Systematic Review

A Systematic Review of the Normal Sacroiliac Joint Anatomy and Adjacent Tissues for Pain Physicians

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Background: The sacroiliac joint (SIJ) forms a complex joint and has shown to be underappreciated in its involvement with lower back pain. Research efforts have intensified on SIJ anatomy and biomechanics because of its predisposing position to pain and dysfunction in individuals suffering from lower back discomfort. Previous work has focused on SIJ anatomy including bone and joint structure, innervation, as well as biomechanics and the treatment of SIJ pain. However, to date, no review exists describing the range of 'normal' anatomic features of the SIJ.

Objectives: To describe the normal appearance of the SIJ and adjacent tissues, as opposed to 'abnormal' conditions involving SIJ morphology. It will also identify key areas that require further study because of lacking information or disagreement.

Study Design: A systematic literature review.

Setting: The research took place at the University of Otago, New Zealand. All published research on 'normal SIJ anatomy' available from MEDLINE, OVID, Scopus, Web of Science, PubMed, and Science Direct were included, available until December 2018, in English, French, and German. Subject areas included bony landmarks, joint type, bone morphology, ligamentous attachments, muscular and fascial relationships, blood supply, fatty infiltration, and morphologic variation.

Methods: Articles met the selection criteria if they contained specific information on SIJ anatomy, including bone morphology and architecture, ligaments, muscle attachments, innervation, vasculature, and the presence of fat. Biomechanics and kinematics related keywords were used as the literature often couples these with the anatomy. Keywords of individual articles were named as 'structures of interest.'

Results: A total of 88 primary and 101 secondary articles were identified in the time frame from 1851 to 2018. Primary articles provided quantitative data and detailed anatomic descriptions. Secondary articles did not focus specifically on the anatomy of the SIJ. Although research appeared to be in general agreement on bony landmarks, joint type, myofascial attachments, vasculature, and innervation of the SIJ, there was only part consensus on ligament attachments and cartilage structure. Information regarding bone density of the articulating surfaces of the SIJ is lacking. Despite its potential clinical significance, fatty infiltration within the joint lacks research to date.

Limitations: Only the given databases were used for the initial search. Keyword combinations used for this review may not have been inclusive of all articles relevant to the SIJ. Work in languages other than the ones listed or work that is not available via the internet may be missing.

Conclusions: This study provides an overview of normal SIJ structures, including all neuromusculoskeletal elements related to the joint. There is a lack of knowledge on the SIJ ligaments warranting further investigation. Furthermore, there are discrepancies in relation to the nomenclature, layers, attachment sites, and on the topographical relationships between ligamentous tissues and nerves. Subsequent studies on the quantification of fat and bone density in the SIJ have been suggested. These could be useful radiologic parameters to assess the condition of the joint clinically. This review may provide insight into the clinical signs and abnormal biomechanical features of the joint for the purposes of treating SIJ pain.

Key words: Bone density, bony landmarks, fat infiltration, innervation, ligaments morphology, muscles, sacroiliac joint, vasculature

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In today's society, 70%-85% of individuals suffer from pelvic girdle pain (PGP) in their lifetime. Interest has arisen on the subject of the sacroiliac joint (SIJ) because of its direct involvement in PGP and lumbopelvic pain, but this is still underappreciated as a source of mechanical lower back pain (1-3). Pathological findings have emerged on structural abnormalities, infection, SIJ degeneration, as well as inflammatory and metabolic disorders, with few specifically looking at the joint composition (4,5). Previous review articles on the SIJ have focused on some parts of the descriptive anatomy, diagnosis, and treatment of SIJ syndrome (2,6-13). Other studies have also emerged on the biomechanics of the SIJ, in terms of the structural relationships of the joint (14-21). However, none have indicated its role in pathogenesis. Understanding the 'normal' SIJ biomechanics is important when considering changes that may occur in association with pathogenesis around the SIJ. Furthermore, the detection of an 'abnormal state' could be clinically significant in relation to the detection of SIJ diseases and dysfunction.

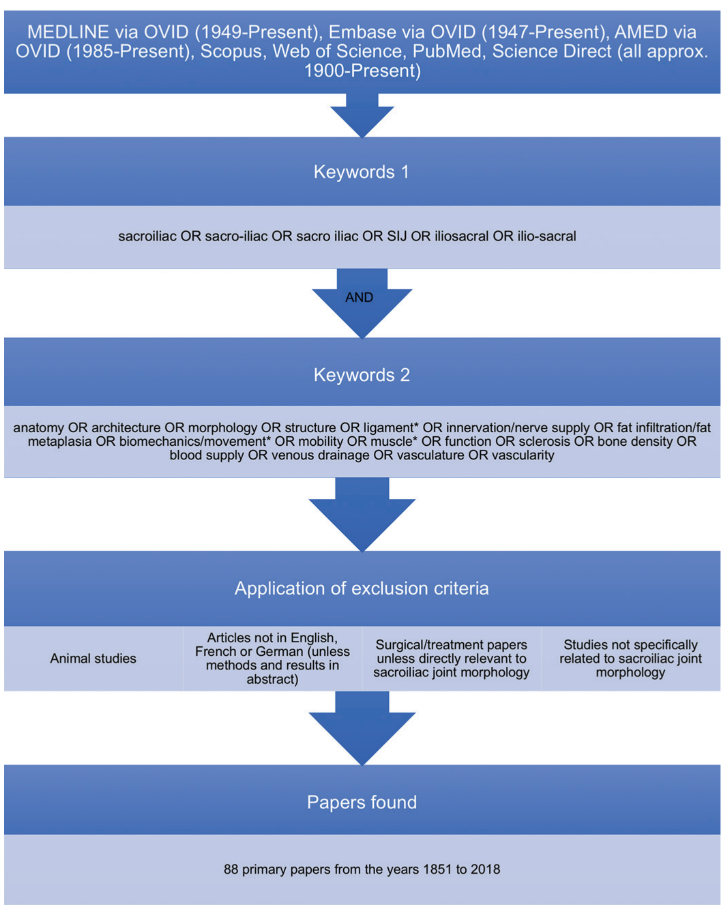


Fig. 1. *Research strategy followed for finding relevant literature, including the databases searched and keywords entered (keywords 1 AND keywords 2) and research exclusion criteria, * refers to the plural.*

Our objective was to provide a systematic review of the literature on the anatomic features of the SIJ. These include the morphologic features of the ilium and sacrum, the ligaments associated with the SIJ, the muscular attachments and myofascial relationships, vasculature, innervation, the presence of fat within the joint, and anatomic variation. It will provide insight into the original studies on the various structures from articles published from June 1851 to January 2018 in English, French, and German. This will enable the assessment of the present anatomic knowledge of the SIJ and uncover discrepancies within the literature. Furthermore, it will provide a basis for the 'normal' appearance of the structures of the SIJ, while also enabling the comparison of this state with a potentially 'abnormal' state of the structures of the SIJ.

Methods

Articles were chosen if they contained specific information on the SIJ anatomy including morphology and architecture, ligaments, muscle attachments, innervation, vasculature, and presence of fat. Surgical research was included if they had relevant anatomic information on the SIJ that also matched the inclusion criteria. Figure 1 details the method undertaken in this study of relevant articles including the databases searched, keywords, and exclusion criteria applied. Biomechanical and mobility-related keywords were used as the literature often couples the anatomy with biomechanics. Keywords of individual articles listed in the following text were named as 'structures of interest' (Table 1). These are not specifically linked to the SIJ in most studies but anatomically significant to the joint.

Results

Of the 88 primary sources included in this review, 5 studies had unknown

Table 1. *Muscles, ligaments, and fascia with a direct relation to the SIJ. These are the 'structures of interest'.*

Muscles of the pelvis and thigh	Ligaments associated with the SIJ	Fascia of the pelvis and thigh
biceps femoris	anterior sacroiliac ligament	deep pelvic fascia
erector spinae	iliolumbar ligament	thoracolumbar fascia
gluteus maximus	Illi's ligament	
gluteus medius	interosseous sacroiliac ligament	
gluteus minimus	long posterior sacroiliac ligament	
latissimus dorsi	lumbosacral ligament	
multifidus	posterior sacroiliac ligament	
piriformis	sacrospinous ligament	
psoas major and minor	sacrotuberous ligament	
quadratus lumborum	'Zaglas' ligament	
semimembranosus		
semitendinosus		
transversus abdominis		

sample sizes (22-26). The most common structures discussed were the ligaments and innervation, with vasculature and fat presence being the minority. Muscle studies were limited as most information was derived from ligament studies and not on the muscle morphology directly. Figure 2 details the strategy followed for the screening of the relevant literature.

Bony Landmarks and Joint Characteristics of the SIJ

Typically, the SIJ is described as being composed of 2 distinct parts: the syndesmosis and articular parts (Fig. 3) (27-29).

Iliac and Sacral SIJ-Related Landmarks

The bony landmarks of the sacrum and ilium are generally well described in the literature (22,30-49). Figures 4, 5, and 6 recount SIJ-related landmarks.

Classification of the SIJ

The SIJ classification differs from it being a diarthrosis, an amphiarthrosis, or presenting features of both as a 'diarthro-amphiarthrosis' (Table 2) (22,25,30-

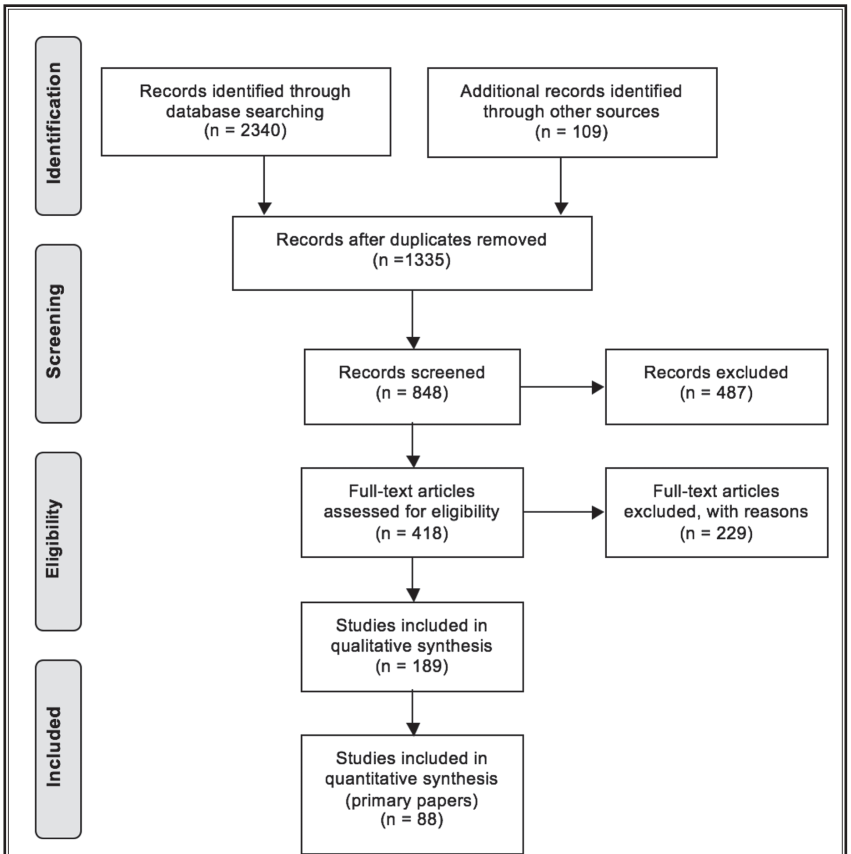


Fig. 2. *PRISMA flow chart for the methodology undertaken for the screening of relevant literature based on Moher et al. (191). Primary papers (14,16,17,20,22-26,28-33,38,42,43,50-57,69,71,73,74,78-84,86-97,99,100,102,105-108,110-117,121,126,130,132,133,136,137,146-157,169-172,179), secondary papers (1-13,15,18,19,21,27,34-37,39-41,44-49,58-68,70,72,75-77,85,98,101,103,104,109,118-120,122-125,127-129,131,134,135,138-145,155,158-168,173-178,180-183,185-190).*

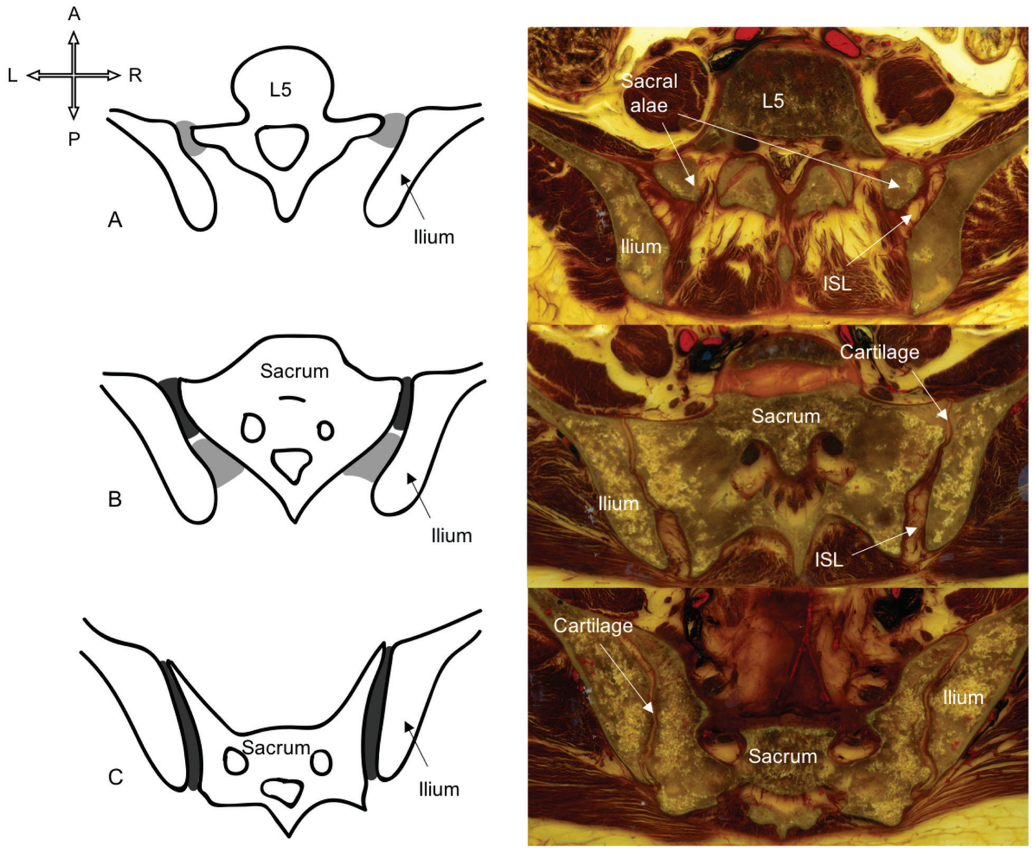


Fig. 3. *Transverse sections of a pelvis at L5 (A), at mid sacrum S2 (B), and at S4 (C) with corresponding E12-plastinated slices (right). Darker gray regions highlight the cartilaginous (synovial) portion, the lighter gray regions show the ligamentous (syndesmotic) portion with the ISL. A, anterior; L, left; P, posterior; R, right.*

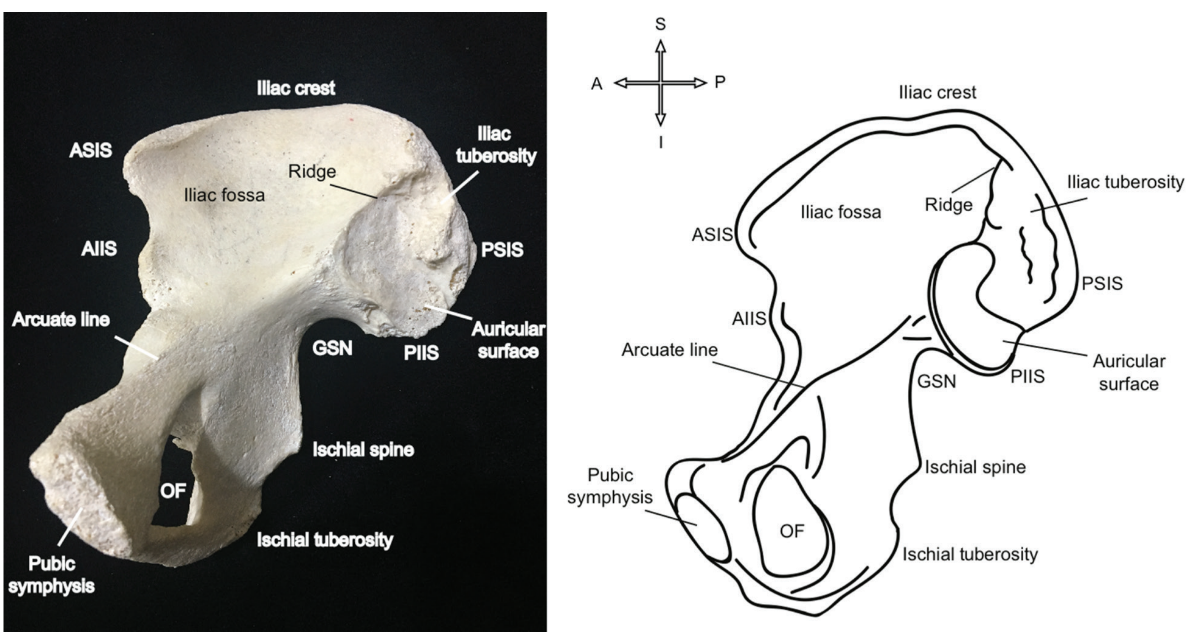


Fig. 4. *Landmarks of the medial ilium based on Otter, (41) and Postacchini et al., (31). AIIS: anterior inferior iliac spine, ASIS: anterior superior iliac spine, PSIS: posterior superior iliac spine, PIIS: posterior inferior iliac spine, Ridge: constant ridge from iliac crest to auricular surface, GSN: greater sciatic notch, OF: obturator foramen. A: anterior, P: posterior, S: superior, I: inferior.*

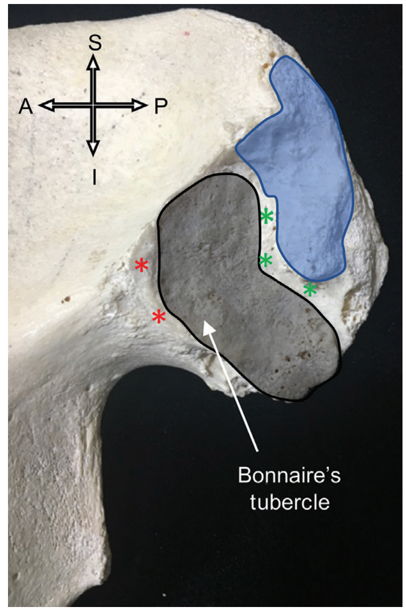


Fig. 5. *Landmarks of the medial iliac surface. Gray area: auricular surface, blue area: iliac tuberosity, green asterisks: smooth narrow depression, red asterisks: pre-auricular sulcus. A, anterior; I, inferior; P, posterior; S, superior.*

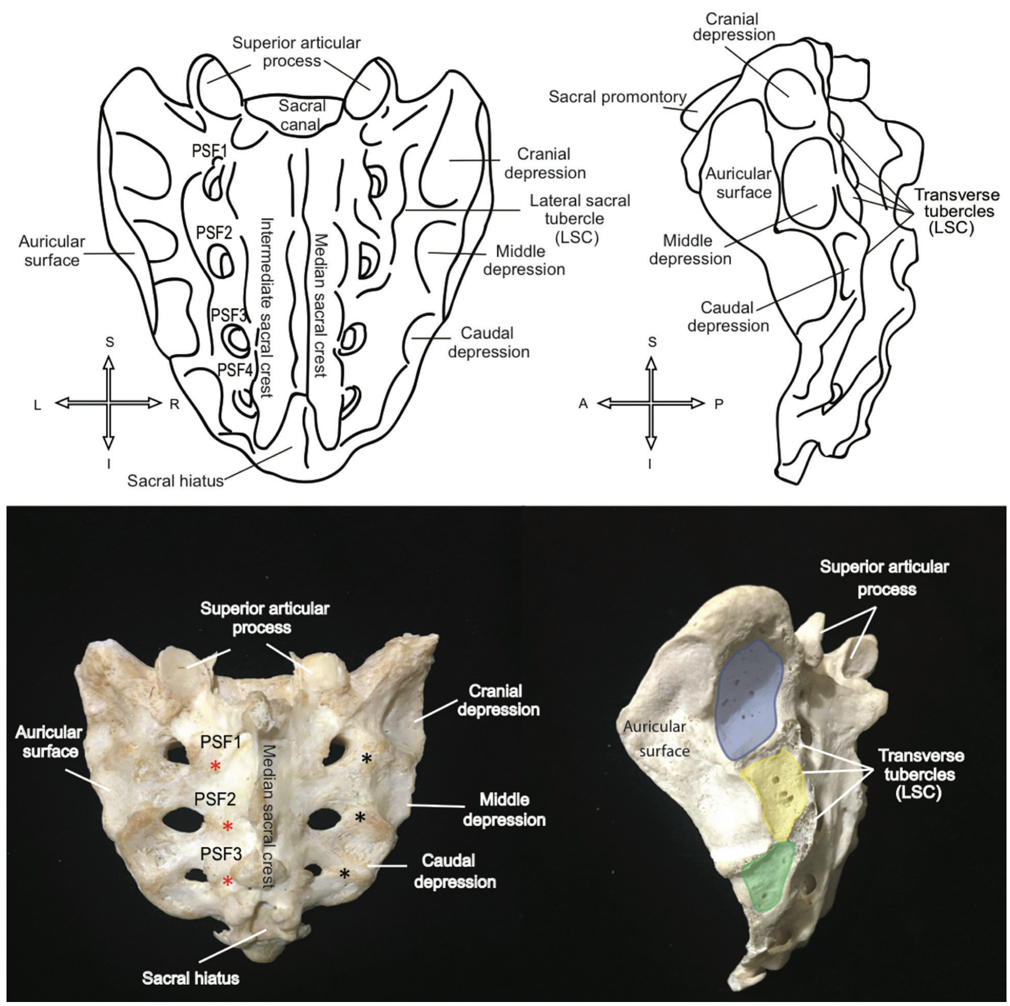


Fig. 6. *Landmarks of the posterior (left) and lateral sacrum (right). PSF1-4: posterior sacral foramina 1-4, cranial depression (shaded blue), middle depression (shaded yellow), caudal depression (shaded green), LSC (black asterisk on each tubercle), intermediate sacral crest (red asterisk on each tubercle). A, anterior; I, inferior; L, left; P, posterior; R, right; S, superior.*

32,50-57). Most argue that the joint is diarthrodial as it presents the classic features of a synovial joint (25,30,32,50,51,55,58-60). Two studies describe the joint as being an amphiarthrosis (42,61). One study suggests that because of its shape it should be classified as a condylarthrosis. Arguably, it is not a symphysis, nor a synarthrosis, because of the presence of the interosseous sacroiliac ligament (ISL) in the dorsal aspect of the joint. It is not an amphiarthrosis as the cartilage does not continue throughout the whole joint space (53). However, research indicates that SIJ changes through time. Embryologically, the anterior SIJ forms in the same manner as other diarthrodial joints, although cavitation arises later (10th week in utero) and progresses less rapidly until the seventh month of gestation. The joint does not cavitate uniformly as it occurs in other diarthrodial joints (22,62). Children and young adults reflect characteristics of a diarthrodial joint, whereas older individuals present amphiarthrodial characteristics. This is because older individuals gradually decrease in mobility in regions that present features of a diarthro-amphiarthrosis (41,52,55). The classification is sometimes based on movement rather than structure (30,51,53). The study by Walker (63) provides a more encompassing definition: it is a diarthrodial joint with an interosseous portion. This definition however does not account for age-related changes in structure and movement (173).

Cartilage Type and Morphometry of the Articular Surfaces

There is disagreement in the distribution and morphology of the cartilage (64). Some state that the iliac side is composed of fibrocartilage and the sacral side is composed of hyaline cartilage (22,58,61,65-68). Others report a mixture of both cartilages on both sides (22,25,48,54,55,57,59). The sacral cartilage appears smooth, light-gray, and 'glistening' that roughens and becomes yellow with age (25,32,51,55,69,70). The iliac side has a blueish, dull, striated, or striped appearance that also roughens and yellows with age (25,32,51,55,69-71). The iliac cartilage is consistently 2 to 3 times thinner than the sacral with this thickness remaining constant during ageing (25,32,51,58,72). The sacral cartilage is thicker in women than in men, with no significant difference on the iliac side (69). Histologically, degenerative changes arise earlier in the SIJ than in other diarthrodial joints already noticeable in infants. The sacral cartilage remains largely unaltered until old age. The iliac cartilage however, presents osteoarthritic changes (73). It is composed of a dense fibrous network or collagen bundles in infancy and gradually becomes hyaline cartilage over time (54).

There are no significant differences in the values in SIJ articular space width between both genders or between sides (68,74,75). However, there is a reduction in articular width specifically seen after the age

Table 2. *Summary of results of joint type assessment from the literature. aA type of diarthrodial joint; *no data available.*

Study	Joint type classification	Assessment made from	Technique
von Luschka, 1854 (25)	diarthrodial	structural features	histology and dissection
Albee, 1909 (50)	diarthrodial	structural features	cadaveric dissection
Dieulafé and Saint-Martin, 1912 (53)	condylarthrosis[a]	shape and movement	cadaveric dissection
Brooke, 1923 (30)	diarthrodial	degree of movement	cadaveric dissection
Sashin, 1930 (55)	diarthrodial	structural features	cadaveric dissection
Hakim, 1937 (57)	diarthro-amphiarthrosis	structural features	histology and dissection
Delmas, 1950 (52)	diarthro-amphiarthrosis	structural features	N/A
Macdonald and Hunt, 1952 (32)	diarthrodial	structural features	histology and dissection
Bowen and Cassidy, 1981 (51)	diarthrodial	structure and movement	histology and dissection
Gerlach and Lierse, 1992 (42)	amphiarthrosis	N/A*	dissection and imaging
Puhakka et al., 2004 (54)	diarthro-amphiarthrosis	structural features	histology
Egund and Jurik, 2014 (141)	diarthro-amphiarthrosis	structural features	histology

of 12 (74,75). The auricular surfaces present signs of degeneration such as erosion and irregularities that are noticeable in individuals as young as 20 years old, more prominently on the iliac side (21,32,55,56,76,77). A morphometry study of the articular surfaces in adults revealed that the mean area of the joint was approximately 13 cm2 (33). Sexual dimorphism was only present for 2 features: the joint is more inferior in men relative to the anterior superior iliac spine and the surface area is smaller in women (33,78).

Bone Density of the Iliac and Sacral Articular Surfaces

The pelvic bone is made up of low-density trabecular bone covered by a layer of high-density cortical bone. This enables the pelvis to be a low weight structure capable of withstanding high loads. One study tested the theory of muscle forces on the entire pelvic bone. They discovered a higher strain in the subchondral and trabecular bone than that of the cortical shell (79). The distribution of the subchondral bone density shows a consistent pattern with the highest density along the auricular surfaces, whereas centrally there are lower density grades in the region of the 'degenerative zones' (80). Vogler et al (81) reported the appearance of bone density in healthy individuals and found that it develops in a 'non-uniform' and 'ill-defined' manner on the iliac side versus a 'uniform' and 'well-defined' manner on the sacral side.

Regarding the internal trabecular bone arrangement of the sacrum, cortical thickness did not vary between genders nor with age, ranging from 0.5 to 2.25 mm thickness with specification of the zones with higher density at the anterior aspect of the S1-S2 portion of the sacrum (82,83). One study specifically examined the bone densities of the sacral and iliac articulating counter parts. They found that the sacral side is approximately half as dense as its iliac counterpart at the anterior, central, and posterior portions (84). Regarding the subchondral bone architecture of the iliac and sacral counterparts, the sacral subchondral bone plate is thin with trabecular spongiosa inserting into it at a right angle. The iliac bone however is thicker, with the trabecular spongiosa inserting into the bone plate obliquely (73).

Ligaments of the SIJ

The SIJ is composed of intrinsic and extrinsic ligaments sometimes referred to as 'capsular' and 'accessory ligaments' (85,86). The intrinsic ligaments are the anterior sacroiliac ligament (ASL), the ISL, the posterior sacroiliac ligament (PSL), and the long posterior sacroiliac ligament (LPSL), and the extrinsic ligaments are the iliolumbar ligament (ILL), the sacrotuberous ligament (STL), and the sacrospinous ligament (SSL) (85).

The ASL

The ASL is a thickening of the anterior and inferior parts of the joint capsule. It is a thin ligament, passing from the anterior aspect of the sacrum to the anteromedial border of the ilium (Fig. 7) (17,42,54,55,86). It crosses the SIJ anteroinferior from the sacrum to insert onto the periosteum of the ilium near the auricular margins (28,54). It is shown to be a single structure in 3 studies (28,54,55).

It has also been described as consisting of the upper, middle, and lower parts spreading in a fan-like shape from the anterior sacrum to the wing of the ilium (17,42,57,86). Weisl (86) reports the superior part of the ASL arising from the ventral half of the lateral border of the sacral ala and continues to the adjacent medial border of the iliac fossa. The thickness and width of the ASL increase at the pelvic brim while spreading along the ilium for 20 mm mingling with fibers from the ILL superiorly. On the anterior aspect, inferior fibers of the ASL attach laterally in a line at the first 3 sacral foramina converging together dorsolaterally (86). The inferior part of the ASL is continuous with a number of structures, namely the PSL, SSL, and STL (Fig. 8) (20). Figures 9 and 10 detail a summary of attachment sites of the ASL.

The Posterior Sacroiliac Ligamentous Complex

There is difficulty describing the fascicles and parts of the PSL as its fibers merge with other structures like the ISL, LPSL, SSL, and STL (55,86). The LPSL attaches inferiorly to the lateral sacral crest (LSC) of S3-S5, whereas the PSL has variable attachment sites on the sacrum (Fig. 11) (86,87). The ISL is deep to the PSL, however the LSPL is lateral to the PSL with some fibers mixing with it.

The Interosseous (Axial) Ligament

The ISL, which is sometimes called the 'axial ligament' or 'vague ligament' (8,57,88), fills the syndesmotic joint space. This space is posterior to the auricular surfaces as the deepest layer (Figs. 11 and 12). The ISL attaches to the iliac tuberosity and is only present in the cranial part of the joint (17,38,50,55,57,86). The fibers are described as having a dorsolateral (cranial group) and cranial (caudal

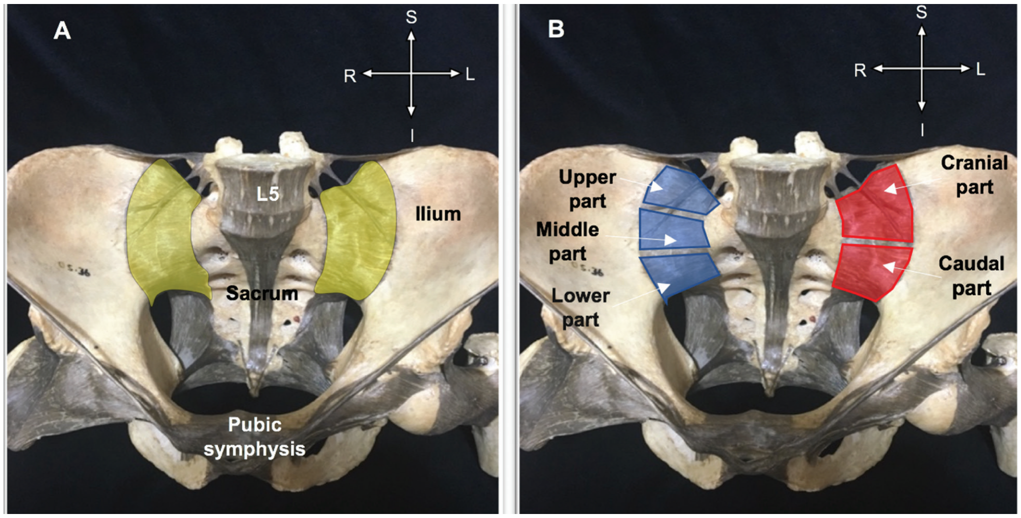


Fig. 7. *Photographs of a dissected superior anterior sacroiliac joint. (A) the anterior sacroiliac ligament shaded in yellow on each side according to Jaovisidha et al., (28), Puhakka et al., (54) and Sashin (55). (B) the anterior sacroiliac ligament as separate entities, blue shading according to Gerlach and Lierse (42); Right side red shading according to Weisl, (86). S: superior, I: inferior, L: left, R: right.*

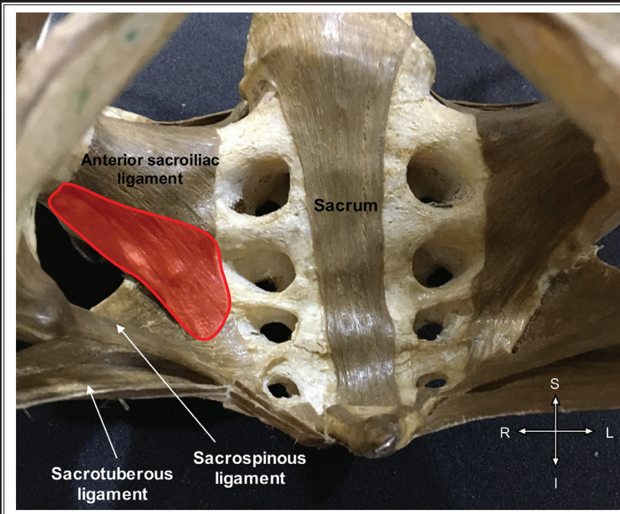


Fig. 8. *Anterior-inferior view of the pelvic outlet on a dry specimen. The inferior portion of the ASL is highlighted in red. I, inferior; L, left; R, right; S, superior.*

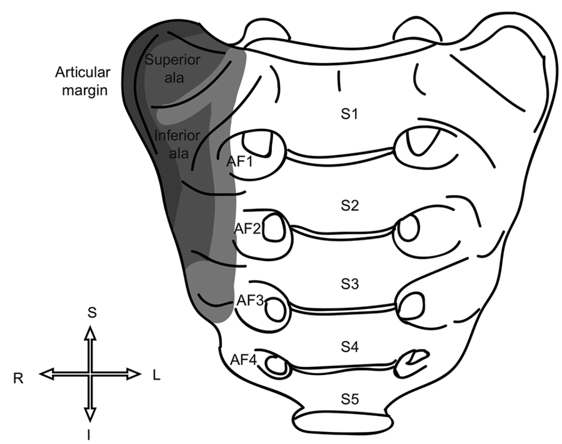


Fig. 9. *Attachment sites of ASL on the anterior sacrum. Darkest zones are referenced the most in the literature (more than 3 articles). AF1-4, anterior sacral foramina 1-4; I, inferior; L, left; R, right; S, superior; S1-5, sacral segments 1-5.*

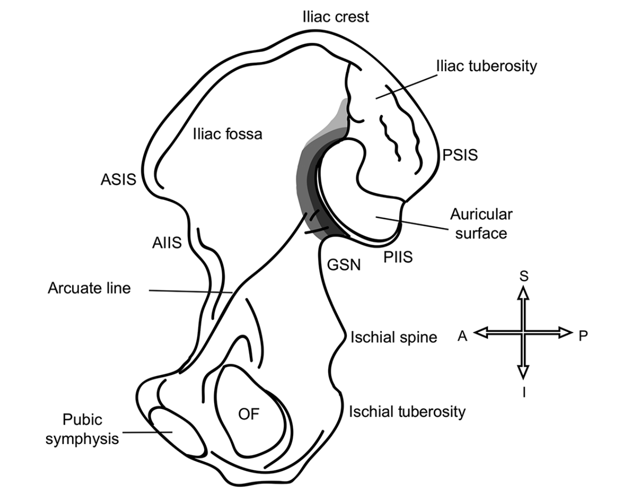


Fig. 10. *Attachment sites of ASL on the medial ilium. Darker zones are referenced the most in the literature with a higher degree of consensus between authors. A, anterior; AIIS, anterior inferior iliac spine; ASIS, anterior superior iliac spine; GSN, greater sciatic notch; I, inferior; OF, obturator foramen; P, posterior; PIIS, posterior inferior iliac spine; S, superior.*

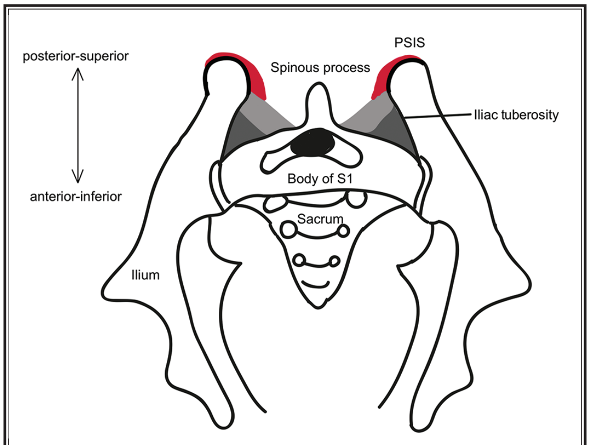


Fig. 11. *Superior view of the pelvic inlet and ligament attachment site of the ISL. Transverse section at the level of S1. The dark gray region is the ISL, the lighter gray shading is the PSL, the red shading is the LPSL.*

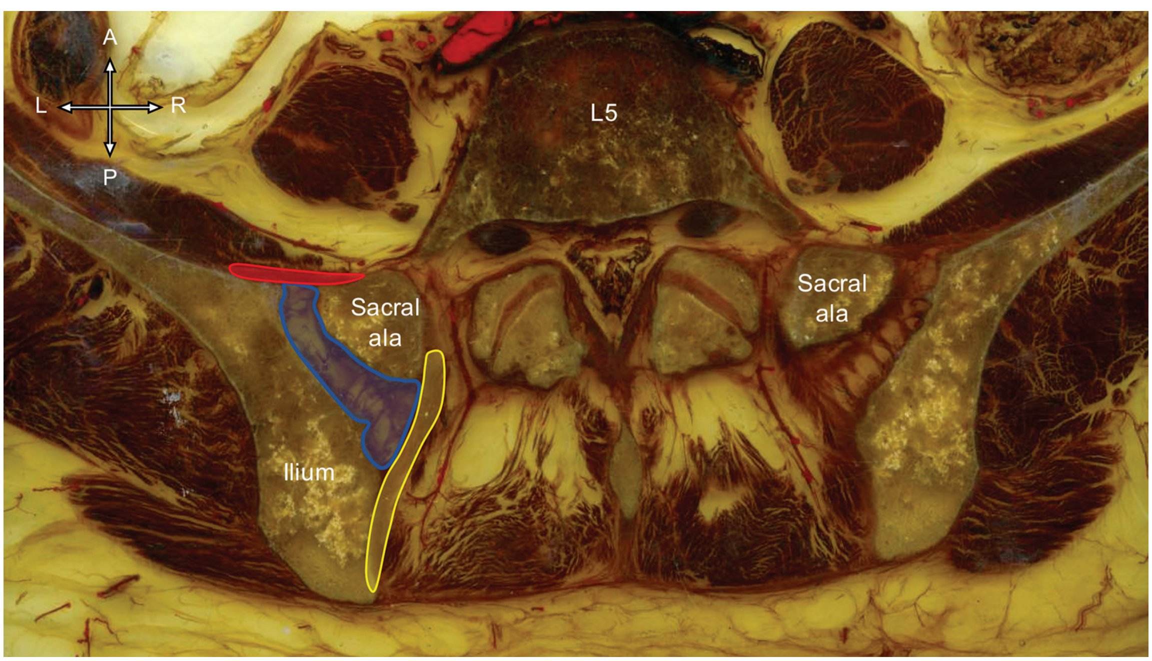


Fig. 12. *E12-plastinated slice at the level of L5 at a superior view. The interosseous portion filled with the ISL is highlighted in blue, the ASL in red, and the PSL in yellow. A, anterior; L, left; P, posterior; R, right.*

group) direction from their sacral attachments. Each group has approximately 13 bundles of parallel fibers with the caudal ones being longer and flatter than the cranial ones. Bundles insert into the retro-auricular regions of the sacrum and ilium. Dorsally and cranially they reach the LSC border of the sacral ala and run up to the crest and medial border of the iliac fossa (86). Sashin (55) stated that these layers interweave together.

The PSL

The PSL is located posterior to the articular space (17). The PSL 'cranial group' runs dorsolaterally and the PSL 'caudal group' runs cranially. One part of the cranial group passes dorsolaterally from the lateral edge of the dorsal half of the sacral ala to the ridge on the ilium. It extends between the crest and auricular surface. The fibers of the PSL merge with the ASL superiorly. Posteriorly, it is sometimes a separate entity from the rest of the PSL. The caudal group forms the true PSL. Some fibers pass dorsolaterally as a single, sometimes split band arising from the iliac tuberosity to the first sacral segment, lateral sacral tubercle, and base of the articular process. Other fibers run cranially from the LSC of S2-S3 and insert on the inferior inner lip of iliac crest and posterior superior iliac spine (PSIS) (86). One study describes the PSL as being composed of various fibrous bands originating from 3 centers all intermingling as the PSL layer. To summarize, the layer attaches from the LSC to the first sacral depression and to the ilium on the PSIS and iliac tuberosity, attaching to the adjacent bony structures in between these sites (Fig. 13) (42).

The most superficial layer PSL can contain up to 4 fibrous bands arising from the PSIS to the respective posterior medial sacral tubercles arranged in a combination of various patterns (Fig. 14) (57). Figures 15 and

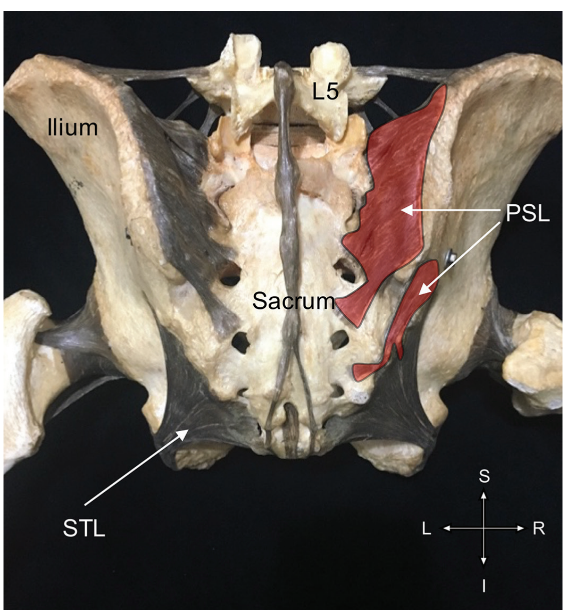


Fig. 13. *Posterior articulated pelvis with the PSL highlighted in red. Note that in this figure it is composed of 2 sections. I, inferior; L, left; R, right; S, superior.*

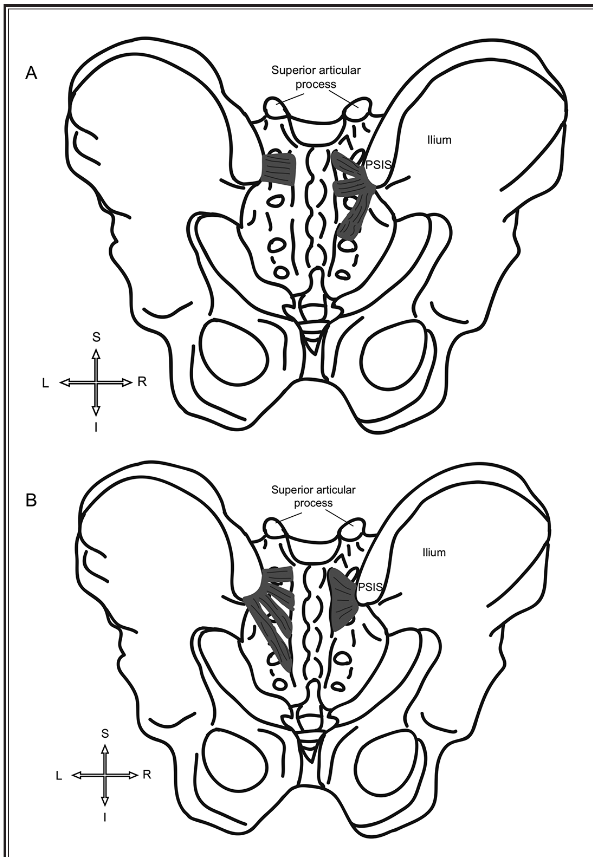
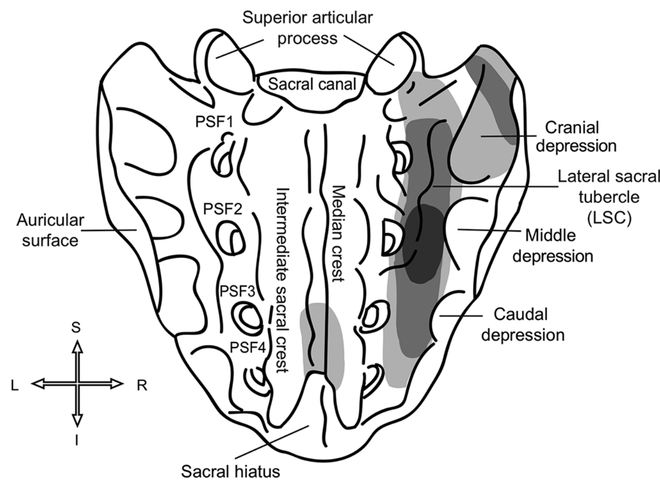


Fig. 14. Patterns of the posterior sacroiliac ligaments according to Hakim, (57). (A) On the left, a rectangular structure found in 64% of specimens from the posterior superior iliac spine (PSIS) to the S1-S2 levels of the intermediate sacral crest. The right side displays the two (sometimes three) bands bifurcations from the PSIS to S1, S2 and S3 posterior medial sacral tubercles found in 63% of individuals, three bands found in 53%. (B) The four bands pattern from the posterior superior iliac spine (PSIS) to the intermediate sacral crest found in 50% of individuals is on the left. The fan shape arrangement on the right was found in 36% of specimens. S: superior, I: inferior, L: left, R: right.

Fig. 15. *Attachment sites of the PSL on the posterior sacrum. Darkest zones are referenced the most in the literature with a higher degree of consensus between authors. I, inferior; L, left; PSF1-4, posterior sacral foramina 1-4; R, right; S, superior.*



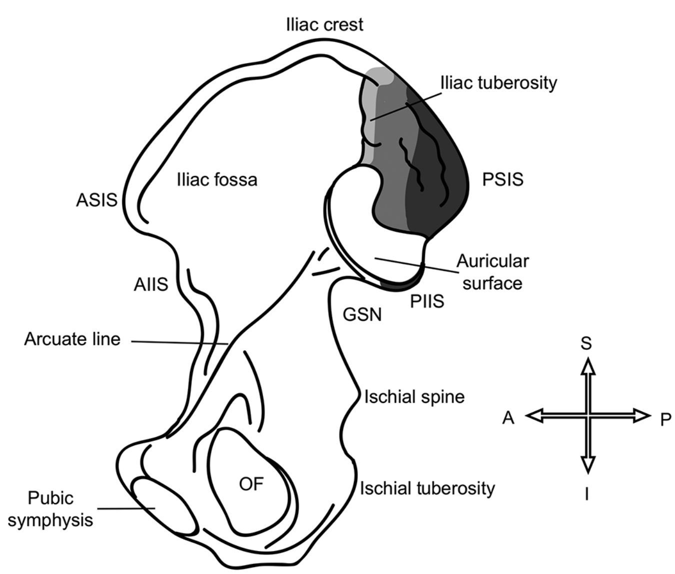


Fig. 16. *Attachment sites of the PSL on the medial ilium. Darker zones are referenced the most in the literature with a higher degree of consensus between authors. A, anterior; AIIS, anterior inferior iliac spine; ASIS, anterior superior Iliac spine; GSN, greater sciatic notch; I, inferior; OF, obturator foramen; P, posterior; PIIS, posterior inferior iliac spine; S, superior.*

16 detail a summary of attachment sites for the PSL in the literature.

The LPSL

The LPSL is a fibrous sheet running from the PSIS to the third or fourth lateral sacral tubercles (Fig. 17) (86,87,89,90). There is no consensus if the LPSL is a single structure or a composition of various ligamentous parts (86,87,89). The LPSL cranial fibers form a fascial sheet of weak fascicles passing dorsolaterally from the superior articular process and from each of the posterior sacral tubercles to the inner lip of the iliac crest. The caudal fibers compose the so-called LPSL (86). It is formed of parallel fibers flattened dorsoventrally and it is separated from the caudal fibers of the PSL by the lateral branches of the dorsal sacral rami (86,89,90). Figures 18 and 19 detail a summary of the attachment sites of the LPSL in the literature.

The ILL

The ILL is comprised of one to 4 different ligament bands (8,91). Some state that the ILL is one band originating from the transverse process of L5 to the posterior part of the iliac crest (42,88).

The ILL is often described to be formed of 2 bands (92-99). An anterior band arises from the tip of the

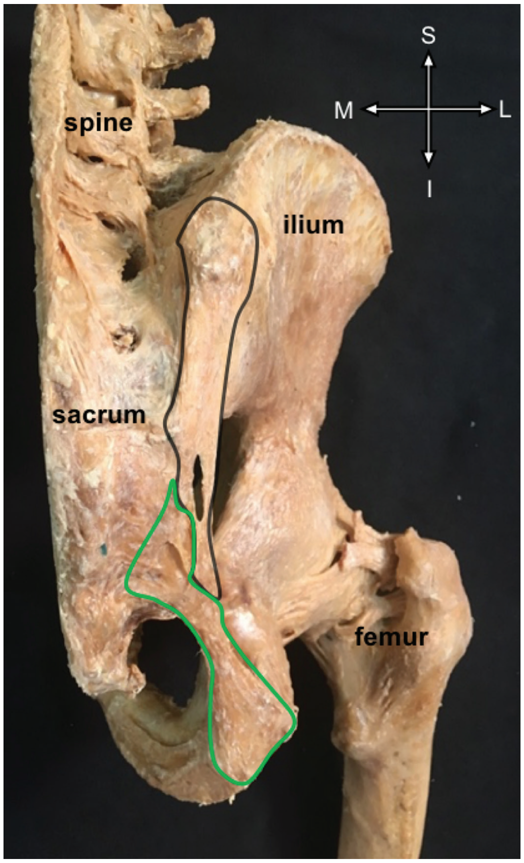


Fig. 17. *Posterior view of an E12-plastinated hemipelvis. The LPSL (black section) is blending with the course of the STL inferiorly (green section). I, inferior; L, lateral; M, medial; S, superior.*

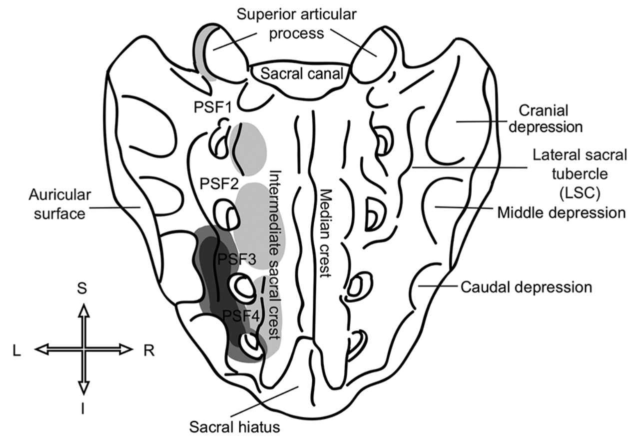


Fig. 18. *Attachment sites of the LPSL on the posterior sacrum. Darkest zones are referenced the most in the literature with a higher degree of consensus between authors. I, inferior; L, left; PSF1-4, posterior sacral foramina 1-4; R, right; S,* superior.

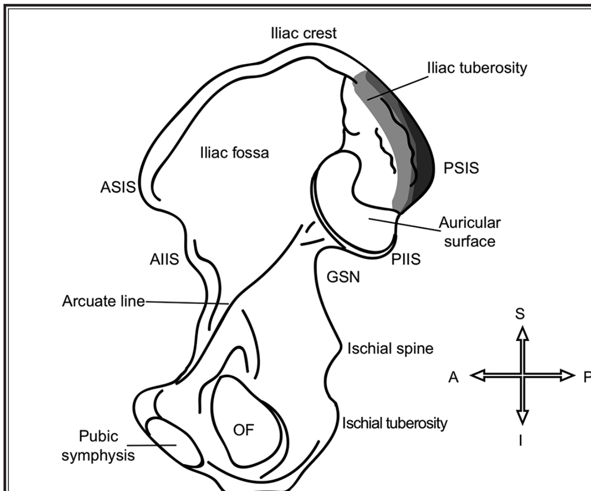


Fig. 19. *Attachment sites of LPSL on the medial ilium. Darker zones are referenced the most in the literature with a higher degree of consensus between authors. A, anterior; AIIS, anterior inferior iliac spine; ASIS, anterior superior Iliac spine; GSN, greater sciatic notch; I, inferior; OF, obturator foramen; P, posterior; PIIS, posterior inferior iliac spine; S, superior.*

transverse process of L5 to the periosteum on the anterior margin of the iliac crest (92-94,100). It has a torsional inferolateral direction in its course from L5 to the ilium (96). In one study, it has an origin on the transverse process of L4 in approximately 17% of the specimens (97). The posterior band runs from L5 to the posterior margin of the iliac crest in a 'torsion-like manner' (92,95,96). Another study found that the posterior and anterior bands were 2 distinct structures in 69% of their specimens. In the remaining 31%, the bands coursed together as one (100).

The ILL has been described as 4 individual parts: a dorsal band, a ventral band, a lumbosacral band, and a sacroiliac part (Fig. 20) (91,101). Although previously there was no mention of the sacroiliac part, unless the lumbosacral band was defined as a conjunction of the two (57). The 'lumbosacral band' of the ILL has also been reported as the 'lumbosacral ligament' (57,102-106). It is present in all specimens bilaterally, running from the body of the first sacral vertebrae to meet with the ILL or connect directly to the transverse process of L5 (103,105,106).

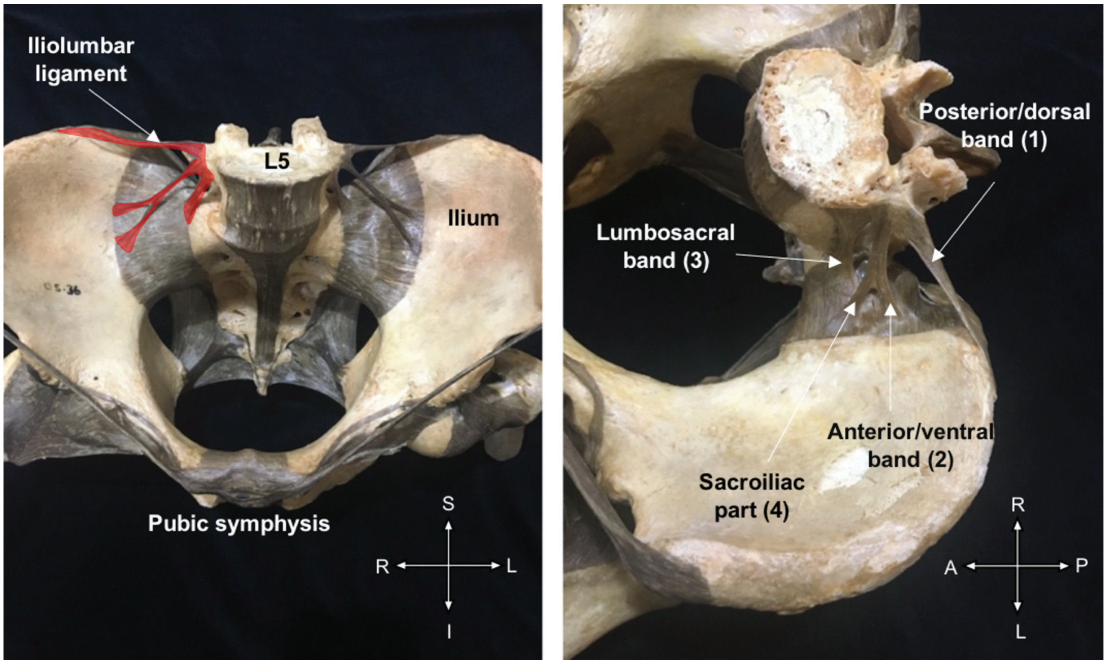


Fig. 20. *The ILL on a dry specimen, anterior/superior view (left) with shaded components of the ILL (red), superior-lateral view (right). (1) From the transverse process of L5 is a dorsal band running to the cranial part of the iliac tuberosity on the medial part of the iliac crest. (2) The ventral band running from the ventrocaudal part of the transverse process of L5 to the ventrocaudal part of the iliac tuberosity on the sacropelvic surface. (3) A lumbosacral band running from the ventrolateral aspect of the vertebral body of L5 and ventromedial part of the transverse process of the middle ventrolateral part of the base of the sacrum near the SIJ. (4) A sacroiliac part running from the cranial surface of the ala of sacrum directly caudal to the transverse process of L5 to the ventromedial part of the iliac tuberosity together with the ventral band. A, anterior; I, inferior; L, left; P, posterior; R, right; S, superior.*

An imaging study determined the interindividual variation that occurs for the ILL. The ligament ranges from being a thick to thin, broad, small or even long band, and has various directions and attachment sites within the same gender (98). In individuals of African descent, it was found that the ILL was composed of one single thicker band in contrast with 2 bands in Caucasian individuals (107). Figures 21 and 22 detail a summary of the attachment sites of the ILL.

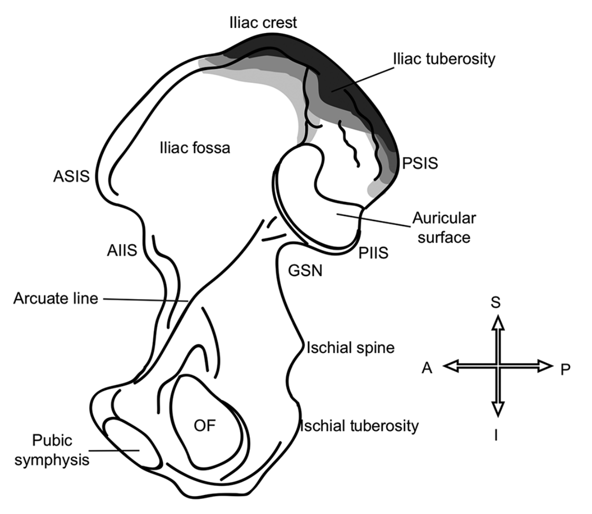


Fig. 21. *Attachment sites of the ILL on the medial ilium. Darker zones are referenced the most in the literature with a higher degree of consensus between authors. A, anterior; AIIS, anterior inferior iliac spine; ASIS, anterior superior Iliac spine; GSN, greater sciatic notch; I, inferior; OF, obturator foramen; P, posterior; PIIS, posterior inferior iliac spine; S, superior.*

The STL and the SSL

The SSL and STL prevent the sacrum from tilting when forces are applied (Fig. 23) (35,108-110). The SSL arises from the anterolateral surface of the last 2 sacral segments and the first coccygeal segment to the ischial spine (42,55). The sacral fibers are mingled with the ASL superiorly and the ischial fibers merge with the STL (42,111).

Medially, the STL arises along a line running from the posterior inferior iliac spine down to the border of the iliac bones to the caudal edge of the sacrum and coccyx (C1-C2). It also attaches to the LSC on a level with S3-S4 and PSL on this line (42,55,112). It inserts on the ischial tuberosity inferiorly (16,42,113). The fibers run in a twisting course inferiorly obliquely from the sacrum crossing the posterior surface of the SSL (96,108). The STL also shares attachments with various muscles and fascia of the pelvis, thigh, and back. These include the erector spinae (ES) muscles, piriformis muscle, gluteus maximus (GMax) muscle, the biceps femoris (BF) muscle, and the thoracolumbar fascia (TLF) (14,87,108,114-116).

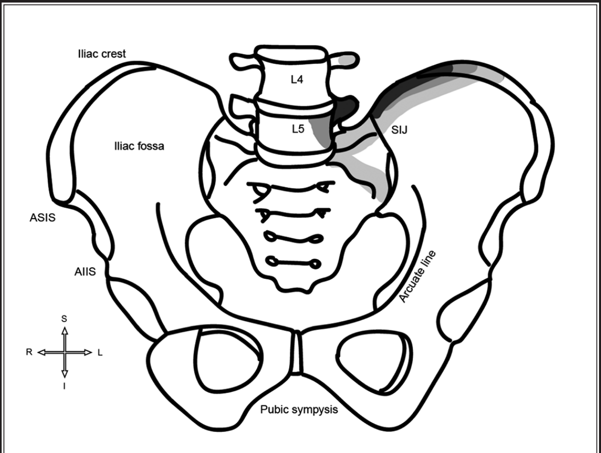


Fig. 22. *Attachments of the ILL on the anterior pelvis and lumbar vertebrae. Darker zones are referenced the most in the literature with a higher degree of consensus between authors. AIIS, anterior inferior iliac spine; ASIS, anterior superior iliac spine; I, inferior; L, left; R, right; S, superior.*

Further Ligaments Related to the SIJ

Additional SIJ ligaments have been reported. A 'polar anteroinferior ligament' is located anteriorly near the lip separating the second and third sacral foramen and inserts on the sacral anteroinferior angle of the auricular surface on the sacrum to the homologous iliac surface. It is described as a short, resistant, oblique band running anteriorly from the iliac surface to the sacral surface. It is formed by 2 fascicles, one anterior and one posterior, separated by a small neurovascular bundle (117). It has a similar location as the 'horizontal ligament on S3' as described by Steinke et al (20) located ventrally covering the third sacral vertebra between the second and third sacral foramen. 'Illi's ligament' has been referred to with many studies disagreeing on its presence, whereas few have proven its existence (88, 118-121). It is a small but strong band of tissue originating below the superior part of the SIJ and slightly posterosuperior to the margin of the articulating surface of the sacrum. It is also 1.5 cm above the superior border of the articulating surface of the

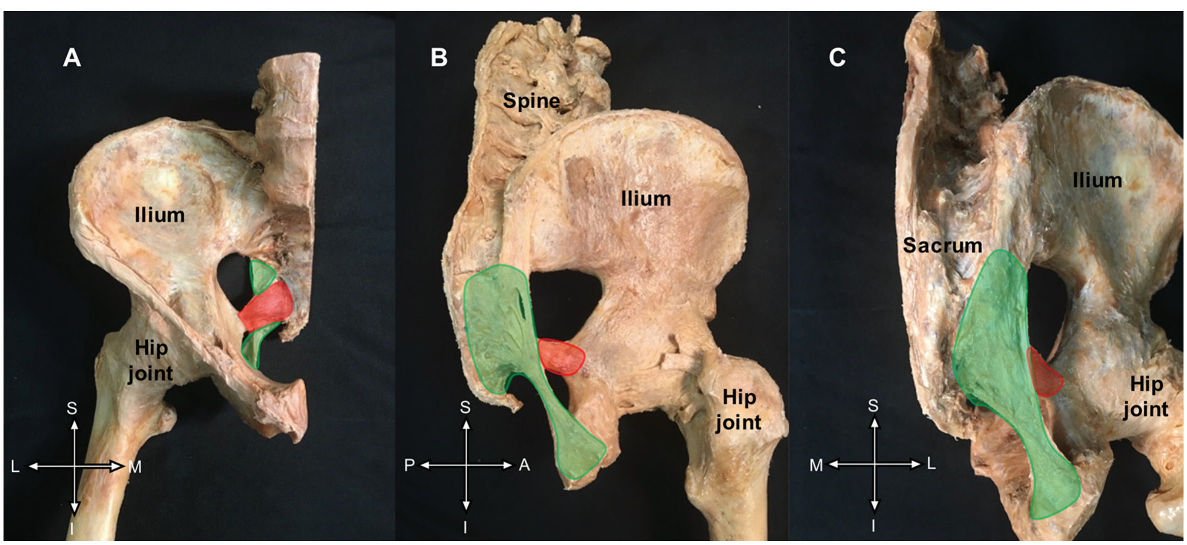


Fig. 23. *Sacrotuberous and SSLs on plastinated prosections of hemipelvis, (A) anterior view, (B) lateral view, (C) posterior view. In green is the STL, in red the SSL. A, anterior; I, inferior; L, lateral; M, medial; P, posterior; S, superior.*

ilium. One author revised this research and found a dense fibrous band of connective tissue coursing from the posterosuperior attachment on ilium (blending with the ISL) to the anteroinferior attachments on the sacrum (histologically found to insert into the hyaline cartilage). It was argued that this structure may be an anterior extension of the ISL, but it is usually a distinct band (121). Gairdner and Barlow (24) described a group of ligaments as 'sacro-sciatic ligaments' presumed to be the PSLs. From these, one ligament named 'Zaglas' is mentioned as one of the bands of the PSL. It is also referred to in the Le Blanche et al (88) study with no further description as to its components. Albee (50) references a 'round ligament' attached to the posterior irregular part of the ilium deduced as being the iliac tuberosity with no mention as to the other attachment site.

Myofascial Relationships of the SIJ

Various muscles cross the SIJ, but none are thought to directly impact it (64,122). Myofascial structures that may influence the joint include: the BF muscle, the coccygeus muscle, the ES muscles, the GMax muscle, the multifidus muscle, the deep pelvic fascia, the piriformis muscle, the quadratus lumborum muscle, the semimembranosus (SemiM) muscle, the semitendinosus (SemiT) muscle and the TLF (4,7,12,26,63,70,123-128). Additionally, the gluteus medius muscle, the latissimus dorsi muscle, the psoas (major and minor) muscles and the transversus abdominis muscles have been mentioned to attach to the TLF in Harrison et al (122). A recount of the studies on the muscle attachments sites in relation to the SIJ ligaments are shown in Table 3.

Fascial Relationships of the SIJ

The TLF is comprised of 2 or 3 layers that unite inferiorly to form a lumbar composite (129,130). The posterior layer is composed of 2 layers referred to as the superficial and deep laminae, and has strong connections with the sacrum, PSIS, L4 and L5, LPSL, and to the aponeurosis of the ES muscles (87,116,130,131). Fibers of the deep lamina are continuous with the STL, suggesting a link between the STL and the superficial laminae of the posterior layer of the TLF (129). The middle portion of the LPSL receives contributions from 3 fascial layers: the ES muscles aponeurosis, the fascial layer deep to the multifidus muscle, and the gluteal aponeurosis (90).

The deep pelvic fascia attaches inferiorly along the course of the obturator internus muscle along the margin of the pubic arch and the STL. Posteriorly, the myofascial margins attach to the greater sciatic notch and the base of the ischial spine. The obturator sheath is also present between the STL and SSL, ischial spine, and the tendon of the obturator internus muscle (16,26).

Attachments of Pelvic Musculature to the SIJ

The attachment sites of the GMax muscle from the superolateral aspect to the inferomedial aspect are: the sacral periosteum, the gluteus medius fascia, the ilium, the TLF, the ES muscles aponeurosis, the LPSL, the STL, and the coccyx (14,16,87,89,109,115,132). It is also continuous with the superficial layer of the superficial laminae of the TLF and with the fascia lata and iliotibial tract of the thigh (132). The piriformis muscle is the only muscle having a direct attachment to the SIJ as it crosses over the joint pulling the pelvis in an oblique direction (10,124). The dorsal aspect of the piriformis muscle is continuous with the STL, and the fibers attach directly to the ventral part of the STL (115). Furthermore, in the fetus, thick collagen fibers corresponding to the final SSL were found in the posteroinferior margin of the coccygeus muscle after 31 weeks in utero (126).

Attachments of Back Musculature to the SIJ

The ES muscles comprise the iliocostalis, longissimus, and sacrospinalis muscles. Sacrospinalis has the most attachments to the SIJ including the medial crest of the sacrum, the spinous processes of the lumbar vertebrae, and vertebral bodies T11 and T12. It also attaches to the posterior part of the inner lip of the iliac crests and the LSCs, blending with the STL and PSL (114). Also, the ES muscles have fibers attaching to the dorsal aspect of the ILL and the medial fibers of the LPSL (87,89,91).

The thoracolumbar transversospinal muscles, which include the 'lumbar multifidus muscle,' arise from the sacral tubercles of the intermediate and median sacral crests, the ES muscles aponeurosis, the posteromedial surface of PSIS, and the medial aspect of the LPSL (114,133). Caudally and medially, these muscles attach directly onto the sacral periosteum and multifidus muscle on the sacrum. They originate from L1-L4 attaching inferiorly to the superior PSIS, SIJ region, and sacral levels S2 and S3 on the medial sacrum (133). Caudal and ventral bands of the ILL attach to medial fibers of the iliacus muscle and the dorsal band to the ES muscles, as well as having medial fibers to the quadratus lumborum muscle (91,96).

Table 3. *Muscle and fascial connections to the ligaments of the SIJ from the literature.*

	Biceps femoris	Coccygeus	Gluteus maximus	Erector spinae	Multifidus	Pelvic fascia	Piriformis	Quadratus Lumborum	Thoracolumbar fascia
Cameron, 1907 (26)						STL			
Bogduk, 1980 (114)				STL, PSL	LPSL				
Hakim, 1937 (57)				PSL	PSL				
Vleeming et al., 1989 (115)	STL		STL	ILL, LPSL			STL		
van Wingerden et al., 1993 (108)	STL								
Vleeming et al., 1995 (116)									STL, LPSL
Vleeming et al., 1996 (87)			LPSL, STL						STL, LPSL
Fujiwara et al., 2000 (100)								ILL	
Pool-Goudzwaard et al., 2001 (91)				ILL, LPSL				ILL	
McGrath et al., 2009 (89)			LPSL	ILL, LPSL					
Hammer et al., 2009 (16)						STL, SSL			
Hammer et al., 2010 (96)				ILL				ILL	
Cornwall et al., 2011 (133)					LPSL				
Hayashi et al., 2013 (126)		SSL	STL						
Bierry et al., 2014 (113)	STL								
Barker et al., 2014 (14)			STL						

Attachments of Thigh Musculature to the SIJ

The BF has muscular attachments to structures of the SIJ, like the STL (108,113,115,133). The BF muscle attaches to the lower part of the STL superficial fibers, with some of its lateral deep fibers also connecting with it (108). Vleeming et al (115) also determined that in half of their cadavers, the BF tendon was connected to the STL, and in some this was completely fused with the ligament (60). Another study compared the hamstring attachments in patients with pain and those without pain. Results showed that the STL was continuous with BF muscle and SemiT muscle in all of their specimens without pain and in 88% of the patients with pain. The STL, however, was not continuous with SemiM muscle in any of the patients (113). In addition, references recounted in Woodley et al (109) describe the STL having attachments with the piriformis muscle, the obturator internus muscle, SemiM muscle, and SemiT muscle.

Vasculature of the SIJ

The common iliac vessels and the internal iliac vessels lie superior to the SIJ at the levels of L5-S2 anteriorly. Posteriorly, the superior gluteal vessels lie anterior to the SIJ at the levels of S2 to S3 (134). The SIJ is supplied by the median sacral artery and the lateral sacral branches of the internal iliac artery. These arise from the posterior sacral iliac blood supply from the gluteal arteries (43,135). A nutrient artery provides blood to the anterior SIJ region originating from the iliolumbar artery (136). It is shown to arise variably from the common iliac artery or the internal iliac artery to course across the SIJ and enter the nutrient foramen of the ilium (43,137,138). Histologically, there is vascular tissue present in the posterior part at the junction between the articular joint space and where the ISL arises (54). Vascular branches originate from the inferior gluteal artery that travels close to the SSL and STL, penetrating the STL close to its origin on the sacrum (139). This occurred via one artery in 69% of specimens and 2 arteries in 8% (16). Lai et al (140) showed variation in both the origin and distribution of the blood supply to the STL. Branches from the inferior and superior gluteal arteries enter the ligament close to the ischial tuberosity and sacrum in a variety of patterns. These could be a combination of one to 4 branches of the inferior gluteal artery entering the STL with one to 2 branches from the superior gluteal artery (Fig. 24) (140). The subchondral bone plate of the SIJ on both the iliac and sacral sides is penetrated by multiple blood vessels that are in close to the articular cartilage. However, the origin of these small blood vessels is not described (54,73,141).

The venous drainage is said to be analogous to the arterial anatomy, mainly from branches of the internal iliac veins (43). The venous drainage of the SIJ was stated to occur from tributary veins from the median and lateral sacral veins forming part of the sacral venous plexus anterior to the sacrum (135,142). The Batson 'pre-sacral' plexus or 'vertebral venous plexus' found within the vertebrae and sacrum is involved in the venous drainage of the SIJ (143-145).

Innervation of the SIJ

The anterior aspect of the SIJ is innervated by segments L4-S2, sometimes L3, and the sacral plexus, and in one study, even the superior gluteal nerve (Table 4) (70,146-148).

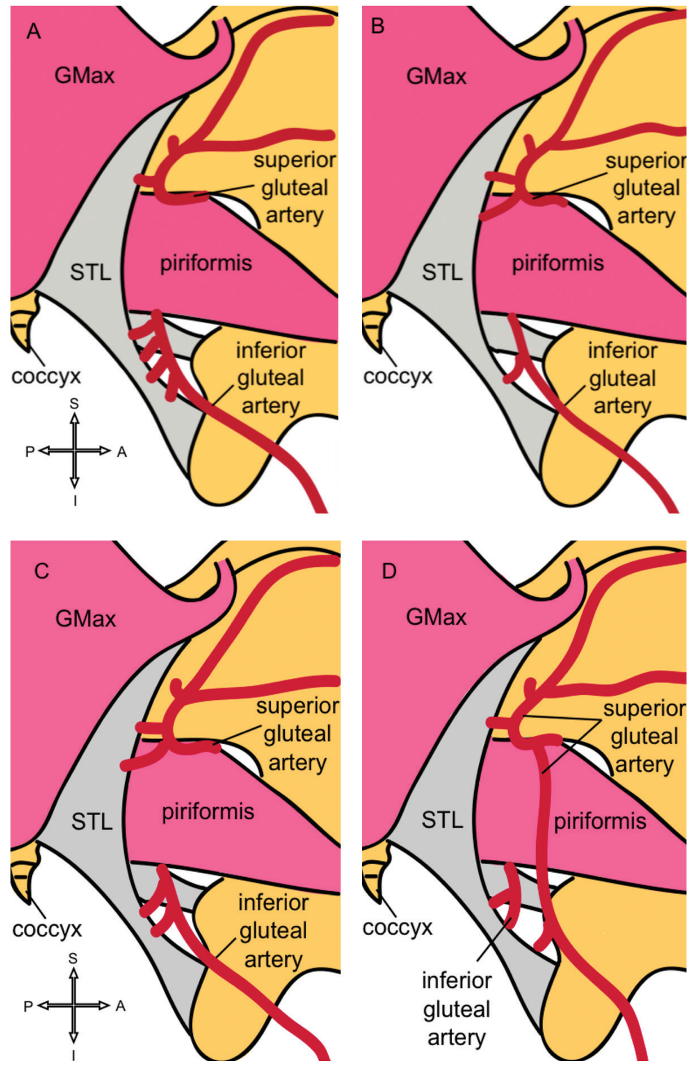


Fig. 24. *Dorsal view of the blood supply of the posterior sacroiliac joint and the sacrotuberous ligament (STL) based on Lai et al., (140). The gluteus maximus muscle (GMax) is reflected to expose the STL and piriformis muscles. (A) Example of pattern 1 with 4 penetrating branches from the inferior gluteal artery and one branch from the superior gluteal artery. (B) Example of pattern 1 with 2 perforating branches into the superior part of the STL and one branch from the inferior gluteal artery into the caudal part of the ligament. (C) Example of pattern 1 with 2 branches from the inferior gluteal artery and 2 branches from the superior gluteal artery penetrating the STL. (D) Example of pattern 2 with one branch perforating into the superior part of the STL from the superior gluteal artery. The superior gluteal artery in this case also crosses over the piriformis muscle providing a branch to the STL inferiorly. The inferior gluteal artery splits in 2 and perforates the caudal STL with 2 branches. S: superior, I: inferior, P: posterior, A: anterior*

The posterior aspect of the SIJ is innervated by a nerve plexus formed by the lateral branches of posterior rami of L5 to S4 (Table 5) (23,70,147-154). The posterior innervation was noted to be asymmetrical between the left and right sides of the body, and interindividual differences were found (23,146-156). Two groups stated the involvement of the sacral plexus in SIJ innervation, when other groups did not mention its contribution. Ikeda (148) stated that the sacral plexus is involved in SIJ innervation, but Grob et al (150) explicitly excluded its contribution. In more detail, the upper anterior portion of the SIJ is innervated by the ventral ramus of L5 and the lower portion by S2 or branches of sacral plexus (148). Two studies found contributions of L4 and L5 (146,156).

Fatty Infiltration of the SIJ

The presence of fat in the SIJ is barely investigated in the literature, and the reason for its presence within the SIJ is not clear to date. Nine anatomy articles mention the presence of 'areolar connective tissue' within the posterior SIJ, which is presumed to be fat (54,55,86,89,91,92,96,152,157). The tissue is found between the meshes of the ISL or between the PSL (54,55,86). Fat is observed posteriorly where the lateral branches of the dorsal sacral rami can be identified between the ISL, the sacroiliac part of the ILL, and the middle of the LPSL (57,89,91,92). Histologically, loose connective tissue with vessels interrupting the ASL was found in the center of the SIJ, with fatty tissue posteriorly within the ligaments (54). Also 'loose connective tissue' or 'fat' surrounding neurovascular structures was found travelling through the deep portion of the LPSL in the posterior part of the joint (141,152).

Magnetic resonance imaging (MRI) scans revealed fat metaplasia (an effect of inflammatory products on normal fat metabolism) producing an accumulation of fat within the subchondral bony areas (158). Fat infiltration within the SIJ has been shown to be an independent predictor of ankyloses. The fat presence was

Table 4. *Innervation of the anterior SIJ from the literature. Shaded sections are the contributing branches found in each study. Dark sections are the most common contributions, light gray sections are for the occasional contribution.*

Study	L3	L4	L5	S1	S2	Superior gluteal nerve	Sacral plexus
Solonen, 1957 (147)	▒	■	■	■	■	▒	
Ikeda, 1991 (148)			■		■		▒
Szadek et al., 2008 (156)		■	■				
Cox et al., 2017 (146)		■	■				

Table 5. *Innervation of the posterior SIJ from the literature. Shaded sections are the contributing branches found in each study. Dark sections are the most common contributions, light gray sections are for the occasional contribution.*

Study	Superior gluteal nerve	L5	S1	S2	S3	S4
Horwitz, 1939 (149)			■	■	■	■
Solonen, 1957 (147)			■	■		
Bradley, 1974 (23)		■	■	■	■	
Ikeda, 1991 (148)		■	■	■	■	■
Grob et al., 1995 (150)			■	■	■	■
Fortin et al., 1999 (155)			■	■	■	
Yin et al., 2003 (151)		■	■	■	■	■
McGrath and Zhang, 2005 (152)			■	■	■	■
Cox and Fortin, 2014 (153)	▒	■	■	■	■	
Roberts et al., 2014 (154)		■	■	■	■	■

higher in cases of ankylosing spondylitis (AS) than in patients presenting no pathology (159,160).

Muscle degeneration is a common feature associated to nonspecific lower back pain. The infiltration of adipose tissue into skeletal muscle is indicative of muscle atrophy commonly associated with a considerable loss in muscle strength and function (161,162). This can compromise joint stability and lead to further injury and lower back pain (163). Previous literature demonstrates that in certain lumbopelvic pain-associated conditions like hip osteoarthritis, lateral hip pain, and other nonspecific lower back conditions, there is a decrease in muscle volume accompanied by fatty infiltration within the muscles (161,163-166). Fatty infiltration has been assessed in the gluteal (167) and lumbar musculature (164,168) and may have a direct impact in SIJ-related biomechanics associated with muscle atrophy in this area.

Morphologic Variations of the SIJ and Accessory SIJs

Accessory SIJs (ASIJs) and morphologic variations of the SIJ have been reported in the literature (22,29,59,157,169-179). ASIJs are additional articular facets within the syndesmotic SIJ, covered with hyaline or fibrocartilage in their own capsule and synovial membrane (Fig. 25) (22,72,157,169,170,175,177). They are generally observed in 8%-40% of specimens (63). A higher frequency of ASIJs has been reported in older specimens (29,63,157,169,174,179). ASIJs appear more commonly in men (25%) than women (21%) (174), and more frequently on the right side of the body (177). There was a higher frequency of ASIJs in obese patients and women with 3 or more childbirths (179). The majority of ASIJ cases revealed only one or 2 articular facets (29,169,171,172). Some found up to 3 ASIJs in 34% of investigated cadavers (22). The facets can range from 2 mm to 1 cm in diameter, and are located in the following areas: posterior to the articular surface (in region of the LSC at the level of the first or second sacral foramen), on the sacrum, on the medial surface of the PSIS, and on the iliac tuberosity (22,29,169-171,178). One study reports the presence of an ‘axial SIJ’ in 92% of cadavers located slightly caudal to the second sacral foramen with the concavity in the sacral side (157). They describe it as an ’extracapsular junction’ in both genders, and therefore, suggest that this should be included in the anatomic description of the SIJ. In their study, the ‘axial SIJ’ is a different type of ASIJ and it is more common (63,157).

The following morphologic variations were reported in patients without SIJ-related problems (29,172,179). The iliosacral complex (Fig. 25C): an iliac projection inserting cranioposteriorly into a sacral recess at the level of the first and second sacral foramen in the interosseous region or the inferior articular portion. It occurred more frequently in women, mostly bilaterally (172). Bipartite appearances (Fig. 25D) reflect dysmorphic posterior iliac changes, which are more frequent in women for one study (29), when this was found to be more common in men in another (179). These occurred in approximately 30% unilaterally with 70% bilaterally, respectively (172). However, this was less common in another study with a result of only 6% unilaterally (179). A crescent-like articular surface (Fig. 25E) describes a bulged sacral surface occurring in approximately 4% of patients, bilaterally and unilaterally. It was also more common in women with no relation to age (29,179). Single semicircular defects (Fig. 25F) in the articular surface occurred in approximately 4% of individuals, mostly bilaterally (29,179). These are more common in women at the posterior superior aspect of the ISL, with all cases found only on the sacral side (172). Small ossification centers of sacral wings (Fig. 25G) appearing as triangular osseous bodies in the superior posterior region were found in 3 individuals aged <30 years. These just occurred in approximately 1% of patients (29,179). Isolated synostosis (Fig. 25H) were noted as unilateral, involving the middle third of the right SIJ at the level of the first sacral foramen occurring in <1% of specimens. Finally, dysmorphic changes were more common in women located below the second sacral foramen unilaterally and bilaterally occurring in 16% of patients (172).

Discussion

This review covers all SIJ-related anatomic structures including less investigated ones, such as bone density, vasculature, and fat presence. The accurate clarification of these properties potentially contributes to the understanding of the biomechanical behavior of the SIJ.

There is a general agreement regarding bony landmarks, joint type, myofascial attachments, vasculature, and innervation of the SIJ.

The standard terminology of the landmarks of the sacrum and ilium is in agreement. The majority of authors classify the joint as a diarthrosis. Knowing its

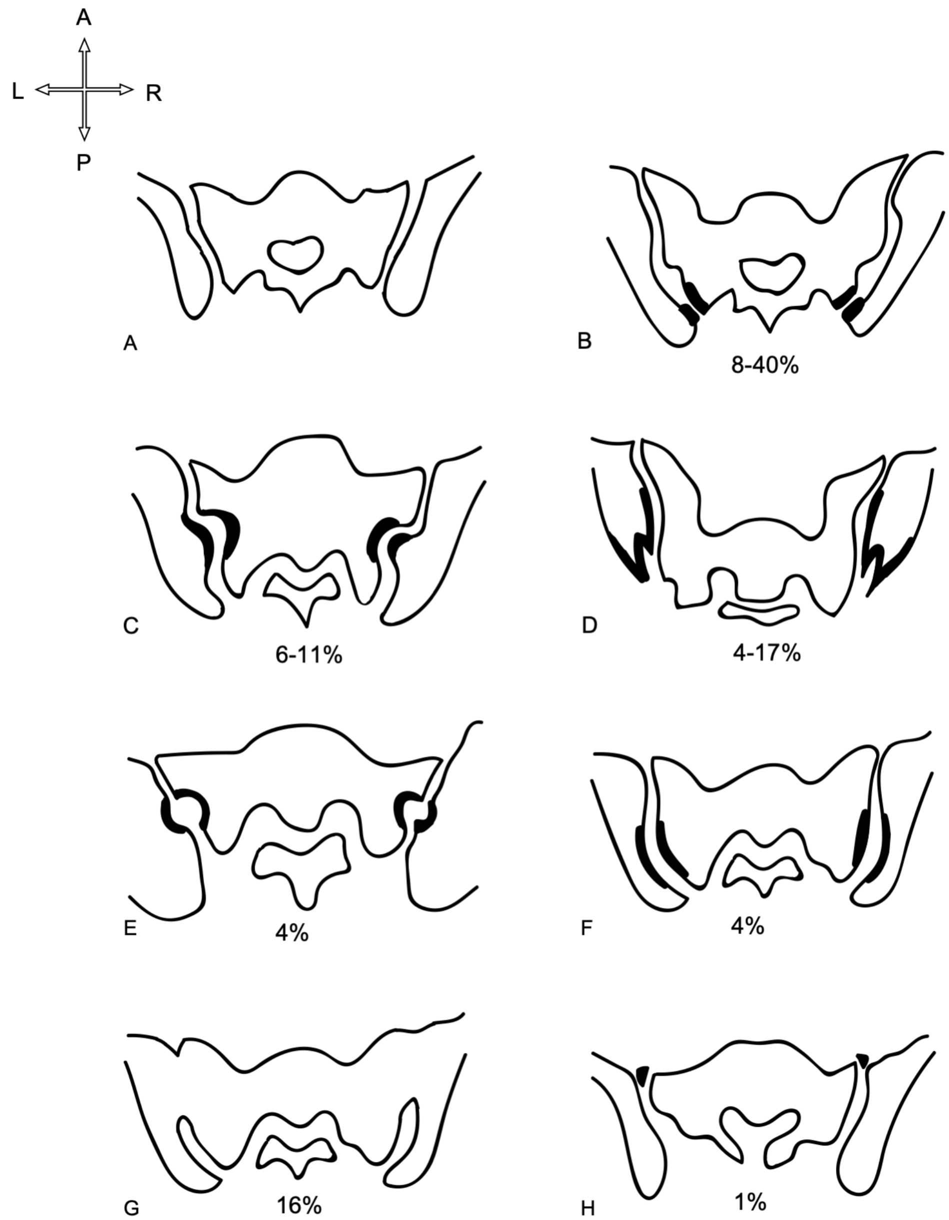


Fig. 25. *Examples of transverse sections of ilium and sacrum as can be found between S1 and S4 showing variation in joint morphology, these may occur in conjunction with one another. (A) 'normal sacroiliac joint' as seen in the majority of cases, (B) accessory sacroiliac joint, (C) iliosacral complex, (D) bipartite appearance/dysmorphic posterior iliac changes, (E) semi-circular defects, (F) crescent articular surface, (G) isolate synostosis (bilateral), (H) sacral wing ossification centers. Percentages represent the occurrence of these characteristic from the studies by Prassopoulos et al., (29), Demir et al., (179) and El Rafei et al., (172). A: anterior, P: posterior, L: left, R: right.*

specific composition is clinically significant to enable to predict the SIJ behavior with regard to pathology and biomechanics over time. The existing disagreements depend on what features are used for the assessment, such as structure, the amount of movement, or even the type of study (180). The term diarthro-amphiarthrosis is a better term, as it encompasses both its reduction of movement through time and its diarthrodial structural characteristics (66). Furthermore, the amphiarthrosis classification is used when movement reduction in the SIJ arises (61). A possible age-related movement reduction can be a consequence of a natural degeneration that negatively impacts the SIJ mobility or the response of the SIJ to the decreased movement of the elderly, or a combination of the 2.

The SIJ is central within the pelvis and transmits forces from the axial skeleton through the legs and spine (8,181). Understanding the muscular relationships, which directly impact the ligamentous structures stabilizing the joint, can help elucidate pain problems that arise secondary to muscular/fascial forces. This is beneficial for physiotherapists who treat patients with SIJ pain to find adequate treatment exercises. Although there is general consensus on the attachment sites of most myofascial structures, further research on the piriformis muscle and a reassessment of the ES muscles would be beneficial to complete the understanding of the attachment sites of these structures, as there is limited published research on these.

The vasculature of the SIJ is crucial for surgeons who must know the relationships of the joint with neighboring structures as they could be damaged during an intervention (136). Further in-depth research on the smaller branches of the common iliac, internal iliac, sacral iliac, and gluteal vessels can be advantageous to improve this knowledge, especially with respect to its interindividual variation within the SIJ and its ligaments.

Innervation of the SIJ is neurologically relevant for the attribution of pain to certain spinal segments. Knowing specific branches is important clinically for diagnosis, treatment, and even surgical intervention into the SIJ. The treatment of pain of SIJ in inflammatory diseases or SIJ dysfunction has had considerable attention. Radiofrequency ablation of the nerves around the SIJ is one of the common options for the treatment of pain (151,153,154,182). The literature on this topic is in general agreement: that the anterior portion of the SIJ is innervated by branches from L4-S2 and the posterior portion by branches from L5-S4.

There is part consensus concerning the cartilage composition and the attachment sites of the ligaments of the SIJ.

The cartilaginous composition of the articular SIJ is not in complete agreement, although general consensus is that hyaline cartilage is present on the sacral side and fibrocartilage on the iliac side. Knowing the composition of the cartilage is important for the understanding of how the joint may evolve with age or with certain common pathologies like osteoarthritis and AS, especially if certain diseases tend to involve a certain type of cartilage. This can help predict which area of the SIJ would be targeted and help in the prevention and subsequent treatment options for a condition.

Literature demonstrates that it is difficult to differentiate the layers of ligaments involved with the SIJ, especially in the posterior region. The anatomy of these ligaments reflects the difficulty in understanding the associated biomechanics of the posterior SIJ. Biomechanics are useful for understanding SIJ pain that may arise from the forces applied to the SIJ through these ligaments. Generally, literature describes the same attachment areas with only slight differences. Furthermore, there may be interindividual differences and pathological states that may influence the results of these studies. Therefore, it may be interesting to research the frequency of the interindividual variation in the 'normal' general population similar to the research by Hakim (57). This research may potentially help determine if a certain ligament pattern tends to be more commonly associated with SIJ pain than others.

The multiple names used for the classification of the SIJ ligaments creates the impression as if 'additional ligaments' exist, which may be underrepresented in the literature. For example, the 'Zaglas' ligament is only mentioned in 2 articles (24,88). This ligament could have been overseen, or it represents a specific variation of the PSL. The most likely scenario is that the ligament is a part of the PSL and was named differently by subsequent authors. Otherwise, the 'sub capsular ligament' has similar attachment sites as the inferior portion of the ASL and could have been determined as a separate entity (117). Similarly, the 'round ligament' could possibly be a part of the ISL, although they differentiate the two (50). This could be owing to the dissimilarity of the course of fibers in the round ligament and the ISL. It is also possible that the ligament reflects 'Illi's ligament' or the posterior part of the ILL. These additional ligaments should be investigated further to classify all SIJ ligaments with the same nomenclature.

Further research is needed regarding the presence of fat in the SIJ

Although literature reports fat in their findings, there are no studies attempting to quantify fat in the SIJ, nor are there any studies looking into its function. Clinically and biomechanically, this could be useful information as perhaps fat within the joint is an age-related 'normal' characteristic, sign of degeneration, or pathology. If fat is a 'normal' characteristic, it could be functionally useful as a cushion for surrounding 'hard structures' such as bones and cartilages when forces are transmitted from the spine to the legs. Therefore, fatty tissue could fulfil a shock absorbing function, as seen in other locations of the human body like the heel pad (183). As stated for the functional fat pad of the heel, it may be directly related to weight (184). Furthermore, the presence of fat in the SIJ could be a developmental relict both embryologically and evolutionary.

Understanding the appearance of fat metaplasia and its appearance within the SIJ would allow clinicians to prepare for a condition to provide the adequate treatment as early as fat is detected. Some studies have shown that there is often fat metaplasia in the bony structures of the SIJ in cases with AS (158-160,185-188). It is an ongoing effect of inflammatory products on normal fat metabolism, producing an accumulation of fat within the subchondral bony areas (158,189). Maksymowych et al (160) determined that fat infiltration within the SIJ is an independent predictor of ankyloses. This was supported by Guo et al (159), in which fat presence was higher in cases of AS than in patients presenting no pathological conditions. Fat metaplasia was tested on healthy patients to find a 'baseline result' for a comparison between patients with AS and those without. Results determined that fat metaplasia was very common and increased with age. This provides us with a range of fat metaplasia values for the general population (186).

Surrounding structures of the SIJ have been reported to contain fat, such as the ILL fibers after the fifth decade of life, making fat related to the natural degeneration of tissues (92). Similar findings were described by Hammer et al (96), in which adipose tissue was present within the space between the 2 bands of the ILL in tissues of cadavers aged >60 years. This could be a potential first step in determining whether fat is related to age and degeneration or whether it is a pathological occurrence. Moreover, fatty infiltration within the muscles is commonly associated with a decrease in muscle strength and atrophy, which influences the joint biomechanics and generates pain (161,162,164). Fat within skeletal muscle and ligaments may be the cause of 'abnormal' biomechanics of a structure because it replaces the healthy fibers that may impact its function. This would suggest a potential 'fatty infiltration' of the ligamentous portion of the SIJ has the potential of generating pain because of its relation to functional impairment.

Further research is needed with regard to the specific bone density of the articulating sacral and iliac counterparts of the SIJ

Loading properties of the pelvis may be related to the distribution of bone density of the articular surfaces. This was previously reported in which a higher incidence of bone osteoporosis was seen in patients suffering from chronic lower back pain owing to their poor mobility, which effectively 'demineralized' the bone (181,190). Clinically, an abnormal increase in bone density is termed 'sclerosis' and is often associated to pathogenesis of some kind that is often seen as a developing change on computed tomography (CT) scans. Interestingly, a higher bone density is seen more commonly developing on the iliac side rather than the sacral side in cases of AS, and is termed 'sclerosis' by clinicians (81,84). This begs the question of whether this change in bone structure is related to the pathology or if it is a 'normal' or degenerative occurrence or a combination of these. Tuite (127) described the sclerosis pattern development of AS as more ill-defined than that of osteoarthritis, suggesting that depending on the condition, sclerosis develops in a specific manner and could be a diagnostic tool for conditions like SIJ dysfunction. To date, there is no range of bone density values of healthy subjects that could be characterized as a 'normal' bone density of the iliac and sacral articular counterparts, nor has the distribution of the bone density of the joint been assessed. Such baseline data would be valuable for the radiologist assessing the joint clinically. These values could then be compared with bone densities seen in pathological states of the joint. Conclusions could be drawn on whether a particular bone density value is part of a 'normal range' or is suspicious for the subsequent development of defined pathologies. Similarly, determining the bone density arrangement within the joint may provide insight in the development of certain pathologies or changes in loads applied to the SIJ in relation to SIJ syndrome. Ideally, medical interventions could be started at an early state of the disease avoiding vast functional impairments of the SIJ.

ASIJs and the anatomic variation of the joint are well-described morphologically; biomechanical influence of these variations should be looked at in depth

It has been demonstrated that morphologic variations are likely to occur in the general population. Considering the high percentage of people suffering from lower back pain during their lifetime, these morphologic differences may be responsible for back pain, and should be considered during diagnosis and treatment and could be investigated using imaging technology like MRI and CT. In addition, ASIJs, although well defined, are often not recognized as a 'true articular part' of the joint that may be problematic for identifying certain pathologies and preventing these in the long run. Considering certain study results, ASIJs are the most common morphologic variation of the SIJ reported and should therefore also be considered as possible pain generating sites.

Limitations of the Study

This review has researched the literature to date on the anatomic properties of the SIJ using a set of guidelines and inclusion/exclusion criteria. All attempts were made to encompass all the relevant literature to date, but some studies may have been missed as only certain databases were used for the initial search. Additionally, keyword combinations used for this review may not have been inclusive of all articles relevant to the SIJ. Also, only English, German, and French articles were included in this review.

Conclusions

There was a part consensus on the ligament attachments and cartilage structure of the joint. Furthermore, although ASIJs and anatomic variation are well-described morphologically, the biomechanical influence of these variations should be investigated in more depth. Clinically relevant areas lacking research identified in this review include the bone density distribution of the SIJ iliac and sacral articulating counterparts, as well as fat presence within the joint space. These are areas that should be investigated further to advance the understanding of the anatomy of the SIJ.

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