Magnetic resonance imaging for the evaluation of ligamentous injury associated with pelvic anterior–posterior compression fracture

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Study protocol

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Abstract

Background

Pelvic anterior–posterior compression (APC) fracture is typically associated with pelvic ligament damage. We used magnetic resonance imaging (MRI) to evaluate ligamentous injury associated with pelvic APC fracture.

Methods

Thirty healthy adults and 26 patients with pelvic APC fractures were enrolled in this study. All healthy adults underwent a series of MRI scans. Pelvic ligament visualization was scored [0 (poor) to 3 (excellent)] to identify the best scanning method. Then, MRI examination of patients with pelvic APC fracture was performed using this method.

Results

For healthy adults, oblique axial and axial scans provided the best visualization of the anterior sacroiliac ligament [ASL; good and excellent scores in 100% (30/30) and 96.7% (29/30) of cases, respectively; both $P < 0.05$ vs. coronal scans], followed by coronal scans [73.3% (22/30)]; sagittal scans provided poor visualization of this ligament (0%). Oblique sagittal scans provided the best visualization of the sacrotuberous ligament (SBL) and sacrospinous ligament [SPL; good and excellent scores in 90% (27/30) and 67.7% (20/30) of cases, respectively]. In patients with type I APC fracture, all three ligaments were intact without injury; in those with type III fracture, all three ligaments had ruptured. All type II APC fractures were associated with ASL rupture; the other two ligaments were injured simultaneously in 8 (42.1%) cases and two ligaments were uninjured simultaneously in 7 (36.8%) of these cases. Four patients had pubic symphysis separation > 30 mm, with no SBL or SPL injury; two patients had about 25 mm separation with SPL injury.

Conclusion

Healthy and injured pelvic ligaments can be evaluated using MRI; oblique axial and axial scanning are best for ASL visualization, and oblique sagittal scanning are best for SPL and SBL visualization. Pubic symphysis separation > 25 mm is not necessarily associated with SPL or SBL injury.

Introduction

Anterior–posterior compression (APC) injury is the most classic pelvic fracture, resulting in damage to the pelvic ligaments [1, 2]. The Young–Burgess classification system defines three types of pelvic APC fracture based on the pattern of ligament injury: type I injury involve only the joint ligaments; type II injury involve anterior sacroiliac ligament (ASL) rupture and sacrotuberous ligament (SBL) and sacrospinous ligament (SPL) injury; and type III injury involve damage to all pelvic ligaments, including the ASL, SBL, and SPL [2, 3]. The assessment of the pelvic ligaments is important to maintain pelvic stability and determine the appropriate treatment for pelvic fracture. The distinction among the 3 types is based on which ligaments are injured, and the treatment varies from nonoperative to internal fixation of both the anterior and posterior portions of the ring based on the injury type. But it is difficult to achieve by general physical examination alone due to the depth of these structures. In addition, the SPL is relatively horizontal and thin, and it overlaps with the SBL a great deal on the sacral side. X-rays are thus used to diagnose SPL and SBL rupture indirectly through measurement of the extent of symphysis pubis separation: distances > 25 mm are widely accepted to indicate that the three ligaments (ASL, SBL, and SPL) are damaged, but the accuracy of this method is uncertain because the ligaments are not directly visualized [4–6]. For patients with SPL and SBL injury, internal fixation is necessary. Thus, auxiliary examinations are required for the assessment of pelvic fracture. Magnetic resonance imaging (MRI) is a noninvasive means of assessing pelvic ligament anatomy that enables high-resolution visualization of soft tissues [7]. Proton density–weighted imaging is useful for the assessment of the thin pelvic ligaments, and T1-weighted imaging (T1WI) can provide high-quality bone marrow images [8]. T2-weighted imaging (T2WI) enhances the comparison of injured and normal tissues [5, 9]. Three-dimensional(3D) fast imaging employing steady-state acquisition enables tissue visualization at higher resolution due to reduced slice thickness, with multiplanar image reconstruction providing more detailed and clear images of anatomical structures [10]. However, the best method for the examination of the pelvic ligaments has not been identified clearly, and various outcomes have been reported. Attias et al. reported that the pelvic ligament anatomy could be visualized completely by standard axial computed tomography (CT) and MRI examinations[5]. The SPL has been found to be visible on axial scan, and the long posterior sacroiliac ligament has been found to be visible on standard axial, coronal, and sagittal scan [11]. In addition, no study has sought to determine the best way to accurately assess normal and injured pelvic ligaments associated with pelvic APC fracture. This study was conducted to identify the best scan method for MRI visualization of normal and injured ASL, SBL, and SPL, and to determine whether pubic symphysis separation > 2.5 cm is associated with the injury of all three ligaments. Our primary hypothesis is that the ligamentous structures could be visualized by MRI, with the results differing among scanning methods. Our secondary hypothesis is that >2.5 cm separation of the pubic symphysis would not necessarily reflect damage to all three pelvic ligaments.

Methods

2.1 Study design and participants

This study was approved by our hospital's institutional review board, and we gained consent from all participants. We first performed MRI of healthy adults to determine the best scanning method for visualization of each ligament, then used that method for MRI of patients with pelvic APC fracture. We planned to recruit 30 healthy normal-weight [standard weight × (1 ± 10%)] adults and a similar number of patients with pelvic APC fractures for the study; the number of healthy volunteers in the study refers to published article and APC fracture patients in recent years. The criteria for normal weight were [height (cm) – 80] × 70% for males and [height (cm) – 70] × 60% for females. The exclusion criteria of healthy adults were: 1) age≤18 years; 2) discomfort symptoms in the sacroiliac joint, such as pain, numbness, and/or rigidity; 3) history of pelvic trauma or surgery; and 4) MRI contraindication or intolerance of MRI noise. The inclusion criteria for patients were: 1) age18 years, 2) ability to cooperate with the examiners and tolerate MRI; 3) hemodynamic stability and fracture occurrence < 14 days previously4) no history of previous sacroiliac joint injury and previous normal sacroiliac joints5patients were associated with APC pelvic fracture. The patients underwent preoperative X-ray, CT and MRI examinations, and three experienced orthopedic traumatologists individually classified the fracture using the Young–Burgess system, with disagreements resolved by discussion until consensus was reached.

2.2MRI examination of healthy adults

MRI examinations were performed using a 3.0-T Signa HDXT device (General Electric Company, Boston, MA, USA) with phased-array coils. The ADW4.2 imaging workstation (Sun Company, Santa Clara, CA, USA) was used for measurement and image post-processing.

The healthy adult participants underwent MRI examination of both sacroiliac joints in the supine position. The sacroiliac joints were placed at the center of the phased-array coils, with the legs in neutral position; the participants were asked to not move during the examination. Axial T1WI, T2WI, proton density–weighted, and 3D- fast imaging employing steady-state acquisition scanning were first performed to calculate contrast noise ratios (CNR) for the fat and tendons and to locate the ASL, SBL, and SPL. Oblique sagittal and oblique coronal T1WI and 3D- fast imaging employing steady-state acquisition scanning were then performed according to the CNR to assess the visualization of the SBL and SPL. Oblique axial and coronal T1WI scanning were performed for visualization of the ASL. (Table1)

Oblique scanning was based on 3D localization. Following identification of the SBL/SPL and ASL origins or osseous anatomical landmarks by axial and sagittal examination, the oblique coronal scan was performed along the line between the two bony landmarks or origins. Following identification of the same osseous anatomical landmarks by axial and coronal examination, oblique sagittal scanning was performed in the same manner. Thus, landmark identification was important for oblique MRI examination. (Fig1; Fig2; Fig3) Besides, the pubic symphysis is composed of bilateral sides of symphysial surface, which is connected by fibrocartilage. There is a pubic symphysis cavity in the middle, whose width is the separation distance of pubic symphysis. (Fig4)

2.3 Image evaluation and MRI examination of patients with pelvic APC fracture

The images were saved in our hospital’s picture archiving and communication system and examined by three experienced musculoskeletal radiologists. All of the APC fracture type were blind to observers, and they assessed the images independently, with disagreements resolved by discussion until consensus was reached. We scored the visualization of each ligament on the images as follows: excellent (3), complete visualization (the ligament could be seen on all sections); good (2), partial visualization (some sections of the ligament could be seen); average (1; only the ligament origin, insertion, or a small portion of the ligament boundary could be seen); and poor (0), poor visualization (the ligament could not be seen). Any disagreement was resolved through discussion. These scores were used to identify the best MRI scan for the visualization of each ligament.

MRI examinations of patients with pelvic APC fracture were then performed using the best scanning method. Axial scanning was performed first, followed by oblique sagittal scanning when the axial results were not good. Ligaments were classified as ruptured (complete or partial disruption of all fibers), injured [images show signal change (i.e., edema), lack of tension, or deformity), or normal (all fibers intact). Pubic symphysis separation was also measured. In cases of bilateral fracture, each fracture was included individually in this study.

Statistical analysis

SPSS version 20.0 (SPSS Inc., Chicago, IL, USA) software was used for data analysis. Ligament visualization scores for healthy adults and ligaments condition between two groups for pelvic patients were compared using the Wilcoxon signed rank test, chi-square test or Fisher's exact test. P values < 0.05 were considered to be significant.

Results

Characteristics of study participants

Thirty healthy adults (20 male, 10 female) and 26 patients with pelvic APC fracture (16 male, 10 female) between January 1st, 2017 and November 30th, 2019 participated in this study. The mean age of the healthy adults was 26.5 ± 13.5 years (range, 20–40 years). All healthy adult participants were of normal weight (mean, 65.7 ± 6.7 kg; range, 45–87 kg). The mean age and weight of the patients with APC fracture were 38.9 ± 5.9 years (range, 29–50 years) and 69.0 ± 10.5 kg (range, 50–83 kg), respectively.

Ligaments visualization in healthy adults

In nearly all cases, ASL visualization scores for axial and oblique axial scans were excellent [score = 3; 100% (30/30) and 96.7% (29/30), respectively], with no significant difference between these methods. The rate of excellent visualization scores for coronal scanning was 53.3% (16/30) (with scores of 3 in 16 cases). The ASL could not be seen on the sagittal scanning. The axial and oblique axial scanning achieved significantly better visualization of this ligament than did the coronal scanning (both P < 0.01), which in turn was significantly superior to the sagittal scanning.(Table 2 and Fig. 5)

Excellent and good visualization of the SPL was achieved on oblique sagittal and axial scans in 67.7% (20/30) and 20% (6/30) of cases, respectively, with no score of 3 assigned to the axial scans. Identification of this ligament on oblique coronal scans was difficult [good to excellent scores in 0%

(0/30) of cases]. Visualization of the SPL was significantly better with the oblique sagittal scanning than with the axial and oblique coronal scanning (both $P < 0.01$).

The SBL was visible on axial scans, but had an inhomogeneous or low signal. The oblique sagittal scanning yielded the best result for this ligament [good to excellent scores in 90% (27/30) of cases], followed by the oblique coronal scanning [good to excellent scores in 56.7% (17/30) of cases] and the axial sequence [good to excellent scores in 30% (9/30) of cases]. Significant differences were observed between the oblique sagittal and oblique coronal ($P = 0.02$) and axial ($P < 0.01$) results, but not between the oblique coronal and axial results.

Overall, these results indicated that axial and oblique axial scans provided the best visualization of the ASL. Oblique sagittal scans provided the best visualization of the SBL and SPL, followed by axial scans; oblique coronal scans provided poor visualization of these ligaments. The SBL and SPL could be observed clearly by 3D- fast imaging employing steady-state acquisition reconstruction of oblique sagittal images (Table 3, Figs. 6 and 7).

Ligaments visualization in patients with pelvic APC fracture

MRI examination of patients with APC fracture from included axial scanning in all cases, and oblique sagittal scanning when axial scan outcomes were not good. According to the Young–Burgess classification system, 6 pelvic APC fracture included in this study were type I, 16 fracture were type II, and 4 fracture were type III. Three type II cases were bilateral. No type I fracture and all type III fracture were associated with rupture of all three ligaments. All type II fracture were associated with ASL rupture; two of these fracture were additionally associated with SBL injury alone, six were additionally associated with SPL injury alone, six were associated with injury of the SBL and SPL, and seven fracture were associated only with ASL rupture. (Table4)

The axial scanning provided visualization of the ASL, enabling the diagnosis of injury of this ligament. Signals for the SPL and SBL were discontinuous on the axial scanning, making injury of these ligaments easy to miss. When performed, the oblique sagittal scanning provided clear visualization of most of the SPL and partial visualization of the SBL, enabling easy assessment of injury of these two ligaments. (Fig4)

Relationship of pubic symphysis separation to ligament injury

About pubic symphysis separation and SBL, SPL injury, although there is statistical significances between two groups (Table5), the degree of pubic symphysis separation was not associated consistently with the pattern of ligaments injury in these patients. No SBL or SPL injury was observed in four patients with >30 mm separation (Fig 9), whereas the SPL was injured in two patients with about 25 mm separation (Fig10).

Discussion

MRI is a noninvasive method for ligament assessment, and it has been used widely in the diagnosis of knee, shoulder, and ankle ligament injuries for many years. MRI has also been used to assess and diagnose pelvic conditions such as sacroiliitis, pelvic organ lesions, and pelvic-floor and hip muscle lesions [12–16]. Recent studies have examined the accuracy of MRI-based diagnosis of pelvic floor dysfunction [17, 18], but no previous study has assessed the performance of MRI in the assessment of the three ligaments that can be damaged in association with pelvic APC injury.

In our study, the pelvis was scanned with TlWI, PDWI, T2WI and 3D-fast with fat-suppression imaging employing steady-state acquisition sequence. Because the ASL, SBL and SPL are thin and difficult to measure directly, we measured the signal intensity of the tendon instead of the ligament, and the signals of the ligaments and tendon are similar. The contrast noise ratio (CNR) was the ratio of the signal intensity of two tissues to the standard deviation of background noise. The higher the contrast to noise ratio (CNR), the more obvious difference between the two tissues. According to the result , the CNR of fat and tendon of TIWI and 3D fast imaging employing steady-state acquisition sequence were higher than the other sequences, and there was no significant difference between the two scan sequences(P=0.259). Thus, we selected TIWI and 3D fast imaging employing steady-state acquisition sequence. In addition, this study demonstrated that axial MRI scanning provide good visualization of the ASL, but only the origins of the SBL and SPL (at the top of the acetabulum), in healthy adults. We could accurately determine the origins of the three pelvic ligaments with the images acquired in this study. Oblique sagittal scanning provided the best visualization of the SBL and SPL, including the insertions of the former on the femoral neck and ischial tuberosity and the bifurcation of the two ligaments at the point of the ischial spine.

Pennal et al. reported that pubic symphysis separation ≤ 2.5 cm was associated with rupture of the pubic symphyseal ligaments, but no SBL or SPL damage, whereas >2.5 cm separation was associated with rupture of the ASL, SBL, and SPL [19]. Separation of the pubic symphysis increases with the degree of external rotational injury, with severe cases reported to result in damage to the posterior sacroiliac ligament complex [20, 21]. Our findings are not consistent with these determinations, as we observed cases of > 30 mm separation with no SBL or SPL injury and cases of about 25 mm separation with obvious SPL injury. Thus, 25 mm separation cannot be used alone to determine the severity of pelvic external rotation injury, particularly ligament injury.

Despite the successful reduction of pelvic fracture, some patients have long-term chronic pain and functional limitations in the pelvic region, which may be related to unrepaired damage to the pelvic ligaments or posterior sacroiliac ligament complex [19, 24–27]. We consider that SBL and SPL injuries require treatment, such as sacroiliac screw placement, whereas such treatment may not be necessary when these two ligaments are not injured. Therefore, the definitive preoperative diagnosis of ligament injuries is essential.

This study has some limitations. First, the sample was small; the examination of additional cases is needed to confirm the findings. Second, the study did not have a double blind design, which may have affected the results. Third, owing to the different surgical plans and the principle of minimizing wound exposure, the ligaments were not entirely exposed in the operation, which result in the lack of surgical confirmation of ligament injury.

Conclusions

In conclusion，MRI examination can be used to visualize healthy and injured pelvic ligaments. We recommend the use of axial scanning for visualization of the ASL and oblique sagittal scanning for visualization of the SPL and SBL. The degree of pubic symphysis separation is not associated consistently with sacrospinous or SBL injury; the traditionally used threshold of 25 mm separation should not be taken to indicate inevitable damage to SBL and SPL.

Declarations

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Authors’ contributions

XSG, XLS designed the study and obtained the funding. HTY, CWZ collected the data. SBS, GDB, and JZK analyzed the data. JZK and YX interpreted the data. YX, HTY, composed the article. All of the authors read and approved the final manuscript.

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Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Ethics approval and consent to participate

The consent of our ethics committee and the donors’ relatives was given before the experiments.

Consent for publication

The consent for publication of the data was obtained from the relatives of the donors before the start of the study.

Competing interests

The authors declare that they have no competing interests.

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Abbreviations

MRI=Magnetic Resonance Imaging；APC=Anterior posterior compression; ASL= anterior sacroiliac ligament; SBL=sacrotuberous ligament; SPL= sacrospinous ligament; CNR= contrast noise ratios; T1WI = T1-weighted imaging; T2WI =T2-weighted imaging, PDWI=proton density-weighted images.

References

1. Tile M, Helfet DL, Kellum JF: Fracture of the Pelvis and Acetabulum. 3rd Edition, Lippincott, Williams & Wilkins, Philadelphia, 2003
2. Young JW, Burgess AR, Brumback RJ et al: Lateral compression fracture of the pelvis: the importance of plain radiographs in the diagnosis and surgical management. Skel Radio. 1986;15:103-109.
3. Young JW, Burgess AR, Brumback RJ , Poka A: Pelvic fracture: value of plain radiography in early assessment and management. Radiology. 1986;160:445-451.
4. Steinke H, Hammer N, Lingslebe U, Höch A, Klink T et al: Ligament-induced sacral fracture of the pelvis are possible. Clin Anat (New York, N.Y.). 2014;27(5):770-7.
5. Attias N, Arzani S, Duncan G et al: Sectional imaging anatomy: pelvic ring ligaments. J Computer Assist Tomog. 2001;25(6):975-979.
6. Bitti GT, Argiolas GM, Ballicu N, Caddeo EB, et al: Pelvic floor failure: MR imaging evaluation of anatomic and functional abnormalities. Radio Society North Am, Inc. 2014;34(2):429-448.
7. Dietrich TJ, Zanetti M, Saupe N et al: Articular cartilage and labral lesions of the glenohumeral joint: diagnostic performance of 3D water-excitation true FISP MR arthrography. Skel Radio. 2010; 39(5):473-80
8. Doro CJ, Forward DP, Kim H et al: Does 2.5 cm of symphyseal widening differentiate anteroposterior compression I from anteroposterior compression II pelvic ring injuries? J Orthop Trauma. 2010; 24(10):610-5.
9. Dujardin FH, Roussignol X, Hossenbaccus M et al: Experimental study of the sacroiliac joint micromotion in pelvic disruption. J Orthop Trauma. 2002; 16(2):99-103.
10. Gänsslen A, Pohlemann T, Paul C et al: Epidemiology of pelvic ring injuries. Injury 27(1):A13-A20. Injury-international J Care Injure. 1996;27 Suppl 1:S-A13-20.

11. Gary JL, Mulligan M, Banagan K et al: Magnetic resonance imaging for the evaluation of ligamentous injury in the pelvis: a prospective case-controlled study. J Orthop Trauma. 2014; 28(1):41-7.
12. Hammer N, Steinke H, Bohme J et al: Description of the iliolumbar ligament for computer-assisted reconstruction. Annals of anatomy = Anatomischer Anzeiger : official organ of the Anatomische Gesellschaft. 2010; 192(3):162-7.
13. Hammer N, Steinke H, Lingslebe U et al: Ligamentous influence in pelvic load distribution. Spine J : official journal of the North American Spine Society. 2013; 13(10):1321-30.
14. Hammer N, Steinke H, Slowik V et al: The sacrotuberous and the SPL–a virtual reconstruction. Annals of anatomy = Anatomischer Anzeiger : official organ of the Anatomische Gesellschaft. 2009; 191(4):417.
15. Molière S, Dosch JC, Bierry G. Diagn Interv Imaging:Pelvic,acetabular and hip fracture: What the surgeon should expect from the radiologist.2016; 97(7-8):709-23.
16. M K, M F, V P et al. Practical guide to dynamic pelvic floor MRI. J Magnetic Resonance Imaging : JMRI. 2018; 47(5):1155-1170.
17. L P, AC M-T, C Z-C et al. Exploratory study of the interest of MR susceptibility- imaging for the pre-operative assessment of pelvic endometriosis extent. Eur J Radio. 2019;118:245-50
18. Pennal GF, Tile M, Waddell JP et al: Pelvic disruption: assessment and classification. Clin Orthop Relate Res. 1980: (151):12-21.
19. Metz RM, Bledsoe JG, Moed BR. Does Posterior Fixation of Partially Unstable Open-Book Pelvic Ring Injuries Decrease Symphyseal Plate Failure? A Biomechanica Study. J Orthop Trauma.2018;32;Suppl 1:S18-S24
20. Jaovisidha S, Ryu KN, De Maeseneer M et al: Ventral sacroiliac ligament. Anatomic and pathologic considerations. Invest Radio. 1996; 31(8):532-41.
21. Marsh JL, Slongo TF, Agel J et al: Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma. 2007; 21(10 Suppl):S1-133.
22. Moore AE, Jeffery R, Gray A et al: An anatomical ultrasound study of the long posterior sacro-iliac ligament. Clini Anatomy (New York, N.Y.) 2010; 23(8):971-7.
23. Pool-Goudzwaard A, Hoek van Dijke G, Mulder P, et al: The iliolumbar ligament: its influence on stability of the sacroiliac joint. Clin Biomech (Bristol, Avon). 2003; 18(2):99-105.
24. Puhakka KB, Melsen F, Jurik AG et al: MR imaging of the normal sacroiliac joint with correlation to histology. Skel Radio. 2004; 33(1):15-28.
25. Steinke H, Hammer N, Lingslebe U et al: Ligament-induced sacral fracture of the pelvis are possible. Clin Anatomy (New York, N.Y.). 2014; 27(5):770-7.
26. Vives MJ. Orthopedic Imaging: A Practical Approach. 4th Ed. J Spin Cord Med. 2006;29:173.

27. Shepard N, Samim M, Kim Y, Razi A. A Practical Approach to Spine Magnetic Resonance Imaging. JBJS reviews2020; 8(3):e0099.

Tables

Table1 Scan parameters of different sequences in MRI of normal pelvis

	TR/TE	ETL	FOV	NEX	Thickness	Matrix	Bandw	CNR
T1	589/10	13	38	1.0	3mm	224×320	50	136.25±36.5
T2	2400/68	14	36	1.0	3mm	256×320	62.5	84.2±35.5
PDWI	2400/28	12	38	2.0	3mm	256×320	83.3	52.3±22.5
3D-FIESTA	5/2	-	18	2.0	0.8mm	256×256	62.5	144.5±48.5

TR= repetition time; TE=echo time; ETL= echo train length; FOV= field of view; NEX= number of excitation
CNR= contrast to noise Ratio

Table 2 The score result of anterior sacroiliac ligament in different scan methods

	3	2	1	0
Axial	29	1	0	0
Sagittal	0	0	1	29
Coronal	16	6	8	0
Oblique axis	30	0	0	0

3 The score result of sacrospinous ligament and sacrotuberous ligament in different scan methods

	sacrotuberous ligament				sacrospinous ligament			
	3	2	1	0	3	2	1	0
	0	9	19	2	0	6	14	10
ıe sagittal	21	6	3	0	11	9	8	2
ıe coronal	11	6	7	6	0	0	0	30

Table 4 Ligaments injury of patients with various APC pelvic fracture types

	Anterior Sacroiliac Ligament(I/N)	Sacrotuberous Ligament (I/N)	Sacrospinous Ligament (I/N)
APC type I	0/6	0/6	0/6
APC type II	19/0	8/11	12/7
APC type III	4/0	4/0	4/0

I=injury, images showed ligament signal change, like edema, ligaments rupture, or ligament was deformed; N= no ligament injury sign was visualized, all fibers were intact.

Pubic symphysis separation	≤2.5cm N/I	>2.5cm N/I	P value
anterior sacroiliac ligament	6/0	0/23	—
sacrotuberous ligament	12/0	4/13	—
sacrospinous ligament	9/2	4/14	<0.01

Table5 The result of pubic symphysis separation and ligamentous conditions

N=normal, I=injury.

Figures

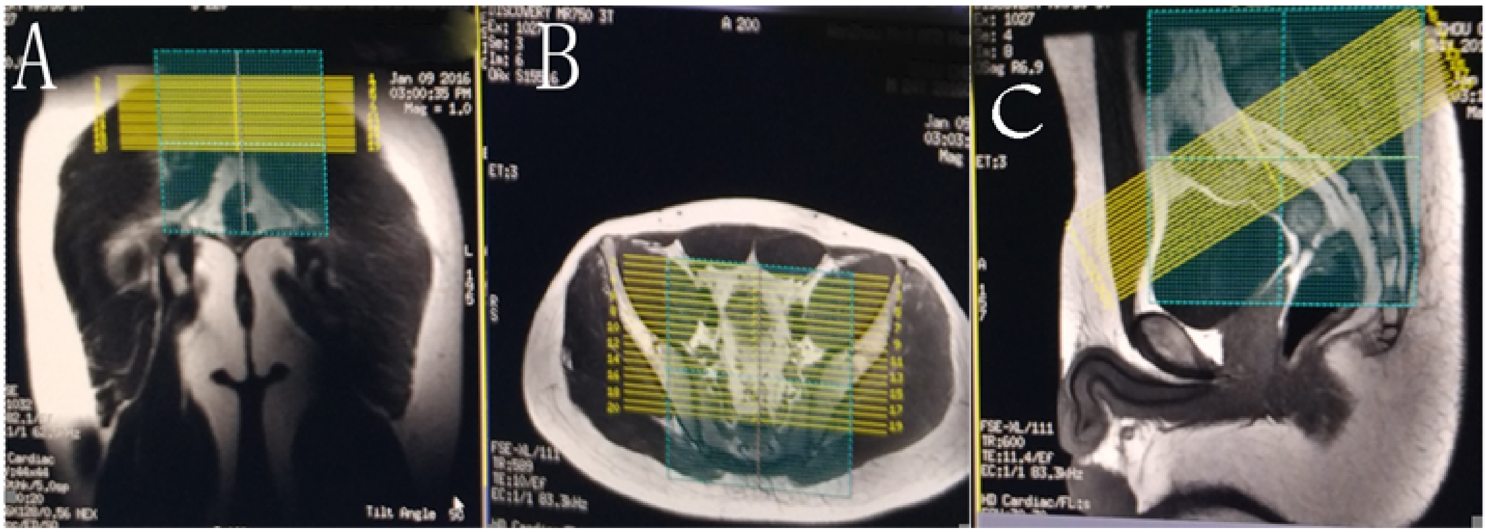

Figure 1

The explanation of oblique axial scanning method for ASL. First, we found ASL in the coronary scanning image, then we draw parallel lines of ASL (A) or we found the sacroiliac joint in the axial scanning image and draw vertical lines of sacroiliac joint (B). Second, we found ASL in the oblique axial scanning according to the yellow lines (C).

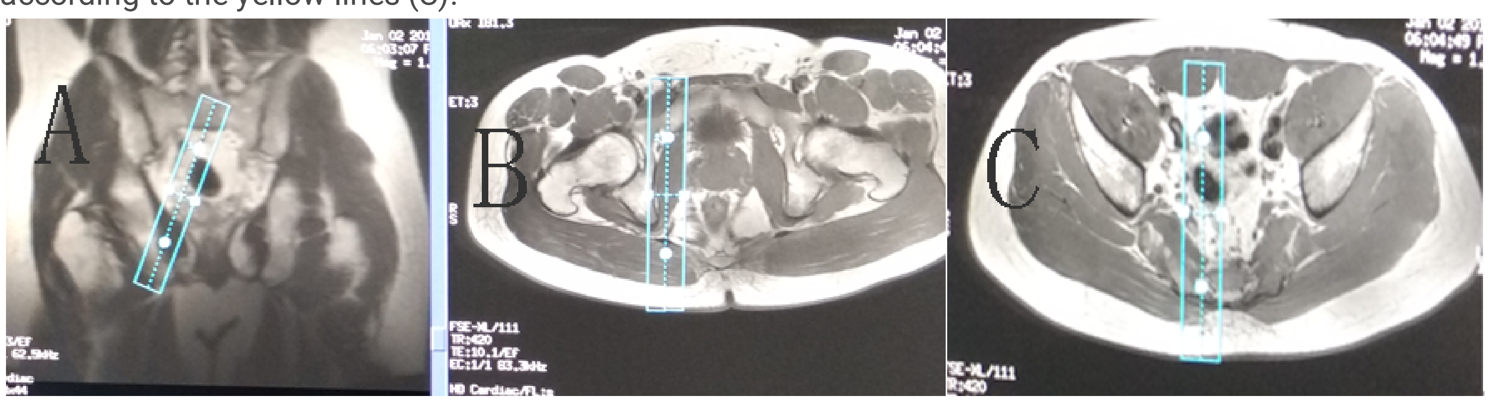

Figure 2

Oblique sagittal 3D scanning positioning method. Find the start points of SBL and SPL on the axial and coronal scanning respectively (A□B), then sagittal scanning is performed along the connection line of the two points (C□D).

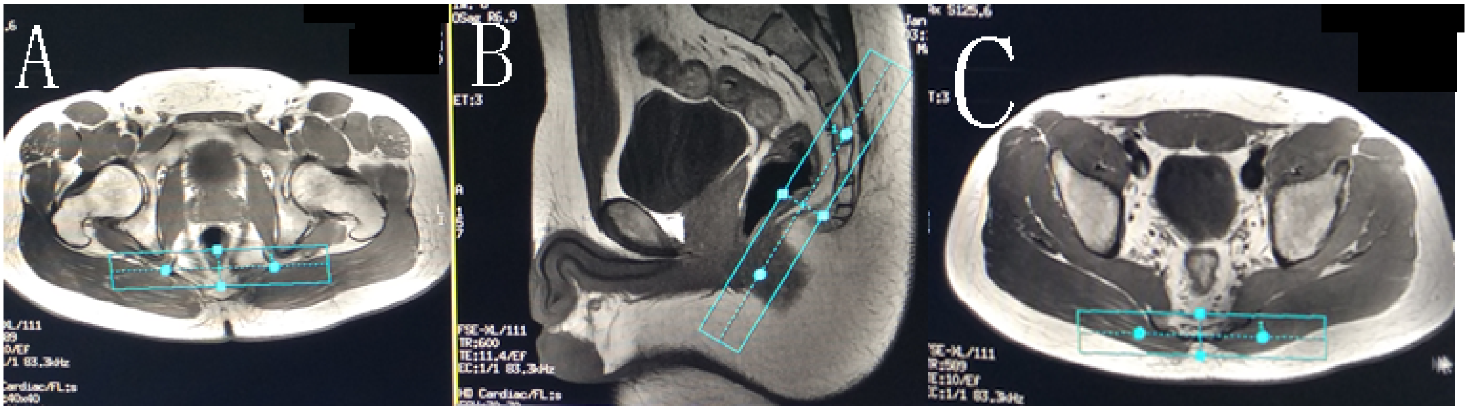

Figure 3

Oblique coronal 3D scanning positioning method. Find the start points of SBL and SPL on the axial and sagittal scan respectively (A□B), then coronal scanning is performed along the connection line of the two points (C□D).

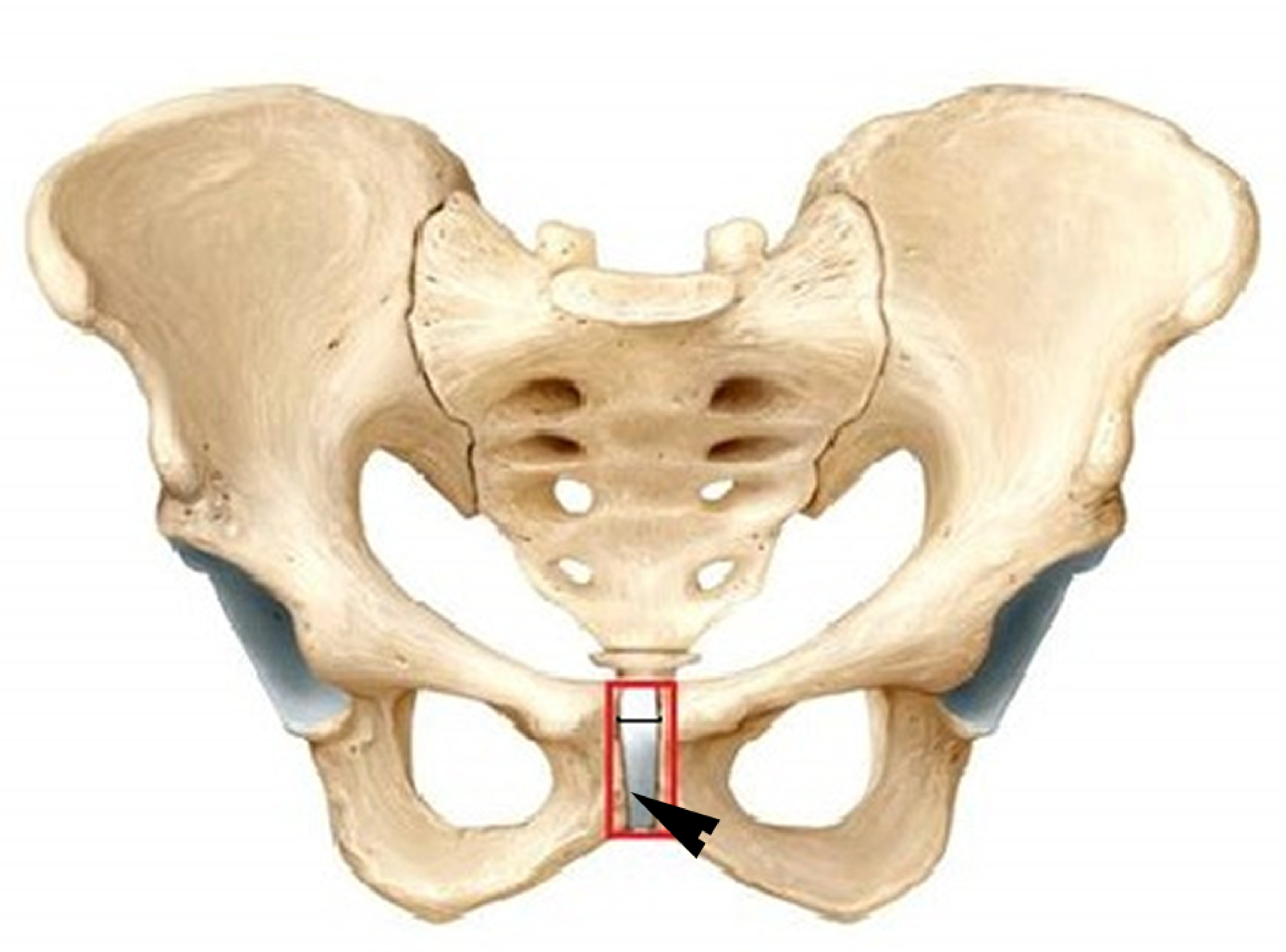

Figure 4

Red rectangle is the pubic symphysis cavity，the black line is the separation distance that we measured (black arrow).

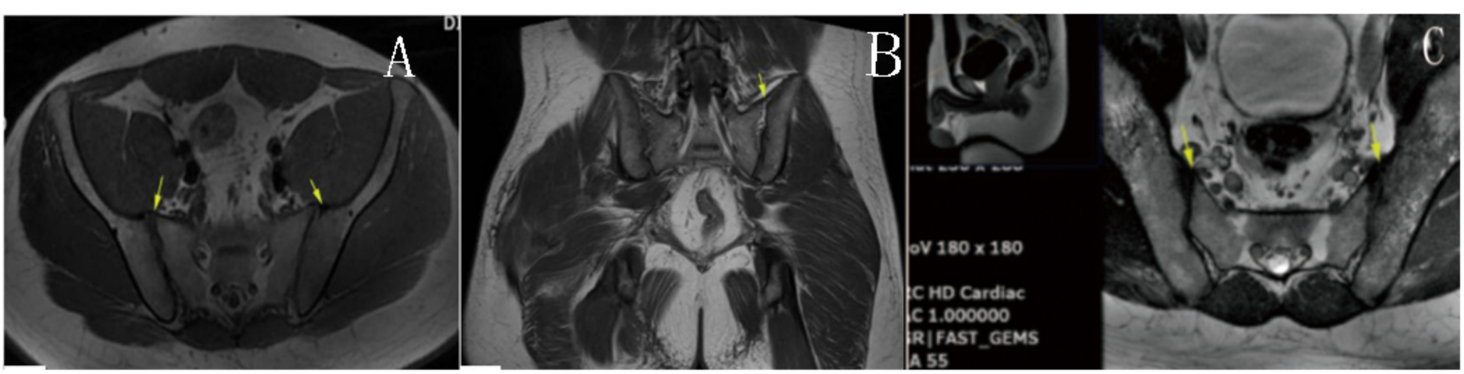

Figure 5

A. Axial T1-weighted (T1W) MRI showing complete visualization of the bilateral ASL structures (yellow arrows). B. Coronal T1W image showing visualization of the left (but not right) ASL (yellow arrow). C. Image from an oblique axial 3D-fast imaging employing steady-state acquisition scanning showing complete visualization of the bilateral ASL structures (yellow arrows).

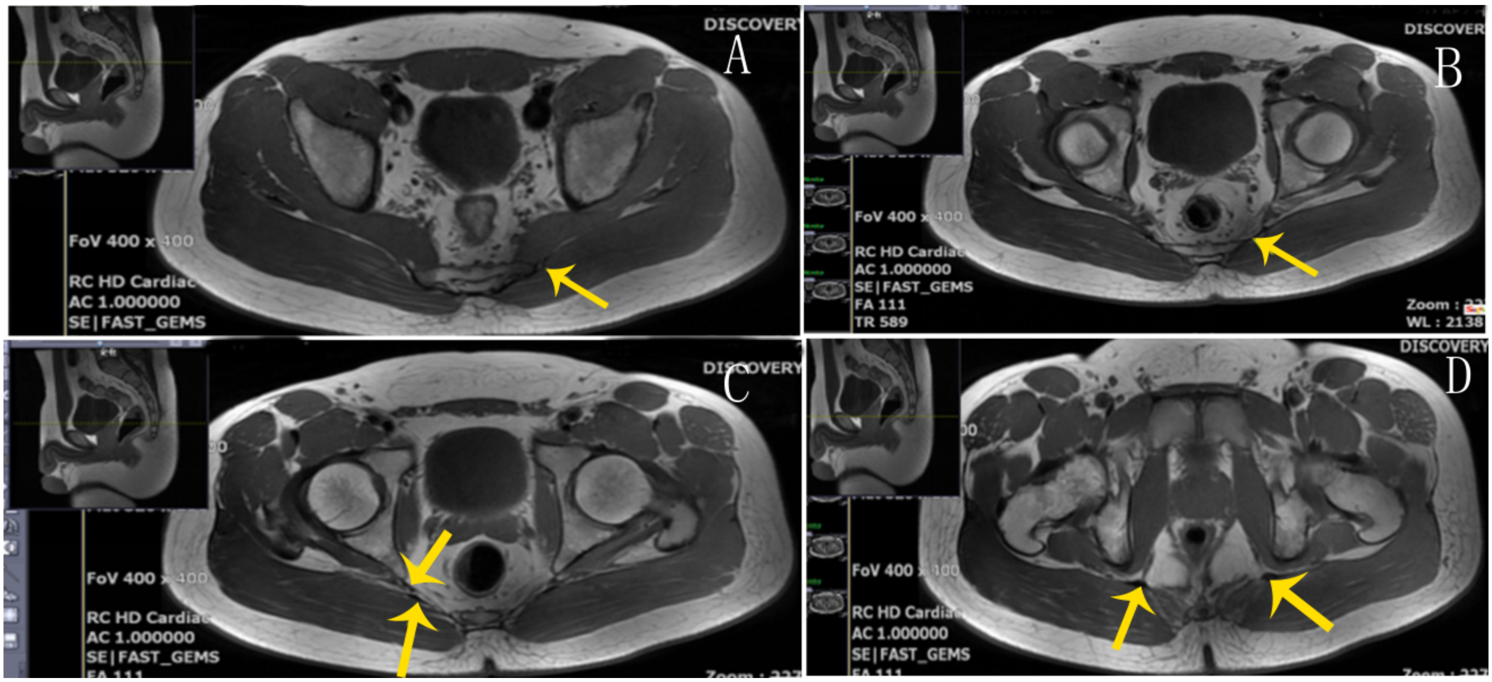

Figure 6

A. Axial T1-weighted (T1W) image at the top of acetabular plane showing the origin (yellow arrow) of the SPL and SBL on the sacral side. B. Axial T1W image from the middle of the acetabular plane showing the main part of the SBL (yellow arrow). C. Axial T1W image at the top of acetabular plane showing the origins of the SPL at the ischial spine and the sacrospinous and SBLs (upper and lower yellow arrows, respectively). D. Axial T1W image of the femoral neck and ischial tuberosity plane showing the bilateral insertions (yellow arrows) of the SBL at the ischial tuberosity.

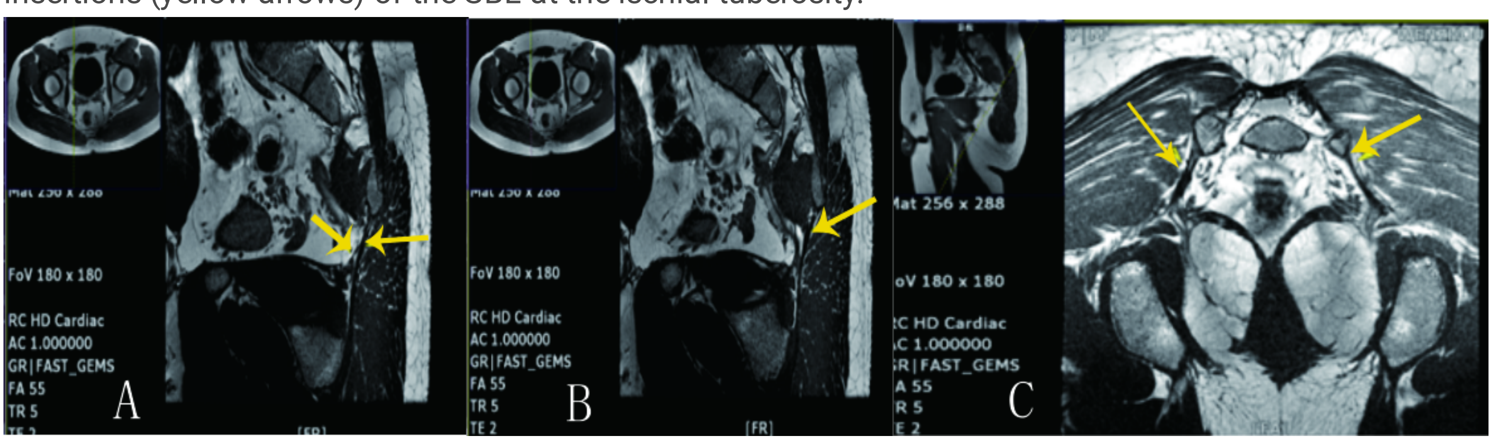

Figure 7

A. Images from an oblique sagittal 3D- fast imaging employing steady-state acquisition scanning showing the main parts of the SPL and SBL (left and right arrows, respectively) B. The main part of the SBL (yellow arrow). C. Image from an oblique coronal 3D-fast imaging employing steady-state acquisition scanning showing the bilateral sacrotuberous ligaments (yellow arrows), but not the sacrospinous ligaments.

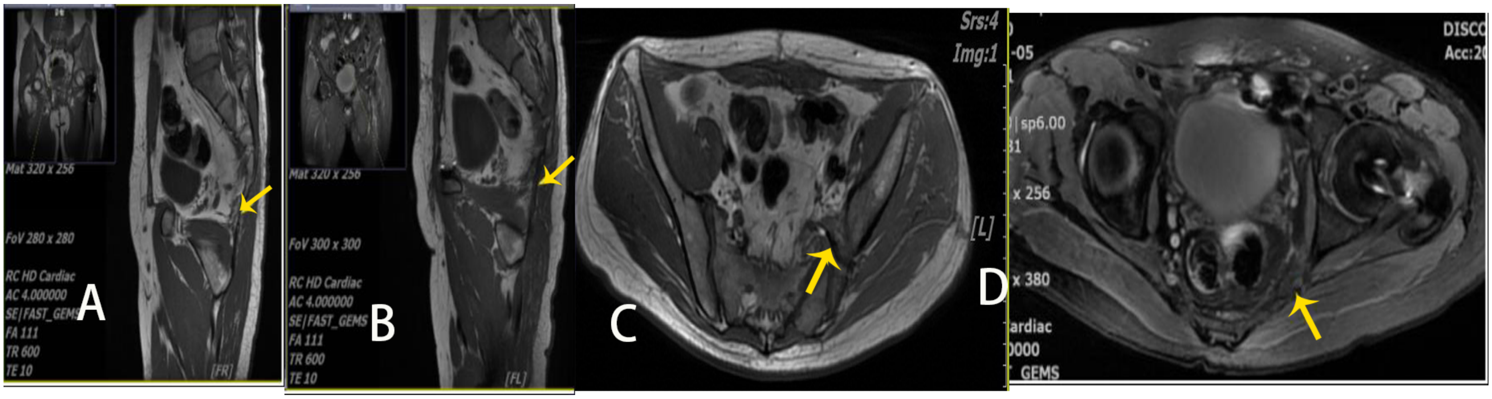

Figure 8

A, B. T1W oblique sagittal images of a patient with a type II pelvic APC fracture. A. Image of the normal side showing the complete and clearly visible SBL and SPL (yellow arrow). B. Image of the injured side showing altered signal of the SPL and SBL, which are deformed and thickened (yellow arrow). C. T1W axial image showing rupture of the left ASL (arrow) and the normal right side (yellow arrow). D. T2W axial image showing rupture of the left SBP and SPL (yellow arrow).

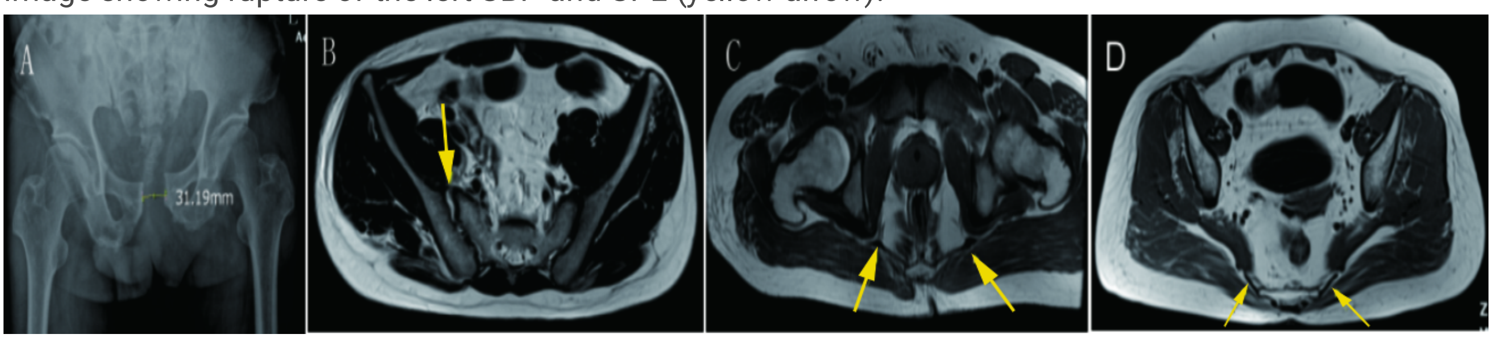

Figure 9

Images of a patient with a type II pelvic APC fracture without vertical displacement. A. X-ray showing 31.19 mm pubic symphysis separation. B. Axial T2W image showing that the sacroiliac joints were edematous and the signal of the right (but not left) ASL was interrupted (left yellow arrow). C. Axial T1-weighted (T1W) image in the femoral neck plane showing intact bilateral sacrotuberous ligaments at the ischial tuberosity, with no sign of injury to these ligaments or the sacrospinous ligaments (bilateral yellow arrows). D. Axial T1W image showing intact SBL and SPL (bilateral yellow arrows).

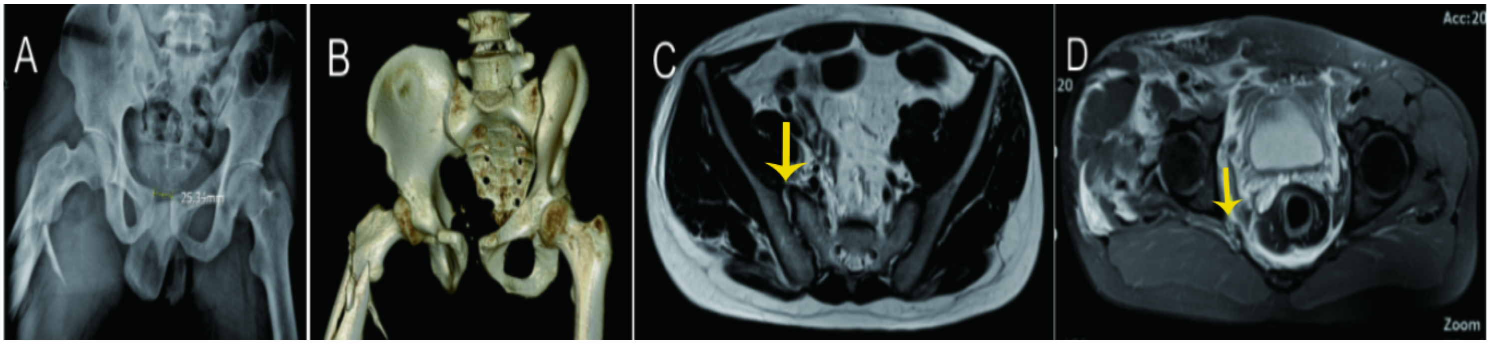

Figure 10

Images of a patient with a type II pelvic APC fracture without vertical displacement. A. Radiograph showing 25.34 mm pubic symphysis separation. B. Reconstructed three-dimensional CT image showing an avulsion fracture of ischial spine, indirectly indicating SPL injury. C. Axial T2W image showing that the sacroiliac joints were edematous and the signal of the right (but not left) ASL was interrupted (left yellow arrow). D. Axial proton density–weighted image showing that the signal of the right SPL was interrupted at the ischial spine, indicating SPL rupture (left yellow arrow). The left SPL and posterior SBLs are intact, with no sign of injury.