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Anatomy to understand pelvic trauma: structure and function of several ligaments around the sacroiliac and pubic symphysis, and bone mineral density of the pelvic bones

Short title: Anatomy to understand pelvic trauma: pelvic ligaments and BMD

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Abstract

This review is based on the literature published between 2000 and 2023 and presents an up-to-date evidence-based discussion of anatomical considerations relevant to the management of pelvic trauma. In addition, it discusses the significance of the pelvic ligaments in stabilizing the pelvic ring and of bone mineral density (BMD) in fragility fracture of the pelvis (FFP), which is becoming increasingly common in today’s aging societies. Following an overview of the anatomy and function of the sacroiliac joint (SIJ), the pubic symphysis, and the surrounding ligaments, the suitability of the widely used Young-Burgess classification of high-energy impact pelvic ring fractures, which emphasizes the role of the ligaments in pelvic ring injuries, is discussed. Based on the current body of knowledge, using 2.5 cm of pubic symphysis diastasis as the determinant for surgical intervention for anterior-posterior compression fracture is questioned, and evaluation under anesthesia and lateral stress radiography for accurate diagnosis and treatment planning is proposed instead. The review underscores the need for further research on how the pelvic ligaments can provide optimal stability in the treatment of various types of pelvic fracture. On the other hand, for fragility fracture of pelvis (FFP) in older adults caused by low-energy trauma, the emphasis is on the fragility of the bones. To better manage FFP, the importance of understanding the distribution of BMD in the pelvis is highlighted. Dual-energy X-ray absorptiometry is a common method for measuring BMD, but it has drawbacks. The advantages of measuring BMD using Hounsfield units on computed tomography scans as an alternative method are discussed. An understanding of these issues may lead to better

management of the increasing number of FFP cases in older people with reduced BMD.

和文抄録

題目: 骨盤外傷を理解するための解剖学;仙腸関節と恥骨結合の靭帯の構造と機能および骨盤骨の骨密度

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抄録: 本稿では2000年から2022年までの文献レビューを基に骨盤外傷の管理と治療戦略における解剖学的考察と今日の高齢化社会で一般的となりつつある骨盤脆弱性骨折における骨盤骨の骨密度の重要性について述べる。初めに仙腸関節と恥骨結合およびその周囲の靭帯の解剖学とその機能について概説する。高エネルギー外傷による若年者の骨盤輪骨折についてYoung-Burgess分類を使用して骨盤輪の損傷時における靭帯の役割を強調する。APC型の骨盤輪骨折に対する治療の基準として恥骨結合離開が2.5cm以上とされる従来の考え方に疑問を呈した。代わりとして、麻酔下でのストレス撮影（EUA）や自重を用いたX線側面像（LSR）を不安定性の正確な評価と治療の計画立案を提案する。一方で、低エネルギー外傷によって引き起こされる高齢者の脆弱性骨盤輪骨折に対しては骨が脆弱であることが強調される。脆弱性骨盤輪骨折をより良く管理するためには,骨盤骨の詳細な骨密度を理解することが重要であったが、一般的な検査方法であるDEXA法では評価が不十分であった。代わりとしてCT scanでのHounsfield単位 (HU) を用いた測定がなされて

いる。これらの結果は骨折型の理解や手術方法の立案に役立つ可能性が高い。

Introduction

Pelvic ring fractures may be caused by high-energy trauma, such as a road traffic accident, or by fragility fracture of the pelvis (FFP) in response to low-energy trauma, such as a fall, in individuals with reduced bone mineral density (BMD) 1). The bony anatomy of the pelvic ring, formed from the sacrum and the two innominate bones, each with an ilium, ischium, and pubis, has no inherent stability and needs strong ligamentous attachments to maintain the ring structure. Displacement occurs when the ring is disrupted at two or more sites 2). High-energy traumatic fractures of the pelvic ring can be life-threatening and require immediate intervention 3). The Young-Burgess classification is widely used in the management of high-energy trauma fractures and classifies such fractures according to bone and ligament failure. Therefore, a thorough understanding of the anatomy and stabilizing function of the relevant ligaments is needed, especially those around the sacroiliac joint (SIJ) and the pubic symphysis. This narrative review discusses the anatomy of these ligaments, focusing on their role in stabilizing the pelvic ring during movement and their significance in terms of the Young-Burgess classification of pelvic fractures.

Clinicians managing low-energy traumatic FFPs often have concerns about inadequate surgical fixation; although the ligaments are intact, the bone tissue is fragile as a result of decreased BMD and can fracture easily. In view of the increasing incidence of FFPs as a result of loss of BMD in today’s aging societies, this review discusses the most recent literature on pelvic BMD and the methods used to measure it when planning treatment. The literature published between 2000 and

2023 was searched using the PubMed database.

1 Sacroiliac joint

1.1 Bony anatomy

The SIJ connects the spine to the pelvis and allows transfer of load between the lumbar spine and the legs [1). Located within the pelvis between the sacrum and ilium, the SIJ is a diarthrodial synovial joint [4) with a width of 1–2 mm and is surrounded by a fibrous capsule that is attached to the sacrum and ilium [5). The dorsal area of the joint houses the fibrous interosseous sacroiliac ligament (ISL), while the ventral area contains the L-shaped synovial articular cartilage. The sacral joint is covered with approximately 1 mm of hyaline cartilage, which has a more fibrocartilaginous appearance. The cortical bone is extremely thin and has a width of less than 1 mm [6).

1.2 Ligamentous anatomy of the SIJ

1.2.1 Anterior sacroiliac ligament

As described in the excellent comprehensive review by Ashby et al. [7), the anterior sacroiliac ligament (ASL) is located on the anterior aspect of the SIJ [8). It has long transverse fibers that run from the sacral base and lateral sacrum to the medial margin of the auricular surface of the ilium. The superior portion is an extension of the iliolumbar ligament (ILL). Caudally, it merges with the cranial fibers of the sacrospinous ligament [9). The fibers of the ASL are mainly thin and weaker than those of the posterior sacroiliac ligament (PSL) [5). However, the ASL is well developed where it runs over the SIJ obliquely to connect the third sacral segment to the ilium near the arcuate line and the posterior inferior iliac spine 7),8).

1.2.2 Interosseous sacroiliac ligament

The ISL is situated deep within the dorsal sacroiliac ligament, positioning itself between the ilium and the sacrum. It has a unique, funnel-shaped architecture with the apex linked directly to the sacrum. This ligament completely encapsulates the axial joint and occupies the dorsal and cranial space within the synovial portion of the joint, thereby conferring considerable multidirectional structural stability. Remarkably, the ISL has the most significant osseous origin and volume among all the SIJ ligaments. The substantial structure and size of the ISL means it as the strongest of all the ligaments supporting the SIJ, highlighting its pivotal role in maintaining the stability and functionality of the joint 7).

1.2.3 Posterior sacroiliac ligament

The PSL exhibits distinct proximal and distal zones of bony anchoring, with an intervening segment housing a nexus of three layers: the erector spinae aponeurosis, the intricate deep fascial layer, and the gluteal aponeurosis 7). Short PSLs trace a path from the posterior tuberosity of the ilium, culminating at the lateral facet of the sacrum. These ligaments, with their fibers primarily oriented horizontally, contribute to the depth of the ligamentous complex 7). Long PSLs, characterized by considerable resilience, are constituted by several bundles of fibers. They span from the lateral crest of the sacrum, reaching towards the posterior superior iliac spine and the terminal of the iliac crest 5). This strategic anatomical positioning affords a protective mechanism against potential posterior flaring or joint diastasis 10).

1.2.4 Iliolumbar ligament

Originating from the transverse processes of L4 and L5 and extending to the iliac crest, the ILL is attached to the pelvis via two primary bands reaching the sacroiliac capsule 8) and restricts sagittal movement of the SIJ 11).

1.2.5 Sacrotuberous ligament

The sacrotuberous ligament, with its vertical orientation and broad base that attaches to the posterior superior iliac spine, the PSL, the lateral sacral crest, and the lateral margins of the lower sacrum/upper coccyx, plays a critical role in the kinematic chain. It supports the direct transmission of mechanical force and load from the spine and sacrum to the lower limbs 11). Anchoring to the medial margin of the ischial tuberosity, the sacrotuberous ligament contains superficial fibers that are continuous with the biceps femoris tendon. Working in concert with the sacrospinous ligament, it firmly secures the sacrum to the ischium, effectively preventing upward tilt 12).

1.2.6 Sacrospinous ligament

The sacrospinous ligament, which is characterized by a thin and triangular profile, occupies a position posterior to the attachment of the sacrotuberous ligament. It forms a crucial connective link from the outer margins of the sacrum and coccyx to the ischial spine of the ilium. Interestingly, this ligament exhibits some blending with the sacrotuberous ligament, demonstrating the intricacy of this ligamentous network 8).

1.3 Function

The fundamental roles of the SIJ encompass shock absorption, torque conversion, and pelvic stabilization. However, because of its flat shape, the SIJ becomes less stable when subjected to shear loads. The primary source of kinematic support for the connection between the pelvis and the vertebral column provided by the SIJ is rooted in the interconnected ligaments and fascial structures in this area. The primary source of the pelvic ring's structural stability comes from the posterior SIJ complex. This complex is characterized by its unique physical structure and weight-bearing capacity. A suspension bridge-like arrangement of posterior SIJ ligaments, including the ISL, ILL, and PSL, further reinforces it 13). Furthermore, the ventral side of the iliopsoas ligament considerably enhances the stability of the SIJ in the sagittal plane, and the ventral side of the ILL significantly improves the stability of the L5-sacral segment 11). Wang and Dumas reported that the transverse segments of both the ASLand PSL resist lateral rotation of the SIJ, with the superior portion of the anterior segment of the posterior ligaments and the inferior segment of the posterior ligaments acting against nutation 14). These anterior and posterior ligaments together inhibit around 30% of sacral gliding 7). The PSL connects to the erector spinae via the posterior layer of the thoracolumbar fascia 9); however, the ASL lacks any muscle attachment, with the posterior ligament playing a more substantial role in stability 15). The smooth, planar articular surfaces of the SIJ allow multidirectional movement, with the robust ISL primarily constraining motion 16). The role of the ISL is to provide strong joint stability and the axis of rotation for the SIJ 17). Cadaveric studies indicate that the sacrotuberous ligament has a major role in the kinematic chain linking the pelvis and the vertebral column 7). Sacral nutation is restrained by mechanical load exerted on this ligament, an effect that is amplified by the long head of the biceps femoris and the gluteus maximus, both of which anchor to the sacrotuberous ligaments 9). The primary role of the sacrospinous ligament is to inhibit rotation of the ilium beyond the sacrum. Dujardin et al. observed a decrease in the stability of the SIJ when the sacrospinous and sacrotuberous ligaments were severed and the ischial tuberosity was compressed 18). The structural integrity of the SIJ is maintained by a collaborative network of ligaments, which includes the ASL, PSL, ISL, ILL and the sacrotuberous and sacrospinous ligaments.

2 Pubic symphysis

2.1 Bony anatomy and interpubic disc

As described by Becker et al. in their systematic review of the anatomy of the pubic symphysis 19), the pubic symphysis is essentially a joint that is 10 mm wide and consists of a fibrocartilaginous disc positioned between the articulating surfaces of the pubic bone. These surfaces, which are oblique, oval, and slightly convex in orientation within the sagittal plane, have dimensions averaging 30–35 mm in length and 10–12 mm in width and are shielded by a layer of hyaline cartilage measuring 1–3 mm in thickness. The interpubic disc, noted for its wedge or Y-shaped axial cross-section with a posterior-directed apex, has a fibrocartilaginous core enveloped by a dense periphery of collagenous tissue. The pubic ligament is connected to this disc 19),20). The pubic symphysis is almost immobile under the influence of four ligaments.

2.2 Anatomy of the ligaments

2.2.1 Superior pubic ligament

The superior pubic ligament (SPL) bridges the superior margins of the joint, extending laterally to the pubic tubercles, and it connects to various structures including the interpubic disc, pectineal ligament, line alba, and periosteum of the superior pubic ramus. With average dimensions of 27.7 mm in width, 16.0 mm in length, and 3.94 mm in thickness, the SPL does not have significant muscle attachments 21).

2.2.2 Inferior pubic ligament

The inferior pubic ligament (IPL), also referred to as the subpubic or arcuate pubic ligament, forms an arch spanning the inferior pubic rami 8). As Pieroh et al. describe in their comprehensive description of the pubic ligaments 21), the IPL, measuring on average 29.0 mm in width, 14.4 mm in length, and 4.5 mm in thickness, has attachments with the gracilis muscle and partially with the adductor brevis muscle, and it is noted for being the strongest of all the pubic ligaments and thicker than the SPL, anterior pubic ligament (APL), and posterior pubic ligament (PPL).

2.2.3 Anterior pubic ligament

The APL, which measures on average 24.5 mm in width, 30.7 mm in length, and 4.6 mm in thickness 21), links the pubic bones at the front and integrates with their peripheral periosteum. It is thickly resistant and has a key role, after the interpubic disc, in maintaining stability of the pubic symphysis.

Its deeper layers run more transversely and can blend with the interpubic disc. Its more superficial fibers cross obliquely and interconnect with the tendinous insertions of the rectus abdominis muscle, the oblique abdominal muscles, and the pyramidalis muscle 19).

2.2.4 Posterior pubic ligament

The PPL, which is positioned on the posterior aspect of the pubic symphysis, tends to consist of a small number of thin fibers. As an independent ligament, it strengthens the pubic periosteum and interconnects with the lateral pubic bladder or puboprostatic ligament. The PPL is not associated with any significant muscle attachments 21).

2.3 Function

The pubic symphysis, despite rotating less than 1° during routine activity, is exposed to various forces, including inferior traction, superior compression when standing, and shearing forces during single-leg stance 19). Its primary function is to aid joint stability rather than joint mobility, which it accomplishes through the reinforcement provided by the four above-mentioned pubic ligaments (SPL, IPL, APL, and PPL). Recent reports highlight the critical role of the IPL and SPL in vertical stabilization and the main contribution of the APL to horizontal stabilization 21),22). Although the substantial sagittal and coronal dimensions of the APL mean that it can resist high opposing forces in the horizontal plane, and its thickness, muscle connections, and differential layering of fibers make it a key stabilizer 23), the IPL has a stronger stabilizing effect 21),22). Indeed, the IPL is the most pivotal ligament for maintaining symphysis stabilization, and it is consistently under tension during daily activities [19),22)]. The mechanical strength of the PPL, consisting of only a few thin fibers, remains unclear [21)].

3 Pelvic fracture and ligament stability

Hammer et al. reported that the load distribution during standing was applied to the posterior pelvic ligaments, including the ISL, ILL, ASL, PSL and the sacrospinous and sacrotuberous ligaments. However, the pubic ligaments have a minor effect on overall pelvic motion, primarily facilitating horizontal load transfer at the acetabulum and the ilium [24)]. The posterior structures, which include the SIJ, afford approximately 60% of pelvic stability [25)]. The stability of the posterior pelvis should be evaluated accurately and rapidly in patients with pelvic fractures. In terms of fracture classification, the widely used Young-Burgess system categorizes pelvic fractures based on pelvic ring stability and injury mechanism as anterior-posterior compression (APC), lateral compression (LC), or vertical shear injuries. APC and LC injuries are further divided into three stages to indicate their degree of instability, while the extremely unstable vertical shear injury is categorized as a single stage [26)].

Within the framework of the APC classification, the initial rupture is thought to occur at the symphysis pubis, subsequently extending to the sacrospinous and sacrotuberous ligaments, the ASL, and the ISL, with the final disruption seen in the PSL [27)]. APC I injuries are marked by disruption at the pubic symphysis or pubic bone but still retain rotational stability of the pelvis, typically showing less than 2.5 cm of symphyseal widening and no findings of posterior instability. In contrast, APC II injuries manifest as rotational instability of the pelvis as a result of disruption of the anterior ligamentous structures and typically have a pubic symphysis diastasis exceeding 2.5 cm and anterior widening of the SIJ. APC III injuries are characterized by disruption of the ISL and PSL, leading to both vertical and rotational instability of the pelvis 28). A significant distinction lies at a symphysis pubis diastasis of 2.5 cm, which differentiates a stable pelvis (APC I) from a rotationally unstable pelvis (APC II). This differentiation has substantial clinical implications, considering that APC I injuries do not usually require operative treatment whereas many surgeons opt for operative management of APC II injuries. Upon rupture of the ASL, the average distance of the pubic symphysis is approximately 2.38 cm, which is close to the threshold of 2.5 cm. However, specific measurements across samples have demonstrated variability in the 1.4–4.0 cm range, casting doubt on whether a symphyseal diastasis of 2.5 cm indicates rotation instability 29). Stress imaging has recently been performed as an alternative to dilatation of the pubic symphysis to 2.5 cm for accurate diagnosis of APC1 and APC2. Evaluation under anesthesia (EUA), which assesses the stability of the pelvic ring by adding stress, is reported to be important. Using this method, external force is manually applied to the pelvic ring from various directions to evaluate rotational and vertical instability 30). This stress examination is performed under fluoroscopy and involves three primary manipulations: adduction and internal rotation of the lower limbs with pressure applied through the greater trochanters; external rotation in the frog-leg position and a lateral force directed at the knees;

and finally a push-pull maneuver involving longitudinal traction on one leg and concurrent vertical load on the other leg 30). EUA resulted in 27%–50% of APC I injuries being changed to APC II 30),31), meaning that some APC1 injuries include rupture of the ASL. Furthermore, EUA identified APC2 fractures involving a heterogeneous spectrum of injuries. APC2 injuries have traditionally been associated only with external rotational instability. However, when evaluated with EUA, 37% of APC2 injuries also showed rotational instability in the sagittal plane, suggesting a more complex injury pattern 30). This finding also suggests that the sacrotuberous ligament, the sacrospinous ligament, and the ASL might be compromised, leading to rotational instability in the axial plane 26),15). Therefore, Sagi et al. have proposed that the Young-Burgess classification be modified to introduce two subcategories: APC2a for injuries that might be adequately managed with anterior fixation alone and APC2b for injuries that might benefit from both anterior and additional posterior fixation 30)(Table 1).

Moreover, Young and Burgess have further characterized LC injuries according to the degree of posterior ring injury. LC1 is a stable type with pubic and sacral fractures, LC2 is unstable with pubic and iliac wing fractures (crescent fractures), and LC3 is completely unstable and is either LC1 or LC2 with contralateral APC injury (windswept pelvis) 26). The distinction between LC1 and LC2 injuries plays a crucial role in determining the surgical approach, considering that LC1 fractures represent a heterogeneous spectrum of injuries 32). An unstable type of anterior fracture often includes comminuted and/or oblique fractures of the ipsilateral superior pubic ramus and inferior pubic ramus [33]. LC1 fractures with an initial sacral displacement of over 10 mm tend to have worse outcomes with non-operative management [34],[35]. However, the absence of these features does not mean that the pelvis is stable. Sagi et al. performed EUA and found that 39% of LC1 injuries demonstrated instability requiring anterior and/or posterior stabilization. These injuries are subdivided into LC1a injuries that are stable and do not require internal fixation and LC1b injuries that may benefit from internal fixation [30]. Thus, EUA of the pelvis could provide valuable insights about pelvic ring instability and warrants further investigation as a diagnostic tool.

However, EUA has some disadvantages. It is costly, requires use and resourcing of the operating room, and carries the risks associated with anesthesia and sedation [33]. In contrast, lateral stress radiography (LSR) in the emergency department does not require use of an operating room or anesthesia and reduces the examiner's exposure to radiation [36],[37]. This method also allows for standardization of the force applied to the pelvis and enables formal displacement measurements on radiographs that cannot be easily achieved intraoperatively with fluoroscopy [38].

LSR and EUA have been shown to have equivalent capability for identifying unstable LC1 pelvic injuries, with sensitivity and specificity of 100% for both modalities [37]. Another study found that patients with a displacement of 10 mm or more on LSR were more likely to face challenges when mobilizing because of pain, which resulted in delayed surgical intervention, an extended hospital stay, and use of more opioids. The authors of that study recommended that these patients undergo surgery [36]. Currently, various methods are used to evaluate pelvic instability, including conventional radiography and computed tomography, as well as EUA and LSR.

Olson and Matta defined a stable pelvic ring as one that is capable of enduring the physiological forces exerted during protected weight-bearing or during mobilization from bed to chair without any unusual deformation of the pelvis until bone or soft tissue healing is achieved 39). Further research is needed on the ligaments surrounding the SIJ, pelvic floor, and APC and LC pelvic injuries to provide the stable pelvic ring advocated by Olson and Matta.

4 Bone mineral density in the pelvis

Osteoporosis, a common condition among older adults, is associated with a heightened risk of fragility fractures 40),41). The incidence of acetabular fractures has increased the most in patients over 60 years of age over the past 25 years, rising 2.4-fold 42). Suneja et al. investigated the incidence of pubic bone fractures in individuals aged 60 years or older using National Electronic Injury Surveillance System data from 2002 to 2019. The incidence of pubic bone fractures in 2019 was found to be approximately 3 times higher than that in 2002 43). When compared by ethnicity, Asian women had the highest incidence. These are important data for Japan, where the population is aging rapidly and an increase in the number of cases of FFPs is likely.

Low-energy traumatic pelvic fractures in older adults have characteristics that are different from those in their younger counterparts. Older patients are often considered non-urgent cases because there is no vascular injury, but there is a history of fragile bones 41). When performing reconstructive surgery on an osteoporotic pelvis, it is crucial to understand the strength of the bone at the fracture site as the degree of BMD affects the fixation strength of the bone screws used 44). Therefore, determining the BMD of the pelvis should be a pivotal step in deciding the treatment plan.

Dual-energy X-ray absorptiometry (DEXA) is widely used to measure BMD 45), but it is difficult to measure the distribution of pelvic BMD using this method because of the complex shape of the pelvis. DEXA often overestimates BMD as well, because of degenerative changes and vessel calcification 46). Recent studies have offered an alternative to DEXA, namely, using Hounsfield units (HU) obtained on computed tomography (CT) scans to measure BMD 40),47). HUs reflect attenuation and the method uses a standardized linear attenuation coefficient. The radiodensity of air is defined as -1,000 HU and that of water as 0 HU at standard temperature and pressure. There is a significant correlation between HU levels and BMD, with HU providing valuable information about the quantity of bone present48). For example, according to Gausden et al. 47), HU values at the distal radius, thoracic vertebrae, femoral head, femoral neck, and proximal humerus have been used to evaluate BMD in the diagnosis of osteoporosis because of the significant correlation between BMD and HU values at these sites.

Wagner et al. published their first investigation of the sacral HU value in 2016. They found that this value was not consistent in the sacrum, with lower values seen in the lateral sacrum and the S2 vertebral body 40). In 2018, they noted that older patients with sacral fractures had extremely low values of 40 HU in the S1 and 20 HU in the S2 and outside of the sacrum 49). These results could be one cause of the high incidence of H-type sacral fractures in older adults. Radley et al. also investigated HU values in the sacrum but in younger adult patients aged 18–50 years and found them to be 320 HUat S1 and 229 HU at S2 50). Furthermore, Thiesen et al. found a difference in the HU values recorded in the sacral vertebral bodies. The HU values in the upper part of S1 and near the anteroposterior cortical bone of S1 were high, as were those in the anterior cortical bone of S2 2). Inagaki et al. reported HU values for various parts of the pelvic bones, excluding the sacrum 51). They measured HU values for the pubic bone, the anterior and posterior walls and the roof of the acetabulum, the ischial tuberosity, and the body of the ilium. They also found that HU values were not distributed across the pelvis in a consistent manner, ranging from 120 to 240 HU in the younger group and from 30 to 120 HU in the older group. The HU values for the pelvis were shown to be significantly lower in the older group than in the younger group. Regardless of age, the acetabular roof had the highest values and the anterior pelvis had the lowest. HU values were also found to be higher in the posterior pelvis than in the anterior pelvis 51) (Table 2). Bredow et al. reported that using pedicle screws in vertebrae of 120 HU or less resulted in screw loosening 52). Given that most HU values in the pelvis of older adults are below 120, screw fixation to the pelvic bone may be inadequate in many cases. This poses a clinical problem for older patients with pelvic fractures, which often require implant fixation that is reliant on screws for anchorage. It is also worth noting that screw fixation through the contralateral cortical bone provides more strength than fixation in cancellous bone 53). Furthermore, spinal surgeons have shifted their approach in osteoporotic bone to guide the trajectory through cortical bone, which increases screw pull-out strength and stability 54). Consequently, for improved outcomes, screws should theoretically be anchored through the cortical bone on the opposite side to the fracture. This knowledge is important in preoperative assessment for percutaneous screw fixation, which is a minimally invasive procedure, primarily because the density of cortical and cancellous bones directly influences screw purchase and pull-out strength 44). Therefore, understanding the distribution of BMD in the pelvis can improve our understanding of pelvic fracture patterns and their surgical management.

Conclusion

This review has outlined the anatomy and function of the ligaments around the pelvis and presented evidence-based discussion of the relationship between fractures of the pelvis and the pelvic ligaments. A more precise understanding of the role that each ligament plays in maintaining stability will further help with the development and selection of surgical interventions for the various pelvic ring injuries. In particular, the extent of injury to the posterior pelvic ligaments should be investigated in depth, because they are primarily responsible for the stability of the pelvis. Changes to the current Young-Burgess classification system to incorporate findings from EUA and LSR would be beneficial, and valuable insights could be afforded by further research on the involvement of ligaments in APC II and other injury patterns.

Knowing the distribution of BMD in the pelvis contributes to understanding the different pelvic fracture patterns and their surgical treatment. Such knowledge is also vital as pelvic fractures are becoming increasingly common in older adults, and Asian women are at particular risk. Recent evaluations of BMD of the pelvis using the HU value as an alternative to the DEXA method have revealed low enough HU values in older patients that a screw may pull out. New techniques of screw fixation should therefore be investigated to address this issue.

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Table 1 Damaged ligaments, instability, and surgical treatment by injury mechanism

Injury mechanism		Damaged ligaments	Instability	Surgical treatment
APC Ⅰ		Pl	non	non
APC Ⅱ	Ⅱa	PI and ASL	Horizontal rotation	Anterior fixation
	Ⅱb	PI, ASL, STL, and SSp	Horizontal and sagittal rotation	(Anterior) and posterior fixation
APCⅢ		PI, ASL, STL, SSp, ISL, PSL, and ILL	Horizontal, sagittal rotation and vertical force	Anterior and posterior fixation

APC Anterior posterior compression, PI Pubic ligament, ASL Anterior sacroiliac ligament, STL Sacrotuberous ligament,SSp Sacrospinous ligament, ISL Interosseous sacroiliac ligament,PSL Posterior sacroiliac ligament, ILL Iliolumbar ligament

Table 2 HU values at each pelvic region (mean)

	Pubis	AW	Roof	PW	IT	BI
Young men	131	134	235	179	217	219
Older men	35	37	120	89	109	109
Young women	121	118	230	172	210	210
Older women	32	26	118	76	95	92

AW anterior wall, BI body of the ilium, IT ischial tuberosity, Pubis pubic bone, PW posterior wall