A recent study has described the influence of the iliolumbar ligaments on SIJ stability (Pool-Goudzwaard et al. 2003). Due to the above-mentioned muscular and ligamentous connections, movement of the sacrum with respect to the iliac bones, or vice versa, affects the joints between L5–S1 and between the higher lumbar levels. Anatomical and functional disturbances of the pelvis or lumbar region influence each other. Due to the tightness of the fibrous connections and the specific architecture of the SIJ, mobility in the SIJ is normally very limited, but movement does occur and has not been scientifically challenged (Weisl 1955, Solonen 1957, Egund et al. 1978, Lavignolle et al. 1983, Miller et al. 1987, Sturesson et al. 1989, 2000a, 2000b, Vleeming et al. 1990a, 1990b, 1996) (Figure 2.2.1).

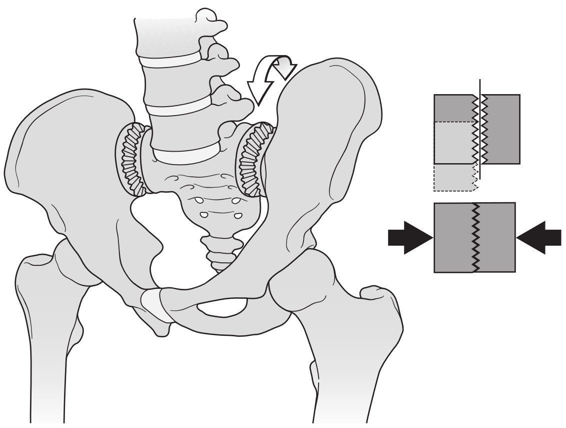

Figure 2.2.1 • Whimsical depiction of sacroiliac joints with friction device

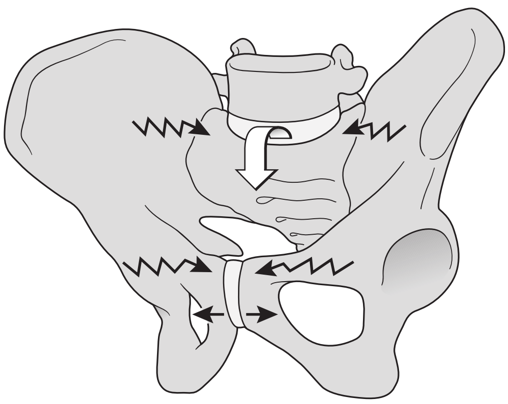

Figure 2.2.2 • Nutation in the sacroiliac joint. The iliac bones are pulled to each other due to ligament tension (among others) and compress the sacroiliac joints (upper black arrows). It can be expected that especially the upper (anterior) part of the pubic symphysis is compressed

The main movements in the SIJ are forward rotation of the sacrum relative to the iliac bones (nutation) and backward rotation of the sacrum relative to the ilia (counternutation) (Figure 2.2.2). It was shown that even at advanced age (>72 years) the combined movement of nutation and counternutation can amount to 4°; normally movements are less than 2° (Vleeming et al. 1992a). In the latter study, the SIJ with the lowest mobility showed radiologically marked arthrosis. Ankylosis of the SIJ was found to be an exception, even at advanced age. This finding is in agreement with the studies of Stewart (1984) and Miller et al. (1987).

Nutation is increased in load-bearing situations, e.g. standing and sitting. In lying prone, nutation is also increased compared to supine positions (Weisl 1955, Egund et al. 1978, Sturesson et al. 1989, 2000a, 2000b). Counternutation normally occurs in unloaded situations like lying down (supine). Counternutation in supine positions can be altered to nutation by maximal flexion in the hips, using the legs as levers to posteriorly rotate the iliac bones relative to the sacrum, as in a labour position, creating space for the head of the baby during delivery.

The anatomy of the sacroiliac joint

The SIJs are relatively flat, unlike ball and socket joints such as the hip. Generally speaking, flat articular surfaces are less resistant to shear forces and therefore the presence of flat surfaces in the pelvis seems surprising. This anatomical configuration gives rise to three questions:

1. Why did nature create a seemingly flat SIJ?
2. What specific adaptations are available to prevent shear in the SIJs?
3. Why is the SIJ not perpendicularly orientated to the forces of gravitation?

Why did nature create a seemingly flat SIJ?

A large transfer of forces is required in the human SIJ, and indeed flat joints are theoretically well-suited to transfer large forces (Snijders et al. 1993a, 1993b). An alternative for effective load transfer by these flat joints would be a fixed connection between sacrum and iliac bones, for instance by ankylosis of the SIJ. The SIJs in humans serve a purpose: to economize gait, to allow shock and shear absorption, and to alleviate birth of (in the evolutionary sense) abnormally large babies. The principal function of the SIJs is to act as stress relievers, ensuring that the pelvic girdle is not a solid ring of bone that could easily crack under the stresses to which it is subjected (Adams et al. 2002).

What specific adaptations are available to prevent shear in the SIJs?

The SIJs are abnormal compared to other joints because of cartilage changes that are present already before birth. These occur especially at the iliac side of the joint and were misinterpreted as degenerative arthrosis (Sashin 1930, Bowen & Cassidy 1981). These cartilage changes are more prominent in men than in women and, according to Salsabili et al. (1995), the sacral cartilage is relatively thick in females. This gender difference might be related to childbearing and possibly to a different localization of the centre of gravity in relation to the SIJ (Dijkstra et al. 1989, Vleeming et al. 1990a, 1990b). Vleeming et al. (1990a, 1990b) considered these changes to reflect a functional adaptation. The features seem to be promoted by the increase in body weight during the pubertal growth spurt and concern a coarse cartilage texture and a wedge and propeller-like form of the joint surfaces.

Studies of frontal slides of intact joints of embalmed specimens show the presence of cartilage-covered bone extensions protruding into the joint. These protrusions seemed irregular but are in fact complementary ridges and grooves. Joint samples taken from normal SIJ with both coarse texture and complementary ridges and grooves were characterized by high-friction coefficients (Vleeming et al. 1990b). All these features are expected to reflect adaptation to human bipedality, contributing to a high coefficient of friction and enhancing the stability of the joint against shear (Vleeming et al. 1990a). As a consequence, less muscle and ligament force is required to bear the upper part of the body (Figure 2.2.3).

The 'keystone-like' bony architecture of the sacrum further contributes to its stability within the pelvic ring. The bone is wider cranially than caudally, and wider anteriorly than posteriorly. Such a configuration permits the sacrum to become 'wedged' cranially and dorsally into the ilia within the pelvic ring (Vleeming et al. 1990a, 1990b). The SIJ has evolved from a relatively flat joint into a much more stable construction (Figure 2.2.4).

To illustrate the importance of friction in the SIJ, the principles of form and force closure were introduced (Vleeming et al. 1990a, 1990b). Form closure refers to a theoretical stable situation with closely fitting joint surfaces, where no extra forces are needed to maintain the state of the system, given the actual load situation. If the sacrum would fit in the pelvis with perfect form closure, no lateral forces would be needed. However, such a construction would make mobility practically impossible. With force closure (leading to joint compression) both a lateral force and friction are needed to withstand vertical load. Shear in the SIJ is prevented by the combination of the specific anatomical features (form closure; see Figure 2.2.5) and the compression generated by muscles and ligaments that can be accommodated to the specific loading situation (force closure). Force closure is the effect of changing joint reaction forces generated by tension in ligaments, fasciae and muscles and ground reaction forces (Figure 2.2.5).

Why is the SIJ not perpendicularly orientated to the forces of gravitation?

Force closure ideally generates a perpendicular reaction force to the SIJ to overcome the forces of gravity (Vleeming et al. 1990b). This shear prevention system was named the self-bracing mechanism and such a mechanism is present elsewhere in the body, e.g. in the knee, foot and shoulder. When a larger lever is applied and/or coordination time becomes less, the general effect in the locomotor system will be closure or reduction of the degrees of freedom of the kinematic chain, leading to a reduction in the chain's mobility or a gain of stability by increasing force closure (Huson 1997).

In self-bracing of the pelvis, nutation of the sacrum is crucial. This movement can be seen as an anticipation for joint loading. Hodges et al. (2003) use the terminology 'preparatory motion' for a comparable phenomenon in the lumbar spine. So, nutation is seen as a movement to prepare the pelvis for increased loading by tightening most of the SIJ ligaments, among which are the vast interosseous and short dorsal sacroiliac ligaments. As a consequence the posterior parts of the iliac bones are pressed together, enlarging compression of the SIJ.

Ligaments and their role in self-bracing the pelvis

In self-bracing the pelvis, nutation in the SIJ is crucial (see above); this involves several ligaments. To further explain self-bracing of the pelvis we will

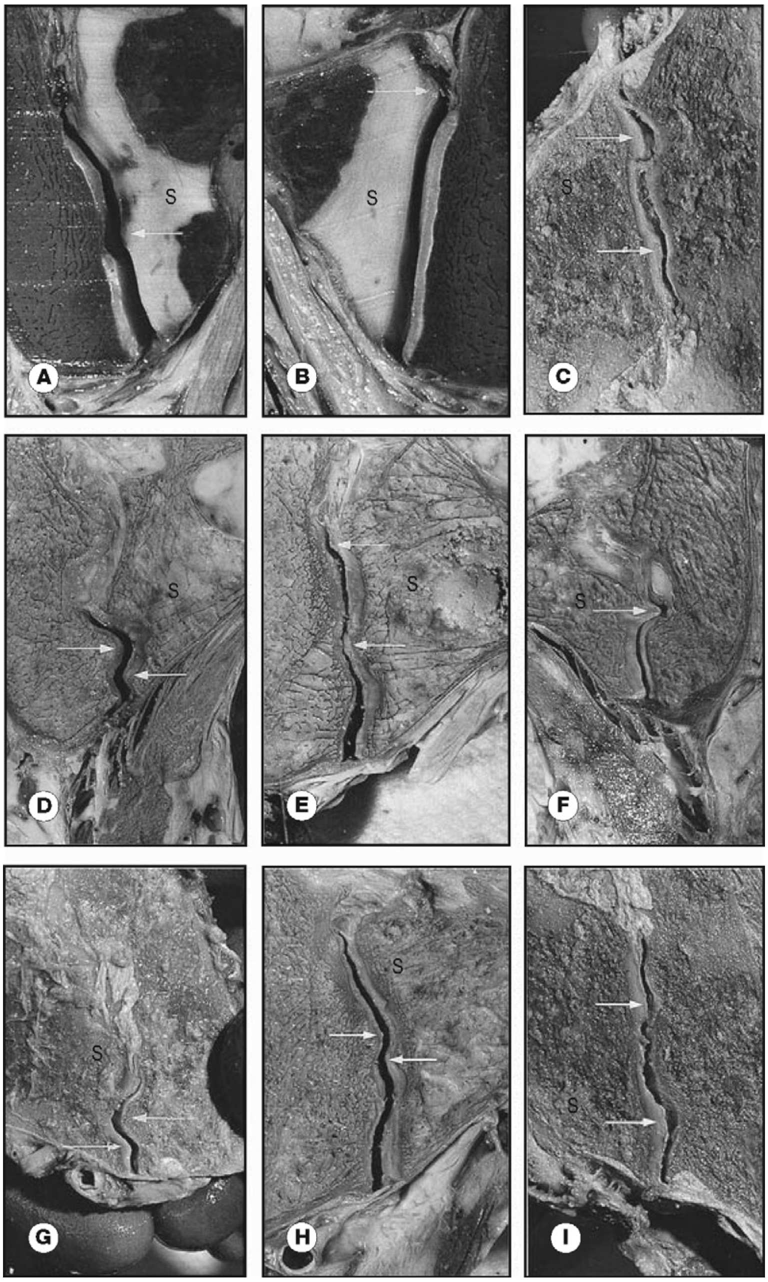

Figure 2.2.3 • Frontal sections of the sacroiliac joint (SIJ) of embalmed male specimen. S indicates the sacral side of the SIJ. (A) and (B) concern a 12-year-old boy; (C)–(I) concern specimen older than 60 years. Arrows are directed at complementary ridges and depressions. They are covered by intact cartilage, as was confirmed by opening the joints afterwards

discuss two sets of ligaments (Figure 2.2.6): the sacrotuberous ligaments (Vleeming et al. 1989a, 1989b, van Wingerden et al. 1993) and the long dorsal SI ligaments (Vleeming et al. 1996, 2002). In the literature, specific data on the functional and clinical relevance of the long ligaments are not available. In several anatomical atlases and textbooks, the long ligament and the sacrotuberous ligament are portrayed as fully continuous ligaments. The drawings generally convey the impression that the ligaments have identical functions. As shown by the contrasting effects of nutation and contranutation on these ligaments (see below), this is not the case. Essentially, the long ligament connects the sacrum and posterior superior iliac spine (PSIS), whereas the main part of the sacrotuberous ligament

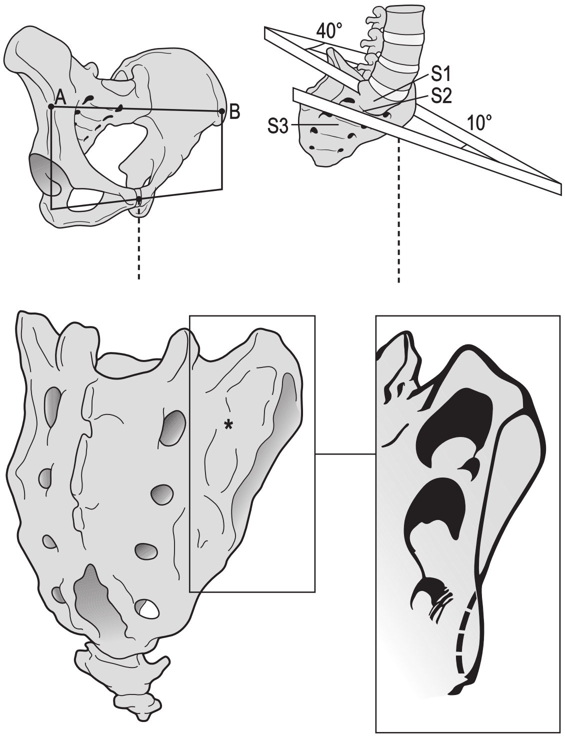

Figure 2.2.4 • (Top left) Pelvis in erect posture. (Top right) View of the sacrum from ventrolateral side, showing the different angles between left and right sacral articular surface. (Bottom left) Dorsolateral view of the sacrum. The * indicates a cavity in the sacrum in which an iliac tubercle fits. (Bottom right) Sacral articular surface at the right side. The different angles reflect the propeller-like shape of an adult sacroiliac joint

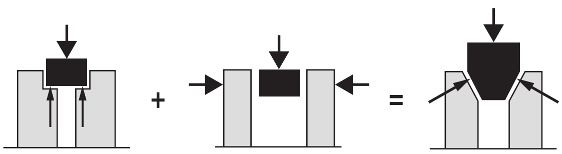

Figure 2.2.5 • Model of the self-locking mechanism. The combination of form closure and force closure establishes stability in the sacroiliac joint

connects the sacrum and ischial tuberosity. However, some of the fibres derived from the ischial tuberosity pass to the iliac bone. Generally, they are denoted as part of the sacrotuberous ligament, although 'tuberoiliac ligament' would be more appropriate. In the *terminologia anatomica* such a ligament does not exist. In fact, this also holds for the long (dorsal SI) ligament, reflecting one of the problems of topographical anatomy.

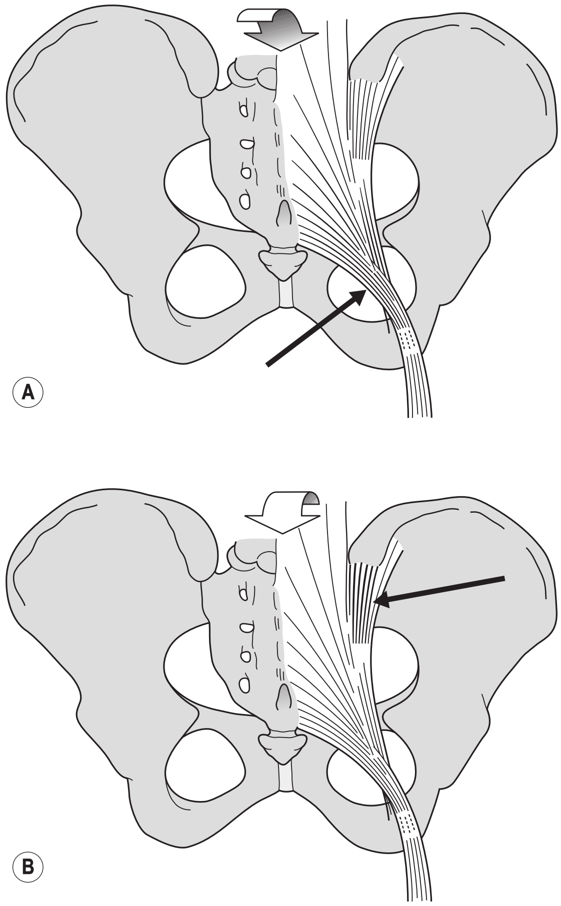

Figure 2.2.6 • (A) Nutation winds up the sacrotuberous ligament. (B) Counternutation winds up the long dorsal sacroiliac ligament

Sacrotuberous ligaments

In embalmed human specimens, we could demonstrate a direct relation between nutation and tension of the sacrotuberous ligament (Figure 2.2.6A). By straining this ligament, we found a decrease of nutation (Vleeming et al. 1989a, 1989b), indicating that these ligaments are well-suited to restrict nutation. It can be expected that the opposite (diminished ligament tension) will increase nutation.

Long dorsal sacroiliac ligaments

In view of the capability of the sacrotuberous ligaments to restrict nutation, we wondered which ligament(s) could restrict counternutation. Because of its connection to the PSIS and to the lateral part of the sacrum (Figure 2.2.6B), we expected that the long dorsal SI ligament could fulfil this function. The ligament can be easily palpated in the area directly caudal to the PSIS and is of special interest since women complaining of lumbopelvic back pain during pregnancy frequently experience pain within the boundaries of this ligament (Mens et al. 1992, Njoo 1996, Vleeming et al. 1996). Pain in this area is also not uncommon in men. The ligament is the most superficially located SIJ ligament and therefore well-suited to mirror asymmetric stress in the SIJ. As this ligament is not well known in medical practice, we will summarize data from an anatomical and biomechanical study (Vleeming et al. 1996) that assessed the function of the ligament by measuring its tension during incremental loading of biomechanically relevant structures.

For that purpose, the tension of the long ligament ($n = 12$) was tested under loading. Tension was measured with a buckle transducer. Several structures, including the erector spinae muscle and the sacrum itself, were incrementally loaded (with forces of 0–50 N). The sacrum was loaded in two directions (nutation and counternutation).

Anatomical aspects

At the cranial side, the long ligament is attached to the PSIS and the adjacent part of the iliac bone, at the caudal side to the lateral crest of the third and fourth sacral segments. In some specimens, fibres also pass to the fifth sacral segment. From the sites of attachment on the sacrum, fibres pass to the coccyx. These are not considered to be part of the long ligament.

The lateral expansion of the long ligament directly caudal to the PSIS varies between 15 and 30 mm. The length, measured between the PSIS and the third and fourth sacral segments, varies between 42 and 75 mm. The lateral part of the long ligament is continuous with fibres of the sacrotuberous ligament, passing between the ischial tuberosity and the iliac bone. The variation is wide. Fibres of the long ligament are connected to the deep lamina of the posterior layer of the thoracolumbar fascia, to the aponeurosis of the erector spinae muscle and to the multifidus muscle.

Biomechanical aspects

Forced incremental nutation in the SIJ diminished the tension in the long ligament, whereas forced counternutation increased the tension. Tension increased also during loading of the ipsilateral sacrotuberous ligament and erector spinae muscle. Tension decreased during traction on the gluteus maximus muscle. Tension also decreased during traction on the ipsilateral and contralateral posterior layer of the thoracolumbar fascia in a direction simulating contraction of the latissimus dorsi muscle.

Obviously, the long dorsal SI ligament has close anatomical relations with the erector spinae/multifidus muscle, the posterior layer of the thoracolumbar fascia, and a specific part of the sacrotuberous ligament (tuberoiliac ligament). Functionally, it is an important link between legs, spine and arms. The ligament is tensed when the SIJs are counternutated and slackened when nutated. Slackening of the long dorsal SI ligament can be counterbalanced by both the sacrotuberous ligament and the erector spinae muscle.

Pain localized within the boundaries of the long ligament could indicate, among others, a spinal condition with sustained counternutation of the SIJ. In diagnosing patients with a specific low back pain (LBP) or pelvic girdle pain (PGP), the long dorsal SI ligament should not be neglected. Even in cases of arthrodesis of the SIJ, tension in the long ligament can still be altered by different structures.

This observation implies that the tension of the long ligament can be altered by displacement in the SIJ as well as by action of various muscles. Obviously, nutation in the SIJ induces relaxation of the long ligament, whereas counternutation increases tension. This is in contrast to the effect on the sacrotuberous ligament (see Figure 2.2.5). Increased tension in the sacrotuberous ligament during nutation can be due to SIJ movement itself as well as to increased tension of the biceps femoris and/or gluteus maximus muscle. This mechanism can help to control nutation. As counternutation increases tension in the long ligament, this ligament can assist in controlling counternutation (see Figure 2.2.6).

Ligaments with opposite functions, such as the long and sacrotuberous ligaments, apparently do not interact in a simple way. After all, loading of the sacrotuberous ligament also leads to a small increased tension of the long ligament. This effect will be due to the connections between long ligament and tuberoiliac (part of the sacrotuberous ligament) ligament, and possibly also to a counternutating moment generated by the loading of the sacrotuberous ligament.

A comparable complex relation might hold for the long ligament and the erector spinae, or more specifically the multifidus muscle. As the multifidus is connected to the sacrum (MacIntosh & Bogduk 1986, 1991; see Chapter 1), its action induces nutation. As a result, the long ligament will slacken. However, the present study shows an increase in tension in the long ligament after traction to the erector spinae muscle. This counterbalancing effect is due to the connections between the erector spinae muscle and the long ligament, and opposes the slackening. In vivo, this effect might be smaller because the moment of force acting on the sacrum is raised by the pull of the erector spinae muscle and the resulting compression force on the spine (Snijders et al. 1993b). This spinal compression was not applied in this study. Both antagonistic mechanisms – between long and sacrotuberous ligaments and between the long ligament and the erector spinae muscle – might serve to preclude extensive slackening of the long ligament. Such mechanisms could be essential for a relatively flat joint such as the SIJ, which is susceptible to shear forces (Snijders et al. 1993a, 1993b). It can be safely assumed that impairment of a part of this interconnected ligament system will have serious implications for the joint as load transfer from spine to hips and vice versa is primarily transferred via the SIJ (Snijders et al. 1993a, 1993b).

As shown earlier (Vleeming et al. 1996), traction to the biceps femoris tendon hardly influences tension of the long ligament. This is in contrast to the effect of the biceps on the sacrotuberous ligament (Vleeming et al. 1989a, 1989b, van Wingerden et al. 1993). The observations might well be related to the spiralling of the sacrotuberous ligament. Most medial fibres of the ligament tend to attach to the cranial part of the sacrum, whereas most fibres arising from a lateral part of the ischial tuberosity tend to attach to the caudal part of the sacrum (see Figure 2.2.6A). The fibres of the biceps tendon, which approach a relatively lateral part of the ischial tuberosity, pass mainly to the caudal part of the sacrum. As a consequence, the effect of traction to the biceps femoris on the tension of the long ligament can only be limited.

The effect on the long ligament of loading the posterior layer of the thoracolumbar fascia depends on the direction of the forces applied. Artificial traction to the fascia mimicking the action of the transverse abdominal muscle has no effect. Traction in a craniolateral direction, mimicking the action of the latissimus dorsi muscle, results in a significant decrease in tension in the ipsilateral and contralateral long ligaments. As shown in another study (Vleeming et al. 1995), traction to the latissimus dorsi influences the tension in the posterior layer of the thoracolumbar fascia, ipsilaterally as well as contralaterally, especially below the level of L4. Thus slackening of the long ligament could be the result of increased tension in the posterior layer by the latissimus dorsi. This might itself lead to a slight nutation, leading to more compression and force closure of the SIJ. As shown in this study, slackening of the long ligament can also occur due to action of the gluteus maximus muscle, which is ideally suited to compress the SIJ.

It is inviting to draw conclusions when palpation, directly caudal to the PSIS, is painful. However, pain in this area might be due to pain referred from the SIJ itself (Fortin et al. 1994a, 1994b), but also due to counternutation in the SIJ. Counternutation is part of a pattern of flattening the lumbar spine (Egund et al. 1978, Lavignolle et al. 1983, Sturesson et al. 1989) that occurs in particular late in pregnancy when women counterbalance the weight of the fetus (Snijders et al. 1976). However, such a posture combined with counternutation could also result from a pain-withdrawal reaction to impairment elsewhere in the system. Hence, only specific pain within the boundaries of the long ligament can be used as a diagnostic criterion (Vleeming et al. 2002). An example of a pain-withdrawal reaction could be the following: pain of the pubic symphysis following delivery (Mens et al. 1992) could preclude normal lumbar lordosis and hence nutation owing to pain of an irritated symphysis. After all, lumbar lordosis leads to nutation in the SIJ (Weisl 1955, Egund et al. 1978, Lavignolle et al. 1983, Sturesson et al. 1989). Nutation implies that the left and right PSISs approach each other slightly while the pubic symphysis is caudally extended and cranially compressed (Lavignolle et al. 1983, Walheim & Selvik 1984). In this example the patient will avoid nutation and flattens the lower spine, leading to sustained tension and pain in the long ligament. In a study by Mens et al. (1999), it was shown that a positive active straight leg raise test coincides with a counternutated position of the SIJ in many patients.

In conclusion: functionally, the long dorsal SI ligament is an important link between legs, spine and arms. In women with lumbopelvic back pain frequently pain is experienced within the boundaries of this ligament, which is tensed with counternutation and slackened with nutation. The erector muscle and the sacrotuberous ligament can counterbalance this slackening. The connections between ligaments and muscles with opposing functions could serve as a mechanism to preclude excessive slackening of ligaments.

Before focusing on the role of the muscles, we will draw attention to the thoracolumbar fascia.

The role of the thoracolumbar fascia in stabilizing the lumbopelvic area

To deepen our knowledge of the role of the thoracolumbar fascia the posterior layer of the thoracolumbar fascia was loaded by simulating the action of various muscles (Vleeming et al. 1995).

Anatomical aspects

The posterior layer of the thoracolumbar fascia covers the back muscles from the sacral region, through the thoracic region as far as the fascia nuchae. At the level of L4–L5 and the sacrum, strong connections exist between the superficial and deep lamina. The transverse abdominal and internal oblique muscles are indirectly attached to the thoracolumbar fascia through a dense raphe formed by fusion of the middle layer (Bogduk & MacIntosh 1984) of the thoracolumbar fascia and both laminae of the posterior layer. This 'lateral raphe' (Bogduk & MacIntosh 1984, Bogduk & Twomey 1987) is localized laterally to the erector spinae and cranial to the iliac crest.

Superficial lamina (Figure 2.2.7)

The superficial lamina of the posterior layer of the thoracolumbar fascia is continuous with the latissimus dorsi, gluteus maximus, and part of the external oblique muscle of the abdomen and the trapezius muscle. Cranial to the iliac crest, the lateral border of the superficial lamina is marked by its junction with the latissimus dorsi muscle. The fibres of the superficial lamina are orientated from craniolateral to caudomedial. Only a few fibres of the superficial lamina are continuous with the aponeurosis of the external oblique and the trapezius. Most of the fibres of the superficial lamina derive from the aponeurosis of the latissimus dorsi and attach to the supraspinal

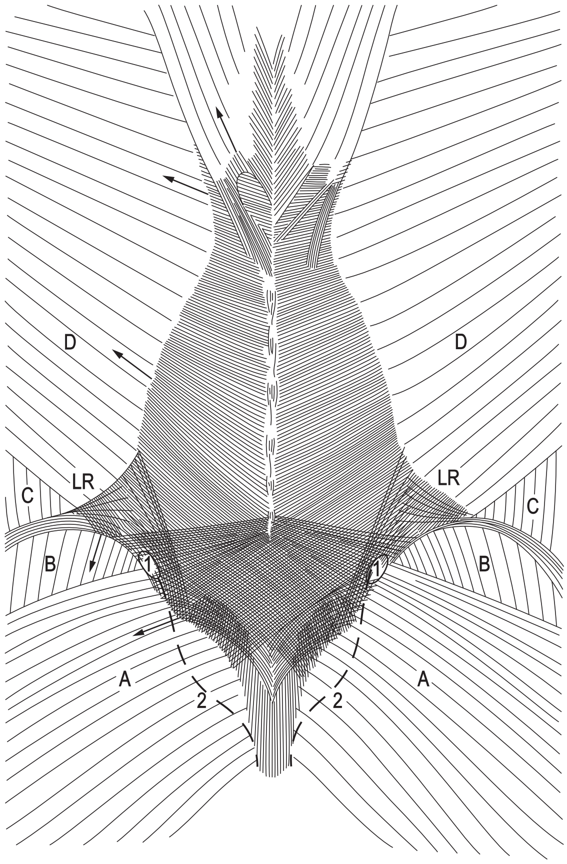

Figure 2.2.7 • The superficial lamina. A, Fascia of the gluteus maximus; B, fascia of the gluteus medius; C, fascia of external oblique; D, fascia of latissimus dorsi. 1, posterior superior iliac spine (PSIS); 2, sacral crest; LR, part of lateral raphe. Arrows (at left) indicate, from cranial to caudal, the site and direction of the traction (50 N) given to trapezius, cranial and caudal part of the latissimus dorsi, gluteus medius and gluteus maximus muscles, respectively. Reproduced from Vleeming et al. (1995), *Spine*, with permission.

ligaments and spinous processes cranial to L4. Caudal to L4–L5, the superficial lamina is generally loosely (or not at all) attached to midline structures, such as supraspinal ligaments, spinous processes and median sacral crest. In fact, they cross to the contralateral side, where they attach to sacrum, PSIS and iliac crest. The level at which this phenomenon occurs varies; it is generally caudal to L4 but in some preparations already occurs at L2–L3.

Barker & Briggs (1999) showed that the superficial lamina is also continuous superiorly with the rhomboids. They could not confirm the findings of Bogduk et al. (1998) in relation to thickening of the fascia and the presence of posterior accessory ligaments. This is in agreement with the findings of Vleeming et al. (1995).

At sacral levels, the superficial lamina is continuous with the fascia of the gluteus maximus. These fibres are orientated from craniomedial to caudolateral. Most of these fibres attach to the median sacral crest. However, at the level of L4–L5, and in some specimens even as caudally as S1–S2, fibres *partly or completely* cross the midline, attaching to the contralateral PSIS and iliac crest. Some of these fibres fuse with the lateral raphe and with fibres derived from the fascia of the latissimus dorsi. Owing to the different fibre directions of the latissimus dorsi and the gluteus maximus, the superficial lamina has a cross-hatched appearance at the level of L4–L5, and in some preparations also at L5–S2. The lamina becomes thicker and stronger especially over the lower lumbar spine and SIJ.

Barker & Briggs (1999) showed that the *deep lamina* (Figure 2.2.8) is continuous cranially with the tendons of the splenius cervicis and capitis muscles. At lower lumbar and sacral levels, the fibres of the deep lamina are orientated from craniomedial to caudolateral. At sacral levels, these fibres are fused with those of the superficial lamina. As, in this region, fibres of the deep lamina are continuous with the sacrotuberous ligament, an indirect link exists between this ligament and the superficial lamina. There is also a direct connection with some fibres of the deep lamina. In the pelvic region, the deep lamina is connected to the PSIS, iliac crests and long dorsal SI ligament. This ligament originates from the sacrum and attaches to the PSIS. In the lumbar region, fibres of the deep lamina derive from the interspinous ligaments. They attach to the iliac crest and more cranially to the lateral raphe, to which the internal oblique is attached. In some specimens, fibres of the deep lamina cross to the contralateral side between L5 and S1. In the depression between the median sacral crest and the posterior superior and inferior iliac spines, fibres of the deep lamina fuse with the fascia of the erector. More cranially, in the lumbar region, the deep lamina becomes thinner and freely mobile over the back muscles. In the lower thoracic region, fibres of the serratus posterior inferior muscle and its fascia fuse with fibres of the deep lamina.

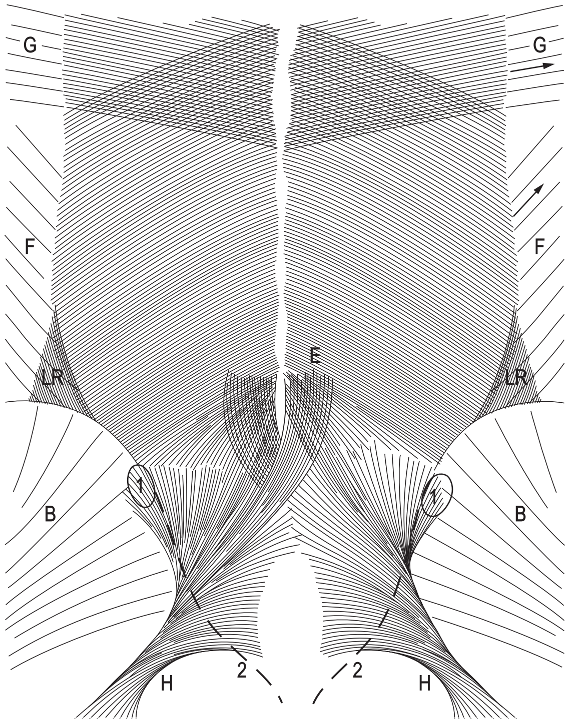

Figure 2.2.8 • The deep lamina. B, Fascia of the gluteus medius; E, connections between the deep lamina and the fascia of the erector spinae; F, fascia of the internal oblique; G, fascia of the serratus posterior inferior; H, sacrotuberous ligament; 1, the posterior superior iliac spine (PSIS); 2, sacral crest; LR, part of lateral raphe. Arrows (right) indicate, from cranial to caudal, traction to serratus posterior inferior and internal oblique muscles, respectively. Reproduced from Vleeming et al. (1995) *Spine*, with permission.

Biomechanical aspects

Traction to the superficial lamina

Depending on the site of the traction, quite different results were obtained (Vleeming et al. 1995). Traction to the cranial fascia and muscle fibres of the latissimus dorsi muscle showed limited displacement of the superficial lamina (homolaterally up to 2–4 cm). Traction to the caudal part of the latissimus dorsi caused displacement up to the midline. This midline area is 8–10 cm removed from the site of traction. Between L4–L5 and S1–S2, displacement of the superficial lamina occurred even contralaterally. Traction to the gluteus maximus also caused displacement up to the contralateral side. The distance between the site of traction and visible displacement varied from 4 to 7 cm. The effect of traction to the external oblique muscle varied markedly between the different preparations. In all preparations, traction to the trapezius muscle resulted in a relatively small effect (up to 2 cm).

Traction to the deep lamina

Traction to the biceps femoris tendon, applied in a lateral direction, resulted in displacement of the deep lamina up to the level L5–S1. Obviously, this load transfer is conducted by the sacrotuberous ligament. In two specimens, displacement occurred at the contralateral side, 1–2 cm away from the midline. Traction to the biceps tendon directed medially showed homolateral displacement in the deep lamina, up to the median sacral crest.

As shown by the traction tests, the tension of the posterior layer of the thoracolumbar fascia can be influenced by contraction or stretch of a variety of muscles. It is noteworthy that especially muscles such as the latissimus dorsi and gluteus maximus are capable of exerting a contralateral effect especially to the lower lumbar spine and pelvis. This implies that the ipsilateral gluteus maximus muscle and contralateral latissimus dorsi muscle both can tension the posterior layer.

Hence, parts of these muscles provide a pathway for mechanical transmission between pelvis and trunk. One could argue that the lack of connection between the *superficial* lamina of the posterior layer and the supraspinous ligaments in the lumbar region is a disadvantage for stability. However, it would be disadvantageous only in case strength, coordination and effective coupling of the gluteus maximus muscle and the caudal part of the contralateral latissimus dorsi muscle are diminished. It can be expected that increased strength of these mentioned muscles accomplished by torsional training could influence the quality of the posterior layer. Following this line of thinking, the posterior layer of the thoracolumbar fascia could play an integrating role in rotation of the trunk and in load transfer, and hence instability of the lower lumbar spine and pelvis.

Barker & Briggs (1999) make the interesting comment that the posterior layer is ideally positioned to receive feedback from multiple structures involved in lumbar movements and may regulate ligamentous tension via its extensive muscular attachments to both deep stabilizing and more superficial muscles. They also report that the fascia displays viscoelastic properties and thus is capable of altering its structure to adapt to the stresses placed on it. The posterior layer has been reported to stiffen with successive loading and adaptive fascial thickening is possible.

Barker & Briggs (1999) also comment that when adaptive strengthening of the posterior layer takes place, one might expect to facilitate this by using exercises that strengthen its attaching muscles, both deep and superficial. Adaptive strengthening therefore would be expected to occur with exercises using contralateral limbs such as swimming and walking and torsional training. It also might occur with recovery of muscle bulk and function (erector spinae/multifidus) during lumbopelvic stabilization exercises.

Bogduk et al. (1998) do not agree with the concept that the latissimus dorsi has a role in rotating the spine and comment that the muscle is designed to move the upper limb and its possible contribution to bracing the SIJ via the thoracolumbal fascia is trivial. In contrast to this, Kumar et al. (1996) showed that axial rotation of the trunk involves agonistic activity of the contralateral external obliques, and ipsilateral erector spinae and latissimus dorsi as agonistic muscles to rotate the trunk.

Mooney et al. (2001) used the anatomical relation of the latissimus dorsi and the contralateral gluteus maximus muscles to study their coupled effect during axial rotation exercises and walking. They concluded that in normal individuals, walking a treadmill, the functional relationship between the mentioned muscles could be confirmed. It was apparent that the right gluteus maximus muscle had on average a lower signal amplitude compared to the left ($n = 15$; 12 right-handed). This reciprocal relationship of muscles correlates with normal reverse rotation of shoulders versus the pelvis in normal gait. They showed that during right rotation of the trunk the right latissimus dorsi muscle is significantly more active than the left, but that the left gluteus maximus muscle is more active than the right. In patients with SIJ problems a strikingly different pattern was noticed. On the symptomatic side the gluteus maximus was far more active compared with the healthy subjects. The reciprocal relation between latissimus and gluteus maximus muscles, however, was still present. After an intense rotational strengthening training programme, the patients showed a marked increase in latissimus dorsi muscle strength and diminished activity of the gluteus muscle on the symptomatic side.

The importance of these findings could be that rotational trunk muscle training is important, particularly for stabilizing the SIJ and lower spine. These