INFLUENCE OF MUSCULAR IMBALANCES ON PELVIC POSITION AND LUMBAR LORDOSIS: A THEORETICAL BASIS

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Abstract

This body of research originated as the theoretical basis for part of a dissertation.

The aim of this literature review was to obtain a clear picture of the relationships between individual systems which contribute to the development of muscle imbalances. In particular the relationships involved in activation of muscles located in the abdominal wall and back, the position of the pelvis and spine, the associated skeletal muscles found in these areas, as well as the behavior of abdominal muscles in relation to breathing. Based on an analysis of the literature, it was possible to make some generalizations that should be taken into account during the planning of scientific experiments, as well as the planning of preventive or therapeutic strengthening exercises:

1) There is a mutual relationship between the position of the pelvis and the shape of the spine, as well as the function of the abdominal and back muscles.
2) The position of the pelvis and the shape of the lumbar spine are subject to influence from other parts of the musculoskeletal system. These influences come from both the lower limbs and the upper regions of the torso.
3) Skeletal muscle structure, pelvic position and the shape of the spine vary with age. There is a relative increase in the number of slow-twitch fibres within the muscles, which leads to changes in postural functionality. The pelvis gradually tilts forward and results in horizontalization of the sacrum and a deepening of lumbar lordosis.
4) Previously noted age-related changes can exacerbate pathological conditions of the lower back.
5) Muscles can generally be divided into two groups: those muscles which are primarily involved in local stabilization and those primarily involved in movement and coordination of multiple sections of the musculoskeletal system.

Key words: *abdominal muscles; breathing; pelvic position; skeletal muscle structure; muscular imbalance*

INTRODUCTION

The aim of this literature review was to obtain new information from those areas that are important for understanding the functional relationships between the pelvis and spine, and which relationships can influence diagnostic and therapeutic rehabilitation procedures.

REVIEW

A fairly typical change in pelvic shape involves pelvic torsion (Rychlíková 2002, Lewit 2003). Clinically, this is a well-known state and is quite often seen in rehabilitation practices. With these types of changes in shape we find asymmetry in the position of the anterior and posterior superior spines. In an overwhelming number of cases, the plane of the right anterior superior spine tilts into a position below the plane of the left posterior superior spine.

Lewit (2003) stated that "the right posterior superior spine is usually located higher than the left". Uneven heights of the anterior and posterior spines during torsion of the pelvis, were noted by Rychlíková (2002), although there is no comment regarding which spine was above and which was below.

Greenman described other changes in pelvic shape (1986) and called it "innominate shear dysfunction". This theory describes asymmetry in the position of the anterior superior spine only. According to Greenman, one anterior superior iliac spine protrudes medially (in-flare) and the other is flattened laterally (out-flare).

Silverstolpe (1989) defined "pelvic dysfunction", although it was not clearly described and the authors make no mention of asymmetry of the pelvis and sacroiliac joint.

Cummings et al. (1993), Cibulka et al. (1998), and Freburger and Riddle (1999) describe a variety of pelvic asymmetries (such as anterior or posterior pelvic rotation), which were characterized by changes in positions of the anterior superior iliac spine and the posterior superior iliac spine. In some of this work, the types of SI joint dysfunction are described, but the implications of the dysfunction are not made clear.

The above mentioned authors only described normal and pathological functions of the SI joint in the craniocaudal direction, e.g. Lewit's sacroiliac shift. None of the authors considered the possible effects of the described pathology on the function of SI joints in other directions, including the posteroanterior direction, which is commonly seen in clinics. Thus, from the above descriptions, it was not possible to form a complete spatial image of SI joint function. Additionally, the magnitude of individual spine displacements relative to shape changes went without comment.

The position and movement of the pelvis are under the influence of a number of factors, including skeletal muscles that are attached to the pelvis (primarily the abdominal and back muscles) and the position of the spine and sacrum, which is also part of the pelvis.

When studying the function of abdominal wall muscles and back muscles, two methods are generally used: a histochemical analysis of skeletal muscle fibers, and kinesiological electromyography. The first method reveals the construction of skeletal muscles relative to different types of muscle fibers. Their composition depends on skeletal muscle function. Monitoring electrical activity in skeletal muscles via EMG, enables the study of muscle movement timing. The combined results provide better insights into the tonic postural activity of muscles in the abdominal wall and back (Caix et al. 1984).

It can also be expected that the structure and function of skeletal muscle will change with age, as well as with various pathological conditions of the spine, especially those in the lumbar region, which is commonly referred to as "low back pain".

Knowledge of the internal structure and arrangement of skeletal muscles is also useful when considering the tonic postural functions of the muscles in the abdominal wall and back. In animals, it has been shown that postural muscles have a higher content of collagen fibers (tissue) than phasic muscles. For example, the cross-sectional areas of the *m. soleus* and *m. triceps surae* have a greater percentage of endomysium and perimysium than phasic muscles such as the *m. rectus femoris* (Kovanen et al. 1984, Kovanen, 1989).

On the other hand, it can be expected that the shape and position of the spine will have a reverse effect on skeletal muscle activity (Claus et al. 2009). Various static and dynamic studies of pelvic positioning and its dependence on different regions of the spine were primarily carried out via X-rays taken from a lateral projection.

Abdominal and back muscles are understandably involved in muscular chains that pass through the entire body. If body weight is distributed unequally, then there will be pathological flexion or extension in muscle chains, which will further disturb the balance of the abdominal and back muscles. The primary location of these muscle chains tend to be in remote areas of the body (Tichý 2009).

Activation of the muscles in the abdominal wall and back

Alvim et al. (2010) investigated the influence of the extensor part of the m. gluteus maximus on pelvic tilt, which also affects stability of the lumbar spine. They studied the position of the pelvic bones in standing subjects from the lateral side by taking photos of young, healthy people before and after induction of muscle fatigue. They evaluated the tilt of the left and right pelvic bones. They found that the *m. gluteus maximus* affected the position of the pelvic bone, and observed that after fatigue, the tilt of the bone had increased.

Negrão Filho Rde et al. (2009) investigated EMG activity of abdominal muscles in 19 healthy ballet dancers using two tests. One test was performed while the pelvis was tilted backward during MVC (maximum voluntary contraction) of the abdominal muscles, and the other while holding both lower limbs stretched out above the floor. Electrical activity was recorded in *m. rectus abdominis*, *mm. obliqui externus* and *internus abdominis*. They found that when actively tilting the pelvis backward, the *m. obliquus internus abdominis* was more active than during contraction of the abdominal muscles. When stabilizing the pelvic area while the lower limbs were outstretched, the *m. obliquus externus abdominis* was more active.

Workman et al. (2008) studied muscle activity in 16 healthy volunteers during two movement tests using an EMG:

1) Holding an outstretched lower limb 5 cm above the ground;
2) Janda's posture test.

In both tests, muscle contractions changed position of the pelvis (tilted forward, neutral position, tilted backward). Electrical activity was monitored in the upper and lower part of *m. rectus abdominis, m. obliquus externus abdominis, m. rectus femoris*, and *m. biceps femoris*. They found that the position of the pelvis has a significant effect on the activation of these muscles in the torso and the hip joint. Activation of the *m. biceps femoris* reduces the activity of the *m. rectus femoris*, but increases the activity of both parts of *m. rectus abdominis*.

Danneels et al. (2001) studied the electrical activity of different muscles in 29 healthy subjects while they performed different variants of asymmetrical lifting. EMG activity was monitored in 7 hip, abdominal and back muscles. They found that the *m. obliquus internus abdominis, m. rectus femoris* and *m. multifidus* contracted symmetrically on both sides in all variants. In contrast to these results, they found left-to-right differences in the activities of the *m. obliquus externus abdominis, m. gluteus maximus, m. iliocostalis lumborum* and *m. latissimus dorsi*. Based on these results, they concluded that muscles with bilaterally symmetrical contractions are local stabilizers, whereas muscles which contracted unilaterally were global stabilizers and prime movers.

Shields and Heiss (1997) used EMG to analyse abdominal muscle activity and their synergies in 15 men. There were two exercises: one in which the subject pulled himself into a ball by pulling the thighs up against the abdomen, and the other with both lower limbs lying outstretched while lying face down. They then monitored the activities of the *mm. rectus abdominis, obliquus externus* and *internus abdominis*. They found that there were two synergies in the abdominal muscles: in one, there was high activity in the *m. rectus abdominis* together with *m. obliquus externus abdominis*; in the other, there was low activity directly within the abdominal muscle itself, but high activity in both oblique abdominal muscles.

Congdon et al. (2005) studied the effects of hamstring length on pelvic position during flexion of the hip joint. The knee joint was held in full extension, in 45° and 90° of flexion. The position of the pelvis and thighs were monitored using 3D analysis. The results showed that the position and movement of the pelvis were significantly influenced by the position of the knee and the angle of hip joint flexion.

O'Sullivan et al. (2002) observed 20 healthy people of both sexes using EMG. They used surface electrodes on the abdominal and back muscles during standardized sitting and standing. The results showed that during unstable standing, the *m. obliquus internus abdominis* and *m. erector spinae* in the thoracic region, and superficial the *m. multifidus* in the lumbar region, significantly reduced their activity in comparison to quiet standing. By contrast, the activity of the *m. rectus abdominis* increased.

Hashemirad et al. (2009) used EMG to examine the activity of the *m. erector trunci* through the use of surface electrodes. 30 healthy female university students were studied while repeatedly performing both a forward bend with fingers reaching toward the floor (toe-touch), and a modified Schober test. Digital cameras simultaneously monitored the flexion angles of the torso, the hip joint and lumbar spine, and the curvature of the lumbar spine. The results showed that women with a higher score in the toe-touch test achieved greater flexion angles of the torso and hip joint. In these women, the *m. erector trunci* relaxed sooner, while bending forward, and reactivated sooner, while returning to an upright position. For women with higher scores on the modified Schober test, there was a greater change in both the flexion angle and curvature of the lumbar spine. In those women, the *m. erector trunci* relaxed later when bending forward. The authors concluded that flexibility plays an important role in the activation of the torso muscles and in central nervous system strategies while ensuring the body's stability.

Claus et al. (2009) used EMG to study the activity of torso muscles (abdominal and back muscles) by inserting wire electrodes into selected muscles during various lumbar spine positions while sitting, during flat, long and short lordosis, as well as lumbar spine hyperextension. The lowest activity of all muscles was seen while the spine was flat.

Moseley et al. (2002) used surface electrodes and intramuscular EMG to investigate activity in the following torso muscles: the deep and superficial parts of the *m. multifidus, m. erector spinae* and *m. deltoideus* during arm movement. They found that activity in the surface fibres of the *m. multifidus* was dependent on the direction of arm movement, while activity in the deep fibres was not. During repetitive arm movements, activity in the superficial fibres of the *m. multifidus* only appeared during flexion, while deep fibre activity occurred during movements in both directions. From these results, the authors concluded that the surface fibres of the *m. multifidus* are involved in managing the orientation of the entire spine, while deep fibres play an important role in managing intersegmental movement.

Allison et al. (2008), wanted to verify whether or not the deep and superficial torso muscles have different roles in posture and locomotion. They followed EMG activity by using surface and intramuscular electrodes and the abdominal muscles during both one-sided and double-sided arm movements. In the *m. transversus abdominis*, it was clear that its activity was predominantly on the same side as the moving arm. This was not observed in the *m. erector spinae*. This is probably the first work that challenged the dogma of a stabilizing role for the *m. transversus abdominis* as part of the deep stabilization system.

Urquhart et al. (2005a) studied EMG activity in different areas of the *m. transversus abdominis, m. obliquus externus abdominis* and *m. rectus abdominis* during retraction of the lower part of the abdominal wall while contracting the entire abdomen and tilting the pelvis. The results showed that these muscles activate during different activities. The *m. transversus abdominis* was most active during retraction of the lower abdominal wall and different regions of this muscle were involved in various movements. The *m. obliquus internus abdominis* was most involved during retroversion of the pelvis, whereas the *m. obliquus externus abdominis* was most involved during contraction of the entire abdominal wall.

Urquhart and Hodges (2005) investigated the role of abdominal muscles during rotation of the torso. 6 healthy subjects were studied and electrical activity was measured in different areas of the abdominal muscles during rotation. Wire electrodes were inserted into the upper, middle and lower parts of the *m. transversus abdominis, m. obliquus externus* and *m. internus abdominis*. The result was that the *m. transversus abdominis* was active during rotation of the torso, but its activity varied in different areas.

Urquhart et al. (2005b) attempted to determine whether or not there were regional differences in the postural activity of abdominal muscles, and whether this activity changes with posture. The study was conducted with 11 healthy volunteers. They used EMG to monitor the activity of these muscles via intramuscular electrodes located in the upper, middle, and lower regions. The test subjects performed arm movements while standing and sitting. The results showed that there are regional differences in the *m. transversus abdominis* during arm movement. The upper part of the muscle contracted later than the middle and lower parts. The activity of these muscles also affects the position of the body. Muscle activation occurred later while sitting than while standing.

The position of the pelvis and spine

Mac-Thiong et al. (2007) studied pelvic positions in a healthy pediatric population. 341 healthy children aged 3–18 years had lateral X-rays performed while standing in an upright position. 7 parameters were evaluated: thoracic kyphosis, inclination of the thoracic spine, lumbar lordosis, inclination of the lumbar spine, the position of the sacrum, pelvic tilt and the incidence of problems in the pelvic area. The main conclusion of the study was that all of the parameters studied in children were distinct from those in the adult population; however the correlation between the parameters in children did not differ from adults. Construction of the pelvis (morphology) was found to affect the orientation of the sacrum, which affected the shape and position of the lumbar spine.

Gajdosik et al. (1994) studied the influence of hamstring muscle length on pelvic position, the lumbar spine and thoracic spine in men with significantly shortened hamstrings, moderately shortened muscles vs. healthy muscles. The study was done with subjects standing and bent forward with fingers reaching toward the ground. The results showed that short hamstrings decreased the range of flexion of both the pelvic and lumbar spine regions, and increased the range of flexion in the thoracic spine region.

Harrison et al. (2002) used X-ray images to study the effect of rib cage position on the position of the lumbar spine and pelvis. Imaging was performed on 20 volunteers with the rib cage in a neutral position; follow by the rib cage shifted forward and then backward. According to the results, when the rib cage shifts in either direction it changes the tilt of the pelvis. When shifting forward, the pelvic tilt shifted forward by up to 15°; when shifted backward, the change was up to 13°.

Mac-Thiong et al. (2004) investigated the shape of the spine and pelvic position during growth in a healthy pediatric population. They acquired lateral, standing, X-ray images on 180 children aged 4–18 years. They noted the shape of the thoracic spine, lumbar spine, the position (inclination) of the sacrum, as well as pelvic position. They discovered that, as age increased, the forward tilt of the pelvis also increases, as does the increase in lumbar lordosis.

Evcik and Yücel (2003) assessed the positions of the pelvis and spine in two groups of patients; 50 patients with chronic pain in the lower back, and 50 with acute pain in the same area (low back pain). Lateral X-ray images were taken and lumbar spine mobility was assessed, including the maximum range of flexion and extension. It was found that chronic pain in the lower back affects the lower part of the lumbar spine and limits the range of extension.

Korovessis et al. (1999) studied the curvature of the thoracic and lumbar spine, and the position of the *os sacrum* and the lumbosacral transition (L4-S1) in 120 healthy volunteers and 120 patients with low back pain. The study participants were aged 20-79 years. All parameters were evaluated with lateral X-rays. The following conclusions were reached for adults: thoracic kyphosis increased with age and the inclination of the os sacrum decreased. Increased thoracic kyphosis and lordosis of the LS junction (L5/S1) were greater in patients with low back pain, while lumbar lordosis was more pronounced in the group of healthy controls.

Labelle et al. (2005) conducted lateral X-rays in patients with spondylolisthesis of L5/S1. The images evaluated pelvic shape, sacral inclination, pelvic tilt, lumbosacral angle, lumbar lordosis and thoracic kyphosis. The results showed that the shape of the pelvis determines the position of the sacrum. The spine reacts to the position of the sacrum and changes the degree of lumbar lordosis; horizontalization of the sacrum increases lumbar lordosis. The inclination of the sacrum, pelvic tilt and the shape of lumbar lordosis were significantly greater in patients with spondylolisthesis of L5. There was a direct correlation: the greater the degree of spondylolisthesis, the worse the listed parameters. The authors stated that the parameters form a kind of closed chain in which individual adjacent links greatly depend on one another.

Mac-Thiong et al. (2008) performed lateral X-ray images in 120 healthy controls and 131 persons with spondylolisthesis. The images evaluated parameters in the pelvis (pelvic tilt, sacral inclination) and lumbar spine (lumbosacral angle, lumbar lordosis, inclination of the lumbar spine). The parameters were compared between the two groups. The results revealed a correlation between pelvic parameters and spinal parameters.

Barrey et al. (2007) studied the relationship between the spine and pelvis in 85 patients with degenerative diseases of the lumbar spine. Specifically, these were disc herniation, disc degeneration and degenerative spondylolisthesis. Lateral X-ray images taken of patients were evaluated for: pelvic tilt, sacral inclination, lumbar lordosis, thoracic kyphosis and the position of the vertical line from C7. The control group consisted of 154 persons. Patients in all three groups showed a significant ventral shift of the vertical line from C7, flattening of the lumbar spine and verticalization of the *os sacrum*.

The structure skeletal muscle

Ng et al. (1998) conducted a literature review which dealt with the composition of muscle fibre types and the function of back muscles in both healthy people, and those suffering from low back pain. In healthy people, the back muscles of the thoracic and lumbar areas were predominantly Type I muscle fibres, which have a larger diameter compared to Type II fibres. This is consistent with their postural functions. The diameter of Type II muscle fibres were also smaller in women than in men. In patients with low back pain, selective atrophy of Type II muscle fibres was observed.

Mannion et al. (1997a) studied the size of muscle fibres and their distribution in the *m. erector spinae* in a group of 45 healthy, young people of both sexes. They conducted percutaneous biopsies in the paravertebral area along the T10 through L3 vertebrae. They discovered that, in this area, there were no differences in terms of the percentage of Type I and Type II muscle fibre representation. Men had more fibres than women. In men, both Type I and Type II muscle fibres were approximately equal in size; in women, Type I fibres were markedly greater in size than Type II fibres.

Häggmark and Thorstensson (1979) studied muscle fibre type composition in biopsy specimens from 4 abdominal wall muscles (*mm. rectus abdominis, obliquus externus, obliquus internus* and *transversus abdominis*) taken from 13 healthy subjects of both sexes. They discovered that the ratio between Type I and Type II fibres was approximately the same in all tested muscles. The Type II fibres in the *m. transversus abdominis* were smaller in size relative to the other muscles.

Kalima et al. (1989) conducted a literature review that involved macroscopic anatomy, the innervation, muscle fibre-type composition and function of lumbar back muscles of the *m. erector spinae* and *m. multifidus*. The review showed that the innervation and function of both muscles were so different that it would be impossible to consider them as a single structural and functional unit. The relative number of slow and fast twitch fibres varied considerably, and was clearly dependent upon the patient's health status. In ill individuals, these changes are apparently caused by the selective atrophy of fast twitch fibres in connection with inactivity, but these changes were also linked to sedentary lifestyles in healthy controls.

Mannion et al. (1997b) compared the muscle fibre types of back muscles in a group of 21 healthy people, and a group of 21 suffering from low back pain. In comparison to healthy controls, those with low back pain had a significantly higher proportion of Type IIB muscle fibres than Type I. The size of individual fibre types between the two groups did not differ. The areas occupied by Type 1 and Type II fibres differed between the two groups. A larger surface area was found in Type IIB fibres. This means that, in patients with low back pain, muscle fibres exhibited a more phasic profile.

Demoulin et al. (2007) carried out a literature review regarding back muscles in healthy subjects, and those suffering from low back pain. In healthy persons, the muscles contained a greater number of Type I fibres, which reflected their postural role. In patients, there was considerable incidence of atrophy in Type II fibres. EMG studies showed that patients with chronic low back pain experienced increased levels of paraspinal muscle fatigue.

Nikolić et al. (2001) observed changes in muscle fibre size and the representation of different muscle fibre types in three muscles, each of which had different functions dependent upon age. The observed muscles were the *m. vastus lateralis, m. deltoideus* and *mm. intercostales externi*. The study was conducted in 30 men aged 20–80 years. Increased age was accompanied by a reduction in muscle fibre size in all muscle types. The ratio of Type I and II fibres also varied. With increasing age, the number of Type I fibres increased and the number of Type II fibres decreased. However, not all muscles were affected to the same degree.

Lexell (1995) examined changes in skeletal muscle during the aging process. He evaluated biopsy samples taken from younger and older people. He found that, with increasing age, there was a reduction in the volume of muscle mass, which was replaced by fat and connective tissue. Age atrophy was also more associated with Type II muscle fibres.

Abdominal muscles and breathing

The interplay of the diaphragm and deep stabilizing muscles of the torso are described as an important functional unit for the dynamic stabilization of the spine (Hodges et al. 2005, Kolář 2007). Dysfunction of this interplay is considered to be one of the most common factors in the development of vertebral difficulties (Hodges and Richardson 1996) and also in the formation of structural changes of the spine (herniation, spondylolisthesis, spondylarthrosis, etc.).

Postural stability is present during most torso and limb movements, even when breathing or holding your breath (Hodges et al. 2001, Gandevia et al. 2002, Kolář 2009), and therefore a lot depends on its quality. If muscular interplay is not physiological, paraspinal muscles (extensors of the spine) are overloaded. These muscles cannot compensate for such a deficiency which increases compressive forces on spinal structures.

The biomechanics and management functions of the diaphragm are extensive, and significant issues affect a wide range of medical disciplines. Not only are Pneumology and Thoracic Surgery are affected, but rehabilitation and gastroenterology as well.

Even though there has recently been a significant change in how the function of the diaphragm is viewed, it does not mean that all the relationships regarding its activities are now perfectly clear. The diaphragm is usually studied in terms of respiratory function (Suga et al. 1999, Plathow et al. 2005), and measured by its height (Kondo et al. 2005, Takahashi et al. 2007) and movement (Gierada et al. 1995, Kiryu et al. 2006). However, almost none of the mentioned works address postural function. The studies that exist, map diaphragm function during various types of respiration, or during activation associated with breath control, a situation which is not tied to respiration (Kolář 2009, Kolář et al. 2012).

De Troyer (1983) observed the EMG activity of abdominal muscles during quiet breathing while the body was in different positions; 10 healthy subjects were studied. Bipolar needle electrodes were inserted into the upper and lower portions of the *m. rectus abdominis* and *m. obliquus internus abdominis*. Movement of the thorax and abdominal wall were monitored using magnetometers. The abdominal muscles were always electrically quiet when in the supine position. In 8 out of 10 people, tonic activity was observed in these muscles while standing. Tonic activity of the abdominal muscles has always been associated with a reduction in abdominal cavity volume during the respiration cycle, and a reduction in lung volume at the end of exhalation. It is reasonable to conclude that: 1) tonic activity of the abdominal muscles is present in most people while standing; 2) abdominal muscle activity is related to the pressure abdominal organs exert against the abdominal wall.

Martin and De Troyer (1982) studied abdominal muscle activity in 8 healthy subjects while sitting and standing. Unipolar needle electrodes were introduced into the *mm. rectus* and *obliquus internus abdominis*. The anteroposterior dimension of the abdominal wall was measured using a magnetometer. They found that abdominal muscle activity was associated with changes in the posteroanterior dimension of the abdominal cavity. The supine position did not induce any abdominal muscle activity.

Kera and Maruyama (2005) studied the effect of posture on the expiratory activity of abdominal muscles. The study involved 15 young men. EMG was used to monitor the activity of the *m. rectus, obliquus externus* and *obliquus internus abdominis* while the body was in different positions. Lung volumes were measured with a spirometer. The measurements were performed while standing, sitting, lying supine and sitting with the elbows placed on the knees. The study participants breathed spontaneously and maximally. In the standing position, the *m. obliquus internus abdominis* was most active during inspiration and expiration, which was apparently due to visceral organ pressure against the abdominal wall. The *m. obliquus externus abdominis* was most active during inspiration while sitting while sitting with the elbows placed on the knees during expiration. The activity of the *m. rectus abdominis* did not change with body position, nor did it change during inspiration or expiration. The authors attributed these differences to the different anatomical arrangements of the measured muscles and the influence of gravity.

Abe et al. (1999) monitored EMG activity using wire electrodes that were inserted into the *m. rectus, obliquus externus, obliquus internus* and *transversus abdominis*. 9 healthy subjects were examined while lying supine and standing upright. They concluded that changes in body position were associated with changes in abdominal muscle activity.

Abe et al. (1999) studied EMG activity using wire electrodes in the *m. rectus, obliquus abdominis externus, obliquus internus abdominis* and *transversus abdominis*. They found that expiration was an active process even during quiet breathing. During expiration, the abdominal muscles were active in different ways; the *m. transversus abdominis* was the most active, less active was the *m. transversus abdominis*, and least active was the *m. rectus abdominis*.

Loring and Mead (1982) studied abdominal muscle activity during respiration. They followed movements of the rib cage and abdominal wall using magnetometers. They concluded that abdominal wall muscles were not active when breathing in the supine position; however, abdominal muscle contraction occurred while breathing in a sitting or standing position.

CONCLUSION

The aim of this literature review was to obtain a clear picture of the relationships between individual systems which contribute to the development of muscle imbalances. In particular the relationships involved in activation of muscles located in the abdominal wall and back, the position of the pelvis and spine, the associated skeletal muscles found in these areas, as well as the behavior of abdominal muscles in relation to breathing. Our review led to the following observations and conclusions.

1. The position of the pelvis as a whole, as well as individual pelvic bones, influence not only the abdominal and back muscles, but also the muscles of the lower limbs which attach to the pelvis, such as the *m. gluteus maximus* or muscle groups of the posterior thigh (hamstrings). The position of the lower limb joints are also of great importance.
2. It is well established that the individual muscles of the abdominal wall have different functions; for example, the *m. obliquus internus abdominis* is most active during pelvic retroversion and contraction of the *m. obliquus externus abdominis* tightens the entire abdominal wall (e.g. when lying with the legs outstretched and slightly elevated above the floor).
3. The concept that the *m. transversus abdominis* is a purely postural muscle involved in the deep stabilization system has been seriously undermined. It turns out that this muscle consists of several parts that are functionally different, and which are involved in many voluntary motor functions.
4. The *m. multifidus* and *m. erector trunci* are quite different functional units in terms of structure, function and innervation. It is not unreasonable to suggest that the muscle fibres situated superficially are more involved with movements of the entire spine, while deeper fibers are more involved in intersegmental stabilization.
5. Pelvic position and the shape of individual sections of the spine are different in children and adults. From a functional point of view, however, it is important to

realize that the correlations between the parameters of individual sections are the same in both children and adults. Bad positioning in one section of the axial skeleton affects the position of other sections.

6. The position of the pelvis and lumbar spine changes with age. From childhood through to old age, the pelvis gradually tilts forward and lumbar lordosis deepens. Pelvic tilt, sacral inclination, and lumbar lordosis are worse in patients with low back pain and, the C7 vertebrae is shifted ventrally toward the vertical line during these difficulties.
7. Back muscles in the thoracic and lumbar regions of healthy people are dominated by slow-twitch fibres (Type I) as opposed to fast-twitch fibres (Type II), which is consistent with their postural functions. The diameter of Type II muscle fibres is smaller in women than in men. The same proportion of both types of muscle fibres were found in the superficial (*m. erector truncata*) and deep (*m. multifidus*) back muscles.
8. In both sexes, all abdominal muscles were found to have the same ratio of Type I and Type II muscle fibres. In the *m. transversus abdominis*, the Type II muscle fibres were smaller.
9. The ratio of muscle fibre types varies with age and results in a relative increase in the number of Type I muscle fibres. Atrophy gradually occurs, which further affects Type II muscle fibres in the muscles and increases fat and connective tissue content. In patients with lower back pain, selective atrophy of Type II muscle fibres occurs.
10. Abdominal muscles do not participate in quiet breathing. While sitting and standing, their activity is associated with visceral organ pressure on the abdominal wall. Abdominal wall muscle activity during breathing depends on body position and breathing intensity. While lying on the back, all muscles are inactive. While seated, the *m. obliquus externus abdominis* is the most active during breathing and while standing the *m. obliquus internus abdominis* is most active. Body position does not affect the activity of the *m. rectus abdominis*. During strenuous breathing the *m. transversus abdominis* appears to be most active.

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