Principles of the Integrated Model of Function and its Application to the Lumbopelvic-hip Region

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INTRODUCTION

This chapter introduces the principles of an integrated model for managing impaired function. This model comes from anatomical and biomechanical studies of the pelvis, as well as from the clinical experience of treating patients with lumbopelvic pain (Lee 2001, Lee & Vleeming 2003). This approach addresses why the pelvis is painful and no longer able to sustain and transfer loads as opposed to one which seeks to identify pain generating structures. Several studies have sought to understand pelvic function. The anatomical research on the SIJ and the connections between it and the lumbopelvic muscles (Snijders et al 1993a, Vleeming et al 1990a,b, Vleeming et al 1995b, Vleeming et al 1996) led to conclusions regarding the role the passive and active elements play in stabilization of the pelvis (form and force closure of joints). The timing of specific muscle activation (Hodges & Richardson 1997a, Hodges 1997b, 2003, Hodges et al 1999, 2001, 2003b, Hungerford 2002) and the pattern of muscular co-contraction (or lack thereof) in patients with low back pain (Danneels et al 2000, Hides et al 1994, Hides et al 1996, Hodges 2003, Hodges & Moseley 2003, Hodges & Richardson 1996, Hungerford 2002, O’Sullivan 2000, O’Sullivan et al 2002) further enhanced the force closure theory and suggested a crucial role for motor control. Based on this knowledge, functional tests for the pelvis were developed (Buyruk et al 1995a,b, 1999, Lee 1999, Mens et al 1999, 2001) and treatment protocols were established (Richardson et al 1999, Lee 1999, O’Sullivan 2000). Clinically, it was soon apparent that the patient’s emotional state could significantly influence the outcome. Over time, the ‘Integrated Model of Function’ was developed (Lee & Vleeming 1998, 2003).

THE INTEGRATED MODEL OF FUNCTION

The integrated model of function has four components – three that are physical

1. form closure (structure),
2. force closure (forces produced by myofascial action) and
3. motor control (specific timing of muscle action/inaction during loading)

and one that is psychological

4. emotions.

The proposal is that joint mechanics can be influenced by multiple factors (articular, neuromuscular and emotional) and that management requires attention to all.

Managing dysfunction requires an understanding of function. A primary function of the lumbopelvic-hip region is to transfer the loads generated by body weight and gravity during standing, walking and sitting (Snijders et al 1993a,b). How well this load is managed dictates how efficient function will be.
According to Panjabi (1992a,b) stability (effective load transfer) is achieved when the passive, active and control systems work together. Snijders & Vleeming (1993a,b) believe that the passive, active and control systems produce approximation of the joint surfaces, essential if stability is to be insured. The amount of approximation required is variable and difficult to quantify since it is essentially dependent on an individual’s structure (form closure) and the forces they need to control (force closure). The term ‘adequate’ has been used (Lee & Vleeming 1998, 2003) to describe how much approximation is necessary and reflects the non-quantitative aspect of this measure. Essentially, it means ‘not too much’ and ‘not too little’; in other words, just enough to suit the existing situation. Consequently, the ability to effectively transfer load through the pelvis is dynamic and depends on:

1. optimal function of the bones, joints and ligaments (form closure or joint congruency) (Vleeming et al 1990a,b).

FORM CLOSURE
The term ‘form closure’ was coined by Vleeming & Snijders (Snijders et al 1993 a,b, Vleeming et al 1990a,b) and is used to describe how the joint’s structure, orientation and shape contribute to stability and potential mobility. All joints have a variable amount of form closure and the individual’s inherent anatomy will dictate how much additional force (force closure) is needed to ensure stabilization when loads are increased. The ‘form’ of the lumbar spine, pelvic girdle and hip (the bones, joints and ligaments) has been described in detail in Chapter 4. The potential mobility (biomechanics) for each region will be discussed in Chapter 6.

The lumbar spine
The ‘form’ of the lumbar spine contributes to its ability to resist compression, torsion and posteroanterior shear, forces encountered during activities of daily living, in the following ways.

Compression
Compression of an object results when two forces act towards each other. The main restraint to compression in the lumbar spine is the vertebral body/annulus–nucleus unit, although the zygapophyseal joints have been noted (Bogduk 1997, Farfan 1973, Gracovetsky et al 1985, Gracovetsky & Farfan 1986, Kirkaldy-Willis 1983) to support up to 20% of the axial compression load. Both the annulus and the nucleus transmit the load equally to the end-plate of the vertebral body. The thin cortical shell of the vertebral body provides the bulk of the compression strength, being simultaneously supported by a hydraulic mechanism within the cancellous core, the contribution of which is dependent upon the rate of loading. When compression is applied slowly (static loading), the nuclear pressure rises distributing its force onto the annulus and the end-plates. The annulus bulges circumferentially and the end-plates bow towards the vertebral bodies. Fluid is squeezed out of the cancellous core via the veins; however, when the rate of compression is increased, the small vessel size may retard the rate of outflow such that the internal pressure of the vertebral body rises, thus increasing the compressive strength of the unit. In this manner, the vertebral body supports and protects the intervertebral disc against compression overload (McGill 2002). The anatomical structure which initially yields to high loads of compression is the hyaline cartilage of the end-plate, suggesting that this structure is weaker than the peripheral parts of the end-plate (Bogduk 1997). The fracture appears radiographically as a Schmorl’s node (Kirkaldy-Willis et al 1978, 1983). This lesion is commonly
seen at the higher lumbar levels. McGill states that the vertebral bony elements fail at the higher load rates whereas the end plate (no specification as to which part) fails first at low rates (McGill 2002). The zygapophyseal joints do not contribute to weight bearing when in the neutral position, given that their sagittal and coronal components are oriented vertically. When the segment is extended, the inferior articular process of the superior vertebra glides inferiorly and impacts the pars interarticularis. When axial compression is applied in this lordotic position, load can be transferred through the inferior articular process to the lamina (Bogduk 1997).

**Torsion or rotation**

When a force is applied to an object at any location other than the center of rotation, it will cause the object to rotate about an axis through this pivot point. The magnitude of the torque force can be calculated by multiplying the quantity of the force by the distance the force acts from the pivot. Axial rotation of the lumbar vertebra occurs when the bone rotates about a vertical axis through the center of the body and is resisted by anatomical factors located within the vertebral arch (65%) as well as by the structures of the vertebral body/intervertebral disc unit (35%) (Bogduk 1997, Gracovetsky & Farfan 1986).

At the lumbosacral junction, the superior articular process of the sacrum is squat and strong in comparison to the inferior articular process of the L5 vertebra which is much longer and receives less support from the pedicle. Consequently, the inferior process is more easily deflected when the zygapophyseal joint is loaded at 90° to its articular surface. This process can deflect 8° to 9° medially during axial torsion beyond which trabecular fractures and residual strain deformation will occur (Bogduk 1997, Farfan 1973).

The structure and orientation of the annular fibres is critical to the ability of the intervertebral disc to resist torsion. ‘The concentric arrangement of the collagenous layers of the annulus ensures that when the disk is placed in tension, shear or rotation, the individual fibres are always in tension’ (Kirkaldy-Willis 1983). Under static loading conditions, injuries occur with as little as 2° and certainly by 3.5° of axial rotation (Gracovetsky & Farfan 1986). The iliolumbar ligament plays an important role in minimizing torque forces at the lumbosacral junction. The longer the transverse process of the L5 vertebra and consequently the shorter the iliolumbar ligament, the stronger is the resistance of the segment to torsion (Farfan 1973).

Axial compression also increases the segmental torque strength by 35% (Gracovetsky & Farfan 1986). During forward flexion of the lumbar spine, the instantaneous center of rotation moves forward thus increasing the compressive load and consequently the ability of the joint to resist torsion (Farfan 1973, Gracovetsky & Farfan 1986).

**Posteroanterior translation**

Translation occurs when an applied force produces sliding between two planes. Posteroanterior translation occurs in the lumbar spine when a force attempts to displace a superior vertebra anterior to the one below. The anatomical factors which resist posteroanterior shear at the lumbosacral junction are primarily the impaction of the inferior articular processes of L5 against the superior articular processes of the sacrum and the iliolumbar ligaments (Bogduk 1997). Secondary factors include the intervertebral disc, the anterior longitudinal ligament, the posterior longitudinal ligament and the midline posterior ligamentous system (Twomey & Taylor 1985).

Dynamically, the posterior midline ligaments, the thoracodorsal fascia and the muscles which generate tension within this system are important in balancing the anterior shear forces which occur when large loads are lifted (force closure) (Adams & Dolan 1997, Bogduk 1997, Gracovetsky & Farfan 1986, Hides et al 1994, 1996, Hodges & Richardson 1996, Hodges et al 2003b, Richardson & Jull 1995, Vleeming et al 1990a,b, 1995a, 1997). The optimal method of loading the spine should balance both compression and translation such that the magnitude of the resultant force does not exceed the strength of the joint. Consequently, both the articular (form closure) and the myofascial components (force closure) are required to balance the moment of a large external load.

**The pelvic girdle**

How does the ‘form’ of the pelvic girdle contribute to stability of the sacroiliac joints (SIJs)? The SIJs transfer large loads and their shape is adapted to this task. The articular surfaces are relatively flat and this helps to transfer compression forces and bending moments (Snijders et al 1993a,b, Vleeming et al 1990a,b). However, a relatively flat joint is theoretically more vulnerable to shear forces. The SIJ is anatomically protected from shear in
three ways. First, the sacrum is wedge-shaped in both the antero-posterior and vertical planes and thus is stabilized by the innominates.

The articular surface of the SIJ is comprised of two to three sacral segments and each is oriented differently (Solonen 1957). Secondly, in contrast to other synovial joints, the articular cartilage is not smooth but irregular, especially on the ilium (Sashin 1930, Bowen & Cassidy 1981), Chapter 4). Thirdly, a frontal dissection through the SIJ reveals cartilage covered bony extensions protruding into the joint (Vleeming et al 1990a), the ridges and grooves. They seem irregular, but are in fact complementary. All three factors enhance stabilization of the SIJ when compression (force closure) is applied to the pelvis. Again, both the articular (form closure) and the myofascial components (force closure) are required to balance the moment of a large external load.

The pubic symphysis has less form closure than the SIJ in that the joint surfaces are relatively flat. The joint surfaces are bound by a fibrocartilaginous disc which is supported externally by superior, inferior, anterior and posterior ligaments. The pubic symphysis is vulnerable to shear forces in both the vertical and horizontal plane and relies on dynamic elements (myofascia), in addition to the passive structures, for stability.

The hip
The hip is subjected to forces equal to multiples of the body weight and requires osseous, articular and myofascial integrity for stability. The ‘form closure’ factors which contribute to stability at the hip include the anatomical configuration of the joint as well as the orientation of the trabeculae and the orientation of the capsule and the ligaments during habitual movements.

During erect standing, the superincumbent body weight is distributed equally through the pelvic girdle to the femoral heads and necks. Each hip joint supports approximately 33% of the body weight which subsequently produces a bending moment between the neck of the femur and its shaft (Singleton & LeVeau 1975). A complex system of bony trabeculae exists within the femoral head and neck to prevent superoinferior shearing of the femoral head during erect standing (Kapandji 1970). The hip joint is an unmodified ovoid joint, a deep ball and socket, and its shape precludes significant shearing in any direction yet facilitates motion (Ch.6).

FORCE CLOSURE

If the articular surfaces of the lumbar spine, pelvic girdle and hip were constantly and completely compressed, mobility would not be possible. However, compression during loading is variable and therefore motion is possible (Ch. 6) and stabilization required. This is achieved by increasing compression across the joint surface at the moment of loading (force closure). The amount of force closure required depends on the individual’s form closure and the magnitude of the load. The anatomical structures responsible for force closure are the ligaments, muscles and fascia.

For every joint, there is a position called the close-packed, or self-locked, position in which there is maximum congruence of the articular surfaces and maximum tension of the major ligaments. In this position, the joint is under significant compression and the ability to resist shear forces is enhanced by the tension of the passive structures and increased friction between the articular surfaces (Vleeming et al 1990b, Snijders et al 1993a,b). For the zygapophyseal joints of the lumbar spine this position is end range extension, for the sacroiliac joints full nutation of the sacrum or posterior rotation of the innominate (Vleeming et al 1989a,b, van Wingerden et al 1993) and for the hip joint extension combined with abduction and internal rotation.

Studies have shown (Egund et al 1978, Hungerford 2002, Lavignolle et al 1983, Sturesson et al 2000) that
nutation of the sacrum occurs bilaterally whenever the lumbopelvic spine is loaded. The amount of sacral nutation varies with the magnitude of the load. Full sacral nutation (self-locking or close packing) occurs during forward and backward bending of the trunk (Sturesson et al 2000). Counternutation of the sacrum, or anterior rotation of the innominate, is thought to be a relatively less stable position for the SIJ. The long dorsal ligament becomes taut during this motion; however, the other major ligaments (sacrotuberous, sacrospinous and interosseous) are less tensed (Vleeming et al 1996).

The orientation of the capsule and the articular ligaments of the hip joint contribute to force closure of the hip during functional motions. Extension of the femur winds all of the extra-articular ligaments around the femoral neck and renders them taut. The inferior band of the iliofemoral ligament is under the greatest tension in extension. Flexion of the femur unwinds the ligaments, and when combined with slight adduction, predisposes the femoral head to posterior dislocation if sufficient force is applied to the distal end of the femur (e.g. dashboard impact).

During lateral rotation of the femur, the iliotrochanteric band of the iliofemoral ligament and the pubofemoral ligament become taut while the ischiofemoral ligament becomes slack. Conversely, during medial rotation of the femur, the anterior ligaments become slack while the ischiofemoral ligament becomes taut (Hewitt et al 2002).

Abduction of the femur tenses the pubofemoral ligament, and the inferior band of the iliofemoral ligament as well as the ischiofemoral ligament. At the end of abduction, the neck of the femur impacts onto the acetabular rim, thus distorting and evertting the labrum (Kapandji 1970). In this manner, the acetabular labrum deepens the articular cavity (improving form closure) thus increasing stability without limiting mobility. Adduction results in the iliotrochanteric band of the iliofemoral ligament while the others remain relatively slack. Adduction of the flexed hip tightens the ischiofemoral ligament (Hewitt et al 2002). The ligamentum teres is under moderate tension in erect standing as well as during medial and lateral rotation of the femur.

Function would be significantly compromised if joints could only be stable in the close-packed position. In the neutral spinal position, an osteoligamentous spine (T1 to sacrum with no muscles attached) will buckle under approximately 20N (about 4.4 lb) of compression load (Lucas & Bresler, 1961, Panjabi et al 1989, Panjabi 1992a,b). Stability for load transfer is required throughout the entire range of motion and this is provided by the active, or neuromyofascial, system.

In 1989, Bergmark proposed that muscles could be classified into two systems – a local and a global system (Bergmark 1989). The local system pertains to those muscles essential for segmental or intrapelvic stabilization while the global system appears to be more responsible for regional stabilization (between the thorax and pelvis or pelvis and legs) and motion (Bergmark 1989, Comerford & Mottram 2001, Richardson et al 1999). There is a significant neurophysiological difference in the timing of contraction of these two muscle systems. When loads are predictable, the local system contracts prior to the perturbation (in anticipation) regardless of the direction of movement (Hodges & Richardson 1997a, Hodges 1997b, 2003, Hodges et al 1999, 2001c, Moseley et al 2002, Moseley et al 2003) whereas the global system contracts later and is direction dependant (Radebold et al 2000, 2001, Hodges 2003). While some researchers have embraced this classification (Comerford & Mottram 2001, Richardson et al 1999) others have not (McGill 2002).

The research is still lacking which enables classification of all muscles according to this system and clinically it appears that parts of some muscles may belong to both systems.
With respect to the lumbopelvic region, the following muscles fit the criteria for classification as local stabilizers - the muscles of the pelvic floor (Bo et al 1994, Constantinou & Govan 1982, Hodges 2003, Sapsford et al 2001), the transversus abdominis (Hodges & Richardson 1997a,b, Hodges 2003), the diaphragm (Hodges & Gandevia 2000a,b, Hodges 2003) and the deep fibres of multifidus (Moseley et al 2002, 2003). As research continues, more muscles will likely be added to this list. The deep (medial) fibres of psoas (Gibbons et al 2002), the medial fibres of quadratus lumborum (Bergmark 1989, McGill 2002), the lumbar parts of the lumbar iliocostalis and longissimus (Bergmark 1989) and the posterior fibres of the internal oblique (Bergmark 1989, O'Sullivan 2000) are some likely candidates. This text will focus on those in which the research clearly indicates that they are local stabilizers; however, it is not the intent to state that they are the only muscles that fit this role.

The role of the local muscle system

The function of the lumbopelvic local system is to stabilize the joints of the spine and pelvic girdle in preparation for (or in response to) the addition of external loads. This is achieved through several mechanisms some of which include:

- increasing the tension of the thoracodorsal fascia (Cresswell 1993, Hodges 2003, Hodges et al 2003b, Vleeming et al 1995a, Willard 1997) and/or
- increasing the articular stiffness (Hodges et al 1997a, Hodges 2003, Richardson et al 2002).

Research has shown (Bo & Stien 1994, Constantinou & Govan 1982, Hodges 1997b, Hodges & Gandevia 2000a,b, Hodges 2003, Hungerford 2002, Moseley et al 2002, 2003, Sapsford et al 2001) that when the central nervous system can predict the timing of the load, the local system is anticipatory when functioning optimally. In other words, these muscles should work at low levels at all times and increase their action before any further loading or motion occurs.

Transversus abdominis

Dr. Paul Hodges' first PhD focused on the role of transversus abdominis in healthy individuals and the response of this muscle in patients with low back pain (Hodges & Richardson 1996, 1997a). He was able to show that transversus abdominis is an anticipatory muscle for stabilization of the low back and is recruited prior to the initiation of any movement of the upper or lower extremity. He also showed that this anticipatory recruitment of transversus abdominis is absent or delayed in patients with low back pain. Dr. Paul Hodges has just completed his second PhD (2003 – Neuromechanical control of the spine). This series of studies provides further information on how lumbopelvic stability is achieved. According to Hodges (2003) a key finding from this research is that:

‘When the upper limbs were moved rapidly in response to a light, the anticipatory postural adjustment did not stiffen the trunk, but rather there was a consistent pattern of trunk motion that was specific to the direction of limb movement.’

Stability is achieved through motion, not rigidity. Small angular displacements of the vertebra preceded the limb movement and occurred in the opposite direction (preparatory movement) to the predicted movements of the segment (resultant movement). In other words, during rapid bilateral flexion of the upper limbs, a small amount of segmental extension occurred in the lumbar spine (preparatory movement) before the arms moved (flexed). After the arms flexed, the lumbar segments flexed (resultant movement) a small amount. The opposite preparatory and resultant movements were noted during bilateral extension of the upper limbs. Transversus abdominis was the first trunk muscle recruited in all of these experiments yet did not render the trunk rigid. Hodges (2003) proposes that movement is used to dissipate or dampen the imposed internal and external forces which occur as a result of the perturbation. Therefore optimal stability requires mobility and a finely tuned motion control system. The clinical application of this research (Ch. 10) supports exercise programs which foster mobile stability (movements with control) as opposed to rigidity and bracing.

As part of a very interesting study with pigs, Hodges (Hodges et al 2003b) differentiated a) the role of intra-
abdominal pressure (IAP), b) the vertebral attachments of the crura of the diaphragm and c) the fascial attachments of the middle layer of the thoracolumbar fascia on stability (resistance to flexion and extension) at L3-4. The pigs were anaesthetized and pins inserted into the spinous processes of L3 and L4. The resistance to segmental flexion and extension of L3-4 was measured under different conditions.

1. The phrenic nerve was stimulated and the impact of an isolated contraction of the diaphragm on IAP and consequential stiffness (resistance to flexion/extension) at L3-4 was noted. The IAP increased approximately 5 cm H2O and the resistance to flexion at L3-4 increased approximately 10%. There was no difference in the resistance to extension at L3-4.

2. Transversus abdominis was electrically stimulated bilaterally. The intensity of the stimulus was set such that the IAP increased to similar levels as those in the phrenic nerve stimulation trials (#1). The impact of this stimulation on stiffness (resistance to flexion/extension) at L3-4 was noted. Again, resistance increased to flexion at L3-4 but not statistically to extension (although a trend was noted). When transversus abdominis was stimulated unilaterally there was no change in the resistance to either flexion or extension at L3-4. Therefore a bilateral contraction of transversus abdominis is required for stiffness at L3-4 to be increased.

3. To differentiate the role of IAP from the mechanical role of the crura of the diaphragm and the fascial attachments of transversus abdominis three further experiments were done:
   a. A small incision was made in the abdominal wall and the phrenic nerve was stimulated to produce an isolated contraction of the diaphragm. It was noted that the IAP decreased to 17% of the IAP which occurred when the abdomen was closed. Subsequently, the resistance to flexion and extension was measured at L3-4 (the diaphragm was stimulated through the phrenic nerve) and no change was noted. Therefore, the IAP is a significant contributor to resisting flexion at L3-4 (contraction of the diaphragm increased the IAP which in turn produces an extensor moment).
   b. The crura of the diaphragm were then cut and the abdomen closed. When a contraction of the diaphragm occurred through stimulation via the phrenic nerve, the IAP had returned to 87% of the previous measures (#1 above). Subsequently, the resistance to flexion and extension was measured at L3-4 and as previously observed there was an increase in the resistance to flexion. However, in addition, the resistance to extension was significantly decreased suggesting that the crura of the diaphragm provide some mechanical control for extension at L3-4.
   c. The middle layer of the thoracolumbar fascia was cut from the transverse processes at L2-5 first unilaterally and then bilaterally. In both trials, the resistance to flexion and extension was measured at L3-4 following bilateral stimulation of transversus abdominis. Although the IAP increased with the contraction of TrA, there was no difference in the stiffening effect in flexion and a reduction in the stiffness of extension. TrA appears to play a mechanical role (along with the crura of the diaphragm) through its fascial attachments in resisting extension at L3-4.

In conclusion, the IAP, the fascial attachments of transversus abdominis and the crura of the diaphragm play a significant role in controlling flexion and extension in the lumbar spine (measured only at L3-4). The IAP is increased through contraction of both the diaphragm and transversus abdominis and produces an extension moment (resistance to flexion). Extension is resisted by the fascial attachments of transversus abdominis and the crural attachments of the diaphragm.

Although it does not cross the SIJ directly, the transversus abdominis has an impact on stiffness of the SIJ (Richardson et al 2002) through, in part, its direct pull on the large attachment to the middle layer and the deep lamina of the posterior layer of the thoracodorsal fascia (Barker & Briggs 1999). Richardson et al (2002) propose that contraction of the transversus abdominis produces a force which acts on the ilia perpendicular to the sagittal plane (i.e. approximates the ilia anteriorly). They also propose that the ‘mechanical action of a pelvic belt in front of the abdominal wall at the level of the transversus abdominis corresponds with the action of this muscle’. At this time, the specific direction of force produced by an isolated contraction of transversus abdominis (i.e. without co-activation of multifidus) has not been validated through research but this hypothesis has been developed clinically as a means for diagnosis and exercise prescription (see ASLR – Ch. 6).

In a study of patients with chronic low back pain, a timing delay or absence was found in which transversus abdominis failed to anticipate the initiation of arm and/or leg motion (Hodges & Richardson 1997a, 1999, Hodges 2001b, Hodges 2003). Delayed activation of transversus abdominis means that the thoracodorsal fascia is not pretensed and the joints of the low back and pelvis are therefore not stiffened (compressed) in preparation for external loading and are potentially vulnerable to losing intrinsic stability.
Deep fibres of multifidus
Moseley et al (2002) have shown that the deep fibres of the multifidus muscle are also anticipatory for stabilization of the lumbar region and are recruited prior to the initiation of any movement of the upper extremity when the timing of the load is predictable (Moseley et al 2003). In contrast, the superficial and lateral fibres of the multifidus muscle were shown to be direction dependent. In the pelvis, this muscle is contained between the dorsal aspect of the sacrum and the deep layers of the thoracodorsal fascia.

When the deep fibres of the multifidus contract, the muscle can be felt to broaden or swell. As the deep fibres of multifidus broaden, they ‘pump up’ the thoracodorsal fascia much like blowing air into a balloon (Gracovetsky 1990, Vleeming et al 1995a). Using the Doppler imaging system, Richardson et al (2002) noted that a co-contraction of multifidus and transversus abdominis increased the stiffness of the SIJ. These authors state that ‘Under gravitational load, it is the transversely oriented muscles that must act to compress the sacrum between the ilia and maintain stability of the SIJ’. Although multifidus is not oriented transversely, its contraction tenses the thoracodorsal fascia and it is likely this structure which imparts compression to the posterior pelvis. This has yet to be scientifically verified; however, this hypothesis has been developed clinically as a means for diagnosis and exercise prescription (Lee 2002) (see ASLR – Ch. 8).

Several investigators (Danneels et al 2000, Hides et al 1994, Hungerford 2002, Moseley et al 2002, O’Sullivan 2000,) have studied the response of multifidus in low back and pelvic pain patients and note that multifidus becomes inhibited and reduced in size in these individuals. The normal ‘pump-up’ effect of multifidus on the thoracodorsal fascia, and therefore its ability to compress the pelvis, is lost when the size or function of this muscle is impaired. Rehabilitation requires both retraining (Hides et al 1996, O’Sullivan et al 1997) and hypertrophy of the muscle (Danneels et al 2001) for the restoration of proper force closure of the lumbopelvic region.

Together, multifidus and transversus abdominis (along with their fascia) form a corset of support for the lumbopelvic region, the ‘circle of integrity’.

The pelvic floor
The ‘roof and floor’ of this local system are supported by the muscles of the pelvic floor and the respiratory diaphragm. The muscles of the pelvic floor play a critical role in both stabilization of the pelvic girdle as well as in the maintenance of urinary and fecal continence (Ashton-Miller et al 2001, Bo & Stein 1994, Constantinou & Govan 1982, Dietz et al 2003, Peschers et al 2001a, Sapsford et al 2001). Constantinou & Govan (1982) measured the intra-urethral and intra-bladder pressures in healthy continent women during coughing and valsalva (bearing down) and found that during a cough the intra-urethral pressure increases approximately 250ms before any pressure increase is detected in the bladder. This suggests that the urethra anticipates the impending load during coughing. The increase in urethral pressure occurred simultaneously with the increase in bladder pressure during a valsalva (no urethral anticipation). Constantinou & Govan suggest that the timing difference in pressure generation within the urethra and bladder during a cough versus a valsalva may be due to the contraction of the pelvic floor during a cough and relaxation of the pelvic floor during a valsalva.

Sapsford et al (2001) investigated the co-activation pattern of the pelvic floor and the abdominals via needle EMG for the abdominals and surface EMG for the pelvic floor. In two subjects, fine-wire needle EMG was used to detect activation of the right pubococcygeus through the lateral vaginal wall. They found that the abdominals contract in response to a pelvic floor contraction command and that the pelvic floor contracts in response to both a ‘hollowing’ and ‘bracing’ abdominal command. The results from this research suggest that the pelvic floor can be facilitated by co-activating the abdominals and visa versa. Constantinou & Govan’s suggestion that there may be a reflex connection between the pelvic floor and the urethra is supported by this research.
The diaphragm

The diaphragm is traditionally considered to be a respiratory muscle. Hodges (2003), Hodges et al (1997a,b), Hodges & Gandevia (2000a,b) investigated the role of the diaphragm as a stabilizer of the trunk during perturbation studies involving rapid, single (Hodges et al 1997b, Hodges et al 2001c) and rapid, repetitive (Hodges & Gandevia 2000b, Hodges et al 2001c) shoulder flexion. They found that EMG activity in both the costal and crural portions of the diaphragm occurred simultaneously with the transversus abdominis and approximately 20ms prior to any EMG activity noted in the deltoid. They also noted that the anticipatory activity of the diaphragm depends on the magnitude of the perturbation and occurred regardless of the phase of respiration in which the shoulder was rapidly moved (Hodges et al 1997d). This research supports the classification of the diaphragm acting as a local stabilizer of the trunk in addition to its respiratory responsibilities.

Hodges et al (2000a,b) also noted that when loads to the trunk are sustained, the diaphragm responds tonically throughout the respiratory cycle for postural support of the trunk and simultaneously modulates this tonic activation to control the intrathoracic pressure necessary for breathing. An interesting pattern between the amplitude of activation of the diaphragm and the transversus abdominis was noted in the initial study (2000a).

‘The amplitude of diaphragm EMG was higher in inspiration than expiration. The opposite pattern of activity modulation was found for both the right and left TrA. Similar to the diaphragm, TrA was active throughout the respiratory cycle and was modulated with respiration, but the amplitude of TrA EMG was higher during expiration.’ (Hodges et al 2000a).

When repetitive and sustained (10s) perturbation of the trunk was added to the experiment (2000b) another modulation of diaphragm activity was seen. There was a phasic modulation of activity which occurred at the frequency of the limb movement superimposed on the respiratory and tonic/postural activation!

‘Our data suggest that diaphragm EMG has three components: increased tonic activity, phasic modulation with respiration and phasic modulation with movement.’ (Hodges et al 2000b).

In a subsequent study (Hodges et al 2001d), they note that the tonic function (as well as the phasic modulation associated with arm movement) of both the diaphragm and transversus abdominis was reduced or absent after only 60 seconds of hypercapnoea.

Blaney & Sawyer (1997) measured the amplitude of descent of the diaphragm from functional residual capacity to maximal inspiration in subjects who were about to undergo upper abdominal surgery and found the average displacement of the crural portion to be 5.5cm ± 1.1 cm pre-operatively. No significant difference was noted between abdominal vs lateral costal expansion breathing patterns. Post-operatively, the amplitude of the diaphragm descent decreased to 2.0 cm ± 1.0 cm (58% decrease) and again no significant difference was noted between the two breathing patterns. However, they did note that when the subject was instructed to just take a deep breath the amplitude of descent was much less and concluded that the proprioceptive input from the therapist's hands can play a significant role in the excursion of the diaphragm. Blaney et al (1999) subsequently measured diaphragmatic displacement during tidal breathing maneuvers (quiet breathing – not forced, not full) and noted that the excursion of the diaphragm varied with the pattern of breathing. They measured diaphragm displacement during upper chest, abdominal and lateral costal breathing and found the mean amplitude to be 2.2, 3.1 and 2.4 cm respectively. Optimally, Detroyer (1989) has found that quiet breathing should consist of 60% lateral costal expansion and 40% upper abdominal motion.

Summary

In conclusion, when the local system is functioning optimally, it provides anticipatory intersegmental stiffness of the joints of the lumbar spine (Hodges et al 2003b) and pelvis (Richardson et al 2002). This external force (force closure) augments the form closure (shape of the joint) and helps to prevent excessive shearing at the time of loading. This stiffness/compression occurs prior to the onset of any movement and prepares the low back and pelvis for additional loading from the global system. Simultaneously, the diaphragm maintains respiration while the pelvic floor assists in maintaining the position of the pelvic organs (continence) as load is transferred through the pelvis.

The role of the global muscle system

In the past, four slings of muscle systems which stabilize the pelvis regionally (between the thorax and legs) have been described (Vleeming et al 1995a,b, Snijders et al 1993a). The posterior oblique sling contains connections between the latissimus dorsi and the gluteus maximus through the thoracodorsal fascia. The anterior oblique
sling contains connections between the external oblique, the anterior abdominal fascia and the contralateral internal oblique abdominal muscle and adductors of the thigh. The longitudinal sling connects the peronei, the biceps femoris, the sacrotuberous ligament, the deep lamina of the thoracodorsal fascia and the erector spinae. The lateral sling contains the primary stabilizers for the hip joint namely the gluteus medius/minimus and tensor fascia latae and the lateral stabilizers of the thoracopelvic region.

These muscle slings were initially classified to gain a better understanding of how local and global stability of the pelvis could be achieved by specific muscles. It is now recognized that although individual muscles are important for regional stabilization as well as for mobility, it is critical to understand how they connect and function together. A muscle contraction produces a force that spreads beyond the origin and insertion of the active muscle. This force is transmitted to other muscles, tendons, fasciae, ligaments, capsules and bones that lie both in series and in parallel to the active muscle. In this manner, forces are produced quite distant from the origin of the initial muscle contraction. These integrated muscle systems produce slings of forces that assist in the transfer of load. Van Wingerden et al (2001, submitted) used the Doppler imaging system to analyze the effect of contraction of the biceps femoris, erector spinae, gluteus maximus and latissimus dorsi on compression of the SIJ. None of these muscles directly crosses the SIJ yet each was found to effect compression (increase stiffness) of the SIJ.

The global system of muscles is essentially an integrated sling system, comprised of several muscles, which produces forces. A muscle may participate in more than one sling and the slings may overlap and interconnect depending on the task being demanded. The hypothesis is that the slings have no beginning or end but rather connect to assist in the transference of forces. It is possible that the slings are all part of one interconnected myofascial system and the particular sling (anterior oblique, posterior oblique, lateral, longitudinal), which is identified during any motion, is merely due to the activation of selective parts of the whole sling.

The identification and treatment of a specific muscle dysfunction (weakness, inappropriate recruitment, tightness) is important when restoring global stabilization and mobility (between the thorax and pelvis or between the pelvis and legs) and for understanding why parts of a sling may be inextensible (tight) or too flexible (lacking in support).

MOTOR CONTROL

Motor control pertains to patterning of muscle activation (Comerford & Mottram 2001, Danneels et al 2001, Hodges 2003, Hodges et al 1996, 2000, Moseley et al 2002, O’Sullivan et al 1997, O’Sullivan 2000, Richardson et al 1999), in other words, the timing of specific muscle action and inaction. Efficient movement requires coordinated muscle action, such that stability is ensured while motion is controlled and not restrained (Hodges et al 2001c, Hodges 2003). With respect to the lumbopelvic region, it is the coordinated action between the local and global systems that ensures stability without rigidity of posture and without episodes of collapse. Exercises that focus on sequencing muscle activation are necessary for restoring motor control (Lee 2001a, Lee 2003, Richardson et al 1999). The exercises in Chapter 10 focus on balancing tension and releasing compression within the slings of muscle systems and involve an extensive use of imagery. Imagery has been shown (Franklin 1996, Gandevia 1999, Yue & Cole 1992) to be effective in restoring neural patterning and increasing strength. Using imagery and specific sequencing of muscle activation, individual muscles are strengthened, lengthened and appropriately timed/patterned during functional tasks.

EMOTIONS

Written by Dr. Andry Vleeming (from Lee & Vleeming 2003)

Emotional states can play a significant role in human function, including the function of the neuro-musculo-skeletal system. Many chronic pelvic pain patients present with traumatized life experiences in addition to their functional complaints. Several of these patients adopt motor patterns indicative of defensive posturing which suggest a negative past experience. A negative emotional state leads to further stress. Stress is a normal response intended to energize our system for quick flight and flight reactions. When this response is sustained, high levels of adrenaline and cortisol remain in the system (Holstege et al 1996) in part due to circulating stress related neuropeptides (Sapolsky et al 1997a,b) which are released in anticipation of defensive or offensive behavior.

Emotional states (fight, flight or freeze reactions) are physically expressed through muscle action and when
sustained, influence basic muscle tone and patterning (Holstege et al 1996). If the muscles of the pelvis become hypertonic, this state will increase compression of the SIJs (Richardson et al 2002, van Wingerden et al 2001). It is important to understand the patient’s emotional state since the detrimental motor pattern can often only be changed by affecting the emotional state. Sometimes, it can be as simple as restoring hope through education and awareness of the underlying mechanical problem (Butler & Moseley 2003, Hodges & Moseley 2003). Other times, professional cognitive behavioral therapy is required to retrain more positive thought patterns. A basic requirement for cognitive and physical learning is focused, or attentive, training – in other words not being absent-minded. Teaching an individual to be ‘mindful’ or aware of what is happening in their body during times of physical and/or emotional loading can reduce sustained, unnecessary muscle tone and therefore joint compression (Murphy 1992).

CONCLUSION

It has been long recognized that physical factors impact joint function. The model presented here suggests that joint mechanics can be influenced by multiple factors, some intrinsic to the joint itself while others are produced by muscle action which in turn is influenced by the emotional state. The effective management of pain in the lumbopelvic-hip region which is associated with dysfunction requires attention to all four components – form closure, force closure, motor control and emotions with the goal being to guide patients towards a healthier way to live and move. This text will focus on the assessment and treatment of the first three components of this model and its application to the lumbar spine, pelvic girdle and hip.