Functional Anatomy of the Pelvis and the Sacroiliac Joint

A Practical Guide

Exam Edition

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Contents

Abbreviations

AAJ	atlantoaxial joint
AHC	anterior horn cell
AIIS	anterior inferior iliac spine
ASIS	anterior superior iliac spine
ASLR	active straight leg raise
COG	center of gravity
CT	computerized tomography
DDD	degenerative disc disease
DLS	deep longitudinal sling
ERS	extension, rotation, side bending
FABER	flexion, abduction, external rotation
FAI	femoroacetabular impingement
FAIR	flexion, adduction, internal rotation
FRS	flexion, rotation, side bending
Gmax	gluteus maximus
Gmed	gluteus medius
Gmin	gluteus minimus
GTO	golgi tendon organ
HVT	high-velocity thrust
ILA	inferior lateral angle
ITB	iliotibial band
LLD	leg length discrepancy
L-on-L	left-on-left
L-on-R	left-on-right
MET	muscle energy technique
MR	magnetic resonance
MRI	magnetic resonance imaging
MTA	middle transverse axis
NR	neutral, rotation
OAJ	occipitoatlantal joint
PGP	pelvic girdle pain
PHC	posterior horn cell
PIIS	posterior inferior iliac spine
PIR	post-isometric relaxation
PLS	posterior longitudinal sling
PSIS	posterior superior iliac spine
QL	quadratus lumborum
RI	reciprocal inhibition
ROM	range of motion
R-on-L	right-on-left
R-on-R	right-on-right
SCM	sternocleidomastoid
SIJ	sacroiliac joint
SPD	symphysis pubis dysfunction
SPJ	symphysis pubis joint
STJ	subtalar joint
TFL	tensor fasciae latae
TMJ	temporomandibular joint
TP	transverse process
TVA	transversus abdominis

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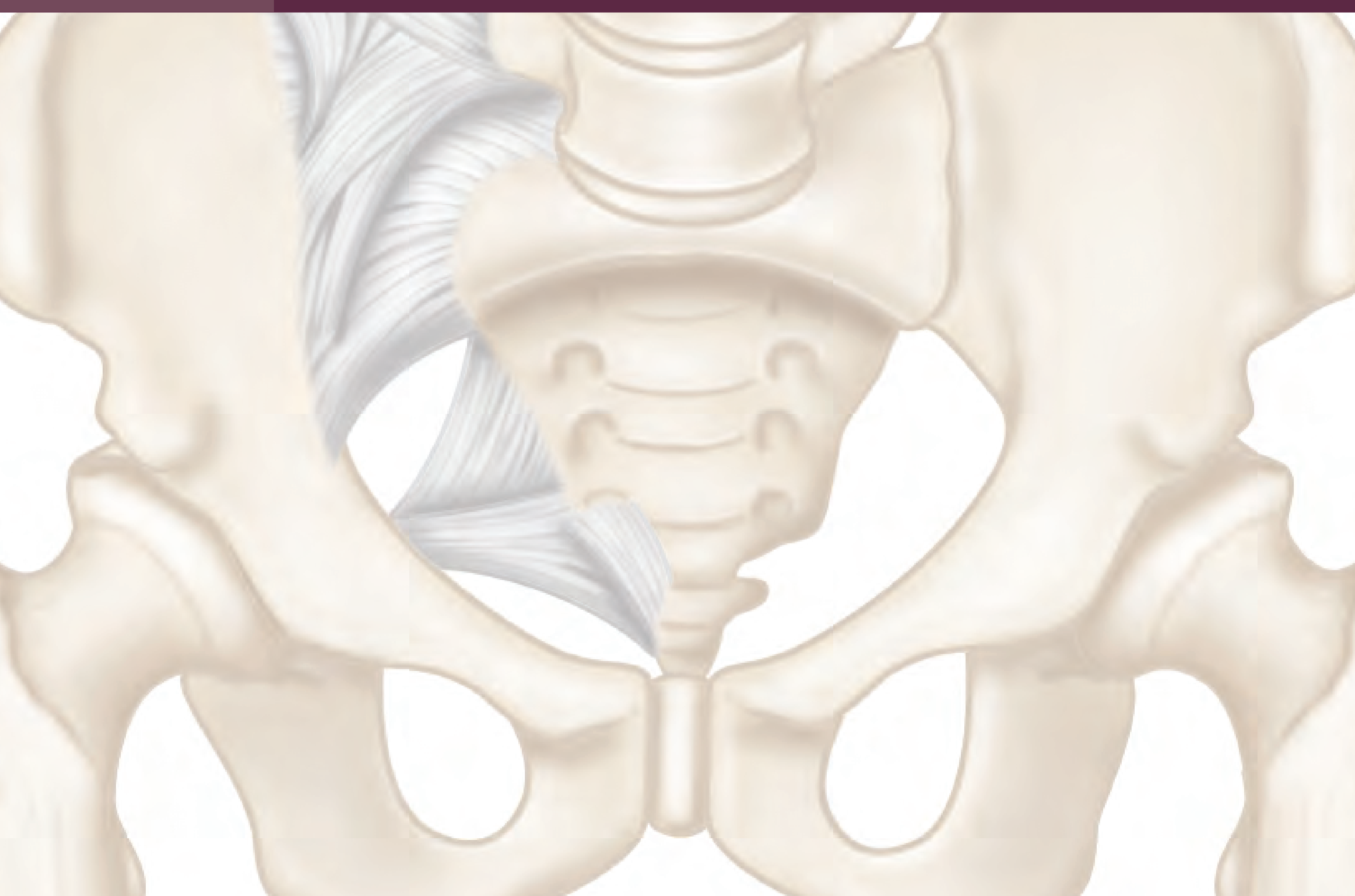
Anatomy of the Pelvis and the Sacroiliac Joint



The pelvic girdle is composed of the sacrum, the coccyx, and the three so-called "hipbones"—the ilium, ischium, and pubis. The bones of the adult pelvis join together to form four joints: the left and right sacroiliac joints (SIJs), the sacrococcygeal joint, and the symphysis pubis joint (SPJ), as shown in Figure 1.1.

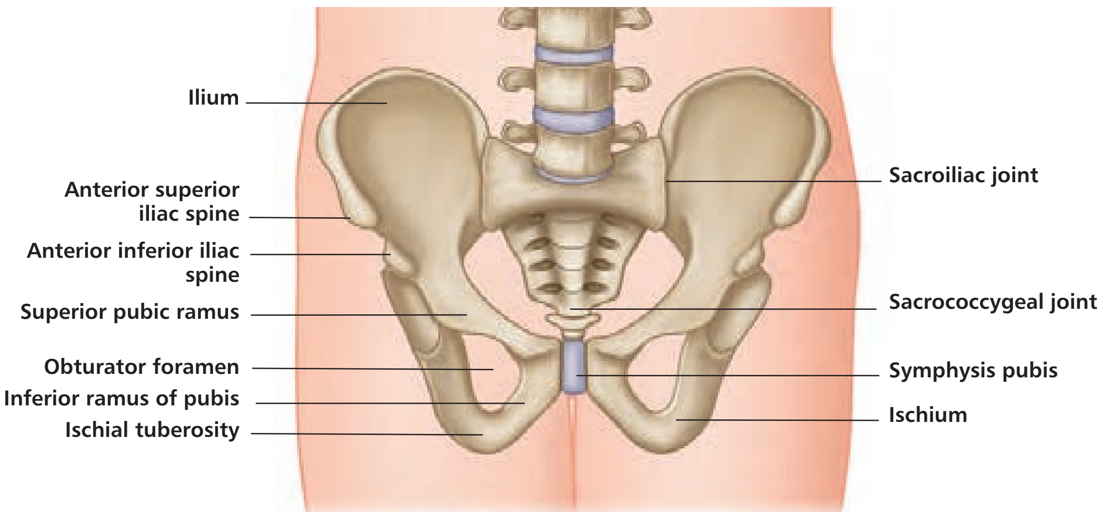


Figure 1.1. Bones of the pelvic girdle, forming the four joints.

At birth the ilium, ischium, and pubis bones are separated by hyaline cartilage; by the end of puberty these bones will have naturally conjoined (fused together), with complete ossification normally occurring by the time a person has reached the age of approximately 20–25. The three bones, once fusion has taken place, are collectively called the *innominate bone*, or simply the *innominate*. On the lateral side of the innominate bone is the acetabulum; this area forms the articulation with the head of the femur to create the iliofemoral (hip) joint, as shown in Figure 1.2.

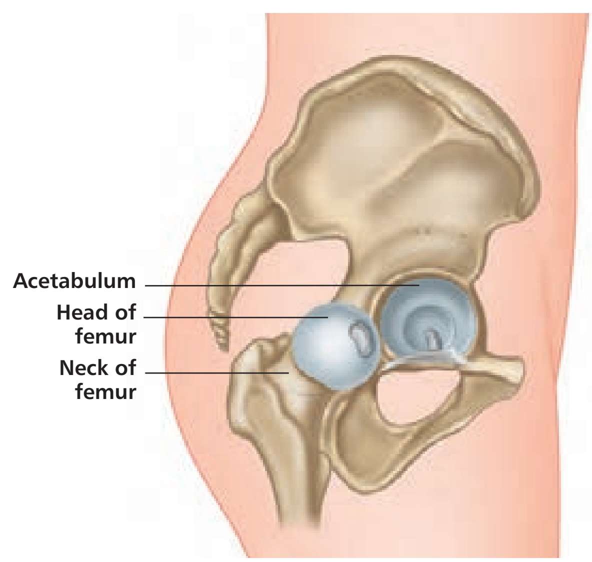


Figure 1.2. Iliofemoral (hip) joint.

Innominate Bones

Ilium

The ilium is fan shaped and is the most superior as well as the largest of the three hipbones; it makes up approximately two-fifths of the deep, cuplike socket of the hip joint, called the *acetabulum*. The body of the ilium together with the sacrum forms the SIJ. This L-shaped articulation is located on the posterior superior aspect of the ilium and has a vertically (vertical plane) orientated "short arm" and a more horizontally (anterioposterior plane) positioned "long arm," as shown in Figure 1.3.

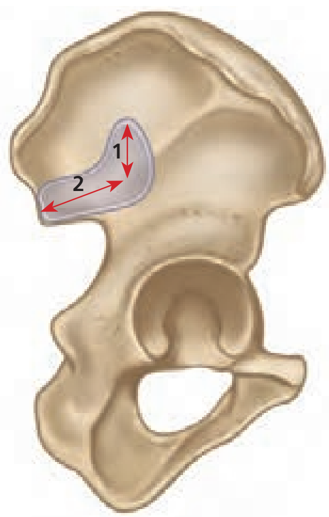


Figure 1.3. L shape of the short (vertical [1]) and long (horizontal [2]) arms of the ilium.

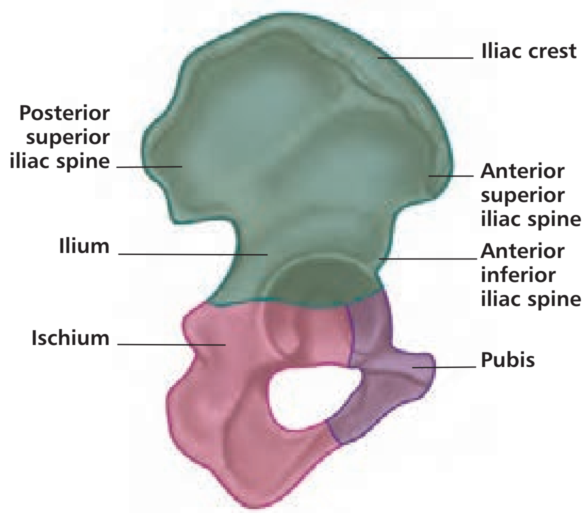


Figure 1.4. Anatomical landmarks of the iliac crest: ASIS, AIIS, and PSIS.

If you place one hand on your hip, you can feel the curved ridge of the superior aspect of the ilium: this is known as the *iliac crest*. From this crest, if you lightly move your fingers down inferior to the anterior aspect of the ilium, you should feel a bony projection known as the *anterior superior iliac spine (ASIS)*; this area allows the attachment of soft tissues (e.g. the sartorius muscle). If you continue slightly inferior to the ASIS, you will come to another bony landmark called the *anterior inferior iliac spine (AIIS)*; this is where one part of the rectus femoris muscle attaches. Palpating the posterior aspect of the ilium as it curves inferiorly, you will feel the bony prominence of the *posterior superior iliac spine (PSIS)*; again this is an attachment for soft tissues. These two bony projections (ASIS and PSIS) are commonly used as palpatory landmarks, as shown in Figure 1.4, when one is assessing the position of the pelvic girdle.

Ischium

The ischium is narrower than the ilium bone and is located inferior to the ilium and behind the pubis. The ischium has an easily palpable landmark called the *ischial tuberosity*, as shown in Figure 1.5; it is commonly called the *sit bone* and provides the necessary landmark for the attachment of the hamstrings. It is this part of the ischium (tuberosity), along with the coccyx, on which you rest your body weight while adopting a sitting position. The ischium is the strongest of the three bones and forms approximately two-fifths of the acetabulum (hip socket).

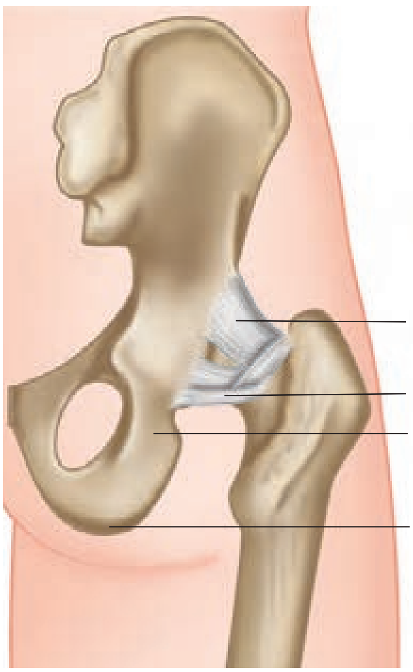


Figure 1.5. Ischium and ischial tuberosity.

Pubis

The pubis, or pubic bone, is the most anterior as well as the smallest of all the three hipbones and makes up approximately one-fifth of the acetabulum. The body of the pubis is wide, strong, and flat, and together with the opposite pubic bone makes up the SPJ. This joint is classified as an *amphiarthrosis*, as it is connected centrally by a broad piece of fibrocartilage, as shown in Figure 1.6. On the superior aspect of the pubis there is a bony projection called the *pubic tubercle*; this structure allows the attachment of the inguinal ligament and is also used as a palpatory landmark when one is assessing the position of the pelvic girdle.

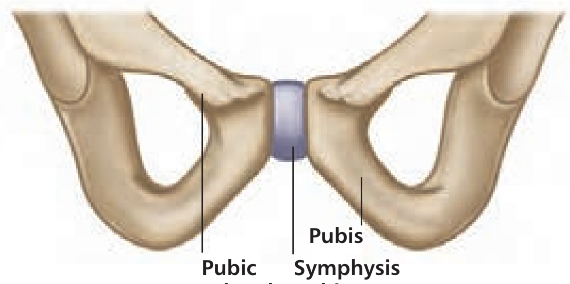


Figure 1.6. Pubis, pubic tubercle and SPJ.

Sacrum

The sacrum (sacred bone) is a large triangular bone located at the base of the lumbar spine and forms the back part of the pelvic cavity. The sacrum starts out from birth as five individual bones before starting to fuse between the ages of 16 and 18; the sacrum is considered to have fully fused into a single bone by the time you have reached 34 years of age.

Considerable differences in the shape of the sacrum between individuals, as well as structural differences between the left and right sides, are well documented. The connection of the sacrum to the ilium forms the SIJ.

The superior aspect of the sacrum is called the *sacral base* and is primarily made up of the 1st sacral segment; the base is angled in a forward direction to form a concavity. The opposite end of the sacrum is called the *sacral apex* and this is made up of the 5th sacral segment, as shown in Figure 1.7. The natural position of the sacrum is called the *sacral angle* and is generally thought to be in the range 40–44 degrees (Figure 1.8), although, as discussed by some authors, the angle can be anywhere from 30 to 50 degrees. Moreover, a specific type of motion called *nutation* (a nodding motion, which will be discussed later) can be responsible for an increase in this angle by anywhere between 6 and 8 degrees on standing up (from a sitting position). The sacral angle increases because of the change in the curvature of the lumbar spine, from an initial flexion curvature when sitting, to an extension curvature (lumbar lordosis) when standing, as one performs the motion from a sitting to a standing posture. This sacral movement allows the whole of the spinal column to adopt an upright position.

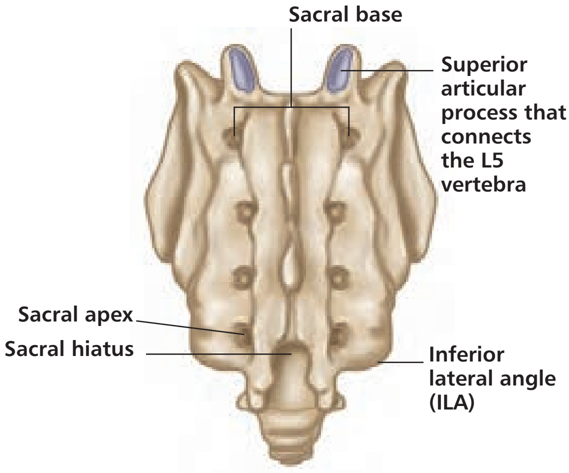


Figure 1.7. Anatomical landmarks of the sacrum (posterior view).

On the lateral sides of the sacrum located between the levels of the first three sacral vertebra (S1–S3) are the *alae* (wings): these auricular (earlike) L-shaped areas of the sacrum make up the articulation with the ilium—i.e. the SIJ. In an earlier paragraph regarding the ilium I mentioned that there is a short vertical arm and a long anteroposterior (horizontal) arm, as shown in Figure 1.8, which will naturally dovetail with each other, like pieces of a jigsaw puzzle.

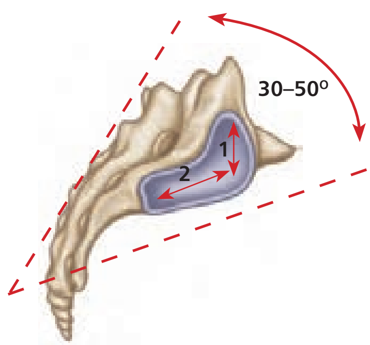


Figure 1.8. The short (vertical [1]) and long (horizontal [2]) arm of the sacrum, and the sacral angle (lateral view).

Another way of looking at the sacrum is as a continuation of the lumbar spine, while the SIJs on either side are mimicking what I generally call *atypical facet joints*. You can think of the sacrum as a single vertebra, and the left and right SIJs as the articulating facet joints, with the superior articular facet being the ilia component and the inferior articular facet being the sacral component (illustrated in Figure 1.11).

Coccyx

The coccyx is the continuation and endpoint of the vertebral column and is commonly referred to as the *tailbone*. It has between three and five (normally four) vertebral segments called the *coccygeal vertebrae*, and most textbooks state that these are actually fused; some authors, however, maintain that the coccygeal vertebrae are indeed separate and individual entities (Figure 1.9).

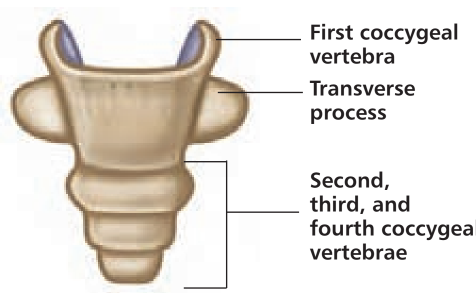


Figure 1.9. Coccyx bone and the individual segments.

There are many muscles with attachments directly on the coccyx: for example, the pelvic floor muscles attach to the anterior surface of the coccyx, and the gluteus maximus (Gmax) muscle and ligaments attach to the posterior surface. Likewise, some ligaments attach directly to the coccyx, such as the sacrococcygeal ligament and some of the fibers of the sacrospinous and sacrotuberous ligaments. The coccyx also plays a role in weight bearing (while sitting), as it forms part of the *tripod* structure, working in conjunction with the left and right ischial tuberosities (sit bones).

Symphysis Pubis Joint

The symphysis pubis joint (SPJ) is classified as a *non-synovial fibrocartilaginous amphiarthrosis*, connecting the left and right pubic bones.

In adults only 0.08" (2mm) of movement (shift) and one degree of rotation are considered to be possible in this joint; however, these values will increase in women during pregnancy and childbirth. The available movement of the SPJ is also influenced by the natural shape of the joint, and by muscular activation from the adductor and abdominal muscles.

The ends of each pubic bone are covered by hyaline cartilage that connects to the piece of fibrocartilage located in the center of the SPJ. The joint has strong superior and inferior ligaments and a thinner posterior ligament (Figure 1.10).

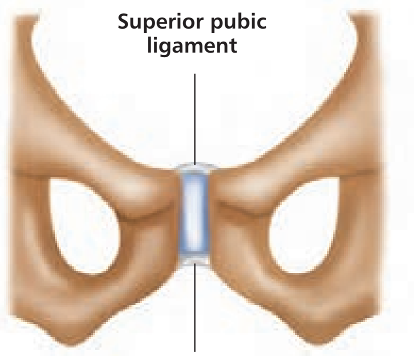


Figure 1.10. Symphysis pubis joint and associated ligaments.

One can think of the design of the symphysis pubis as being similar to the intervertebral discs of the spine, with a central disc of fibrocartilage that cushions against compressive loads, as well as providing shock absorption and contributing to passive stabilization. Because of this similarity, the articular disc of the SPJ is also vulnerable to both degeneration and trauma, particularly when the joint is subjected to traumatic or repetitive shear forces (e.g. osteitis pubis).

Functionally, the SPJ helps to resist tension, shearing, and compression forces, and remarkably is able to widen during pregnancy.

The anatomist Andreas Vesalius, who challenged the Hippocratic belief that the pubic bones separated during childbirth, was the first to recognize this joint in 1543.

Sacroiliac Joint

Lower back pain and the link with the sacroiliac joint (SIJ, or SI joint) date back to the era of Hippocrates (c.460–377 BC); the medical practitioners (obstetricians) at the time felt that under normal conditions the SIJs were immobile. I am very pleased to say that things have progressed enormously over the last few decades with all the information now readily available in respect of the general consensus of the role and function of the pelvic girdle, and in particular of the SIJ. I can guarantee, though, that over time some things will nevertheless change, so this book may well need to be updated in the future.

I have been lecturing courses on the pelvic girdle, and on the SIJ in particular, for many years at my venue based at the University of Oxford, which means I have come into contact with thousands of physical therapists, ranging from osteopaths and physiotherapists to chiropractors and lots of sports therapists, to mention but a few. If I am honest with myself, I personally consider that the area of the pelvis is a relatively difficult subject to try to get across to my students (mainly therapists); this is because I consider the SIJ to be something of a "mystery" to many therapists, and it becomes especially difficult when I am trying to explain the subject matter to my athletes and patients.

The majority of physical therapists attending the course on the pelvic girdle tell me at some point that they see patients and athletes on a daily basis with what they consider to be a presentation of *sacroiliac joint dysfunction*. In the past, patients with presenting SIJ issues have even been referred directly to them by the local GP or a colleague.

Vleeming et al. (2007) say that mobility of the pelvic joints is difficult to measure objectively, especially in the weight bearing position, and that feeling motion at the sacroiliac joint during active and passive motion is difficult to prove.

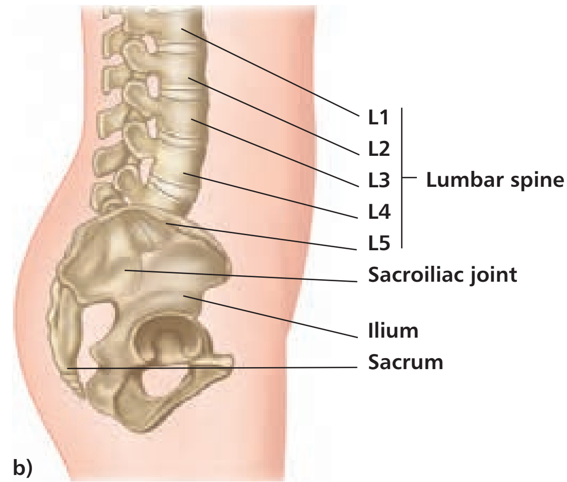
Bearing in mind the above quote, you can imagine that teaching a specific course on this fascinating but undoubtedly complex area of the body is not as straightforward as one might think.

Anatomy

The SIJ, as shown in Figure 1.11, is located between the sacrum and the ilium and is classified as a *true synovial arthrodial joint*, as it contains a joint capsule, synovial fluid, articular cartilage, and a synovial membrane.

The SIJ is unique: on the ilia side, the cartilage is made up mainly of fibrocartilage, whereas on the sacral side, the cartilage consists of hyaline, or articular, cartilage. The articular (hyaline) cartilage is thicker (0.04–0.12", or 1–3mm) on the sacral side than on the ilia side. Kampen and Tillman (1998) found that in adults the cartilage on the sacral surface of the joint can reach 0.16" (4mm) in thickness, but does not exceed 0.04–0.08" (1–2mm) on the iliac surface. The lack of thickness of the cartilage on the ilia side might be one of the factors responsible for hardening (sclerosis).

Regarding the shape of the SIJ, different characteristics between individuals have been clinically proven; moreover, there can be significant structural differences between the left and right sides of the joint surfaces within the SIJs of the same individual. There is also clear evidence of the fact that the paired SIJs, and even the PSISs, are generally asymmetric in appearance, which can also be the case in patients and athletes who present with no symptoms of pain or dysfunction (i.e. are asymptomatic).



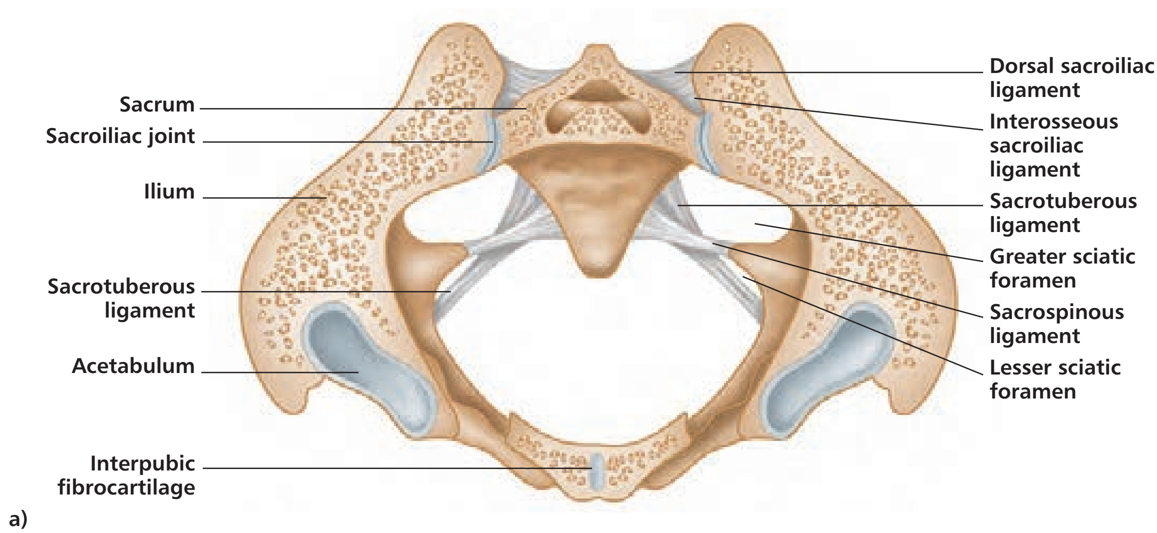


Figure 1.11. Anatomy of the SIJ; a) transverse section; b) lateral view.

The SIJs have an auricular L-shaped appearance, similar to a kidney, with a short (vertical) upper arm and a longer (horizontal) lower arm (as already mentioned earlier).

In terms of motion, the pelvis is capable of moving in all three planes of the body: flexion and extension in the sagittal plane (forward and backward bending); lateral flexion (side bending) in the frontal plane; and rotation of the trunk in the transverse plane. It has been debated that the SIJ can move anywhere between 2 and

18 degrees, but more recent evidence provided by many clinicians demonstrates that there are roughly 2–4 degrees of rotation and 0.04–0.08" (1–2mm) of translation. Studies have shown us that movement is possible, but only in very small amounts; this was demonstrated by Egund et al. (1978) and Sturesson et al. (1989, 2000a, 2000b), who found the motion of the SIJ to be at best approximately 2–4 degrees in rotation and 0.08" (2mm) in translation.

We know that when we are developing through the natural aging process, the SIJ characteristics change. In early life the SIJ surfaces are in general initially flat, but as we start to walk and progress through puberty, these surfaces develop distinct ridges and grooves and lose their naturally flattened appearance. These ridges and grooves actually fit into one another to some extent; this will potentially aid the overall stability of the SIJ, while still allowing some degree of movement.

The text *Greenman's Principles of Manual Medicine* (DeStefano 2011) mentions that "during the aging process, there is an increase in the grooves on the opposing surfaces of the sacrum and ilium that appears to reduce available motion and enhance stability." The author also says that "it is of interest to note that the age at which the incidence of disabling back pain is highest (range: 25 to 45 years) is the same age when the greatest amount of motion is available in the sacroiliac joints."

Because of the relationship of the three main pelvic joints (the two sacroiliac and the symphysis pubis), as well as their relationship to the iliofemoral joint (hip joint), a dysfunction existing in any one of these joints can have a direct impact on the other two/three joints.

Ligaments of the SIJ

The SIJ has very strong ligaments, which increase the joint's stability and make potential dislocations very rare.

Stability of the SIJ is provided partly through ligamentous attachments. These specific ligaments will provide joint integrity as well as resistance to shearing-type forces. The ligaments that bind the sacrum directly to the innominate are (Figure 1.12):

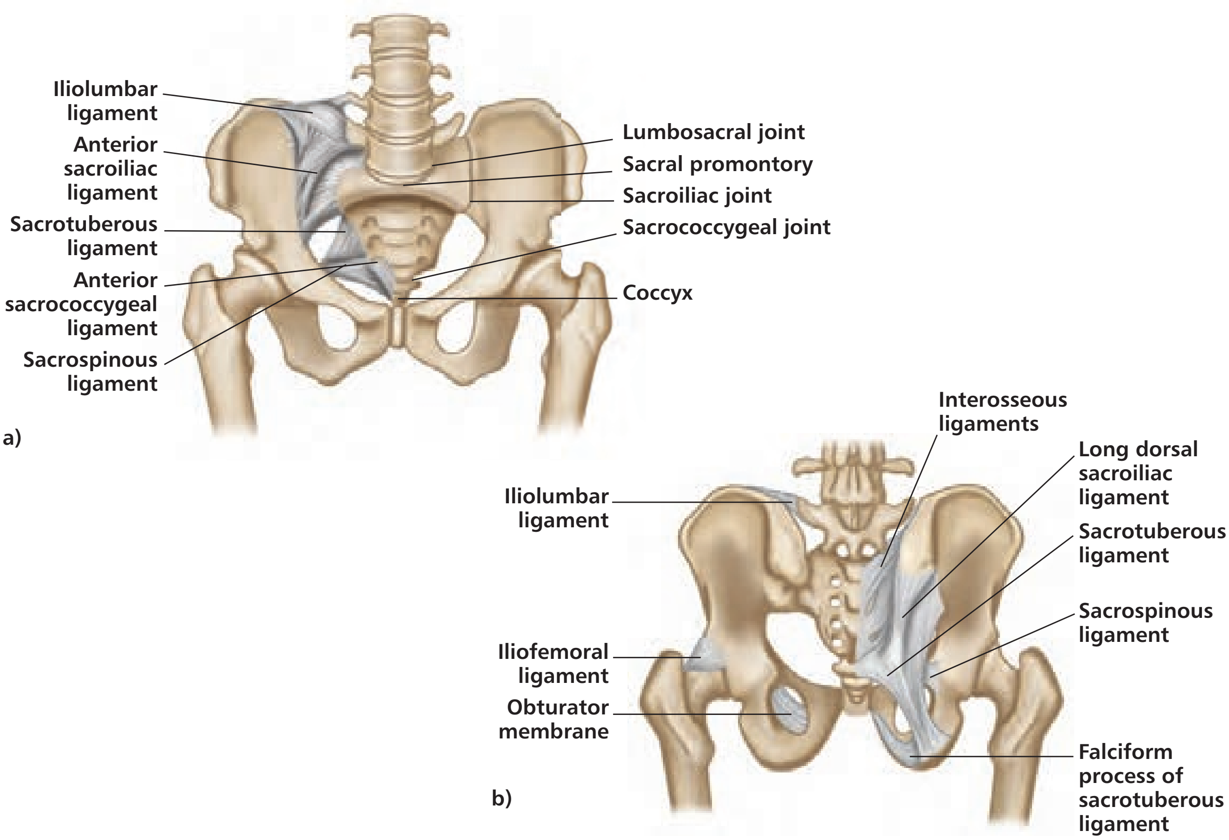


Figure 1.12. Ligaments relating to stability of the SIJ; a) anterior view, b) posterior view.

- Sacrotuberous
- Sacrospinous
- Interosseous
- Long dorsal (posterior sacroiliac)

The iliolumbar ligament will also have a stabilizing influence on the SIJ as well as on the lumbar spine.

Sacrotuberous Ligament

The sacrotuberous ligament attaches from the PSIS and also has an attachment to the posterior sacroiliac ligaments. The ligament then continues and attaches onto the ischial tuberosity and splits into three individual bands: the outer (lateral) side attaches from the PSIS to the ischial tuberosity; the inner (medial) band attaches from the coccyx to the ischial tuberosity; and the superior band connects the PSIS to the coccyx.

Four muscles have an attachment directly to the sacrotuberous ligament and will contribute to the overall stability of the SIJ:

- Biceps femoris
- Gluteus maximus (Gmax)
- Multifidus
- Piriformis

Vleeming et al. (1989a) found that in approximately 50% of subjects the lower border of the sacrotuberous ligament was directly continuous with the tendon of the origin of the long head of biceps femoris; this muscle could therefore act to stabilize the SIJ via the sacrotuberous ligament.

Part of the role of the sacrotuberous ligament is to resist the anterior nodding type of motion of the sacrum known as *nutation*. This ligament will also prevent posterior rotation of the innominate bone with respect to the sacrum. If for some reason there is laxity in the sacrotuberous ligament (along with the sacrospinous ligament), the decreased tension can result in a posterior rotation of the innominate bone, and also lead to increased nutation of the sacrum.

Sacrospinous Ligament

The sacrospinous ligament has an attachment from the lateral aspect of the sacrum and coccyx and attaches to the spine of the ischium, appropriately named the *ischial spine*. The ligament has the appearance of a thin triangle and, together with the sacrotuberous ligament, it modifies the greater sciatic notch in the greater sciatic foramen. In one respect, the function of the sacrospinous ligament is similar to that of the sacrotuberous ligament: it prevents posterior rotation of the innominate bone relative to the sacrum, and also limits nutation (forward motion) of the sacrum relative to the innominate bone.

Interosseous Ligament

The interosseous ligament consists of a dense, short, thick collection of strong collagenous fibers that run in a horizontal plane and connect the sacral tuberosities of the sacrum to the ilium. This ligament lies deep in the narrow recess between the sacrum and the ilium, and has deep and superficial components to it. The main function of the interosseous ligament is to prevent a separation or abduction of the SIJ by strongly binding the sacrum to the ilium, as this will help secure the SIJ interlocking mechanism.

Long Dorsal Ligament (Posterior Sacroiliac Ligament)

The long dorsal ligament attaches from the medial and lateral crests of the sacrum and to the PSIS. There is also a connection of this ligament to the thoracolumbar fascia, as well as to the multifidus and erector spinae muscles.

The long dorsal ligament mainly resists counter-nutation of the sacrum (posterior nutation) as well as anterior rotation of the innominate bone. Consequently, this ligament will naturally slacken when the sacrum is in a state of nutation and/or if there is posterior rotation of the innominate bone.

If sacral torsion is present (discussed in later chapters) and the sacral base is found to be "posterior," this ligament will be under constant tension and may be tender when palpated.

Lee (2004, p. 22) mentions that the skin overlying the long dorsal sacroiliac ligament is a frequent area of pain in patients with lumbosacral and pelvic girdle dysfunction, and that tenderness on palpation of the ligament does not necessarily incriminate this tissue, given the nature of pain referral from both the lumbar spine and the SIJ.

Iliolumbar Ligament

The iliolumbar ligament is a very strong ligamentous structure; it attaches from the transverse processes (TPs) of the 4th and 5th lumbar vertebrae and travels to the inner border of the ilium.

This ligament, which has five individual bands, is one of three vertebrae–pelvis ligaments responsible for stabilizing the lumbosacral spine in the pelvis, along with the two mentioned already, namely the sacrospinous and sacrotuberous. The main function of the iliolumbar ligament is essentially to limit the motion of the lumbosacral junction by stabilizing the connection between the pelvis and the lower lumbar vertebrae (L4 and L5).

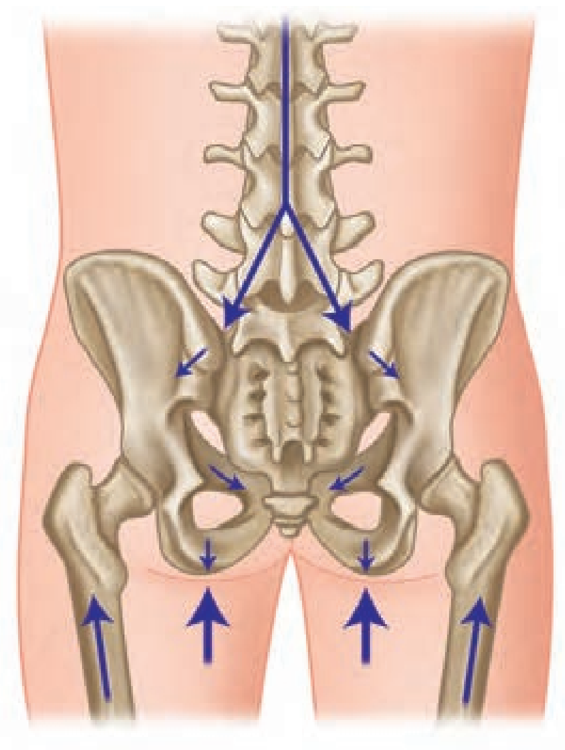


Figure 1.13. Weight transfer forces through the pelvis and the SIJs.

Function of the SIJs

The SIJs' primary responsibility is to transfer the weight of the upper body to the lower extremities. The body weight is transferred through the vertebral column to the lumbar spine (L5), to the sacrum and across the SIJs to the ischial tuberosities, and then out to the acetabula of the hip joints. This mechanism of bony attachments demonstrates the SIJs' role as weight-bearing joints, as shown in Figure 1.13. The SIJs are also able to transfer the forces in the opposite direction when one is walking, standing, or sitting: the pressure is directed through the legs to the innominates and the sacrum, and then dissipated upward through the lumbosacral junction.

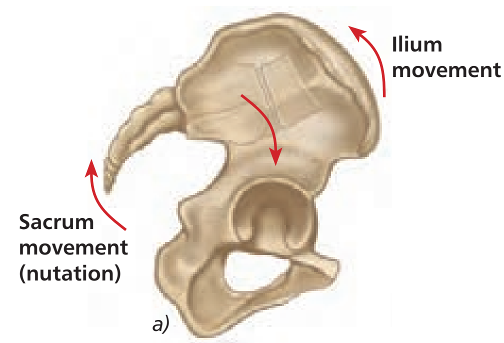
In their secondary role, the SIJs can be thought of as shock absorbers (mainly at the point of heel contact), as they help cushion the increased stress that is forced upon the lumbar spine and in particular upon the lower lumbar intervertebral discs. Authors in the past have suggested that the incidence of lower lumbar disc disease/degeneration increases when the SIJs present with pathological changes.

Lee and Vleeming (2007) discussed the analysis of gait mechanics and demonstrated that the SIJs provide sufficient flexibility for the intra-pelvic forces to be transferred effectively to and from the lumbar spine and lower extremities.

2

Motion of the Pelvis and the Sacroiliac Joint

Previous authors have suggested that there are approximately 14 individual types of dysfunction possible within the pelvic girdle complex. This in itself suggests to me that, because there are so many types of potential dysfunction which can be present within the pelvic girdle, there logically have to be just as many types of natural motion available as well.



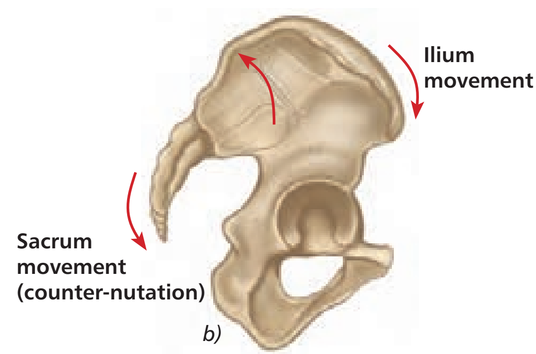


Figure 2.1. (a) Sacral nutation. (b) Sacral counter-nutation.

Pelvis Motion

Put in a relatively simple way, there are three main types of motion available within the pelvic girdle:

- Sacroiliac motion, which comprises the motion of the sacrum on the innominate bone.
- Iliosacral motion, which comprises the motion of the innominate bone on the sacrum.
- Symphysis pubis motion, which typically relates to the motion of the pubic bone on one side with respect to the bone on the other side.

Sacroiliac Motion

Sacroiliac motion is the movement of the sacrum within the innominate bone, and there are two main types: (1) anterior/forward motion, or nutation (think of this as sacral flexion); and (2) posterior/backward motion, or counter-nutation (think of this as sacral extension). Bilateral movement of the sacrum occurs with forward and backward bending of the trunk; on the other hand, unilateral movement of the sacrum occurs with flexion and extension of the hip joint and lower limbs, such as when we initiate the walking/gait cycle.

Nutation

The word *nutation* actually means "nodding", and this motion of the sacral base (top part of the sacrum) is directed anteriorly and inferiorly, while the sacral apex (bottom part of the sacrum)/coccyx moves posteriorly and superiorly relative to the innominate bone, as illustrated in Figure 2.1(a).

During nutation (which is also known as *anterior nutation*), the sacrum is considered to glide inferiorly down the short (vertical) arm and posteriorly along the long (horizontal) arm of the L-shaped articular surface (see Figure 2.2).

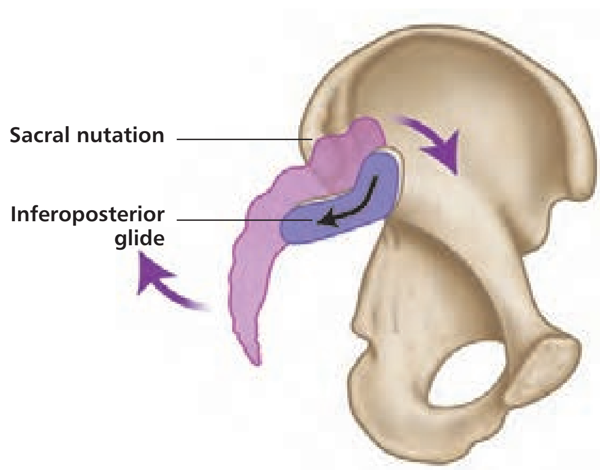


Figure 2.2. Sacral nutation: the sacrum glides inferiorly down the short arm and posteriorly along the long arm.

The natural wedge shape of the sacrum, as well as the ridges and grooves of the articular surfaces, limits nutation. In addition, the interosseous, sacrotuberous, and sacrospinous ligaments will limit how much nutation is possible, as they become taught in this position; this is considered to be the most stable position.

Vrahas et al. (1995) mention that nutation represents a movement that tightens most of the SIJ ligaments, among which are the vast interosseous and dorsal sacroiliac ligaments (with the exception of the long dorsal ligament), thereby preparing the pelvis for increased loading.

Counter-Nutation

In counter-nutation the sacral base moves posteriorly and superiorly, while the sacral apex/coccyx moves anteriorly and inferiorly relative to the innominate bone (Figure 2.1(b)). During this type of motion (which is also known as *posterior nutation*), the sacrum is considered to glide anteriorly along the long arm and superiorly up the short arm of the L-shaped articular surface, as shown in Figure 2.3.

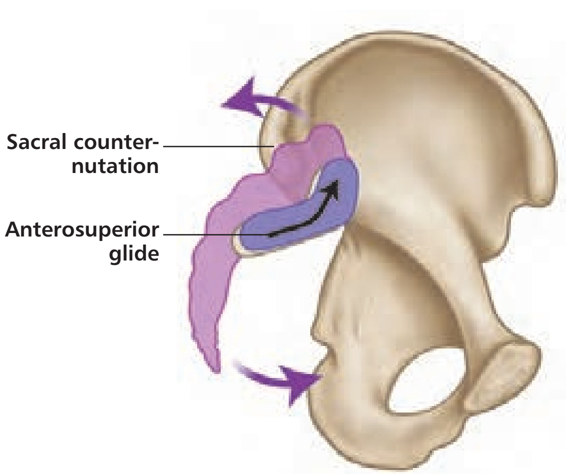


Figure 2.3. Sacral counter-nutation: the sacrum glides anteriorly along the long arm and superiorly up the short arm.

The long dorsal ligament limits this specific motion of counter-nutation. Because of the laxity of the interosseous and sacrotuberous ligaments, this sacral position of counter-nutation is considered to be the least stable.

Iliosacral Motion

Iliosacral motion is the movement permitted by the innominate bone on the sacrum. Bilateral movement (anterior and posterior rotation) of the innominate bones occurs with forward and backward bending of the trunk; on the other hand, unilateral movement (anterior and posterior rotation) of the innominate bone occurs with flexion and extension of the hip joint and lower limbs, for example during the gait cycle (similar to unilateral sacral motion).

Anterior Innominate Motion

When the hip and lower limb are extended, the innominate rotates anteriorly as the L-shaped articular surface glides inferiorly down the short arm and posteriorly along the long arm, as shown in Figure 2.4. This anterior motion of the innominate is reminiscent of counter-nutation of the sacrum.

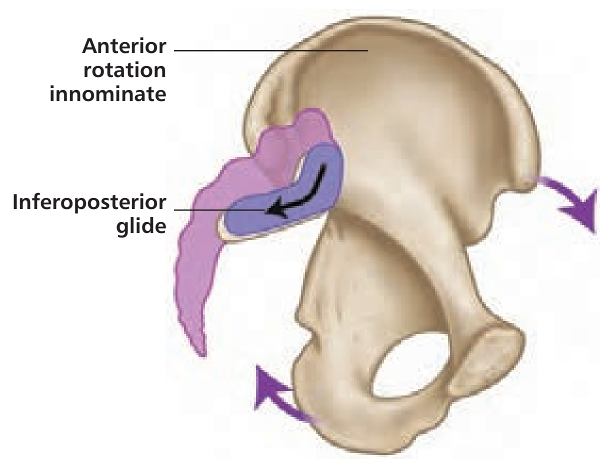


Figure 2.4. Anterior rotation of the innominate bone: the L-shaped articular surface glides inferiorly down the short arm and posteriorly along the long arm.

Posterior Innominate Motion

When the hip and lower limb are flexed, the innominate rotates posteriorly as the L-shaped articular surface glides anteriorly along the long arm and superiorly up the short arm, as shown in Figure 2.5. This posterior motion of the innominate is reminiscent of nutation of the sacrum.

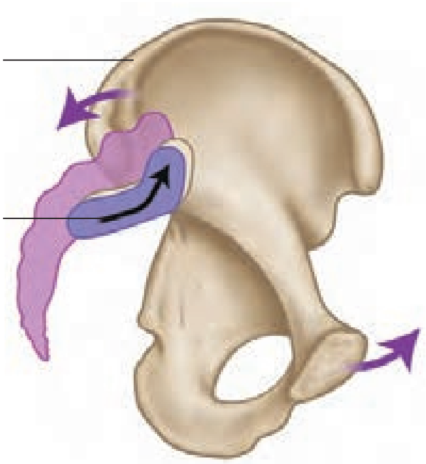


Figure 2.5. Posterior rotation of the innominate bone: the L-shaped articular surface glides anteriorly along the long arm and superiorly up the short arm.

Symphysis Pubis Motion

Anteriorly, the two hipbones are joined together to form a connection known as the *symphysis pubis joint*. During normal walking, the symphysis pubis joint acts as a type of pivot point for the motion of the two hipbones.

Although movement is possible at the symphysis pubis joint, it is normally restricted because of the attachments of the strong superior and inferior ligaments. The limited motion that is available mainly occurs during the walking cycle; however, movement is also possible at this joint when one adopts a stabilized standing position while balancing on one leg.

Symphysis pubis dysfunction (SPD) is generally classified according to the position in which the joint is fixed—either a *superior symphysis pubis* or an *inferior symphysis pubis*, as shown in Figure 2.6.

Studies have shown that if you were to maintain a one-legged standing position for a few minutes, a superior motion (shear) of the symphysis pubis would be seen. If the one-legged motion is maintained over an extended period of time, recurrent SPD can result.

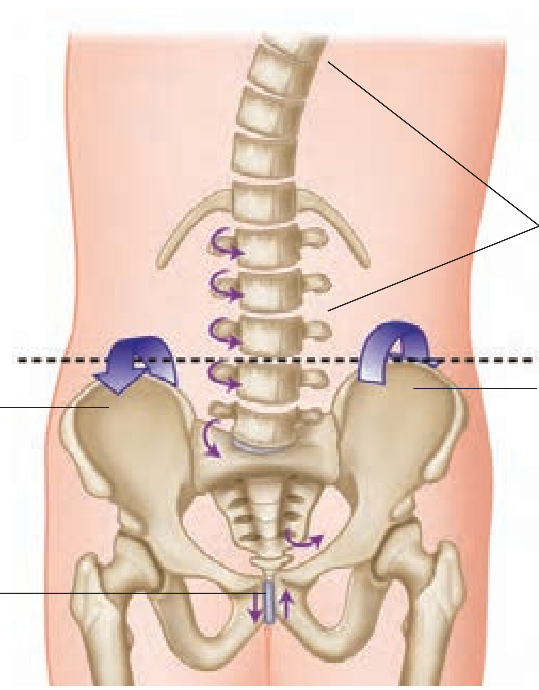


Figure 2.6. Superior and inferior motion of the symphysis pubis joint.

SPD is commonly associated with pregnancy and childbirth; it is thought to affect to varying degrees around one in five women who are pregnant, with around 5–7% of them continuing to experience ongoing painful symptoms after childbirth. During pregnancy, and especially during childbirth, the symphysis pubis ligaments become more lax in order to allow a natural separation of this joint, since this increased movement is needed to widen the internal diameter of the pelvic bowl.

Combined Sacroiliac and Iliosacral Motion

We have looked at the individual motion of the sacrum during nutation and counter-nutation within the innominate bones (sacroiliac) and how the innominate bone rotates around the sacrum (iliosacral). Next, we will combine the motion of the sacroiliac, iliosacral, lumbar, and hip joints during forward and backward bending of the trunk.

When the pelvic girdle, i.e. the two innominate bones and the sacrum, rotate as a unit through the hip joint, this motion is known as an *anterior pelvic tilt* or a *posterior pelvic tilt*.

Bilateral Motion—Forward Bending

Bilateral (both sides) nutation and counter-nutation are the natural movements that the sacrum performs when we forward and backward bend our trunk while in a stable position on two legs.

On the initiation of forward bending of the trunk, the pelvic girdle will shift posteriorly to control the center of gravity in order to maintain the balance. The sacrum will be in a position of nutation and will stay there throughout the full range of motion (ROM). The left and right innominates rotate symmetrically on the femur in an anterior direction (anterior pelvic tilt), and the PSIS will move symmetrically in a cephalic direction (superior) as the lumbar spine (L5) flexes on the sacrum. As trunk flexion continues, there will come a natural point when tension is increased within the sacrotuberous ligament, biceps femoris, and thoracolumbar fascia, and a position where sacral nutation ceases. At this point the innominate bones continue rotating anteriorly; however, because of the increased tension in the soft tissues (explained earlier), especially the hamstrings, the final position of trunk flexion is that in which the sacrum is considered to be in a position of *relative* counter-nutation, even though the sacrum will appear to be in a position of nutation, as shown in Figure 2.7.

Figure 2.7. Bilateral motion during forward bending.

On the return to a standing position, the sacrum remains in a position of nutation until the erect posture is achieved; at this crucial point, the sacrum slightly counter-nutates to maintain a suspension between the two innominate bones. (Note that, even though I have mentioned counter-nutation, the sacrum still maintains an overall position of nutation.)

Bilateral Motion—Backward Bending

This time, on the initiation of backward bending, the pelvic girdle will shift anteriorly, while the innominate bones symmetrically rotate posteriorly on the femur (posterior pelvic tilt); the PSIS can be seen and felt to rotate in a caudal direction (inferiorly), while the thoracolumbar spine continues extension until L5 extends on the sacrum, as shown in Figure 2.8. The sacrum remains in a position of nutation throughout backward bending; this position is considered to be the most stable because of the compression of the SIJs.

Figure 2.8. Bilateral motion during backward bending.

Unilateral (One Side) Motion of the Sacrum

During the walking/gait cycle, the sacrum is required to perform its natural motion in a way that is completely opposite to that during forward and backward bending movements. This time we need a specific type of unilateral (one-sided) motion of the sacrum, not a bilateral motion. What I mean by this is the following: as we walk from point A to point B, we need one side of the sacrum (e.g. the left side) to move forward into *nutation*, while at the same time the opposite side (right side in this case) is moving backward into *counter-nutation* (or posterior nutation). This movement gets a little bit more complex, as the nutation/counter-nutation will naturally induce a movement of *sacral rotation*. The problem we encounter now is that when you have a rotation of the sacrum (or in fact any vertebrae), a coupled (combined) motion with side bending also occurs; the general rule (according to the current research) is that the side bending motion will be coupled to the opposite side of the sacral rotation. This follows what is typically known as a *Type I* or *neutral mechanic* (explained in detail in Chapter 6), in which the rotation and side bending are coupled to the opposite side; for instance, the sacrum can perform a side bending motion to the left side, but it will rotate to the opposite side (to the right side in this case).

Consider the following example to illustrate what I am trying to say. If the *left* side of the sacrum goes forward into anterior nutation, it will rotate to the *right* side (the sacral base will palpate deeper on the left side) and will also side bend to the *left* (Figure 2.9). However, the *right* side of the sacrum will also rotate to the *right* side, but this time the sacral base will be in a posterior nutation position (counter-nutation, as the sacral base will now palpate shallow on the right side).

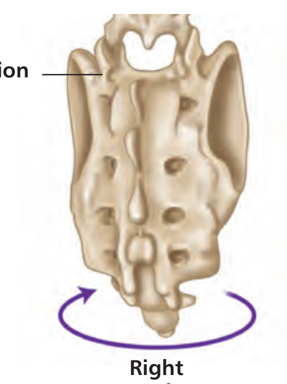


Figure 2.9. Example of a unilateral motion of the sacrum.

The movement discussed above, in which you have a rotation to one side and a side bending motion to the other, is also known as a *sacral torsion*; this specific type of sacral movement is considered to occur around an oblique axis (see figure 2.10).

Sacral Axis

There are approximately six types of sacral axis (Figure 2.10):

- Superior transverse axis
- Middle transverse axis
- Inferior transverse axis
- Left oblique axis
- Right oblique axis
- Vertical axis

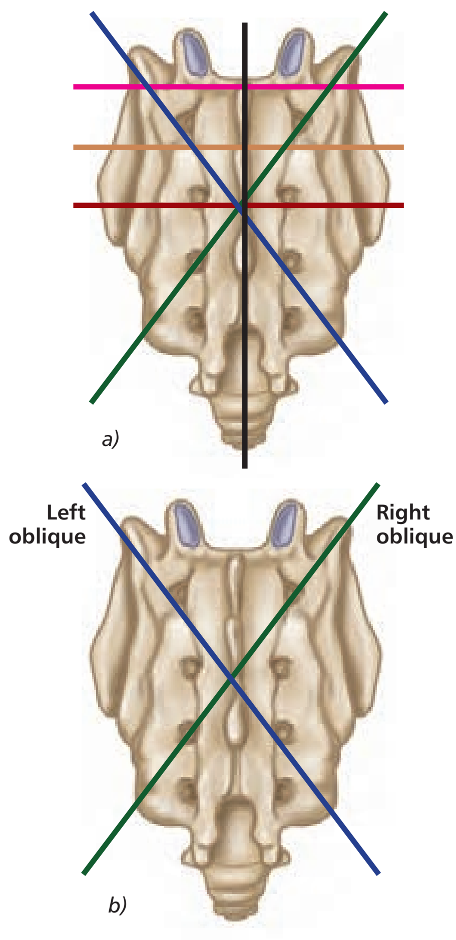


Figure 2.10. (a) Sacral axis, (b) Left oblique axis and right oblique axis.

It is not within the scope of this book to cover all the different sacral axis variations. For this text, however, the one of particular relevance is the middle transverse axis (MTA), because sacral dysfunctions are palpated and treated about this horizontal axis, according to Mitchell terminology. Moreover, this axis is considered to undergo a transformation during the gait cycle into the *oblique axis*, which is the specific axis that will be focused on in this text.

Oblique Axis

It has been suggested by some authors that there is a left oblique axis and a right oblique axis (see Figure 2.10(b)). The *left oblique axis* runs through the left sacral base and continues through the right inferior lateral angle (ILA); the *right oblique axis* runs through the right sacral base and continues through the left ILA.

In Chapter 3 I will take you through exactly how the oblique axis is utilized in combination with the movements of the kinetic chain as we perform sacral motion during the walking/gait cycle. For now, however, we will focus on the two natural physiological motions that the sacrum is capable of: "left rotation on the left oblique axis," which is typically called a *left-on-left* (L-on-L) sacral torsion, and a "right rotation on the right oblique axis," commonly known as a *right-on-right* (R-on-R) sacral torsion.

There are, however, also two non-physiological motions of the sacrum: "left rotation on the right oblique axis," which is typically called a *left-on-right* (L-on-R) sacral torsion, and a "right rotation on the left oblique axis," commonly known as a *right-on-left* (R-on-L) sacral torsion.

When authors mention the word "sacral torsion," they can mean one of two things: a naturally occurring motion of the sacrum that is performed, for example, during the gait cycle (Chapter 3 will explain this); or a dysfunction of the sacrum, in that it becomes fixed in this specific type of position or torsion.

Physiological Motions (Anterior Motion Fixation/Nutation)

Before we look at sacral torsions, let's just remind ourselves of the *neutral* position of the sacrum, as shown in Figure 2.11(a) and indicated by the model in Figure 2.11(b).

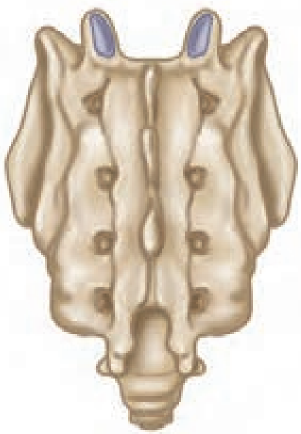


Figure 2.11. (a) Neutral position of the sacrum.

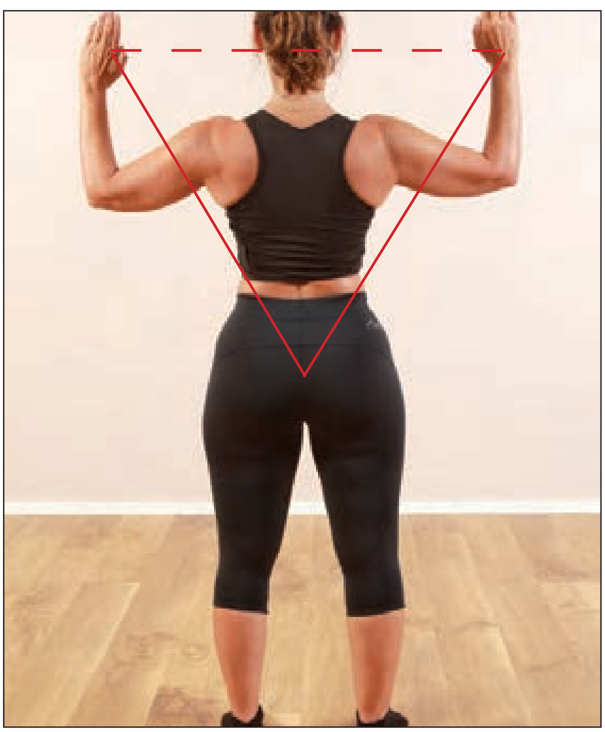


Figure 2.11. (b) Neutral position of the sacrum, as indicated by the model.

Left-on-Left (L-on-L)

Let's discuss a L-on-L sacral motion/torsion a bit further: it relates to the sacral bone being in a position of left rotation on the left oblique axis. This will be specific to the case where the sacrum has rotated to the left side, so the sacral sulcus (the area that is naturally formed by the junction of the sacral base with the corresponding ilium) will palpate as deep on the right. Moreover, the ILA as well as the sacral sulcus will palpate as posterior (shallow) on the left side, which will indicate that the *right* side of the sacrum has anteriorly nutated to the *left*, as shown in Figure 2.12(a).

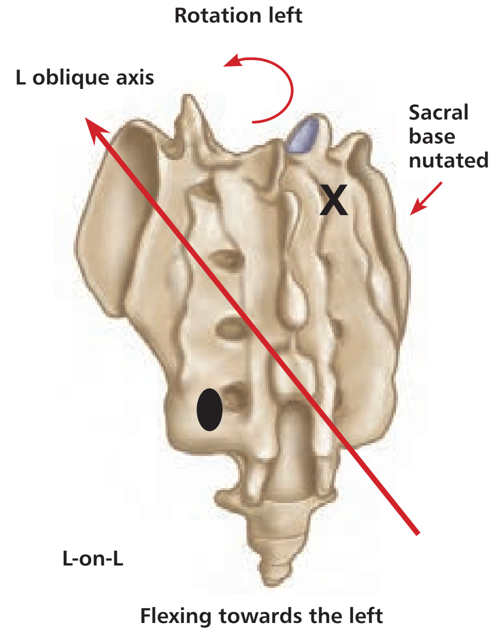


Figure 2.12. (a) Left-on-left (L-on-L) sacral motion/torsion. X = Anterior or deep. ⬮ = Posterior or shallow.

The specific motion of a L-on-L sacral torsion is demonstrated in Figure 2.12(b).

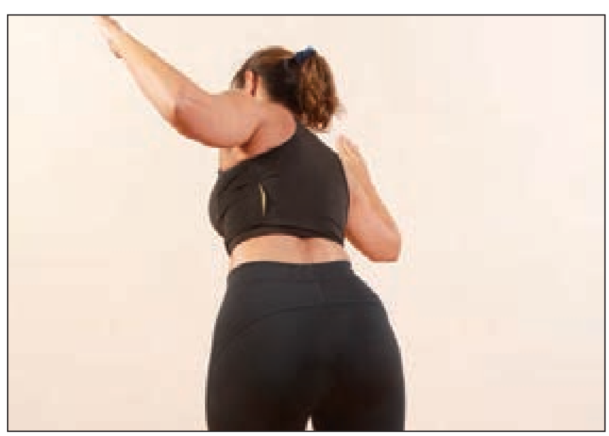


Figure 2.12. (b) L-on-L sacral torsion, as demonstrated by the model—sacral nutation is shown on the right side.

Right-on-Right (R-on-R)

A R-on-R sacral torsion relates to a right rotation on the right oblique axis. This will be specific to a sacrum that has rotated to the right side, so the sacral sulcus will palpate as deep on the left side. The ILA and the sacral sulcus will palpate as posterior (shallow) on the right, which will indicate that the *left* side of the sacrum has anteriorly nutated to the *right*, as shown in Figure 2.13(a).

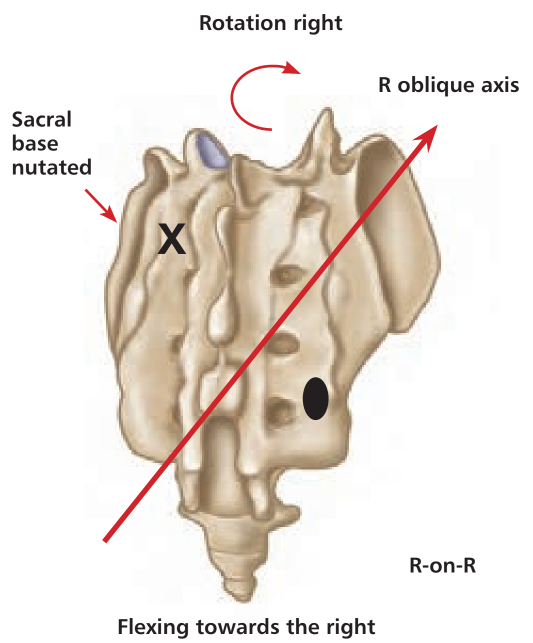


Figure 2.13. (a) Right-on-right (R-on-R) sacral motion/torsion. X = Anterior or deep. ⬮ = Posterior or shallow.

The model in Figure 2.13(b) is demonstrating the specific motion of a R-on-R sacral torsion.

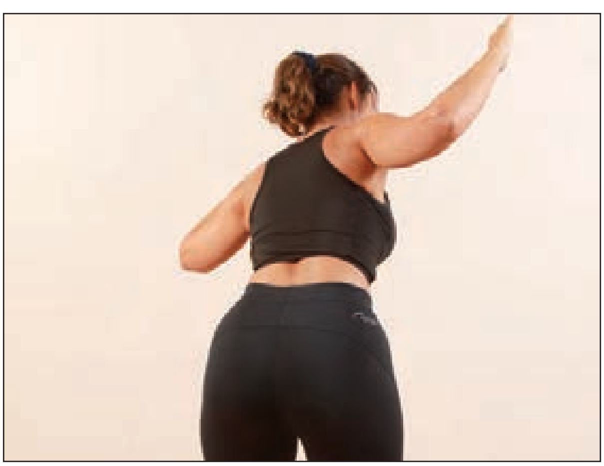


Figure 2.13. (b) R-on-R sacral torsion, as demonstrated by the model—sacral nutation is shown on the left side.

Physiological Summary

As I have already mentioned, L-on-L and R-on-R sacral torsions are naturally occurring motions around the sacrum, although these specific motions can be fixed in a position of nutation. For example, if you have a dysfunctional position, say a L-on-L sacral torsion, then the sacrum is capable of performing this movement, as it is already fixed in this position and is potentially capable of rotating back to a "neutral" position. However, it is unable to perform a "R-on-R" sacral torsion due to the fact that the left side of the sacrum is unable to counter-nutate (posterior nutation), as this side (left) is held in a fixed position of anterior nutation.

You will read in Chapter 3 that most of the activity of our musculoskeletal system will involve the walking/gait cycle. As humans, we especially need to be able to maintain ongoing L-on-L and R-on-R sacral (torsion) motions, since these are of paramount importance to enable us to ambulate normally through the gait cycle. If the sacrum cannot perform these naturally occurring sacral torsions (motion), dysfunction occurs as a consequence.

Non-Physiological Motions (Posterior Motion Fixation/Counter-Nutation)

Non-physiological motions of the sacrum are a little bit more complex to grasp, as they are considered to be *unnatural* motions that occur around an oblique axis of the sacrum. If you do happen to find this type of posterior sacral dysfunction with your patients, it often tends to be caused by the lumbar spine/trunk being placed into a position of increased (forced) flexion with a combined movement of rotation (as in the motion of rotating your body to pick up a heavy weight from the floor).

It may take you a while to think about and understand this next concept but I will try my best to explain this in a relatively simple way, even though many people will still have difficulty understanding what it is I am trying to portray due to the natural complexity of this fascinating area.

Before we start I would like you to think of this motion simply as a backward/posterior torsion, whereas the other two types I mentioned in the earlier paragraphs are forward/anterior torsions.

Left-on-Right (L-on-R)

A *L-on-R sacral torsion* relates to a left rotation on the right oblique axis, and this will be specific to the case where the sacrum has rotated to the *left* side. However, because of the posterior motion of the left side of the sacrum, the sacral sulcus will now palpate as shallow on the *left*, and the ILA will palpate as posterior (shallow) on the *left*; this will indicate that the *left* side of the sacrum has counter-nutated or posteriorly nutated, as shown in Figure 2.14(a).

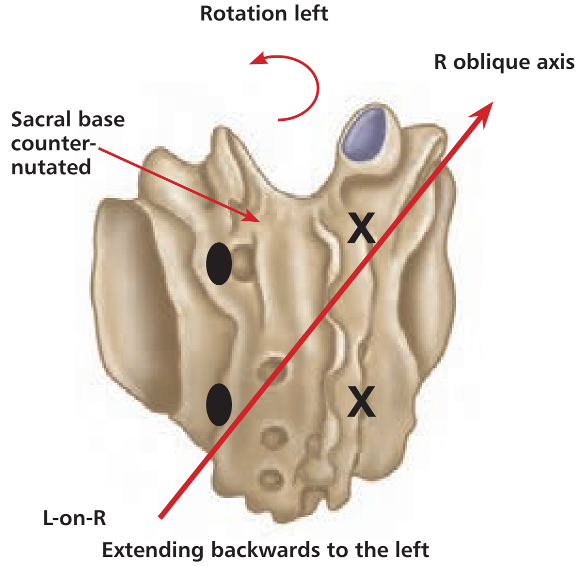


Figure 2.14. (a) Left-on-right (L-on-R) sacral torsion. X = Anterior or deep. ⬮ = Posterior or shallow.

This specific motion of a L-on-R sacral torsion can be seen in Figure 2.14(b), as demonstrated by the model.

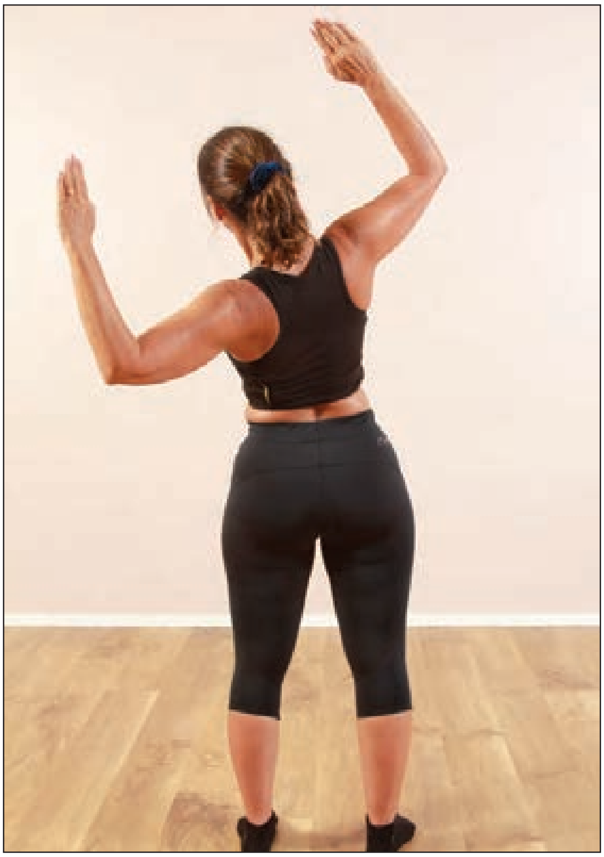


Figure 2.14. (b) L-on-R sacral torsion, as demonstrated by the model—sacral counter-nutation is shown on the left side.

Right-on-Left (R-on-L)

It follows that a *R-on-L sacral torsion* must be the opposite of a L-on-R sacral torsion; thus, the sacral torsion this time relates to a right rotation on the left oblique axis, and this will be specific to the sacrum having rotated to the *right* side. Because of the posterior motion of the right side of the sacrum, however, the sacral sulcus will now palpate as "shallow" on the *right*, and the ILA will palpate as posterior (shallow) on the *right.* This will indicate that the *right* side of the sacrum has counter-nutated, or (if easier to understand) that the sacrum has posteriorly nutated (think of this simply as a backward motion), as shown in Figure 2.15(a).

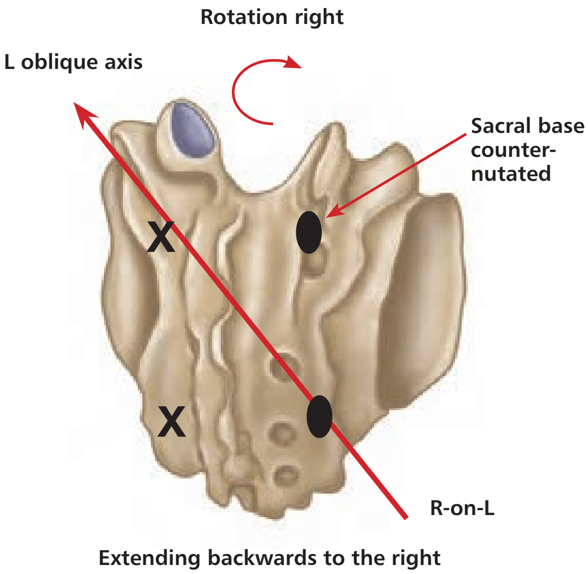


Figure 2.15. (a) Right-on-left (R-on-L) sacral torsion. X = Anterior or deep. ⬮ = Posterior or shallow.

Figure 2.15(b) illustrates the specific motion of a R-on-L sacral torsion, as demonstrated by the model.

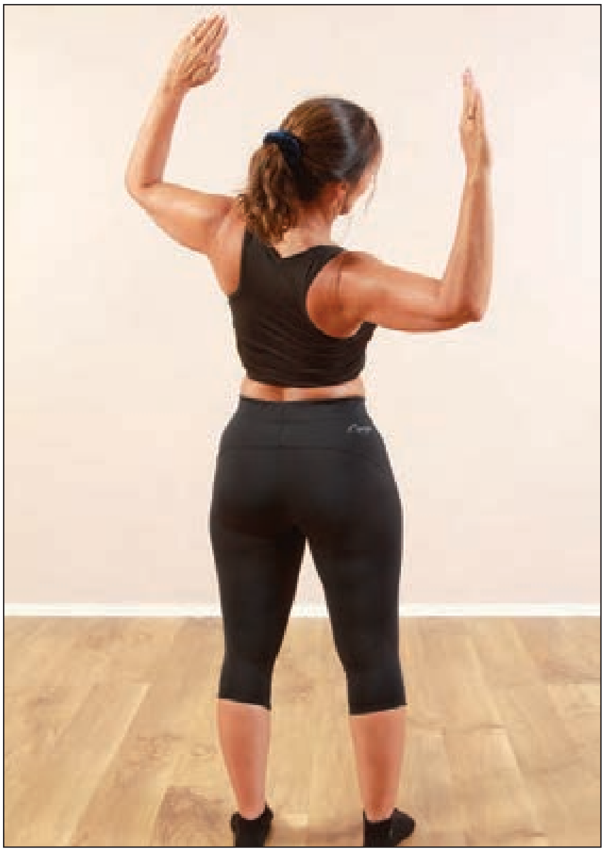


Figure 2.15. (b) R-on-L sacral torsion, as demonstrated by the model—sacral counter-nutation is shown on the right side.

Non-Physiological Summary

What I would like to do now is give a brief review of the main points discussed above, so that you can better understand these specific types of dysfunction. We know that L-on-R and R-on-L sacral torsions are *unnatural* motions of the sacrum, hence their being termed *non-physiological*. These specific motions can be fixed in a position of counter-nutation or a backward torsion. For example, if you have a dysfunctional position of a L-on-R sacral torsion, the sacrum is capable of performing this backward type of movement, as it is already fixed in that position. The sacrum is, however, unable to perform the normal physiological motion of a L-on-L or a R-on-R sacral torsion, because of the fact that the *left* side of the sacrum is unable to nutate, since it is held in a fixed position. Another way of thinking about this is that the left side of the sacrum cannot perform the motion of anterior nutation, or simply go forward on the left, as it is held backward in a fixed position of counter-nutation or posterior nutation.

Sacral Torsions Summary

Tables 2.1 and 2.2 summarize the physiological and non-physiological motions of the sacrum. You will notice that the tables contain extra components, namely the position of the 5th lumbar vertebra, seated flexion test, lumbar spring test, sphinx test, lumbar lordosis curvature, and position of the medial malleolus. All of these will be explained in more detail in later chapters, especially Chapter 12, but have been mentioned here because my aim in this chapter is to whet your appetite to continue reading. For now, I just wanted you to be aware of all the different types of physiological and non-physiological motion that the sacrum is capable of before we progress through the rest of the chapters.

	L-on-L sacral torsion Forward/nutation	R-on-R sacral torsion Forward/nutation
Deep sacral sulcus (neutral)	Right	Left
Shallow sacral sulcus (neutral)	Left	Right
ILA posterior	Left	Right
L5 rotation	Right—ERS(R)	Left—ERS(L)
Seated flexion test	Right	Left
Lumbar spring	Negative	Negative
Sphinx test	Sacral sulci level	Sacral sulci level
Lumbar lordosis	Increased	Increased
Medial malleolus (leg length)	Short left	Short right

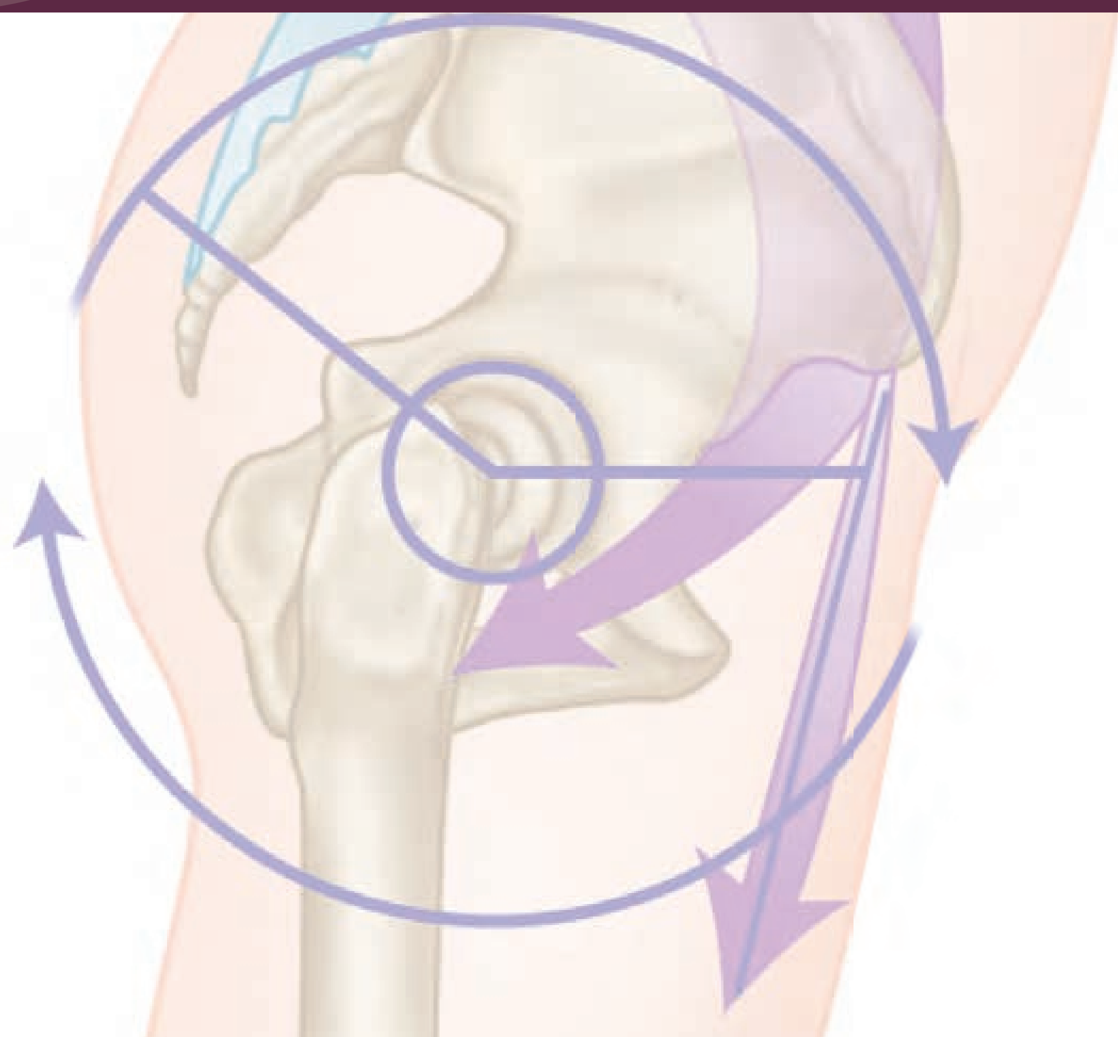
Table 2.1. Normal physiological motion: anterior/forward sacral torsions.

	L-on-R sacral torsion Backward/counter-nutation	R-on-L sacral torsion Backward/counter-nutation
Deep sacral sulcus (neutral)	Right	Left
Shallow sacral sulcus (neutral)	Left	Right
ILA posterior	Left	Right
L5 rotation	Right—FRS(R)	Left—FRS(L)
Seated flexion test	Left	Right
Lumbar spring	Positive	Positive
Sphinx test	Left sacral sulcus shallow (right sacral sulcus deeper)	Right sacral sulcus shallow (left sacral sulcus deeper)
Lumbar lordosis	Decreased	Decreased
Medial malleolus (leg length)	Short left	Short right

Table 2.2. Non-physiological motion: posterior/backward sacral torsions.

3

Sacroiliac Joint Stability, Muscle Imbalances, and the Myofascial Slings



As the incidence of pelvic and lower back pain continues to increase, we will need to look at and understand the muscular relationships that affect the core and lumbo–pelvic–sacral stability. We will then have to decide how to incorporate this knowledge into an assessment and treatment plan, especially for patients and athletes who present with pain associated with the area of the pelvic girdle and lower back.

There are two main factors that affect the stability of the pelvis (or to be more precise the sacroiliac joint (SIJ)): form closure and force closure. These two mechanisms collectively assist in a process known as the *self-locking mechanism*.

Form closure arises from the anatomical alignment of the bones of the innominate and the sacrum, where the sacrum forms a kind of keystone between the wings of the pelvis. The SIJ transfers large loads and its shape is adapted to this task. The articular surfaces are relatively flat, which helps to transfer compression forces and bending movements. However, a relatively flat joint is vulnerable to shear forces. The SIJ is protected from these forces in three ways. First, the sacrum is wedge (triangular) shaped and thus is stabilized between the innominate bones, similarly to a keystone in a Roman arch, and is kept in a state of "suspension" by the ligaments acting upon it. Second, in contrast to other synovial joints, the articular cartilage is not smooth but rather irregular (think back to Chapter 1). Third, a frontal dissection through the SIJ reveals cartilage-covered bone extensions protruding into the joint—the so-called "ridges" and "grooves." They seem rather irregular, but are in fact complementary to each other, and this unusual irregularity is very relevant as it serves to stabilize the SIJ when compression is applied.

According to Vleeming et al. (1990a), after puberty most individuals develop a crescent-shaped ridge running the entire length of the iliac surface with a corresponding depression on the sacral side; this complementary ridge and groove are now believed to lock the surfaces together and increase stability of the SIJ.

If the articular surfaces of the sacrum and the innominate bones fitted together with perfect form closure, mobility would be practically impossible. However, form closure of the SIJ is not perfect and mobility—albeit small—is possible, and therefore stabilization during loading is required. This is achieved by increasing compression across the joint at the moment of loading; the anatomical structures responsible for this compression are the ligaments, muscles, and fasciae. The mechanism of compression of the SIJ by these additional forces is what is commonly called *force closure*. When the SIJ is compressed, friction of the joint increases and consequently reinforces form closure, as shown in Figure 3.1. According to Willard et al. (2012), force closure reduces the joint's "neutral zone," thereby facilitating stabilization of the SIJ.

Force closure is accomplished as follows. The first method is by nutation of the sacrum, which is achieved either by anterior motion of the sacral base or by posterior rotation of the innominate bone. These two types of motion result in a tightening of the sacrotuberous, sacrospinous, and interosseous ligaments; this tightening assists in activating the force closure mechanism, thereby increasing the compression of the SIJ. Counter-nutation, on the other hand, decreases the stability of the SIJ because of the reduced tension in the above-mentioned ligaments.

Cohen (2005) states that because the ilium and sacrum only meet at approximately one-third of their surfaces, the associated ligaments provide the rest of the stability between these bones.

In the second method, force closure is assisted by the activation/contraction of the inner and outer core muscles (local and global muscle systems), as you will read later on in this chapter.

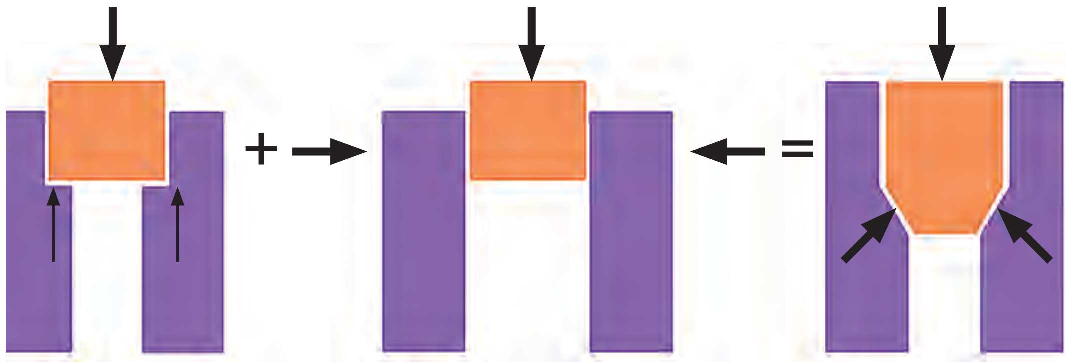


Figure 3.1. The relationship between form/force closure and sacroiliac stability.

The terms *form closure* and *force closure* delineate the active and passive components of this self-locking mechanism and were first identified by Vleeming et al. (1990a, 1990b). Below is a quote from Vleeming et al. (1995) that I personally believe explains the above text.

"Shear in the sacroiliac joints is prevented by the combination of specific anatomical features (form closure) and the compression generated by muscles and ligaments that can be accommodated to the specific loading situation (force closure). If the sacrum would fit the pelvis with perfect form closure, no lateral forces would be needed. However, such a construction would make mobility practically impossible."

Sacroiliac Stability

Several ligaments, muscles, and fascial systems contribute to force closure of the pelvis: these are collectively referred to as the *osteo-articular-ligamentous system*. Recall that when the body is working efficiently, the shear forces between the innominate bones and the sacrum are adequately controlled, and loads can then be transferred between the trunk, pelvis, and legs.

Vleeming and Stoeckart (2007) mention that various muscles are involved in force closure of the SIJ, and that even muscles such as the rectus femoris, sartorius, iliacus, Gmax, and hamstrings have adequate lever arms to influence movement in the SIJ. The effect of these muscles is dependent on open or closed kinematic movements, and whether the pelvis is sufficiently braced.

As you will read shortly, and also in later chapters, there is one muscle in particular that plays a highly significant role in stabilizing the SIJs—this muscle is the Gmax. Some of the Gmax fibers merge and attach onto the sacrotuberous ligament as well as onto a connective tissue structure known as the *thoracolumbar fascia*. Vleeming et al. (1989a) demonstrated this fact on 12 cadaver dissections; they found that the Gmax muscle was directly attached to the sacrotuberous ligament in all cases.

The Gmax connects, via the thoracolumbar fascia, to the contralateral latissimus dorsi to form what is known as the *posterior oblique myofascial sling* (see section "The Outer Core Unit: The Integrated Myofascial Sling System (Global System)" later in this chapter). It has been shown that weakness, or possibly a misfiring sequence, of the Gmax will predispose the SIJ to injury by decreasing the function of this (posterior oblique) myofascial sling. A weakness or misfiring of the Gmax is a potential cause of a compensatory overactivation of the contralateral latissimus dorsi; walking and running (gait cycle, explained in Chapter 4) impose high loads on the SIJ, so this weight-bearing joint will need to be self-stabilizing in order to reduce the effect of the altered compensatory mechanism.

Research has shown that sacral nutation (a nodding type of movement of the sacrum between the innominate bones) is the best position for the pelvic girdle to be at its most stable. As I have already explained in earlier chapters, nutation occurs when moving (for example) from a sitting position to standing, and full nutation occurs during forward or backward bending of the trunk. This motion of sacral nutation tightens the major ligaments (sacrotuberous, sacrospinous, and interosseous) of the posterior pelvis, and the resulting tension increases the compressive force across the SIJ. The increased tension provides the required stability that is needed by the SIJ during the gait cycle as well as when simply rising from a sitting to a standing position.

Vleeming et al. (1989b) showed how load application to the sacrotuberous ligament, either directly to the ligament or through its continuations with the long head of biceps femoris or the attachments of the Gmax, significantly diminishes forward rotation of the sacral base. They demonstrated that this increases the coefficient of friction, thus decreasing movement of the SIJ by force closure.

Sacral Nutation and Counter-Nutation

I find it very beneficial at certain times, especially for you the reader, to try to discuss alternative ways of explaining a relatively complex motion. I therefore thought I would introduce an opinion by another author, Evan Osar (2012), who states that *nutation* is the anterior inferior motion of the sacral base, while *counter-nutation* is the posterior superior motion of the sacral base. Nutation is necessary for the locking of the SIJ during unilateral stance, as shown in Figure 3.2(a). The inability to nutate the sacrum is a leading cause of unilateral stance instability and one of the causes of the classic Trendelenburg gait. Counter-nutation, on the other hand, is necessary in order to unlock the SIJ to allow anterior rotation of the innominate and extension of the hip joint, as shown in Figure 3.2(b). The inability to unlock or counter-nutate the sacrum leads to compensatory increases in lumbopelvic flexion, which in turn lead to and perpetuate lumbar instability.

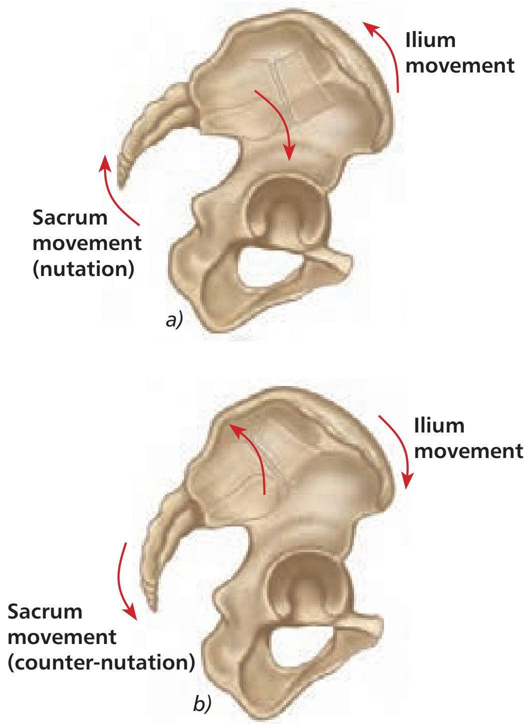


Figure 3.2. (a) Posterior pelvic rotation and sacral nutation. (b) Anterior pelvic rotation and sacral counter-nutation.

Force Closure Ligaments

The main ligamentous structures that influence force closure (Figure 3.3) are: (1) the sacrotuberous ligament, which connects the sacrum to the ischium and has been termed the *key* or *lead* ligament; and (2) the long dorsal sacroiliac ligament, which connects the 3rd and 4th sacral segments to the PSIS and is also known as the *posterior sacroiliac ligament*.

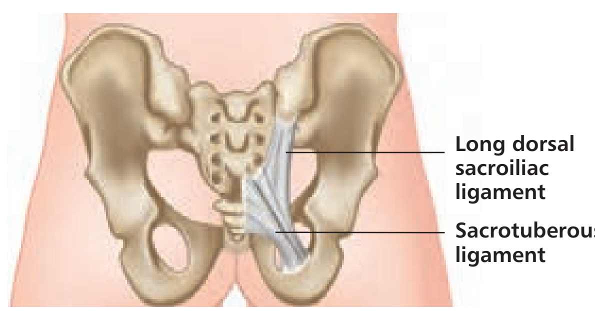


Figure 3.3. Sacrotuberous ligament (key) and the long dorsal sacroiliac ligament.

Ligaments can increase articular compression when they are tensed or lengthened by the movement of the bones to which they attach,