Spinal Stabilisation
2. Limiting Factors to End-range Motion in the Lumbar Spine

Christopher M Norris

Key Words

Lumbar spine, biomechanics, proprioception, muscle length.

Summary

Biomechanical factors which limit range of motion in the lumbar spine are reviewed. The effects of axial compression on the vertebral body, intervertebral disc, and zygapophyseal joints are considered. During axial compression blood is squeezed from the vertebral body leaving a latent period of reduced shock-absorbing ability. Continuous repeated loading of the spine is therefore not recommended during exercise. Intradiscal pressure varies with different body positions, and is especially high during slumped sitting, making this an inappropriate starting position during exercise. Marked loss of height through discal compression is seen following certain weight training exercises making these unsuitable for subjects with discal pathologies. The shock absorbing properties of the disc reduce with age, an important consideration when prescribing exercise for older people. Flexion and extension movements combine sagittal rotation and translation of the vertebrae, leading to facet impaction at end range. Impaction is more damaging with momentum from fast movements. The importance of relative stiffness and muscle length to lumbar-pelvic rhythm is highlighted. The relevance of articular tropism is examined. The proprioceptive role of the deep intersegmental muscles of the spine is considered, and the importance of proprioceptive training during rehabilitation of spinal dysfunction is emphasised.

Introduction

A joint is less likely to be injured if it is loaded within its mid-range of motion rather than at extreme end range. At end range, pain of mechanical origin can occur through over-stretching of the surrounding soft tissues and stimulation of the nociceptor system (McKenzie, 1990). If the stretch is prolonged, the initial acute localised pain will become more diffuse and eventually tissue damage may occur.

An important task for the motor system is to control those degrees of joint motion which are unused in a given task, by putting active muscular constraints on the temporarily redundant movement (Kornecki, 1992). Therefore, to avoid end-range pain, exercises for the lumbar spine often aim at enhancing stability of the area to protect the lumbar joints and associated structures from injury (Richardson *et al*, 1990).

This paper looks at some of the biomechanical factors which limit range of motion, and identifies several structures likely to be damaged by end range tissue stress. The relevance of end range tissue stress to the performance of trunk exercise is discussed.

Movements of the Lumbar Spine

Axial Compression

Vertebral Body

Within the vertebra itself, compressive force is transmitted by both the cancellous bone of the vertebral body and the cortical bone shell. Up to the age of 40 years the cancellous bone contributes between 25% and 55% of the strength of the vertebra. After this age the cortical bone shell carries a greater proportion of load as the strength and stiffness of the cancellous bone reduces with decreasing bone density due to ageing (Rockoff *et al*, 1969). As the vertebral body is compressed, blood flows from it into the subchondral post-capillary venous network (Crock and Yoshizawa, 1976). This process reduces the bone volume and dissipates energy (Roaf, 1960). The blood returns slowly as the force is reduced, leaving a latent period after the initial compression, during which the shock absorbing properties of the bone will be less effective. Exercises which involve prolonged periods of repeated shock to the spine, such as jumping on a hard surface, are therefore more likely to damage the vertebrae than those which load the spine for short periods and allow recovery of the vertebral blood flow before repeating a movement.

Intervertebral Disc

Weight is transmitted between adjacent vertebrae by the lumbar intervertebral disc. The annulus fibrosus of a disc, when healthy, has a certain bulk and will resist buckling. When loads are applied briefly to the spine, even if the nucleus pulposus of a disc has been removed, the annulus alone exhibits a similar load-bearing capacity to that of the fully intact disc (Markolf and Morris, 1974). When exposed to prolonged loading however, the collagen lamellae of the annulus will eventually buckle.

The application of an axial load will compress the fluid nucleus of the disc causing it to expand laterally. This lateral expansion stretches the annular fibres, preventing them from buckling. A 100 kg axial load has been shown to compress the disc by 1.4 mm and cause a lateral expansion of 0.75 mm (Hirsch and Nachemson, 1954). The stretch in the annular fibres will store energy which is released when the compression stress is removed. The stored energy gives the disc a certain springiness which helps to offset any deformation which occurred in the nucleus. A force applied rapidly will not be lessened by this mechanism, but its rate of application will be slowed, giving the spinal tissues time to adapt.

Deformation of the disc occurs more rapidly at the onset of axial load application. Within ten minutes of applying an axial load the disc may deform by 1.5 mm. Following this, deformation slows to a rate of 1 mm per hour (Markolf and Morris, 1974) accounting for loss of height throughout the day. Under constant loading the discs exhibit creep, meaning that they continue to deform even though the load they are exposed to is not increasing. Compression causes a pressure rise leading to fluid loss from both the nucleus and annulus. About 10% of the water within the disc can be squeezed out by this method (Kraemer *et al*, 1985), the exact amount depending on the size of the applied force and the duration of its application. The fluid is absorbed back through pores in the cartilage end plates of the vertebra, when the compressive force is reduced.

Exercises which axially load the spine have been shown to result in a reduction in subject height through discal compression. Compression loads of six to ten times bodyweight have been shown to occur in the L3-L4 segment during a squat exercise in weight training, for example (Cappozzo *et al*, 1985). Average height losses of 5.4 mm over a 25 minute period of general weight training, and 3.25 mm after a 6 km run have also been shown (Leatt *et al*, 1986). Static axial loading of the spine with a 40 kg barbell over a 20 minute period can reduce subject height by as much as 11.2 mm (Tyrrell *et al*, 1985). Clearly, exercises which involve this degree of spinal loading are unsuitable for individuals with discal pathology.

The vertebral end-plates of the discs are compressed centrally, and are able to undergo less deformation than either the annulus or the cancellous bone. The end plates are therefore likely to fail (fracture) under high compression (Norkin and Levangie, 1992). Discs subjected to very high compressive loads show permanent deformation but not herniation (Virgin, 1951; Markolf and Morris, 1974; Farfan *et al*, 1970). However, such compression forces may lead to Schmorls node formation (Bernhardt *et al*, 1992). Bending and torsional stresses on the spine, when combined with compression, are more damaging than compression alone, and degenerated discs are particularly at risk. Average failure torques for normal discs are 25% higher than for degenerative discs (Farfan *et al*, 1970). Degenerative discs also demonstrate poorer viscoelastic properties and therefore a reduced ability to attenuate shock.

The disc's reaction to a compressive stress changes with age, because the ability of the nucleus to transmit load relies on its high water content. The hydrophilic nature of the nucleus is the result of the proteoglycan it contains, and as this changes from about 65% in early life to 30% by middle age (Bogduk and Twomey, 1987), the nuclear load-bearing capacity of the disc reduces. When the proteoglycan content of the disc is high, usually up to the age of 30 years, the nucleus pulposus acts as a gelatinous mass, producing a uniform fluid pressure. After this age, the lower water content of the disc means that the nucleus is unable to build as much fluid pressure. As a result, less central pressure is produced and the load is distributed more peripherally, eventually causing the annular fibres to become fibrillated and to crack (Hirsch and Schajowicz, 1952).

As a consequence of these age-related changes the disc is more susceptible to injury later in life. This, combined with the reduction in general fitness of an individual, and changes in movement patterns of the trunk related to the activities of daily living, greatly increases the risk of injury to this population. Individuals over the age of 40 years, if previously inactive, should therefore be encouraged to exercise the trunk under the supervision of a physiotherapist before attending fitness classes run for the general public.

Zygapophyseal Joints

The superior/inferior alignment of the zygapophyseal joints in the lumbar spine means that during axial loading in the neutral position the joint surfaces will slide past each other. However, it must be noted that the orientation of the zygapophyseal joints may change from those characteristic of the thoracic spine to those of the lumbar spine, anywhere between T9 and T12. Therefore the level at which particular movements will occur can vary considerably between subjects. During lumbar movements, displacement of the zygapophyseal joint surfaces will cause them to impact. Because the sacrum is inclined and the body and disc of L5 is wedge shaped, during axial loading L5 is subjected to a shearing force. This is resisted by the more anterior orientation of the L5 inferior articular processes. In addition, as the lordosis increases, the anterior longitudinal ligament and the anterior portion of the annulus fibrosus will be stretched giving tension to resist the bending force. Additional stabilisation is provided for the L5 vertebra by the iliolumbar ligament, attached to the L5 transverse process. This ligament, together with the zygapophyseal joint capsules, will stretch and resist the distraction force.

Once the axial compression force stops, release of the stored elastic energy in the spinal ligaments will re-establish the neutral lordosis. With compression of the lordotic lumbar spine, or in cases where gross disc narrowing has occurred, the inferior articular processes may impact on the lamina of the vertebra below. In this case the lower joints (L3/4, L4/5, L5/S1) may bear as much as 19% of the compression force while the upper joints (L1/2, L2/3) bear only 11% (Adams and Hutton, 1980).

Flexion and Extension

During flexion movements the anterior annulus of the lumbar discs will be compressed while the posterior fibres are stretched. Similarly, the nucleus pulposus of the disc will be compressed anteriorly while pressure is relieved over its posterior surface. As the total volume of the disc remains unchanged, its pressure should not increase. The increases in pressure seen with alteration of posture are therefore due not to the bending motion of the bones within the vertebral joint itself, but to the soft-tissue tension created to control the bending. 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%. The pressure variations increase dramatically as soon as the lumbar spine is flexed and tissue tension increases. The sitting posture increases intradiscal pressure to 140%, while sitting and leaning forward with a 10 kg weight in each hand increases pressure to 275% (Nachemson, 1987). The selection of an appropriate starting position for trunk exercise is therefore of great importance. Superimposing spinal movements from a slumped sitting posture for example would place considerably more stress on the spinal discs than the same movement beginning from crook lying.

During flexion, the posterior annulus is stretched, and the nucleus is compressed on to the posterior wall. The posterior portion of the annulus is the thinnest part, and the combination of stretch and pressure to this area may result in discal bulging or herniation. Because of the alternating direction of the annular fibres, during rotation movements only half of the fibres will be stretched while half relax. The disc is therefore more easily injured during combined rotation and flexion movements.

As the lumbar spine flexes, the lordosis flattens and then reverses at its upper levels. Reversal of lordosis does not occur at L5-S1 (Pearcy *et al*, 1984). Flexion of the lumbar spine involves a combination of anterior sagittal rotation and anterior translation. As sagittal rotation occurs, the articular facets move apart, permitting the translation movement to occur. Translation is limited by impaction of the inferior facet of one vertebra on the superior facet of the vertebra below (fig 1). As flexion increases, or if the spine is angled forward on the hip, the surface of the vertebral body will face more vertically, increasing the shearing force due to gravity. The forces involved in facet impaction will therefore increase to limit translation of the vertebra and stabilise the lumbar spine. Because the zygapophyseal joint has a curved articular facet, the load will not be concentrated evenly across the whole surface, but will be focused on the anteromedial portion of the facets.

The sagittal rotation movement of the zygapophyseal joint causes the joint to open and is

(a)

(b)

(c)

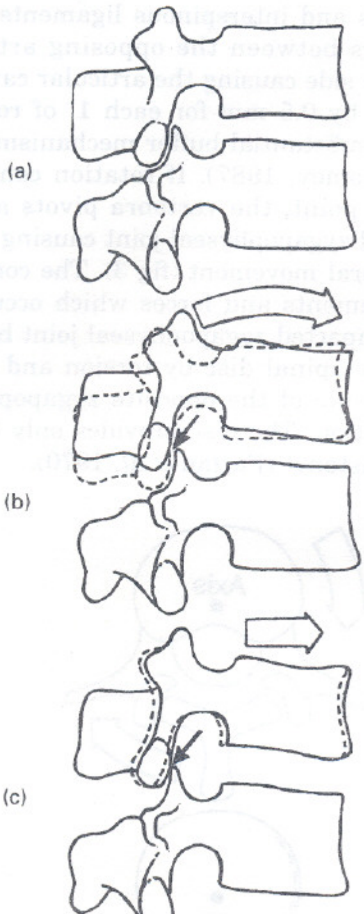


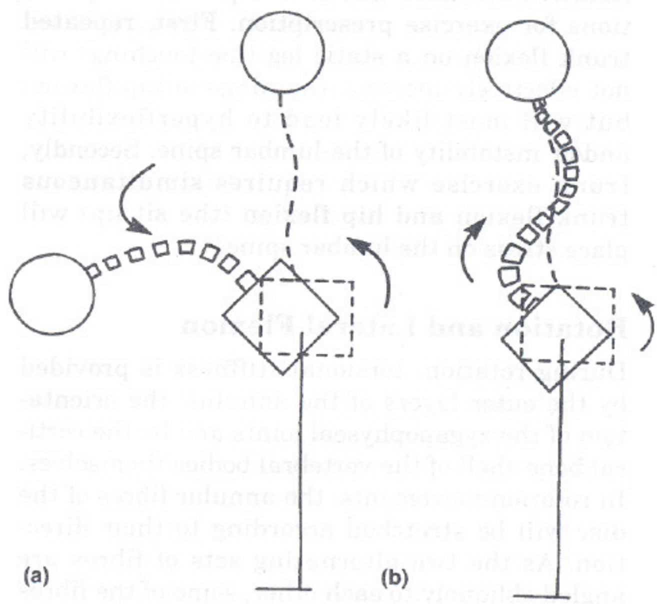
Fig 1: Vertebral movement during flexion: Flexion of the lumbar spine involves a combination of anterior sagittal rotation and anterior translation. As sagittal rotation occurs, the articular facets move apart (b), permitting the translation movement to occur (c). Translation is limited by impaction of the inferior facet of one vertebra on the superior facet of the vertebra below (from Bogduk and Twomey, 1987)

therefore limited by the stretch of the joint capsule. Additionally the posteriorly placed spinal ligaments will also be tightened. Analysis of the contribution to limitation of sagittal rotation within the lumbar spine, through mathematical modelling, has shown that the disc limits movement by 29%, the supraspinous and interspinous ligaments by 19% and the zygapophyseal joint capsules by 39% (Adams *et al*, 1980).

During extension the anterior structures are under tension while the posterior structures are first unloaded and then compressed depending on the range of motion. With extension movements the vertebral bodies will be subjected to posterior sagittal rotation. The inferior articular processes move downwards causing them to impact against the lamina of the vertebra below. Once the bony block has occurred, if further load is applied, the upper vertebra will rotate axially by pivoting on the impacted inferior articular process. The inferior articular process will move backwards, over-stretching and possibly damaging the joint capsule (Yang and King, 1984). With repeated movements of this type, eventual erosion of the laminal periosteum may occur (Oliver and Middleditch 1991). At the site of impaction, the joint capsule may catch between the opposing bones giving another cause of pain (Adams and Hutton, 1983). Structural abnormalities can alter the axis or rotation of the vertebra, so considerable between-subject variation exists (Klein and Hukins, 1983).

Lumbar-pelvic Rhythm

The combination of movements of the hip on the pelvis, and the lumbar spine on the pelvis increases the range of motion of this body area. In forward flexion in standing for example, when the legs are straight, movement of the pelvis on the hip is limited to about 90° hip flexion. Any further movement, allowing the subject to touch the ground, must occur at the lumbar spine. In this example the body is acting as an open kinetic chain and the pelvis and lumbar spine are rotating in the same direction. Anterior tilt of the pelvis is accompanied by lumbar flexion (fig 2a). In the upright posture, the foot and shoulders are static and so spinal movement acts in a closed kinetic chain. In this situation movements of the pelvis and lumbar spine (lumbar-pelvic rhythm) occur in opposite directions (fig 2b). Now, an anteriorly tilted pelvis is compensated by lumbar extension to maintain the head and shoulders in an upright orient-



(a) (b)

Fig 2: Lumbar-pelvic rhythm
(a) Lumbar-pelvic rhythm in open chain formation occurs in the same direction. Anterior pelvic tilt accompanies lumbar flexion
(b) Lumbar-pelvic rhythm in closed kinetic chain formation occurs in opposite directions. Anterior pelvic tilt is compensated by lumbar extension

ation. The relationship between various pelvic movements and the corresponding hip joint action is shown in the table.

Relationship of pelvis, hip joint, and lumbar spine during right lower-extremity weight-bearing and upright posture (Norkin and Levangie, 1992)

Pelvic motion	*Accompanying hip joint motion*	*Compensatory lumbar motion*
Anterior pelvic tilt	Hip flexion	Lumbar extension
Posterior pelvic tilt	Hip extension	Lumbar flexion
Lateral pelvic tilt (pelvic drop)	Right hip adduction	Right lateral flexion
Lateral pelvic tilt (hip hitch)	Right hip abduction	Left lateral flexion
Forward rotation	Right hip MR	Rotation to the left
Backward rotation	Right hip LR	Rotation to the right

MR – medial rotation, LR – lateral rotation

For lumbar-pelvic rhythm to function correctly, hip flexion should be greater than lumbar flexion, and occur first during functional activities. In subjects where there is a history of back pain, however, the reverse situation often occurs leading to stress through repeated flexion of the lumbar spine. The movement of the lumbar spine in relation to the hip demonstrates a feature termed relative stiffness (Sahrmann, 1990; White and Sahrmann, 1994). In a multisegmental mechanical system, the moving parts will take the path of least resistance. This means that in the case of lumbar-pelvic rhythm, if hip flexion is reduced (stiff), lumbar flexion (which offers less resistance) will always occur before hip flexion.

Relative stiffness has two important implications for exercise prescription. First, repeated trunk flexion on a static leg (toe touching) will not effectively increase the range of hip flexion, but will most likely lead to hyperflexibility and/or instability of the lumbar spine. Secondly, trunk exercise which requires simultaneous trunk flexion and hip flexion (the sit up) will place stress on the lumbar spine.

Rotation and Lateral Flexion

During rotation, torsional stiffness is provided by the outer layers of the annulus, the orientation of the zygapophyseal joints and by the cortical bone shell of the vertebral bodies themselves. In rotation movements, the annular fibres of the disc will be stretched according to their direction. As the two alternating sets of fibres are angled obliquely to each other, some of the fibres will be stretched while others relax. A maximum range of 3° of rotation can occur before the annular fibres will be microscopically damaged, and a maximum of 12° before tissue failure (Bogduk and Twomey, 1987). As rotation occurs, the spinous processes separate, stretching the supraspinous and interspinous ligaments. Impaction occurs between the opposing articular facets on one side causing the articular cartilage to compress by 0.5 mm for each 1° of rotation providing a substantial buffer mechanism (Bogduk and Twomey, 1987). If rotation continues beyond this point, the vertebra pivots around the impacted zygapophyseal joint causing posterior and lateral movement (fig 3). The combination of movements and forces which occur will stress the impacted zygapophyseal joint by compression, the spinal disc by torsion and shear, and the capsule of the opposite zygapophyseal joint by traction. The disc provides only 35% of the total resistance (Farfan *et al*, 1970).

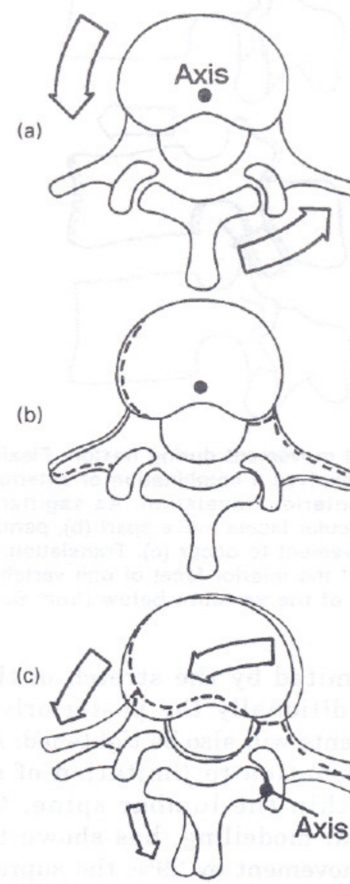


Fig 3: Vertebral movement during rotation: Initially rotation occurs around an axis within the vertebral body (a). The zygapophyseal joints impact (b), and further rotation causes the vertebra to pivot around a new axis at the point of impaction (c) (from Bogduk and Twomey, 1987)

When the lumbar spine is laterally flexed, the annular fibres towards the concavity of the curve are compressed and will bulge, while those on the convexity of the curve will be stretched. The contralateral fibres of the outer annulus and the contralateral intertransverse ligaments help to resist extremes of motion (Norkin and Levangie, 1992). Lateral flexion and rotation occur as coupled movements. Rotation of the upper four lumbar segments is accompanied by lateral flexion to the opposite side. Rotation of the L5-S1 joint occurs with lateral flexion to the same side (Bogduk and Twomey, 1987).

Movement of the zygapophyseal joints on the concavity of lateral flexion is by the inferior facet of the upper vertebra sliding downwards on the superior facet of the vertebra below. The area of the intervertebral foramen on this side is therefore reduced. On the convexity of the laterally flexed spine the inferior facet slides upwards on the superior facet of the vertebra below, increasing the diameter of the intervertebral foramen.

If the trunk is moving slowly, tissue tension will be felt at end range and a subject is able to stop a movement short of full end range and protect the spinal tissues from over-stretch. However, rapid movements of the trunk will build up large amounts of momentum. When the subject reaches near end range and tissue tension builds up, the momentum of the rapidly moving trunk will push the spine to full end range, stressing the spinal tissues. In many popular sports, exercises often used in a warm-up are rapid and ballistic in nature and repeated many times. These can lead to excessive flexibility and a reduction in passive stability of the spine.

Individual Differences in Zygapophyseal Joint Orientation

The shape and orientation of the zygapophyseal joints varies between individuals, and in the same individual, between different spinal levels. Viewed from above the joint surfaces may be flat, slightly curved, or show a more pronounced curvature and be C or J shaped. Curved joint surfaces are more common in the upper lumbar levels (L1-2, L2-3, L3-4) but flat joint surfaces are more often seen at the lower lumbar levels (L4-5, L5-S1) (Horwitz and Smith, 1940).

Where the joint surfaces are flat, the angle that they make with the sagittal plane will determine the amount of resistance offered to both forward displacement and rotation (fig 4). The more the joint is oriented in the frontal plane, the more it will resist forward displacement, but the less able it is to resist rotation. This orientation is usually seen at the lower two lumbar levels. When the joint surfaces are aligned more sagitally, the resistance offered to rotation is greater, but that to forward displacement is reduced. Where the joint surfaces are curved, the anteromedial portion of the superior facet (which faces backwards) will resist forward displacement.

At birth the lumbar zygapophyseal joints lie in the frontal plane, but their orientation changes

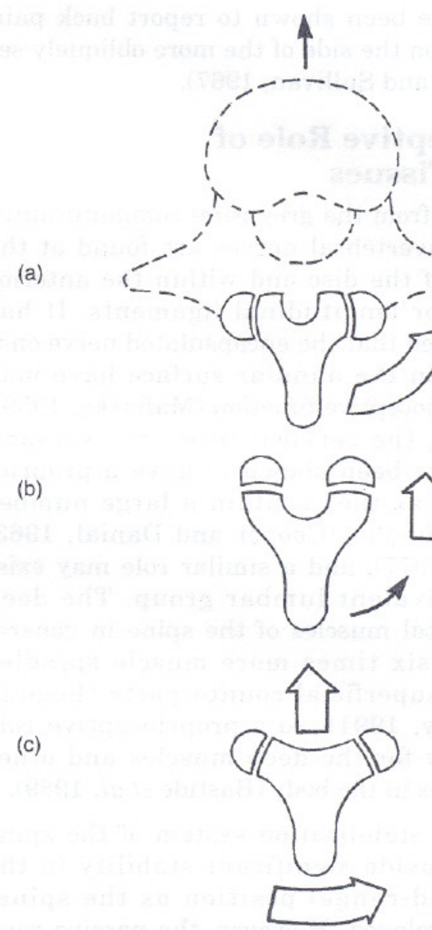


Fig 4: Zygapophyseal joint orientation in:
(a) Sagittal plane will resist rotation but not forward displacement.
(b) Frontal plane will resist forward displacement but not rotation.
(c) Combined plane will resist both movements equally

and they 'rotate' into the adult position by the age of 11 years. Variations occur in the degree, and symmetry, of rotation leading to articular tropism. The incidence of tropism is about 20% at all lumbar levels, and as high as 30% at the lumbosacral level (Bogduk and Twomey, 1987). Tropism will alter the resistance to rotation in the lumbar spine, and has an important bearing on injury. Over 80% of unilateral fissures in the lumbar discs occur in spines where zygapophyseal asymmetry exceeds 10°, with the fissure usually occurring on the side of the more obliquely orientated joint (Farfan *et al*, 1972).

During anterior displacement of the tropic lumbar spine, the upper vertebra of a particular level rotates towards the side of the more frontally oriented zygapophyseal joint. This is because the frontal orientation of the joint provides more resistance to motion causing the vertebra to pivot around this point. This new motion imparts a torsional stress to the annulus of the disc. Over time, the alteration in lumbar mechanics which has occurred can result in an accumulation of stress, and a high number of patients have been shown to report back pain and sciatica on the side of the more obliquely set joint (Farfan and Sullivan, 1967).

Proprioceptive Role of Lumbar Tissues

Nerve fibres from the grey rami communicantes and the sinuvertebral nerves are found at the outer edge of the disc and within the anterior and posterior longitudinal ligaments. It has been suggested that the encapsulated nerve endings found on the annular surface have may have a proprioceptive function (Malinsky, 1959). In addition, the cervical intertransversarii muscles have been shown to have a proprioceptive role as they contain a large number of muscle spindles (Cooper and Danial, 1963; Abrahams, 1977), and a similar role may exist for the equivalent lumbar group. The deep intersegmental muscles of the spine in general have up to six times more muscle spindles than their superficial counterparts (Bogduk and Twomey, 1991), so a proprioceptive role seems likely for the deep muscles and other small muscles in the body (Bastide *et al,* 1989).

The passive stabilisation system of the spine does not provide significant stability in the neutral (mid-range) position as the spinal tissues are relaxed. However, the passive components may have a function in mid range if they act as 'transducers' measuring vertebral positions and motions (Panjabi, 1992). Similar systems are found in the knee ligaments (Barrack *et al,* 1989; Brand, 1986).

Proprioception provides a link between the three stability systems. Muscle force produced by the active system is detected by receptors within the passive tissues and this information is relayed to the neural system. Having measured the muscle tension, the neural system can then adjust this until the required stability of the spine is achieved. Stability in this case is a dynamic process. If one stabilising sub-system is degraded, others can compensate to help maintain stability. In addition there is a functional reserve which may be called on to provide enhanced stability in cases of high demand, for example during heavy lifting.

Injury, disease or disuse may produce a fault in the neural control system which may become chronic. Balance and co-ordination impairment of patients with chronic back pain has been reported, with patients demonstrating greater body sway than normals on balance board tasks (Byl *et al,* 1991). Restoration of balance and co-ordination through proprioceptive training is therefore an important part of spinal rehabilitation.

Muscle Length

Anteroposterior tilting of the pelvis on the femoral heads will change the lumbar lordosis. The lordosis itself is controlled by both intrinsic and extrinsic factors (Bullock-Saxton, 1988). Intrinsic factors include the shape of the sacrum, intervertebral discs and lumbar vertebrae (especially L5), the inclination of the sacral end plate, the length of the iliolumbar ligaments, and the obliquity of the pelvis. Extrinsic factors include the muscles attached to the pelvis and lumbar spine, which will affect pelvic tilt either actively through contraction, or passively through tightness. The abdominal group, hip flexors, lumbar erector spinae, gluteals, and hamstrings can all be considered as extrinsic limiting factors to pelvic tilt (Toppenberg and Bullock, 1986).

The pelvis can be thought of as a 'seesaw' balanced on the hip joints. 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 increases the lumbar lordosis and is commonly a result of lengthening of the abdominal muscles and possibly tightness in the hip flexors. The abdominal muscles have been shown to demonstrate little activity in standing (Sheffield, 1962; Basmajian and Deluca, 1985), which is normally the position in which the increased lordosis is demonstrated. In addition, using standard field tests no correlation has been found between abdominal strength and pelvic tilt (Walker *et al,* 1987). However, a positive correlation has been shown between abdominal muscle length and lordosis (Toppenberg and Bullock, 1986).

Shortening of the iliopsoas has been linked with an increase in lumbar lordosis, with 33% of normal male subjects showing a significant reduction in range of motion (Jorgensson, 1993). The direction of the fibres of iliopsoas means that it exerts considerable compression and shear forces on the lower lumbar spine when contracting maximally. Compression forces may actually exceed trunk weight, while shear forces can equal trunk weight (Bogduk *et al,* 1992). These forces are especially relevant during sit-up exercises (Johnson and Reid, 1991). Shortening of the iliopsoas may also lead to an increase in mobility at the upper lumbar spine and thoracolumbar junction (Jorgensson, 1993) as a compensatory reaction.

In normal subjects, when standing, no significant relationship has been found between hamstring length and either erector spinae length, or pelvic inclination (Toppenberg and Bullock, 1990; Gajdosik *et al*, 1992). However, clinically, patients demonstrating an anterior tilted pelvis and increased lordosis often have a combination of lengthened abdominal musculature and tight hamstrings, a seemingly contradictory situation. It has been suggested that tightness in the hamstrings in this case may be a compensatory mechanism. This may occur firstly to lessen pelvic tilt which has resulted from a combination of tightness in the hip flexors and weakness of the glutei. Secondly the tightness may be from overactivity of the hamstrings as a substitution to supply sufficient hip extension power in the presence of gluteal weakening (Jull and Janda, 1987).

Posterior tilting reduces the lordosis and is commonly seen in sitting, especially with the legs straight. In this case tightness of the hamstrings pulls the posterior aspect of the pelvis down, and fails to allow the pelvis to tilt anteriorly and permit a neutral lordosis (Stokes and Abery, 1980).

The degree of movement available for pelvic tilt is an essential feature for the lumbar-pelvic mechanism. Pelvic tilt itself is more closely related to muscle length than muscle strength, and so it is essential that the length of the muscles attaching to the pelvis be assessed. The imbalance between muscle lengths and the effect this has on resting posture and exercise performance is a key feature of the rehabilitation of active lumbar stabilisation.

References

Abrahams, V C (1977). 'The physiology of neck muscles: Their role in head movement and maintenance of posture', *Canadian Journal of Physiology and Pharmacology*, **55**, 332–338.

Adams, M A and Hutton, W C (1980). 'The effect of posture on the role of the apophyseal joints in resisting intervertebral compression force', *Journal of Bone and Joint Surgery (Br)*, **62B**, 358–362.

Adams, M A and Hutton, W C (1983). 'The mechanical function of the lumbar apophyseal joints', *Spine*, **8**, 327–330.

Adams, M A, Hutton, W C and Stott, J R R (1980). 'The resistance to flexion of the lumbar intervertebral joint', *Spine*, **5**, 245–253.

Basmajian, J V and Deluca, C J (1985). *Muscles Alive*, Williams and Wilkins, Baltimore.

Barrack, R L, Skinner, H B and Buckley, S L (1989). 'Proprioception in the anterior cruciate deficient knee', *American Journal of Sports Medicine*, **17**, 1–6.

Bastide, G, Zadeh, J and Lefebvre, D (1989). 'Are the "little muscles" what we think they are?' *Surgical and Radiological Anatomy*, **11**, 255–256.

Bernhardt, M, White, A A, Panjabi, M M and McGowan, D P (1992). 'Lumbar spine instability' in: Jayson, M I V (ed) *The Lumbar Spine and Back Pain*, 4th edn, Churchill Livingstone, Edinburgh.

Bogduk, N and Twomey, L T (1987, 1991). *Clinical Anatomy of the Lumbar Spine*, 1st and 2nd edns, Churchill Livingstone, Edinburgh.

Bogduk, N, Pearcy, M and Hadfield, G (1992). 'Anatomy and biomechanics of psoas major', *Clinical Biomechanics*, **7**, 109–119.

Brand, R A (1986). 'Knee ligaments: A new view', *Journal of Biomechanical Engineering*, **108**, 106–110.

Bullock-Saxton, J (1988). 'Normal and abnormal postures in the sagittal plane and their relationship to low back pain', *Physiotherapy Practice*, **4**, 94–104.

Byl, N N and Sinnott, P L (1991). 'Variations in balance and body sway in middle-aged adults: Subjects with healthy backs compared with subjects with low-back dysfunction', *Spine*, **16**, 325–330.

Cappozzo, A, Felici, F, Figura, F and Gazzani, F (1985). 'Lumbar spine loading during half-squat exercises', *Medicine and Science in Sports and Exercise*, **17**, 5, 613–620.

Cooper, S and Danial, P M (1963). 'Muscle spindles in man, their morphology in the lumbricals and the deep muscles of the neck', *Brain*, **86**, 563–594.

Crock, H V and Yoshizawa, H (1976). 'The blood supply of the lumbar vertebral column', *Clinical Orthopaedics*, **115**, 6–21.

Farfan, H F, Cossette, J W, Robertson, G H, Wells, R V and Kraus, H (1970). 'The effects of torsion on the lumbar intervertebral joints: The role of torsion in the production of disc degeneration', *Journal of Bone and Joint Surgery*, **52A**, 468.

Farfan, H F, Huberdeau, R M and Dubow, H I (1972). 'Lumbar intervertebral disc degeneration. The influence of geometrical features on the pattern of disc degeneration – A post-mortem study', *Journal of Bone and Joint Surgery*, **54A**, 492–510.

Farfan, H F and Sullivan, J D (1967). 'The relation of facet orientation to intervertebral disc failure', *Canadian Journal of Surgery*, **10**, 179–185.

Gajdosik, R L, Hatcher, C K and Whitsell, S (1992). 'Influence of short hamstring muscles on the pelvis and lumbar spine in standing and during the toe-touch test', *Clinical Biomechanics*, **7**, 1, 38–42.

Hirsch, C and Nachemson, A (1954). 'New observations on mechanical behaviour of lumbar discs', *Acta Orthopaedica Scandinavica*, **22**, 184–189.

Hirsch, C and Schajowicz, F (1952). 'Studies on structural changes in the lumbar annulus fibrosis', *Acta Orthopaedica Scandinavica*, **22**, 184–189.

Horwitz, T and Smith, R M (1940). 'An anatomical, pathological and roentgenological study of the intervertebral joints of the lumbar spine and of the sacroiliac joints', *American Journal of Roentgenology and Radium Therapy*, **43**, 173–186.

Johnson, C and Reid, J G (1991). 'Lumbar compressive and shear forces during various trunk curl-up exercises, *Clinical Biomechanics*, **6**, 2, 97–104.

Jorgensson, A (1993). 'The iliopsoas muscle and the lumbar spine', *Australian Journal of Physiotherapy*, **39**, 2, 125–132.

Jull, G A and Janda, V (1987). 'Muscles and motor control in low back pain: Assessment and management' in: Twomey, L T (ed) *Physical Therapy of the Low Back*, Churchill Livingstone, New York.

Klein, J A and Hukins, D W L (1983). 'Functional differentiation in the spinal column', *Engineering in Medicine*, **12**, 2, 83.

Kornecki, S (1992). 'Mechanism of muscular stabilisation process in joints', *Journal of Biomechanics*, **25**, 3, 235–245.

Kraemer, J, Kolditz, D and Gowin, R (1985). 'Water and electrolyte content of human intervertebral discs under variable load', *Spine*, **10**, 69–71.

Leatt, P, Reilly, T and Troup, J G D (1986). 'Spinal loading during circuit weight-training and running', *British Journal of Sports Medicine*, **20**, 3, 119–124.

Malinsky, J (1959). 'The ontogenetic development of nerve terminations in the intervertebral discs of man', *Acta Anatomica*, **38**, 96–113.

Markolf, K L and Morris, J M (1974). 'The structural components of the intervertebral disc', *Journal of Bone and Joint Surgery*, **56A**, 675.

McKenzie, R A (1990). *The Cervical and Thoracic Spine: Mechanical diagnosis and therapy*, Spinal Publications, Waikanae, New Zealand.

Nachemson, A (1987). 'Lumbar intradiscal pressure' in: Jayson, M I V (ed) *The Lumbar Spine and Back Pain*, 3rd edn, Churchill Livingstone, Edinburgh.

Norkin, C C and Levangie, P K (1992). *Joint Structure and Function: A comprehensive analysis*, 2nd edn, F A Davis, Philadelphia.

Oliver, J and Middleditch, A (1991). *Functional Anatomy of the Spine*, Butterworth-Heinemann, Oxford.

Panjabi, M M (1992). 'The stabilising system of the spine. Part 1. Function, dysfunction, adaptation, and enhancement', *Journal of Spinal Disorders*, **5**, 4, 383–389.

Pearcy, P, Portek, I and Shepherd, J (1984). 'Three dimensional X-ray analysis of normal movement in the lumbar spine', *Spine*, **9**, 294–297.

Richardson, C, Toppenberg, R and Jull, G (1990). 'An initial evaluation of eight abdominal exercises for their ability to provide stabilisation for the lumbar spine', *Australian Journal of Physiotherapy*, **36**, 6–11.

Roaf, R (1960). 'A study of the mechanics of spinal injuries', *Journal of Bone and Joint Surgery (Br)*, **42B**, 810–823.

Rockoff, S F, Sweet, E and Bleustein, J (1969). 'The relative contribution of trabecular and cortical bone to the strength of human lumbar vertebrae', *Calcified Tissue Research*, **3**, 163–175.

Sahrmann, S A (1990). 'Diagnosis and treatment of movement-related pain syndromes associated with muscle and movement imbalances'. Course notes. Washington University.

Sheffield, F J (1962). 'Electromyographic study of the abdominal muscles in walking and other movements', *American Journal of Physical Medicine*, **41**, 142–147.

Stokes, I A F and Abery, J M (1980). 'Influence of the hamstring muscles on lumbar spine curvature in sitting', *Spine*, **5**, 525–528.

Toppenberg, R M and Bullock, M I (1986). 'The interrelation of spinal curves, pelvic tilt and muscle lengths in the adolescent female', *Australian Journal of Physiotherapy*, **32**, 6–12.

Toppenberg, R and Bullock, M (1990). 'Normal lumbo-pelvic muscle lengths and their interrelationships in adolescent females', *Australian Journal of Physiotherapy*, **36**, 105–109.

Tyrrell, A R, Reilly, T and Troup, J D G (1985). 'Circadian variation in stature and the effects of spinal loading', *Spine*, **10**, 2, 161–164.

Virgin, W (1951). 'Experimental investigations into physical properties of intervertebral disc', *Journal of Bone and Joint Surgery*, **33B**, 60.

Walker, M L, Rothstein, J M, Finucane, S D and Lamb, R L (1987). 'Relationships between lumbar lordosis, pelvic tilt, and abdominal muscle performance', *Physical Therapy*, **67**, 4, 512–516.

White, S G and Sahrmann, S A (1994). 'A movement system balance approach to management of musculoskeletal pain', in: Grant, R (ed) *Physical Therapy of the Cervical and Thoracic Spine*, 2nd edn, Churchill Livingstone, Edinburgh.

Yang, K H and King, A I (1984). 'Mechanism of facet load transmission as a hypothesis for low-back pain', *Spine*, **9**, 557–565.