hanging, pelvic raise

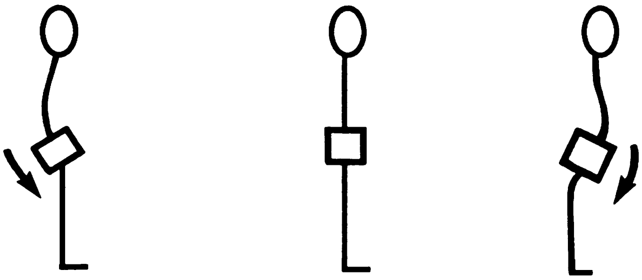

Figure 15. Pelvic tilting

Muscle imbalance

There is often an imbalance of strength and/or flexibility between the various trunk and hip muscles. This imbalance has been shown to be associated with an alteration of pelvic tilt and a reduction in range of spinal flexion[24]. The muscle imbalance may be caused either by daily living or by exercise, both of which can place excessive stress on some tissues while others are worked insufficiently.

Muscles differ in their reaction to physical stress and injury, and have been classified into postural and phasic groups depending on their behaviour (*Table 1*). The postural muscles show an increased tendency to tighten, and around the pelvis this is especially true of the iliopsoas and hamstrings. The phasic muscles (antagonists to the postural type) show a tendency to weaken with inactivity and also after injury. In the case of the lower back, the important phasic muscles which show weakness are the abdominals and gluteals. The combination of muscle tightness and muscle weakness around the pelvis has been termed the 'pelvic crossed syndrome' (*Figure 16*)[25].

Table 1. Muscle imbalance

Postural muscles – tend to tighten
Quadratus lumborum
Erector spinae
Iliopsoas
Tensor fasciae latae
Rectus femoris
Piriformis
Pectineus
Adductors
Hamstrings
Gastrocnemius
Soleus
Tibialis posterior
Phasic muscles – tend to lengthen and weaken
Rectus abdominis
Internal and external obliques
Gluteals
Quadriceps
Tibialis anterior
Peronei

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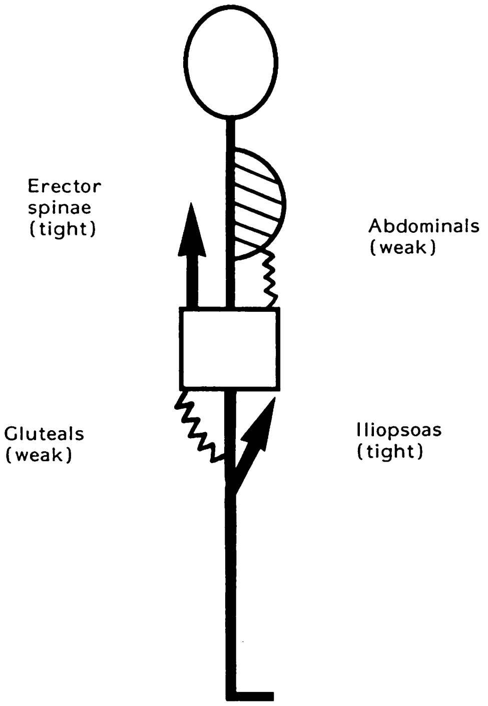

Figure 16. The pelvic crossed syndrome. After Jull and Janda[25]

Tightness of a postural muscle may actually inhibit its phasic antagonist, causing weakness or 'pseudoparesis'[26]. Restoration of strength to the phasic muscle in this case is achieved more effectively by stretching the postural muscle, rather than strengthening the phasic muscle with resistance training.

Restoration of the pelvic tilting mechanism

Both strength and flexibility of the muscles surrounding the pelvis must be assessed for symmetry (right and left sides of the body) and compared against average values. Assessment procedures for this type of examination have been described by various authors[1,5,27,28]. Where clinically appropriate, both flexibility and strength exercises should be prescribed in an attempt to restore muscle balance.

Unfortunately, many exercise programmes in common usage merely reinforce the muscle imbalance already present. For example, prolonged sitting will tend to shorten the iliopsoas creating an imbalance between the hip flexors and hip extensors. An exercise programme which includes repeated sit-up exercises, will increase the hip muscle imbalance already present by strengthening and shortening the iliopsoas. A more effective approach is to use a trunk curl action to strengthen the abdominals, and flexibility exercises to stretch the iliopsoas.

Retraining of the pelvic tilting action is normally required, because even athletes with strong abdominal muscles are often unable readily to control pelvic tilting. The action can be re-educated initially in the supine lying position, and then progressed to kneeling, high kneeling, and standing. The aim is to encourage a strong posterior tilt of the pelvis using the abdominal muscles rather than just the gluteals. Palpation will reveal which muscles are more active. Subjects should be encouraged to breath normally throughout the exercise and not to hold the breath as the abdominals are contracted.

Intra-abdominal pressure

Contraction of the transversus abdominis, and to a lesser degree the internal and external obliques, will cause an increase in intra-abdominal pressure (IAP), when the glottis is closed. The muscles will pull on the rectus sheath and so compress the viscera. Compression of the abdominal contents forces them upwards on to the diaphragm and separates the pelvis from the thoracic cage[29]. The IAP will be greater if the breath is held after a deep inspiration, as the diaphragm is lower, and the comparative size of the abdominal cavity is reduced.

By making the trunk into a more solid cylinder, axial compression and shear loads are reduced and transmitted over a wider area through the IAP mechanism[8]. IAP is greater when heavy lifts are performed, and when the lift is rapid[30].

Increases in IAP have been shown during weightlifting when wearing a weightlifting belt, but abdominal muscle strength may be altered or reduced if a belt is used for all exercise[31]. For this reason athletes are probably better advised to use a belt only for exercises where there is an increased likelihood of back injury.

Strengthening the abdominal muscles with sit-up type movements does not increase IAP permanently[32]. Exercises of this type do not usually mimic the coordination between the abdominal muscles which is inherent in the IAP mechanism[3].

However, abdominal muscle training is of use where lumbar instability exists[33], and exercises such as 'dynamic abdominal bracing' (see below) have been used in an attempt to restore the IAP mechanism after injury.

Restoring muscular stabilization of the trunk

One of the results of the highly mechanized and sedentary lifestyle in the Western world is a reduction in the variety of movements which an individual regularly undertakes. This reduced movement 'vocabulary' can decrease the proprioceptive stimulation needed for skilled motor action[25]. Therefore, in addition to restoring strength and flexibility in the trunk after injury, complex skilled trunk actions should also be used if full function is to be regained.

The use of proprioceptive stimulation, by employing skilled movements, is well-documented during the rehabilitation of ankle injuries[34–36] and may reduce the chance of injury recurrence. This type of rehabilitation is not as widely used when prescribing exercise for the spine. This omission can leave patients able to perform regimented trunk muscle exercises in lying, but less capable of executing controlled, skilled trunk actions in more functional positions.

The traditional sit-up is essentially a movement which focuses on the prime movers of trunk flexion, the rectus abdominis and external oblique. However, the major functional role of the abdominal musculature is to help stabilize the lumbar spine. The transversus abdominis and the oblique abdominals (especially the internal oblique), which encircle the trunk, have a major stabilizing role[8, 37]. Rather than the strength of these muscles, it is the speed with which they contract in reaction to a force tending to displace the lumbar spine which is important[38].

A major aim of training and rehabilitation should be to develop muscular stabilization of the trunk rather than simply trunk flexion strength. Restoration of trunk stability is unlikely to result from traditional sit-up exercises, but could perhaps be regained by using skill-based exercises which rehearse lumbar stabilization during normal activities.

Rehearsal of oblique abdominal and transversus action may be achieved by the use of dynamic abdominal bracing[39, 40], where an athlete is encouraged to expand the abdominal muscles laterally. The athlete places his or her hands over the oblique abdominals just superior to the iliac crests. The action is to contract the oblique abdominals and transversus and so press the hands apart, rather than cause the abdomen to protrude by contracting the rectus abdominis alone. Once this movement can be performed repeatedly, it is used as other tasks are performed such as sitting to standing, lifting, and athletic movements.

The use of proprioceptive stimulation is also of use in retraining muscular stabilization of the trunk[41]. Initially, the subject's lumbar spine and pelvis are correctly aligned by a therapist. The subject is then encouraged to hold this corrected position, with minimal muscle activity, as the therapist pushes the subject's trunk from different directions (*Figure 17*).

A balance board may also be used[38]. Initially a rocker board is used with the subject sitting or in high kneeling. Placing the pivot of the board in the frontal plane will work flexion and extension reaction, while placing the pivot in the sagittal plane will work lateral flexion (*Figure 18*). The pivot is then placed diagonally to combine movements, and progression is made to the wobble board where the pivot point is dome shaped to increase the variety of movements. Other apparatus useful for balance work and muscle reaction includes the large diameter (80 cm) gymnastic ball on which an athlete sits, the minitrampette for kneeling, sitting and standing activities and the 'Fitter' ski-training device (Fitter International, Calgary, Canada). In each case, as the athlete is pushed off balance, the aim is to maintain lumbar stabilization and avoid anterior pelvic tilting and loss of neutral lordosis (*Figure 18*).

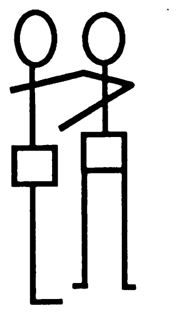

Figure 17. Athlete attempts to hold stable lumbar posture as therapist pushes trunk from various directions

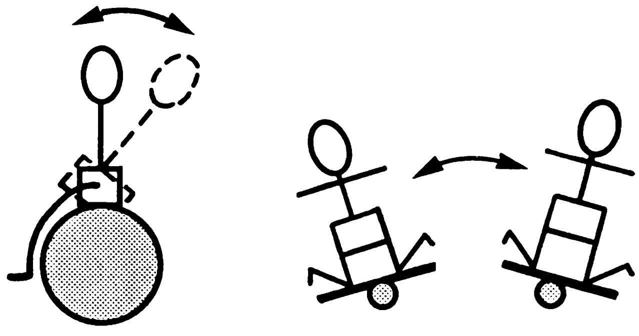

Figure 18. Use of balance board and gymnastic ball for retraining lumbar stabilization

The use of multisensory cues in abdominal muscle training, to enhance muscle contraction and motor control, has met with success[37]. Auditory cues were provided by the therapist speaking to the subject and giving feedback about performance. Visual cues were provided by encouraging the subject to look at the muscles as they functioned, and by using a mirror. Kinaesthetic cueing was accomplished by encouraging the subject to 'feel' the particular action, for example asking them to 'feel the stomach being pulled in'. Tactile cues were provided by the therapist touching the subject's abdomen as muscle contraction began.

A rehabilitation programme which emphasized skill-based exercise therapy for the spine has been shown to be effective in the treatment of a herniated lumbar disc[42], and in the rehabilitation of football players with back injury[43, 44].

The programme aimed to restore automatic control of muscular stabilization of the trunk by teaching the subject to maintain a corrected lumbar–pelvic position while performing progressively more complex tasks. The tasks began in prone and supine positions, later moving to kneeling, standing, and simple dynamic actions, following a neurodevelopmental progression of posture control[44]. When control had been achieved, exercises were progressed to include complex general activities such as weight training, running, swimming, and cycling while maintaining a neutral lumbar–pelvic position. Finally, tasks specific to an athlete's individual sport were used, again with the athlete maintaining lumbar stabilization.

Specificity of abdominal training

Abdominal muscle training must reflect the requirements of a particular sport. The nature of the body's adaptation to any training stimulus is highly specific[45], so any exercise given to an athlete to improve the neuromuscular function of the trunk should closely match the activity the athlete will be required to perform in competition.

The muscle work, energy systems, posture, and movement sequence should all accurately reflect the action which the athlete will be required to perform. A movement analysis should be used to establish the kinesiological requirements of an action. This may vary from the use of a 'trained clinical eye' in the first instance, to a complete laboratory-based biomechanical analysis if necessary.

The training programme utilizes the traditional 'S' factors of fitness; initially stamina, suppleness and strength are focused upon, and later speed and skill activities are added. Muscle work is varied using eccentric as well as isometric and concentric actions, and power training is accomplished by the use of plyometrics[46–48] under close supervision.

The postures used in a particular sporting event are also used as starting positions when exercising the abdominal muscles. In each case the athlete is encouraged to use an efficient posture which reduces stress on the spine.

It should also be noted that excessive practice of exercises which resemble a skilled sports action, but do not involve the action itself, may interfere with skill acquisition and cause a negative transfer effect[49]. For this reason late stage rehabilitation of the injured athlete should involve input from the athelete's coach.

It may be concluded that abdominal muscle exercise forms a valuable part of a physical training programme. Before prescribing abdominal exercises, a musculoskeletal assessment of the lumbar and hip areas should be performed to establish an athlete's individual needs.

The sit-up performed with foot fixation, and the bilateral straight leg raise are not recommended. These exercises can compound hip muscle imbalance, and both hyperextend and hyperflex the lumbar spine to dangerous levels in physically deconditioned subjects.

A typical programme to restore abdominal muscle function after a period of inactivity may include stretching and strengthening exercises to restore muscle balance to the hip and lumbar region. Re-education of the pelvic tilting mechanism should be used, followed by progressive exercise to increase lumbar stabilization. The use of proprioceptive training using balance activities is recommended.

Subjects should be encouraged to maintain a mid-range lumbar position while exercising, particularly when using resistance training apparatus. The final stages of an exercise programme should include activities which are specific to an athlete's competitive activities.

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