



A Proposal for a Standardized Imaging Algorithm to Improve the Accuracy and Reliability for the Diagnosis of Thoracolumbar Posterior Ligamentous Complex Injury in Computed Tomography and Magnetic Resonance Imaging

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Abstract

Study Design: Systematic Literature Review.

Objective: To propose a systematic imaging algorithm for diagnosing posterior ligamentous complex (PLC) injury in computed tomography (CT) and magnetic resonance imaging (MRI) to improve the reliability of PLC assessment.

Methods: A systematic review was conducted following PRISMA guidelines. The Scopus database was searched from its inception until July 21, 2022, for studies evaluating CT or MRI assessment of the PLC injury following thoracolumbar trauma. The studies extracted key findings, objectives, injury definitions, and radiographic modalities.

Results: Twenty-three studies were included in this systematic review, encompassing 2021 patients. Five studies evaluated the accuracy of MRI in detecting thoracolumbar PLC injury using intraoperative findings as a reference. These studies indicate that black stripe discontinuity due to supraspinous or ligamentum flavum rupture is a more specific criterion of PLC injury than high-signal intensity. Thirteen papers evaluated the accuracy or reliability of CT in detecting thoracolumbar PLC injury using MRI or intraoperative findings as a reference. The overall accuracy rate of CT in detecting PLC injury was 68-90%. Two studies evaluate the accuracy of combined CT findings, showing that ≥ 2 CT findings are associated with a positive predictive value of 88-91%. Vertebral translation, facet joint malalignment, spinous process fracture, horizontal laminar fracture, and interspinous widening were independent predictors of PLC injury.

Conclusion: We provided a comprehensive imaging algorithm for diagnosing PLC in CT and MRI based on available literature and our experience. The algorithm will potentially improve the accuracy and reliability of PLC assessment, however it needs multicentre prospective validation.

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Keywords

posterior ligamentous complex, thoracolumbar fractures, imaging algorithm, computed tomography, magnetic resonance imaging

Introduction

The posterior ligamentous complex (PLC) is a four-structure complex that includes the supraspinous ligament (SSL), interspinous ligament (ISL), ligamentum flavum (LF), and facet joint capsules (FC) (Figure 1).¹ PLC disruption can cause late-onset kyphosis and chronic back pain and is thus better treated

surgically.² Thoracolumbar injury classification system (TLICS) and AOSpine classification have recognized PLC integrity as a critical component in fracture classification and treatment algorithms.^{3,4} PLC integrity is one of three key elements of TLICS, along with fracture morphology and neurological condition, that contribute to injury severity score and decision-making (Figure 2).³ Additionally, PLC integrity

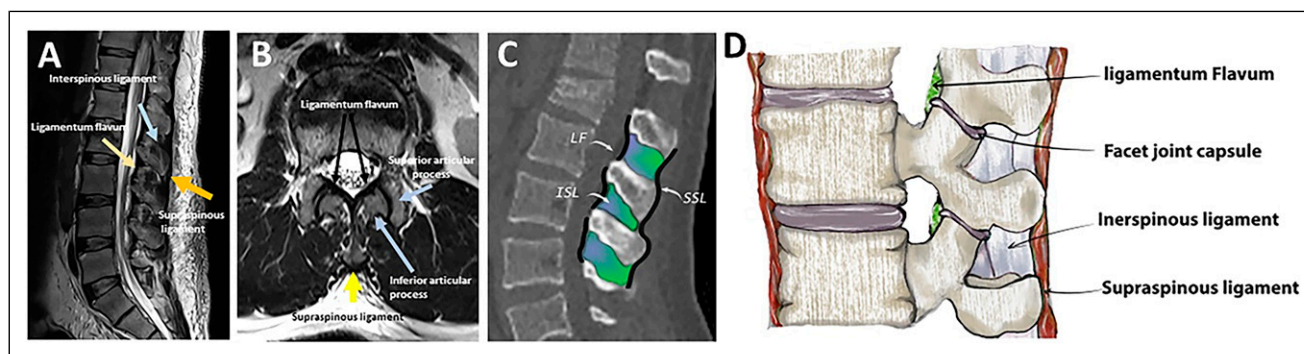


Figure 1. Gross and imaging anatomy of the thoracolumbar posterior ligamentous complex. **(A)** Midsagittal T2-weighted image shows the supraspinous ligament (yellow arrow), interspinous ligament (blue arrow), and ligamentum flavum (yellow arrow) all appear hypointense (dark); **(B)** Axial T2-weighted image shows the supraspinous ligament (yellow arrow), ligamentum flavum (two black arrows), and superior and inferior articular facets (two blue arrows); **(C)** Midsagittal CT images with line drawing show the supraspinous ligament (black line), interspinous ligament (green), and ligamentum flavum (black line); **(D)** Illustration showing the four components of the posterior ligamentous complex. Abbreviations: SSL, Supraspinous ligament; ISL, Interspinous ligament, LF, Ligamentum flavum, FC, facet joint capsule.

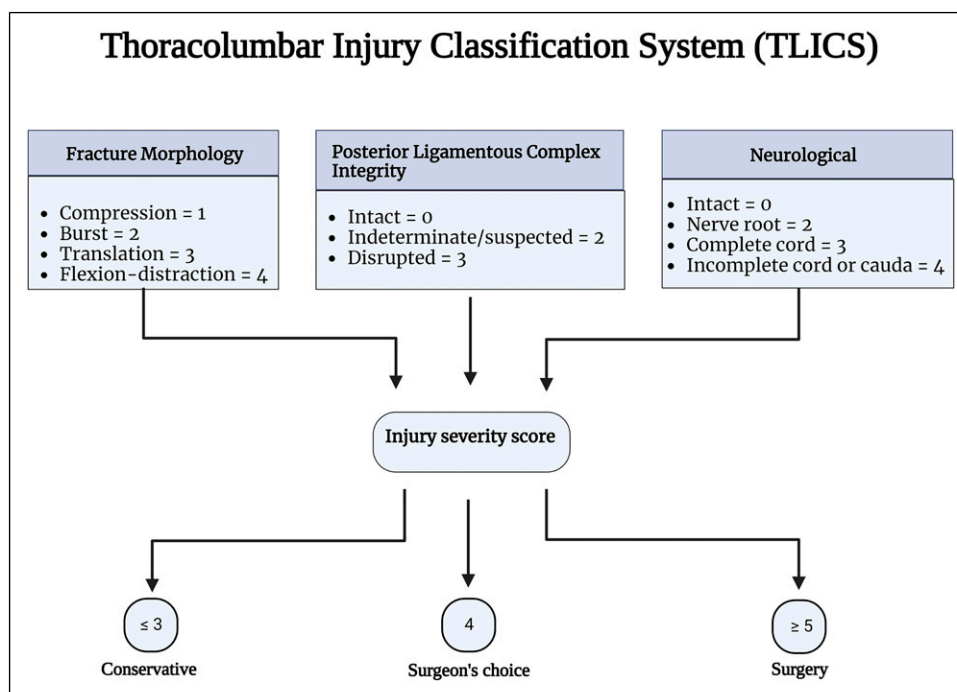


Figure 2. The thoracolumbar injury classification scheme Source- reference.³

is the primary criterion for distinguishing AO type B fractures (tension band injuries) from AO type A (compression fractures without evidence of PLC injury) injuries (Figure 3).⁴

There is much debate about the best imaging modality for PLC assessment.^{1,5} MRI allows direct visualization of PLC structures with high sensitivity and is considered the reference study.⁶ Conversely, CT can only detect secondary signs of PLC injury such as vertebral translation or facet diastasis and has a moderate accuracy (50-80 %) and reliability.^{1,7-10} Important logistical considerations are involved in comparing CT and MRI scans for PLC assessment.¹¹ Compared to CT, the routine use of MRI in trauma settings was limited by poor availability, higher cost, poor feasibility for polytrauma patients, and considerably longer scanning time.¹² Recognizing these limitations, the current TLFs' classification, such as AOSpine and TLICS, were based on CT.

The PLC assessment has been consistently reported to be the most unreliable component of the AOSpine and

TLICS.^{13,14} The poor reliability in PLC assessment resulted in a bias in the clinical decision-making of TLFs and limited the generalizability of research in this area.^{15,16} The low reliability of PLC assessment might be attributed to the lack of consensus-based criteria for defining PLC or a standardized method for image interpretation.¹² Poor reliability is caused by a lack of standard definitions for CT/MRI findings, the best imaging planes/sequences, and the pitfalls and pearls of image interpretation.¹² We propose a systematic imaging algorithm to diagnose thoracolumbar PLC injury based on available literature to improve the previously reported poor reliability.

Methods

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement. No funding was received for this study, and patient consent was not required since no identifiable health

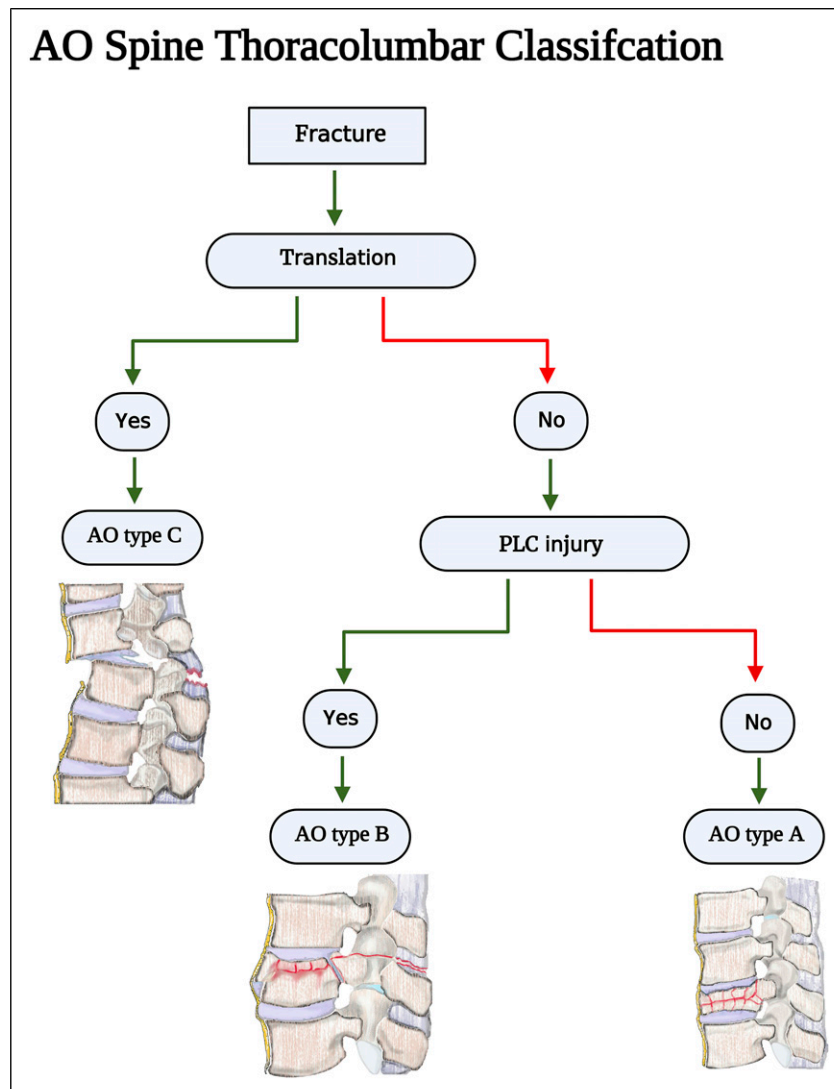


Figure 3. AOSpine Thoracolumbar classification imaging algorithm. Source - reference ⁴

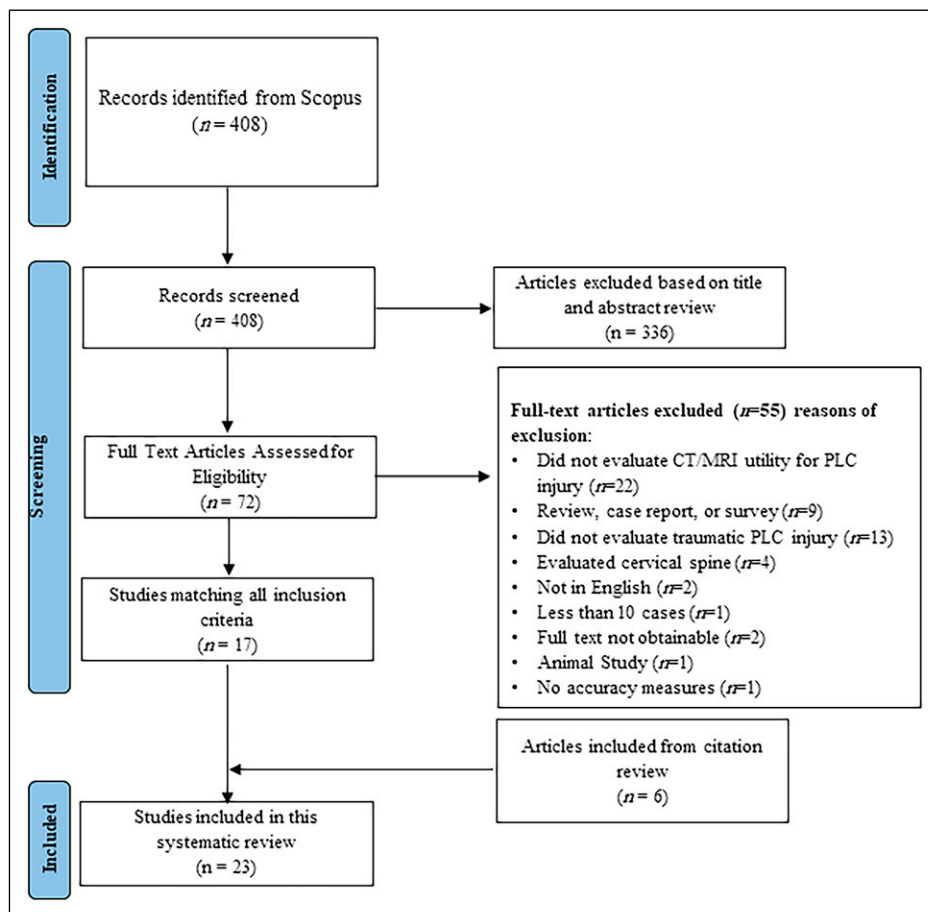


Figure 4. PRISMA Flow Diagram Describing Article Selection for Inclusion. Abbreviations: PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

information was collected, and only published studies were incorporated. We conducted a query of the Scopus database from inception until July 21, 2022, using combinations of the words “posterior ligament/ligamentous complex,” “thoracolumbar,” and “injury.” To ensure the inclusion of all available evidence, we also searched the references of available studies for any studies that met inclusion criteria.

Study Eligibility

Studies were included if they described the accuracy or utility of CT or MRI in assessing the PLC injury in the thoracic, lumbar, or thoracolumbar traumatic fractures. Studies were excluded if (1) a full text of the article could not be obtained, (2) the article was written in a language other than English, (3) they were review papers, (4) they were cadaveric or non-human studies. Authors independently screened the abstracts and titles of identified articles. Any articles not meeting exclusion criteria were automatically included for full-text review. At the full-text stage, articles were screened for inclusion based on the predetermined inclusion criteria. A more senior author reconciled discrepancies.

Data Collection Quality Assessment

The authors extracted data from the included studies with a self-designed table. Contents of data selection included objectives, injury definitions, radiographic modalities, and key findings of included studies. Due to significant data heterogeneity, variability in outcome measures and study objectives, and the different imaging modalities utilized, a meta-analysis of the findings was not performed.

Results

Search Results

The initial Scopus search identified 408 articles, after which the title and abstract screening identified 72 potentially relevant articles (Figure 4). Twenty-three articles encompassing 2021 patients were included after full text and citation review. Twenty-two studies were excluded because they did not assess the clinical utility of CT or MRI for assessment of the PLC, 13 were excluded because they did not evaluate traumatic PLC injury, four were excluded for analysis of the cervical spine, and nine were excluded because they were surveys, case

series, or review articles. Reasons for excluding other articles are further detailed (Figure 4). Four additional studies were identified through a reference review of included studies. The characteristics and key findings of included studies are detailed (Figure 4).

MRI Accuracy or Reliability in Detection of PLC Injury

Five papers evaluated the accuracy of MRI in detecting thoracolumbar PLC injury using intraoperative findings as a reference (Table 1). When PLC injury was defined as high signal intensity (HSI), two studies reported high sensitivity (91%) and specificity (94%) for detecting PLC injury.¹⁷ However, using HSI, Vaccaro et al reported much lower sensitivity (79-90%) and specificity (53-65%) for different PLC components.¹⁸ Pizones et al defined PLC injury as black stripe discontinuity, reporting the MRI sensitivity and specificity were 100% and 91 %, respectively.^{19,20} Only three studies have evaluated the interobserver reliability of detection, revealing moderate to perfect agreement ($K = .39-.89$, Table 1).^{6,14,21}

CT Accuracy or Reliability in Detection of PLC Injury

Thirteen papers evaluated the accuracy or reliability of CT in detecting thoracolumbar PLC injury using MRI or intraoperative findings as a reference (Table 2). The overall accuracy rate of CT in detecting PLC injury was 68-90%.^{12,22-24} Only two papers provided detailed accuracy measures for individual and combined CT findings in detecting PLC injury.^{12,23} The findings from these two studies showed that facet joint malalignment, spinous process fracture, interspinous widening, and horizontal laminar fractures were independently associated with PLC injury in MRI. The accuracy of combined CT findings shows that ≥ 2 CT findings yielded a higher PPV for PLC injury than ≥ 1 CT findings (90% vs 66 % and 82% vs 67%).^{12,23} Only three studies have evaluated the interobserver reliability of CT findings, revealing moderate to excellent agreement ($K = .30-.91$, Table 1).^{10,12,14}

Discussion

The integrity of PLC has been cited as a critical element in the TLFs' classification and treatment algorithm by AO-Spine classification, but no standard approach for PLC evaluation in CT or MRI has been provided.^{3,4} As a result, the reliability of PLC assessments and TLFs' classifications were compromised.^{13,14} Herein, we propose an algorithm for CT/MRI evaluation of a thoracolumbar PLC injury that incorporates a systematic literature review's results and authors' clinical expertise. The systematic review of the literature centered on the diagnostic accuracy and reliability of CT and MRI in PLC injury. Following is a summary of the significant CT and MRI findings for diagnosing PLC injury.

MRI Protocol and Imaging Considerations

The importance of using the optimal MRI sequence parameters cannot be overemphasized.²⁵ However, these parameters vary greatly depending on the MR imaging system's field strength, coil design, and gradient strength; a customized approach is needed for each MRI device.²⁵ The spine trauma protocol includes axial and sagittal T2-WI and T1-WI, sagittal short tau inversion-recovery (STIR), with a slice thickness of 3 mm for sagittal and 4 mm for axial, using a matrix size of 240x320.^{7,26} T2-weighted fat-suppression sequences such as STIR or fat-saturated T2-weighted sequences are needed to distinguish T2 hyperintensity associated with PLC injuries from adjacent fat.²⁷ Compared to the fat-saturated T2-weighted sequence, the STIR sequence provides more uniform fat signal suppression and is less affected by the presence of metallic implants; however, it takes slightly longer to acquire and frequently produces a grainier image.²⁷ There is no evidence that a 3 Tesla (T) MRI scanner is more accurate than a 1.5 Tesla scanner in detecting PLC injury. One study revealed comparable inter-intrareader reliability for 1.5 and 3T.¹² A focused MRI protocol of three levels above and below known TLF has shown a comparable sensitivity to a whole-spine MRI in detecting clinically significant injuries while reducing scanning time.²⁸ For MRI to be highly sensitive for PLC injuries, it should be performed within 72 hours of injury. After this point, MRI's sensitivity decrease due to resorption of the T2 signal hyperintensity produced by edema or hemorrhage, which provides an excellent contrast medium to the low signal intensity ligaments.²⁵

CT Protocol and Imaging Considerations

The CT's perceived image quality and the diagnostic performance depend on the choice of imaging parameters and the post-processing, in particular the reconstruction algorithm use the reformatting parameters.²⁹ The following parameters are recommended for a 64-slice MDCT scanner in a helical mode: 120 kVp, MA 150-600 smart MA, and pitch and speed (mm/rot) 1.375:1/55.00. The slice thickness for axial images of soft tissue and the bone algorithm was 5 mm and .625 mm, respectively, and 3 mm or less for reformatted images.^{12,30}

MRI Findings for Each Component of PLC

Imaging Anatomy of the Posterior Ligamentous Complex. A low signal intensity (dark) on all MRI sequences is typical for PLC components (due to their collagen content), except for the LF, which has an intermediate signal on T1 and T2 sequences (due to its high elastin content, Figures 1A and B).²⁷ Table 3. Summarizes the MRI findings of each PLC component as well as their accuracy.

Supraspinous Ligament. The MRI identification of SSL injury has the highest accuracy for detecting SSL injury

Table 1. Studies on the Accuracy or Reliability of Magnetic Resonance Imaging in Diagnosis of Posterior Ligamentous Complex injury.

Author	Objectives	Levels	Data collection	Number of Patients	Number of reviewers	Number of MRI field strength	Definition of PLC Injury	Key Findings
Aly et al (2022)	Frequency of change of fracture classification by MRI compared to CT alone	T1-L5	Retrospective	244	4	1.5 T and 3 T MRI	Black stripe discontinuity due to SSL or LF rupture	MRI changes the fracture classification in 10 % of cases. Perfect agreement on MRI evaluation of PLC($k = .89$).
Mehta et al (2021)	To evaluate the diagnostic accuracy of MRI in PLC injury compared to intraoperative findings	T1-L3	Prospective	58	2	Not specified	Black stripe discontinuity due to SSL or LF rupture	MRI sensitivity for intact PLC components ranged from 100% SSL to 66.67% LF. MRI specificity ranged from 100% ISL to 52% thoracolumbar fascia.
Lee et al (2015)	To evaluate spine MRI inter-reader and intra-reader reliabilities for the TLICS score	Thoracolumbar	Retrospective	100	1	1.5 T and 3 T MRI	Not specified	Inter-reader agreement of MRI was fair to moderate ($k = .440$ for the first and $.389$ for the second review) for PLC integrity. Intra-reader agreement was $.423$ - $.616$. Experience did not influence difference in inter-reader agreement
Pizones et al(2013)	To study MRI accuracy for detecting PLC injury	T1-L5	Prospective	58	3	Not specified	Black stripe discontinuity due to SSL or LF rupture	MRI sensitivity for injury diagnosis of each isolated PLC component varied between 92.3% ISL and 100% LF 100% SSL. PLC integrity sensitivity and specificity as a whole were 91% and 100%.
Vaccaro et al (2009)	To study MRI accuracy for detecting PLC injury compared to intraoperative findings	T1-L3	Prospective	42	1	Not specified	Any high signal intensity with or without black stripe discontinuity	MRI sensitivity for the various components of the PLC ranged from 79% left FC to 90% ISL. The specificity ranged from 53% thoracolumbar fascia to 65% LF, the PPV ranged from 70.4% left FC to 78.4% ISL, and the NPV ranged from 50.0% thoracolumbar fascia to 88.2% right FC.
Dai et al (2009)	To measure the reliability of MRI in detecting PLC injury.	T11-L1	Retrospective	61	3	1.5-Tesla MRI	Any high signal intensity with or without black stripe discontinuity	The kappa coefficients for ISL or SSL injury ranged $.601$ to $.736$, representing substantial to almost perfect agreement.

(continued)

Table 1. (continued)

Author	Objectives	Levels	Data collection	Number of Patients	Number of reviewers	MRI field strength	Definition of PLC Injury	Key Findings
Schweitzner et al (2007)	To determine the interrater reliability of integrity on MRI and CT	T3-L3	Retrospective	13	13	1.6-slice CT 1.5-Tesla MRI	1) facet joint diastasis on CT; (2) high signal intensity in the region of PLC components on sagittal T2W FAT SAT MRI; and (3) discontinuity of black strip on sagittal T1W MRI	Absolute interrater percent agreement on facet diastasis and posterior edema-like signal in the region of PLC components on sagittal T2-weighted MRI was similar (agreement 70.5%). Facet joint diastasis on CT was the most reliable indicator of PLC disruption ($\kappa = .395$).
Haba et al (2003)	To assess the diagnostic accuracy of MRI in detection of PLC injury compared to intraoperative findings	T2-L5	Retrospective	35	3	.5-1.5-tesla MRI	Any high signal intensity with or without black stripe discontinuity	The diagnostic accuracy of MR imaging in detecting injury of the SSL and ISL was 90.5 and 94.3%, respectively. T1W MRI alone was more specific injury than T2W MRI alone. The overall mean κ coefficient for MR imaging findings of PLC injury was .803, and was greater for ISL ($\kappa = .915$) compromise than SSL ($\kappa = .69$) compromise.
Lee et al (2000)	To assess the reliability of MRI for PLC injury in thoracolumbar spinal fractures.	Thoracolumbar	Prospective	34	1	Not specified	A wide interspinous gap compared with the adjacent interspinous spaces on palpation or plain radiography (more than a 20% increase	SSL injury was suspected on MRI in 27 patients, ISL in 30 patients, and LF in 9 patients. There were 28 SSL injuries, 29 ISL injuries, and 7 LF injuries in operative findings. There was a significant relation between MRI interpretation and operative findings.
Emery et al (1989)	To review the accuracy MRI findings of patients with PLC injury compared to CT alone	Thoracolumbar	Retrospective	37	NR	1.0 T or 1.5 Tesla MRI	Any high signal intensity with or without black stripe discontinuity	MRI detected ligament damage in 17/19 (89%) cases of PLC injury. However, the only misdiagnosed thoracolumbar PLC injury was the only MRI performed without T2 sequences and performed at an outside hospital

Abbreviations: MRI, magnetic resonance imaging; SSL, supraspinous ligament; PLC, posterior ligamentous complex; CT, computed tomography; LF, ligamentum flavum; FC, facet joint capsules; ISL, interspinous ligament.

Table 2. Studies on the Accuracy or Reliability of Computed Tomography in Diagnosis of Posterior Ligamentous Complex Injury.

Author	Data collection	Number of reviewers	Number of Patients	Objectives	Imaging Evaluated	Definition of PLC Injury	Key Findings
Aly et al (2022)	Retrospective	3	41	To determine the impact of MRI on fracture classification for low lumbar fractures compared to CT alone.	64-slice multidetector CT scanner and 1.5-Tesla or 3-Tesla MRI	PLC injury in MRI was defined by black stripe discontinuity and in CT by ≥ 1 of the following presence of: vertebral body translation, facet joint malalignment, horizontal laminar or spinous process fracture, and interspinous widening	CT was highly accurate (95%) for diagnosis of PLC injury in lower lumbar fractures. Addition of MRI after CT did not change the AO classification or TLSS, compared to CT alone
Aly et al (2021)	Retrospective	2	271	To determine diagnostic value of morphological features of horizontal laminar fracture and vertical laminar fracture for diagnosis of PLC injury.	64-slice multidetector CT scanner and 1.5-Tesla or 3-Tesla MRI	Black stripe discontinuity due to SSL or LF rupture	Bilateral HLFs, laminar and pedicle fractures, and displaced HLFs, but not any VLF subtypes, were independently associated with PLC injury, aiding CT-diagnosis of PLC injury
Durmaz et al (2021)	Prospective	3	180	To investigate the role of MRI in decision making for thoracic and lumbar fractures	3-Tesla MRI scanner	Black stripe discontinuity	There was a weak correlation between Xray + CT and post-MRI classification for AO type B fractures, and MRI classified AO type B fractures significantly more accurately than Xray + CT MRI findings were significantly correlated to PLC disruption during intraoperative ligament assessment MRI changed treatment plan in favor of surgery in 33.9% of patients where CT/X-ray suggested non-operative treatment
Aly et al (2021)	Retrospective	2	263	To determine the diagnostic accuracy of combined CT findings for detecting PLC injury in MRI	CT images were obtained using a 64-slice multidetector CT	Black stripe discontinuity on MRI due to SSL or LF rupture	Facet joint malalignment, spinous process fracture, horizontal laminar fracture, and interspinous widening were independently associated with PLC injury Two or more CT findings yielded a positive predictive value of 91% for PLC injury, while a single finding is associated with 34% PPV for PLC injury

(continued)

Table 2. (continued)

Author	Data collection	Number of reviewers	Number of Patients	Objectives	Imaging Evaluated	Definition of PLC Injury	Key Findings
Ganjeifar et al (2019)	Retrospective	98		To evaluate the diagnostic value of CT scan in predicting PLC injuries	MRI and CT type not specified	Not specified	A significant relationship exists between facet joint widening, increased interspinous process distance, and spinous process avulsion fracture with PLC disruption. Diagnostic results of CT were similar to MRI
Khurana et al (2018)	Retrospective	3	105	To determine whether secondary CT findings can predict PLC injury	128-slice CT scanner and 1.5-Tesla or 3.0-Tesla MRI	Any high signal intensity with or without black stripe discontinuity	At least one positive CT finding was found to yield average sensitivity of 82%, while two or more positive findings yielded average specificity of 88%. Interobserver reliability was poorest for interspinous widening. OR of PLC injury was 3.8 to 5.6 with one CT findings vs no positive CT findings, and 13.6 to 25.1 with two or more positive CT findings
Jiang et al (2018)	Retrospective	2	88	To examine the accuracy of some radiographic parameters and interspinous widening in CT to detect PLC injury in MRI	CT with single-detector helical protocol with a 3-mm-overlapping axial slice thickness and image reformattening in the sagittal and coronal planes	Any high signal intensity with or without black stripe discontinuity	On CT, PLC injury was associated interspinous distance ratio, and interspinous distance minus.
Rajasekaran et al (2016)	Retrospective	2	60	To examine the accuracy of interspinous widening in CT to detect PLC injury in MRI	1.5 Tesla MRI	hyperintense signal changes in the PLC complex	An increase in interspinous distance by 2mm, on its own, was associated with a sensitivity of 60 % and specificity of 57 %. When considering presence of both factors of LK greater than 25° and interspinous distance greater than 2.5 mm the specificity was 97 %.

(continued)

Table 2. (continued)

Author	Data collection	Number of reviewers	Number of Patients	Objectives	Imaging Evaluated	Definition of PLC Injury	Key Findings
Barcelos et al (2016)	Retrospective	3	43	To evaluate the reliability of CT findings in the diagnosis of PLC injury	CT with single-detector helical protocol with a 3-mm-axial slice thickness and image reformatting in the sagittal and coronal planes.	facet joint diastasis, sagittal translation, increased interspinous distance, horizontal translation, and rotation of the vertebra	The intraobserver reliability for the PLC injury parameters ranged from .518 to 1.000, except for increased interspinous distance. Interobserver reliability ranged from .303 to .688
Winkhofer et al (2013)	Retrospective	3	100	To evaluate the influence of additional MRI compared with CT alone for the classification of thoracolumbar traumatic fractures	CT with .6 mm slice thickness and 1.5-Tesla MRI	On CT, PLC injury was defined when one or more of the following: facet joints diastasis, avulsion fracture of the superior or inferior aspect of contiguous spinous processes, vertebral translation, or an interspinous spacing greater than that of the level above or below	With CT alone the integrity of the PLC was defined as intact in 80%, suspect in 2%, and injured in 18% of the 100 patients. With CT and MRI together the PLC was assessed as intact in 55 out of 55%, suspect in 3%, and injured in 42% patients.
Pizones e tal (2012)	Prospective	2	33	Impact of MRI on decision making For thoracolumbar traumatic fracture diagnosis and treatment	CT not specified, 1.5-Tesla MRI	Black stripe discontinuity	MRI offers additional information compared to other diagnostic tools: it modified our diagnosis in 40% of our patients, classification fracture pattern in 24% of our fractures and therapeutic management in 16% of our patients.
Lefrink et al (2002)	Retrospective	NR	160	To determine the diagnostic accuracy of CT findings for detecting PLC injury compared to intraoperative findings	Not specified	Intraoperative verification of ligamentous injury	Thirty percent of Type B fractures are misdiagnosed when plain X-rays and CT scans with 2D reconstructions are used as the only preoperative diagnostic tools
Peterslge et al (1994)	Retrospective	2	21	frequency of diagnosis of PLC injury in MRI compared to CT alone	1.0 and 1.5 T MRI	Any high signal intensity with or without discontinuity of SSL	CT predictors of ligamentous injury were present in only 33% of cases with SSL rupture in MRI

Abbreviations: MRI, magnetic resonance imaging; SSL, supraspinous ligament; PLC, posterior ligamentous complex; CT, computed tomography; LF, ligamentum flavum; FC, facet joint capsules; ISL, interspinous ligament.

intraoperatively (PPV,100% and NPV. 96%, Table 3).¹⁹ According to Pizones et al, PLC disruption due to distraction injury follows an orderly rupture progressing from posterior to anterior; therefore, SSL rupture is the inflection point that marks PLC's incompetence.³¹ SSL rupture can be observed as discontinuity of the black stripe, which is best seen in sagittal STIR/T2 images and corroborated by the absence of SSL-related signal intensity in axial T2 images. (Figures 5A and B)²⁶ Occasionally, axial T2 may show SSL is avulsed from the tip of the spinous process. (Figure 5C) SSL and LF injuries are typically graded as "intact" or "disrupted"; hence a thinned but continuous SSL or LF should be reported as "intact" (Figure 5D).³² Detecting a ruptured SSL in the mid-thoracic area may be more challenging due to anatomical variations in the SSL/ISL complex.^{6,26,33} Vascular marking due to a blood vessel crossing the black stripe should not be mistaken as black stripe discontinuity (Figure 5E).

Ligamentum Flavum. LF rupture can be observed as "black stripe discontinuity," which is best seen in parasagittal T2 or STIR images. It is critical to distinguish between a horizontal LF tear (which indicates incompetent PLC) and a vertical LF tear, considered stable (Figures 6A and B).³⁴ On axial T2 images, horizontal LF tears are visible as diffusely macerated ligaments, whereas vertical LF tears appear as unilateral focal (Figures 6B and C). Furthermore, horizontal LF tears appear on several sagittal STIR slices, whereas vertical tears are barely found in a single slice. (Figure 6E) According to the orderly sequence of PLC rupture by Pizones et al, a horizontal LF caused by the distraction mechanism is typically accompanied by SSL/ ISL rupture and represents the advanced stage of PLC incompetence.³¹ Contrarily, a vertical LF tear is typically caused by a vertical laminar fracture due to axial compression and is not associated with other ligamentous injuries.³⁴

Interspinous Ligament. ISL is best evaluated using sagittal STIR or T2 image, which may show hyperintensity for both ISL edema and rupture. ISL edema can be differentiated from ISL rupture by the ill-defined hyperintensity as opposed to the sharp horizontal line across the ligament.³¹ However, the low contribution of ISL to PLC competence makes the distinction between ISL edema and rupture of little practical importance (Figure 7A and B).³⁵

Facet Joint Capsule. Facet joint effusion and widening represent partial capsular ligament injury and can be seen as hyperintensity on axial STIR or T2 images (Figures 8A and B). In contrast, facet dislocations, which indicate complete injury, are better visualized in T1 axial/sagittal images because of their high anatomical resolution (Figures 8B and D).³¹ Thoracic facets' effusion is most easily seen on STIR sagittal sequences, which are perpendicular to the thoracic facets' coronal orientation. T2 axial scans, on the other hand, were the most helpful in identifying a sagittal-orientated lumbar facet injury.²⁶ Although FC is a major contributor to PLC

competence, less emphasis was put on its MRI assessment due to low specificity (52%, Table 3).¹⁹

Thoracolumbar Fascia. While most research uses a "four-structure" definition of the PLC, Vaccaro et al report the thoracolumbar fascia as a fifth component. The fact that thoracolumbar fascia is the least reliable and specific (53%, Table 3) component of PLC may account for its unpopularity.^{18,20}

Definition of PLC Injury in MRI

There is no agreement on the definition of PLC injury in MRI regarding the number of components damaged or the degree of damage (rupture vs edema).¹ There is a debate whether to define PLC injury as "black stripe discontinuity" due to SSL or LF rupture or High-signal intensity (HSI), a broader criterion that includes any hyperintensity whether or not associated with "black stripe discontinuity". Earlier research found HSI to be highly sensitive in detecting PLC injury when using intraoperative findings as a reference.^{17,36} Recent research suggests HSI may overread PLC injury due to a high false positive rate.¹⁸ On the other hand, black stripe discontinuity demonstrated high specificity in detecting PLC injury (Table 3).^{19,26} Furthermore, biomechanical evidence that SSL and LF are the key components of PLC competence further supports the use of "black stripe discontinuity" to define disturbed PLC.^{35,37} Despite low specificity, the HSI criterion is still widely used in research, most likely to increase the sample size.¹ HSI may be easier to assess than black stripe discontinuity, which requires examining each PLC component for partial vs complete injury.^{6,12}

MRI's Pitfalls

A significant drawback of MRI's PLC evaluation is the reported moderate to poor interobserver reliability.³⁸ Differences in experience or training level could explain the moderate reliability. Another possibility is that radiologists and spine surgeons have different perspectives on the MRI sequence or interpretation.²⁶ MRI parameters are more challenging to standardize due to their large numbers and device-specific specifications.²⁵ while black stripe discontinuity is a more specific criterion than HSI; it is still imperfect. Notably, all MRI accuracy studies use intraoperative findings as a reference, restricted to the more severe surgical cases as a spectrum bias.³² Therefore, MRI findings of PLC injury should be integrated with other findings, including X-ray and CT findings.¹⁸

CT Assessment of PLC Injury

CT assessment of PLC injury depends on detecting secondary signs.¹² Table 4 summarizes CT findings suggestive of PLC injury and their accuracy measures. Following is a summary of the most important CT findings for diagnosing PLC injury.

Table 3. Magnetic Resonance Imaging Findings of Thoracolumbar Posterior Ligamentous Complex Injury.

	MRI finding	Best /additional sequence	Positive predictive value ^a	Negative predictive value ^a	Pearls/Pitfalls
Supraspinous ligament	Black stripe discontinuity	Sagittal STIR/T2, Axial T2	100	96	Classified as intact or disrupted: thinned but continuous ligament classified as intact
Interspinous ligament	Hyperintensity	Sagittal STIR/T2	100	92	Edema vs disruption: ill-defined hyperintense signal vs sharp horizontal line crossing through the ligament
Ligamentum flavum	Black stripe discontinuity	Sagittal STIR/T2, Axial T2	100	100	Horizontal vs vertical tear: Localized sharp vertical line vs diffusely macerated ligament
Facet capsule	Facet effusion (partial) Malalignment (complete)	Sagittal STIR (effusion) Axial T1/sagittal T1 (malalignment)	57	100	—

Abbreviations: MRI, Magnetic resonance imaging; STIR, Short tau inversion recovery.

^aThe accuracy measures were obtained from the study by Pizones et al¹⁹ the only paper that uses dichotomous criteria for each ligament.

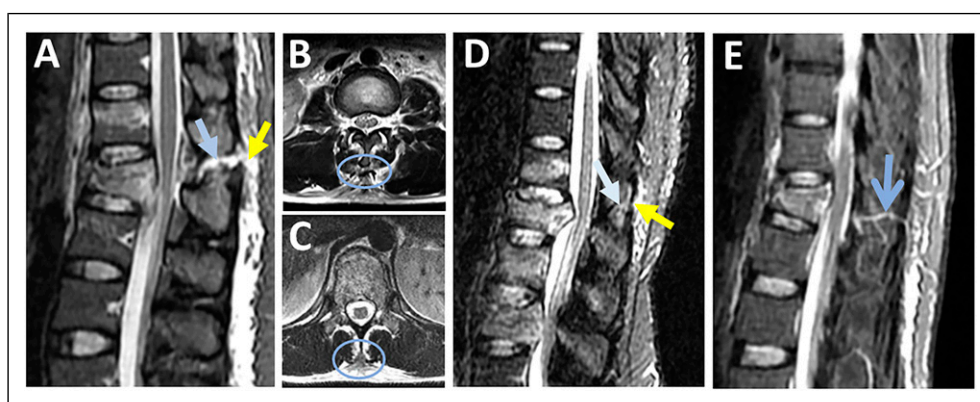


Figure 5. Magnetic resonance imaging findings in supraspinous ligament injury. **(A)** Sagittal STIR images are the best sequence to detect the discontinuous black stripe due to supraspinous ligament rupture (yellow arrow) associated with high signal intensity due to interspinous ligament rupture (blue arrow); **(B & C)** Axial T2-weighted images show supraspinous ligament stripped from the spinous process tip (blue ring, **B**) or the absence of the signal intensity corresponding to the supraspinous ligament (blue ring, **C**): both indicating supraspinous ligament rupture; **(D)** Sagittal T2-STIR image shows thinned, but continuous black stripe due to supraspinous ligament partial injury (yellow arrow) and high signal intensity due to interspinous ligament edema (white arrow); **(E)** vascular marking due to a crossing blood vessel (blue arrow) should not be mistaken for black stripe discontinuity. Abbreviations: STIR: short tau inversion-recovery.

CT Findings of PLC Injury

Vertebral Body Translation. Vertebral body translation (VBT) is the anterior or lateral translation of a cranial vertebra relative to a fractured vertebra, implying severe damage to PLC and the intervertebral disc.^{4,39} While a standardized method for measuring VBT was reported, there is no agreed-upon threshold for VBT in TLFs (Figure 9A and B).³⁹ A possible explanation is that any translation in thoracolumbar region, regardless of magnitude, strongly indicates instability.³⁹ When a severe burst fracture involves the inferior endplate, the retropulsed fragment may migrate posteriorly relative to the caudal vertebra, mimicking translation. In that case, a key point for differentiation is to examine the facet joint to see if it is dislocated or not.

Facet Joint Diastasis. In a survey of expert spine surgeons, facet diastasis was rated as one of the most predictive and reliable CT signs of PLC injury.^{7,12,14} Facet diastasis refers to a wide spectrum of injuries that includes: facet dislocation (complete uncoverage of articular surfaces), subluxed (partial uncoverage), fractured (displaced or non-displaced), or facet joint widening (FJW) (Figure 10; A-H).^{12,23} Controversy exists regarding the diagnostic value of subtle facet injuries such as FJW for PLC injury. Two recent studies have demonstrated that FJW > 3mm on axial CT is not a predictor of PLC injury.^{12,23} Facet subluxation is the most likely morphology to be overlooked for various reasons. First, facet subluxation is classically diagnosed by the naked facet sign that occurs when the inferior articular facets of the cephalad vertebra do not appear adjacent to the superior facets of the

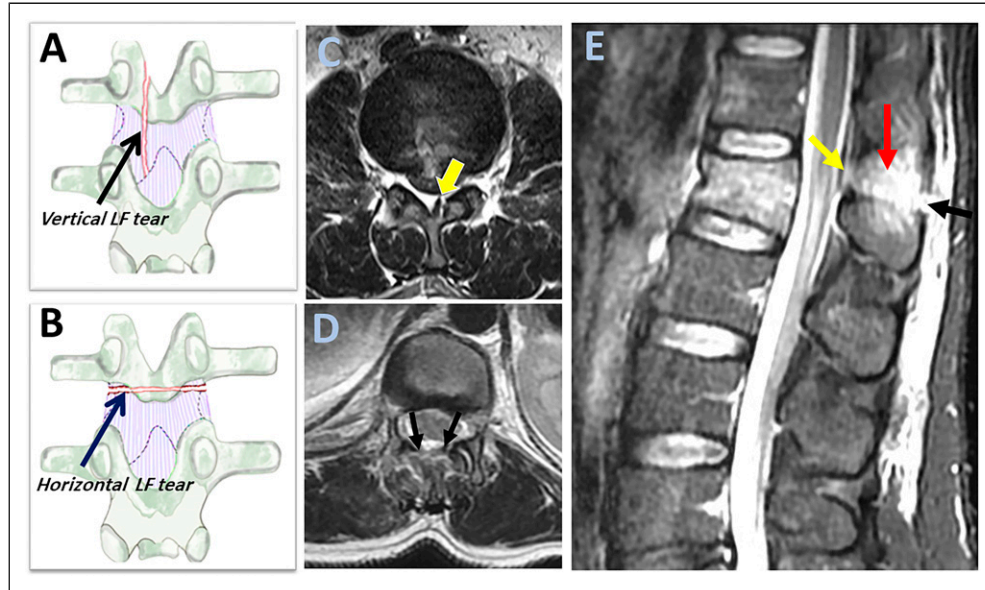


Figure 6. Magnetic resonance imaging findings of ligamentum flavum injury. (A-B) An illustration of the coronal view of a vertebra with the dotted lines indicates the silhouettes of the laminae and inferior articular processes behind the ligament; showing a vertical laminar fracture with an underlying vertical tear in ligamentum flavum (black arrow, A) and a horizontal laminar fracture with an underlying horizontal tear in ligamentum flavum (blue arrow, B); (C-D) Axial T2 image can help to distinguish between horizontal and vertical ligamentum flavum tear as it shows unilateral focal ligamentum flavum tears for vertical tears (green arrow, C) and a diffusely macerated tears for horizontal tear (two black arrows, D); (E) Sagittal STIR image shows black stripe discontinuity due to horizontal ligamentum flavum tear (green arrow) and supraspinous ligament rupture (black arrow) and high signal intensity due to interspinous ligament rupture (red arrow). Horizontal ligamentum flavum tear is more easily visualized in sagittal STIR in multiple slices than the vertical ligament tear. Abbreviations: STIR: short tau inversion-recovery.

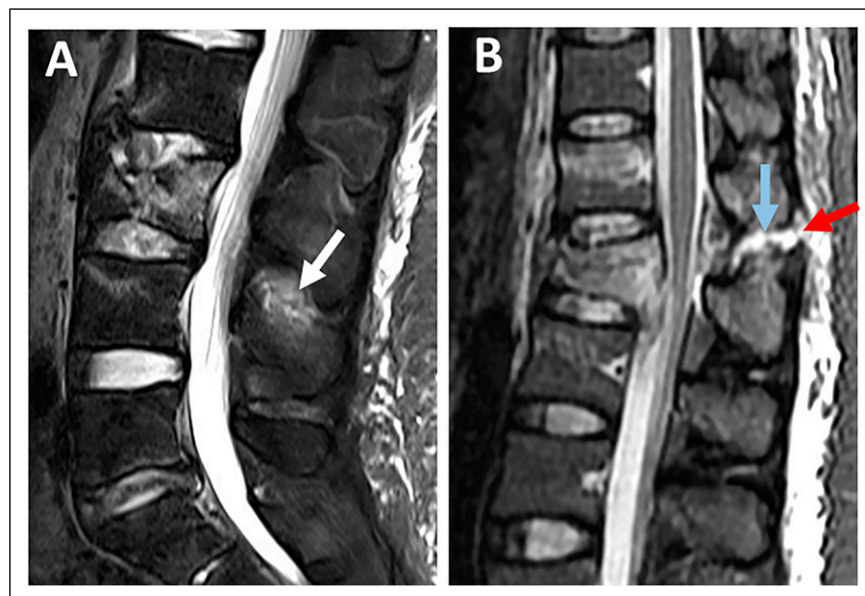


Figure 7. Magnetic resonance imaging findings of interspinous ligament injury. Sagittal STIR images show (A) ill-defined high signal intensity indicating interspinous ligament edema (white arrow); (B) high signal intensity as a sharp horizontal line indicating interspinous ligament rupture (blue arrow) associated with supraspinous ligament rupture (red arrow).

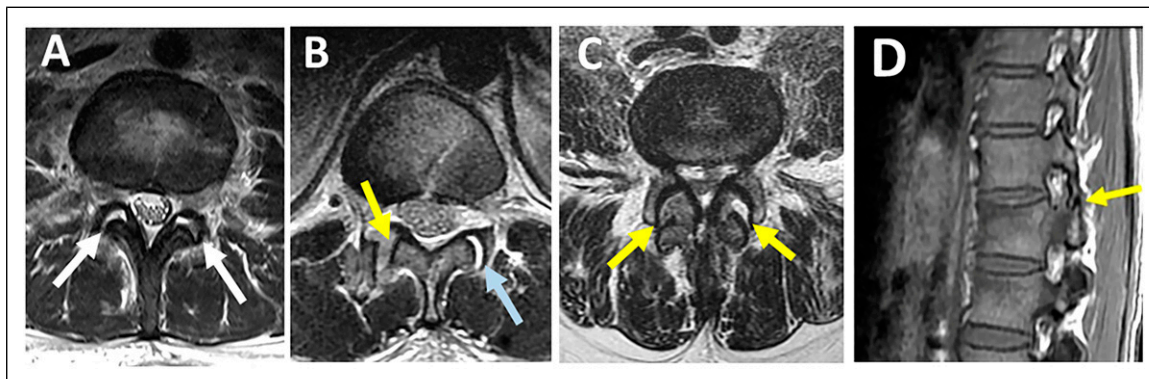


Figure 8. Magnetic resonance imaging findings of facet capsule ligament injury. Axial T2-weighted images (A-C) show (A) high signal intensity due to bilateral facet joint effusion with the preserved alignment of articular surfaces (two white arrows); (B) left facet joint effusion (blue arrow) and right facet subluxation indicating rupture of facet capsule (YELLOW arrow); (C) Bilateral dislocated facets (two YELLOW arrows); (D) Sagittal T1-weighted images are the best to depict the anatomy of subluxed facet (YELLOW arrow).

caudal vertebra in axial CT images (Figures 11A-D). However, in case of slight vertical distraction, a naked facet sign may appear in only one or few axial cuts and could be easily overlooked.⁴³ (Figures 12A-D) Additionally, Harris et al pointed out that the naked facet sign can occur due to minor angulation or flexion and does not always indicate the presence of PLC injury.⁴⁴ Thoracolumbar facets have a variety of sagittal/coronal orientations, so they may dislocate in any plane and be easily missed unless all imaging planes are carefully examined (Figures 12A-D).⁴⁵ Second, facet diastasis may reduce in supine position; however, even when reduced, there is an asymmetry in the facets that can be observed on a careful review of the axial CT images.⁷

Laminar Fracture. The AOSpine has recognized two types of laminar fractures based on their distinct pathomechanics.⁴ Horizontal laminar fracture (HLF) implies a flexion-distraction mechanism of injury, indicating AO type B.⁴ Vertical laminar fracture (VLF), on the other hand, results from severe axial loading with the transfer of energy to posterior elements and vertical split fractures. VLF does not constitute PLC damage; consequently, it is a feature of burst fractures (Figures 13A-K).^{4,46} According to a recent study, HLF, but not VLF, was independently predictive of PLC injury (PPV of 91% vs 48%).³⁴ The following features of HLF were highly associated with PLC injury: displacement > 2mm, bilateral laminar fractures, and laminar, and pedicle fractures.³⁴ A common pitfall is failing to differentiate between HLF and VLF when images are read only in axial images without carefully reviewing the coronal reconstruction images.^{34,41} Indeed, because of their lower prevalence and horizontal orientation, HLF is more likely to be missed, resulting in missing PLC injury.³⁴ The 3-column Denis' concept, which remains popular, implies that all burst fractures with laminar fractures, regardless of type, are unstable, hence undermining the importance of distinguishing between

vertical and horizontal laminar fractures.⁴⁷ Understanding that HLF and VLF, while morphologically similar, are the footprints of distinct injury mechanisms may help to reduce misinterpretation.⁴⁸

Spinous Process Fractures. Avulsion, transverse, or oblique spinous process fracture (SPF) is one of the most reliable and predictive signs of PLC injury.¹² SPF is best seen in sagittal images, but fractures can be seen in axial, coronal, or sagittal images depending on the orientation of the fracture lines (Figures 14A-D). The most common pitfall is missing or ignoring a tiny avulsion SPF, which is highly predictive of PLC injury (Figures 14B and C). Spinous process base fracture may be caused by a vertical split associated with axial loading, but this does not constitute PLC. It is crucial to differentiate SPF from non-united ossification centers within the spinous process's superior or inferior corner, typically with smooth and well-corticated margins.⁴⁹ In osteoporotic patients, SPF can occur even with low-energy trauma and hence are less predictive of PLC injury.

Interspinous Widening. ISW is defined as widening of interspinous distance compared to the adjacent levels, best seen in the midsagittal plane (Figure 9C).¹² Although ISW is considered an important sign of PLC injury; it is the most contentious finding regarding variations in measurement technique or threshold and measurement errors (Figure 9C).^{7,8,48} A wide range of ISW's thresholds (2-7 mm) can be attributed to interindividual and regional differences.^{50,51} Another explanation is that ISW may vary between supine CT and⁴⁸ standing X-ray. Rjasakaran et al reported various ISW's thresholds trade-off sensitivity and specificity and found that > 4 mm yielded a specificity of 90%.^{7,8,12,50} ISW may be difficult to measure in the presence of out-of-plane coronal deformity; in this case, ISW measurements in coronal images may be beneficial.³⁹

Table 4. Proposed Definitions, Accuracy, and Reliability of Computed Tomography Findings of Thoracolumbar Posterior Ligamentous Complex Injury.

CT criteria	Definition	Best imaging plane/ Additional	PPV	NPV	Interobserver		Pearls /pitfalls
					K	K	
Vertebral body translation	Relative listhesis of a vertebra compared to infreadjacent vertebra in the sagittal or coronal plane. ³⁹	Midsagittal /coronal	100 ⁴⁰	79	.623	sagittal translation, .612 coronal translation ¹⁰	Distinguish between translation and retropulsion fragment involving inferior endplate look at the facet management Must be reviewed in all imaging planes.
Facet joint Malalignment	Unilateral or bilateral Facet (s) that were perched, dislocated, or fractured. ^{12,24}	All planes	94 ¹²	76	.656	dislocation, ¹⁰ .57 ¹²	
Facet joint widening	Unilateral or bilateral widening ≥ 3 mm in the axial CT with no evidence of facet malalignment ^{12,24}	Axial	36 ¹²	67	.49	axial, .36 sagittal, ¹⁰ .45 ¹²	It should be distinguished as it has little predictive value for PLC injury
Horizontal laminar fracture	Horizontally-oriented fracture (in the coronal plane) of the lamina, pars /or pedicles, whether unilateral or bilateral ³⁵	Coronal	91 ¹²	81	.76	³⁴	Distinguish between horizontal and vertical laminar fracture best in coronal view
Vertical laminar fracture	Vertically oriented fracture (in the coronal plane) of the lamina located between the medial borders of both pedicles, with or without spinous process involvement. ^{35,41}	Coronal	29 ¹²	65	.91	³⁵	Sometimes vertical split involves the base of the spinous process: this should not be considered a spinous process fracture
Spinous process fracture	Avulsion or transverse fracture of the spinous process ^{12,24}	Midsagittal/coronal	86 ¹²	81	.89	¹²	Avoid missing a tiny avulsion fracture
Interspinous widening	Widening of interspinous distance > 4 mm compared to the adjacent levels. ^{12,24}	Midsagittal	59 ¹²	78	.303, ¹⁰ .63	¹²	In case of coronal plane deformity, measure it in the coronal plane

Abbreviations: CT, Computed tomography; PPV, Positive predictive value; NPV, Negative predictive value; K, Kappa Coefficient.

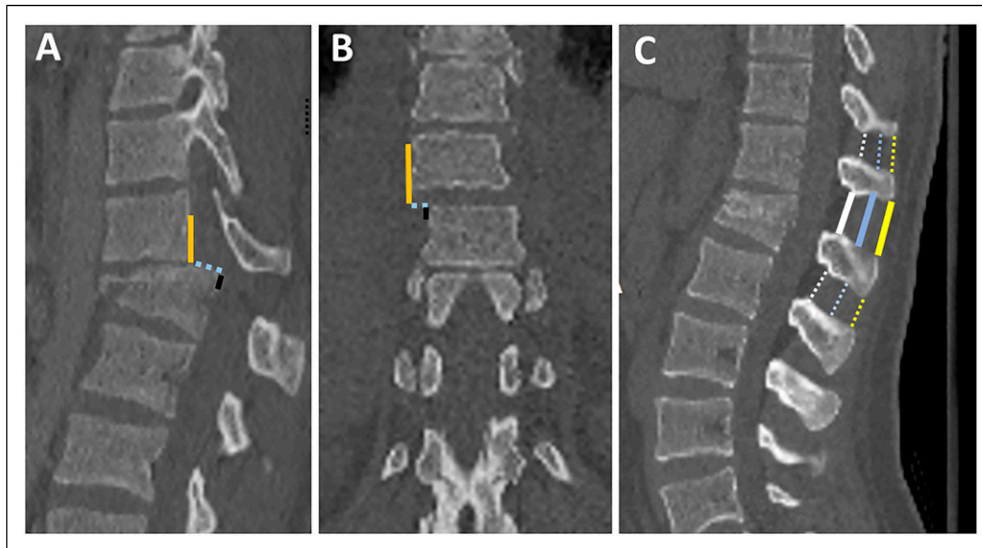


Figure 9. Assessment of vertebral translation and interspinous widening in CT. **(A)** Midsagittal CT image shows the method of measurement of vertebral translation by the distance between the most cephalad, posterior corner of the caudal vertebral body (black line), and a tangent line to the posterior vertebral body of the cranial vertebra (yellow line); **(B)** Coronal CT image shows the method of measurement of vertebral translation by the distance between the most cephalad, lateral corner of the caudal vertebral body (black line), and a tangent line to the lateral vertebral body of the cranial vertebra (yellow line).³⁹; **(C)** midsagittal CT shows various methods of measurement of interspinous widening⁴² (1) **Supraspinous distance**; the distance between the inferior edge spinous process of the upper adjacent vertebra and the superior edge spinous process of the fractured vertebra (solid yellow line) minus the average interspinous distance of the upper and lower adjacent vertebra or the lower vertebrae (2 dashed yellow lines), (2) **Interspinous distance** measured at the middle of the spinous process (blue lines), (2) **interlaminar distance** measured between the lamina (white lines).

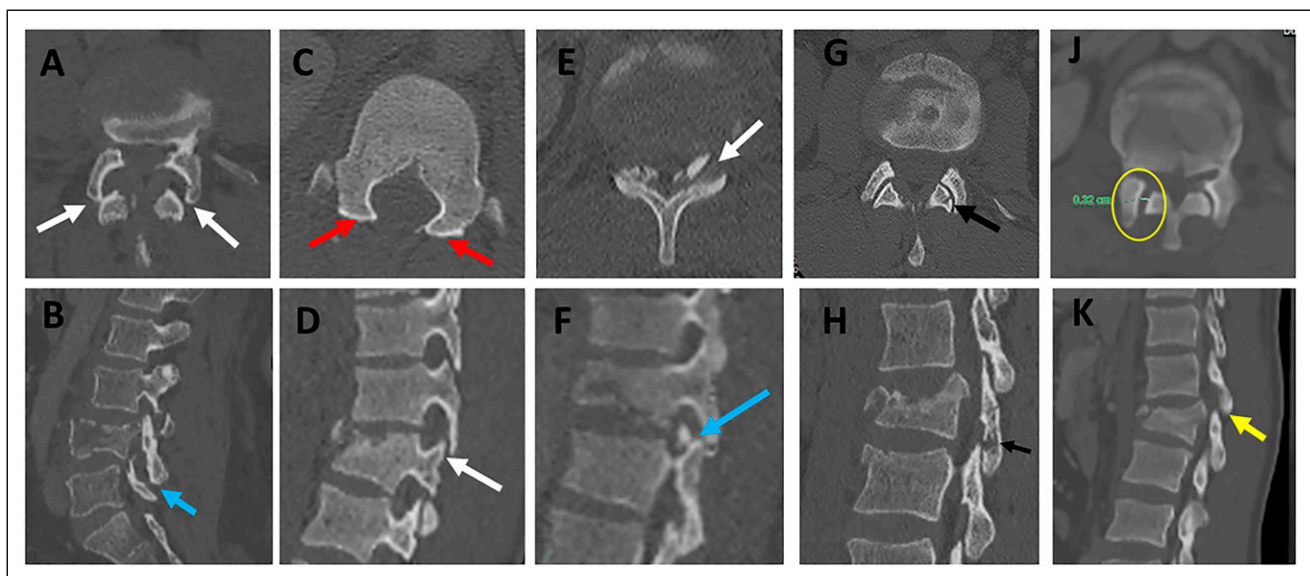


Figure 10. Various patterns of facet diastasis in CT. **Facet dislocation (A, B)** seen in CT axial images show (2 white arrows, **A**) and sagittal CT image (blue arrow, **B**); **Facet Subluxation (C, D)** seen in CT axial images as bilateral naked facet sign (2 red arrows, **C**) and sagittal CT image as a vertical distraction (white arrow, **D**); **Displaced facet fracture (E, F)** seen in CT axial images (white arrows, **E**) and sagittal CT image as a displaced fracture of the left superior articular facet (blue arrow, **F**); **Non-displaced facet fracture (G, H)** is seen in CT axial images (black arrow, **E**) and sagittal CT images as a non-displaced fracture of the left inferior articular facet (black arrow, **F**); **Facet joint widening (J, K)** is seen in CT axial images as widening of the facet joint > 3 mm with the preserved alignment of articular surfaces (yellow circle, **J**) and sagittal CT images (green arrow, **K**). Abbreviations: CT, computed tomography.

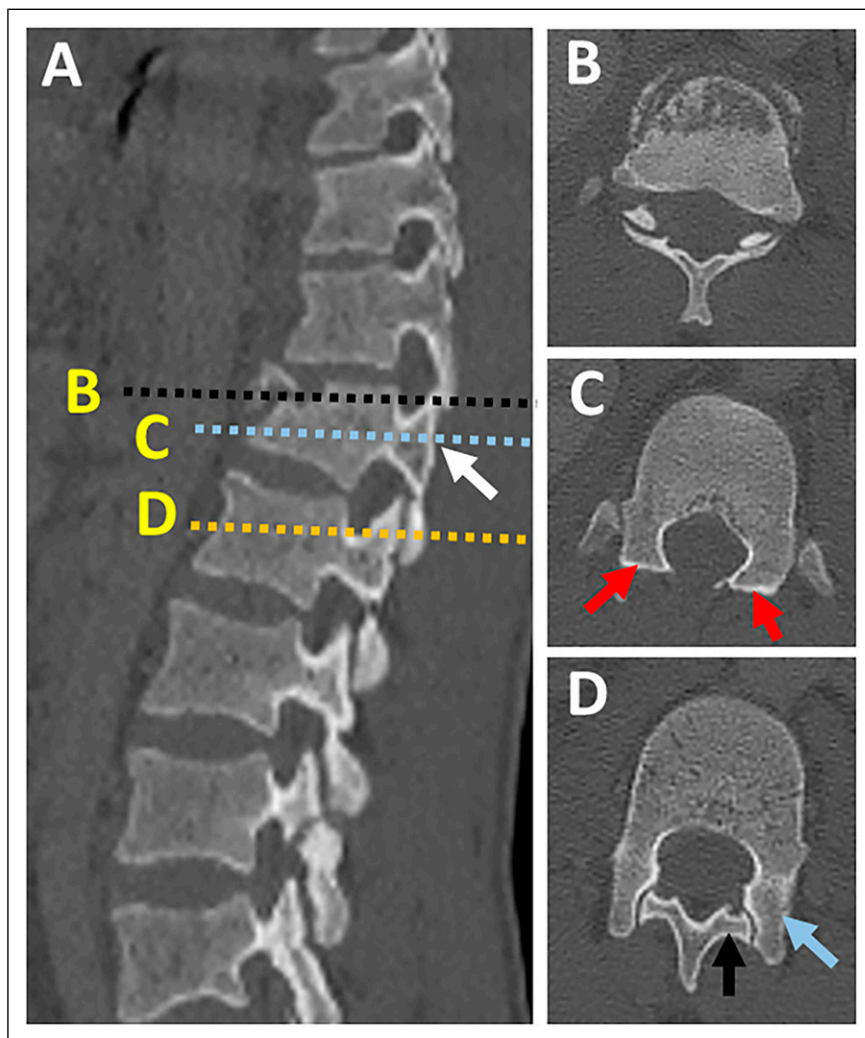


Figure 11. Naked facet sign. **(A)** CT parasagittal images showing vertical facet distraction with partial uncoverage of superior articular process (white arrow); **(B)** Axial CT cut at the level of overlapping facets (black dashed line in image A) shows the overlap of superior and inferior articular process, **(C)** axial CT images at the level of uncovered superior articular facet (dashed blue line in image A) shows naked facet sign (two red arrows), **(D)** axial CT images at the normal level below (dashed yellow line in image A) shows the normal alignment of the facet joint with the superior facet of the level below directed posteromedially (black arrow) and inferior articular facet of the same level directed anterolaterally (blue arrow). Abbreviations: CT, computed tomography.

CT Criteria to Define PLC Injury

The greatest challenge in CT's evaluation of PLC assessment is the lack of agreement on CT criteria for PLC injury.¹ The typical flexion distraction morphology, i.e., horizontal osteoligamentous disruption, is used to diagnose PLC injury in CT.^{3,4} However, this morphology is frequently lacking, leading to disagreement about PLC status in CT.^{13,14} Two recent studies have proposed to define PLC injury in CT based on the diagnostic value of combined CT findings.^{12,23} Such combined analysis reflects the different clinical scenarios encountered in clinical practice; patients may present with one or more CT findings.^{12,23} Vertebral translation, facet joint malalignment, spinous process fracture, horizontal laminar fracture, and interspinous widening were

independent predictors of PLC injury. FJW and VLF were not associated with PLC injury and are most likely responsible for most falsely identified PLC injuries in CT. At least two CT findings have a PPV of 88-91% for PLC injury, suggesting its use as a CT criterion for PLC injury and little added value for MRI testing (Figure 15).^{12,23} In addition, the absence of all four CT findings provided the best ability to rule out PLC injury (A negative predictive value of 91%).^{12,23} The presence of single CT findings lacked sufficient PPV or NPV to rule in or rule out PLC injury; hence it can be used to indicate indeterminate PLC injury in CT and the need for further MRI testing. Currently, there are no clear guidelines on when to do an MRI for PLC assessment.⁵ MRI has been shown in previous studies to

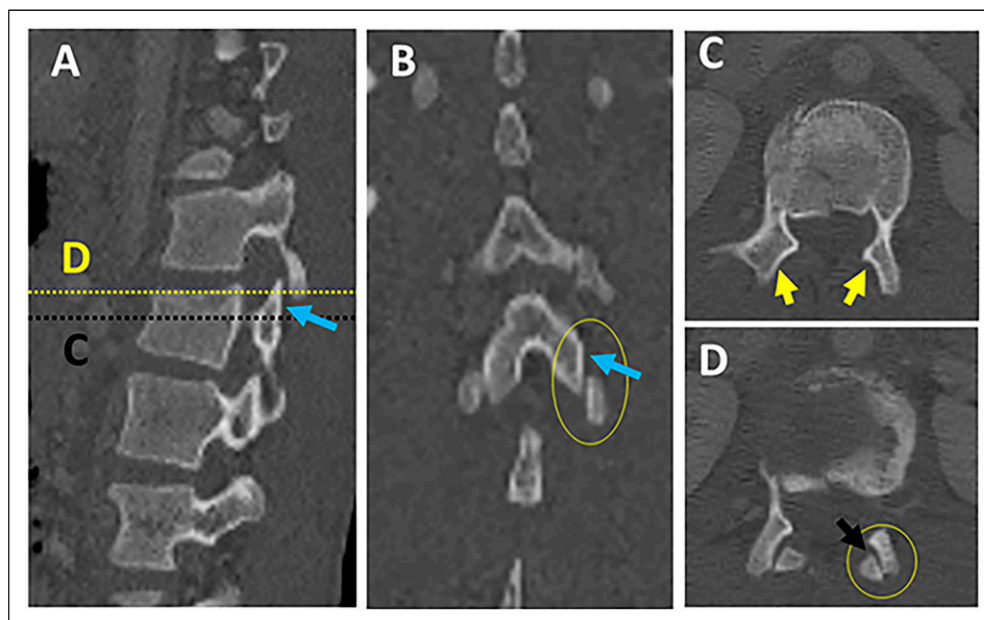


Figure 12. Multiplanar CT assessment of facet subluxation (A-B). (A-B) CT parasagittal and coronal reconstruction images showing vertical facet distraction with partial uncoverage of superior articular facet (blue arrows) ; (C) axial CT images at the level of uncovered superior articular facet (dashed black line in image A) show naked facet sign (2 yellow arrows); (D) axial CT images at the level of uncovered superior articular facet (dashed yellow line in image A) shows the overlap of superior and inferior articular facet with posterior subluxation of an inferior articular facet (black arrow). Abbreviations: CT, computed tomography.

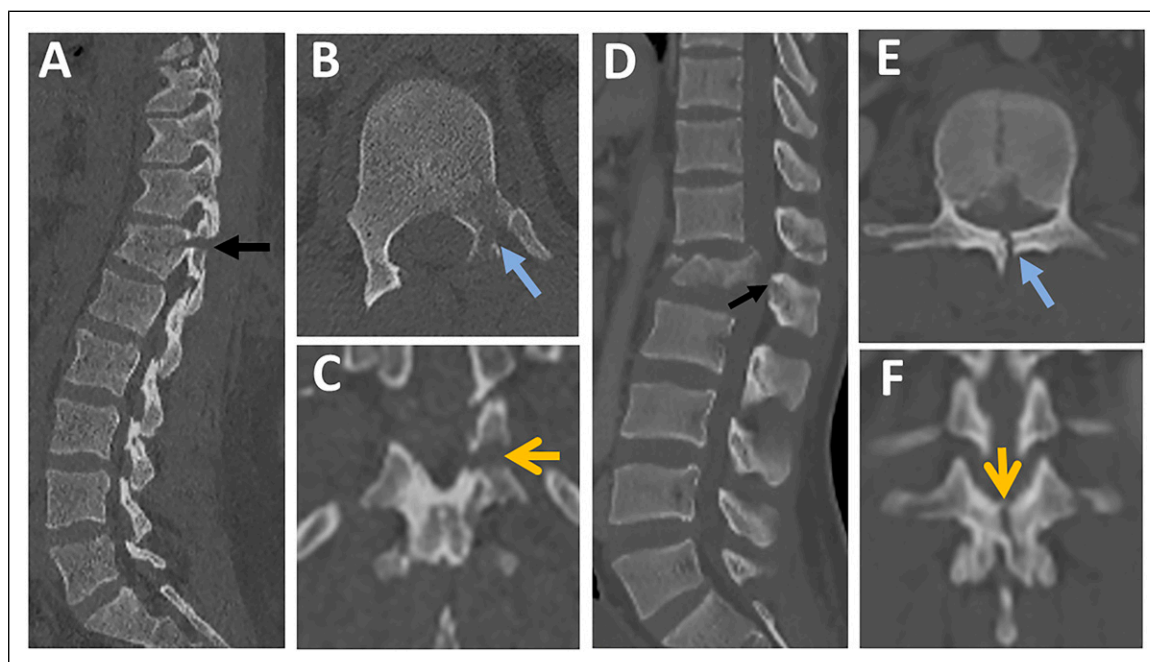


Figure 13. The distinction between horizontal and vertical laminar fractures in CT. (A-C) images from the same patient showing (A) Parasagittal CT image showing a displaced fracture of lamina and pedicle (black arrow); (B) Axial CT image showing a fracture of the left lamina and pedicle (blue arrow); (C) Coronal reconstruction images showing left horizontal lamina fracture (yellow arrow); (D-F) images from the same patient showing (D) Parasagittal CT image showing a fracture of lamina and base of the spinous process (black arrow); (E) Axial CT image showing a vertical fracture of the lamina (blue arrow); (F) Coronal reconstruction images showing the vertical orientation of the laminar fracture (yellow arrow). Abbreviations: CT, computed tomography.

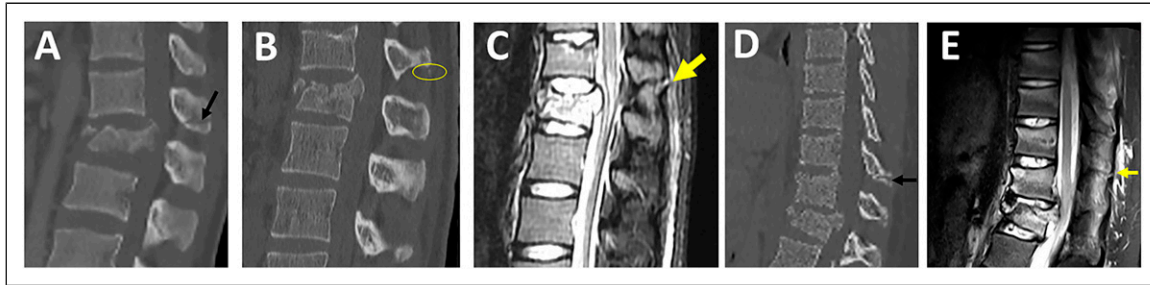


Figure 14. Evaluation of spinous process fractures in CT. Midsagittal CT image showing (A) transverse spinous process fracture (black arrow), (B-C) images from the same patient showing a tiny avulsion spinous process fracture (yellow circle, B) with corresponding supraspinous ligament rupture seen in Sagittal-T2-STIR (yellow arrow, C); (D-E) images from the same patient showing a midsagittal CT shows a spinous process fracture two levels above the burst fracture (black arrow, D) with corresponding supraspinous ligament rupture seen in Sagittal-T2-STIR (yellow arrow, E). Abbreviations: CT, computed tomography; STIR: short tau inversion-recovery.

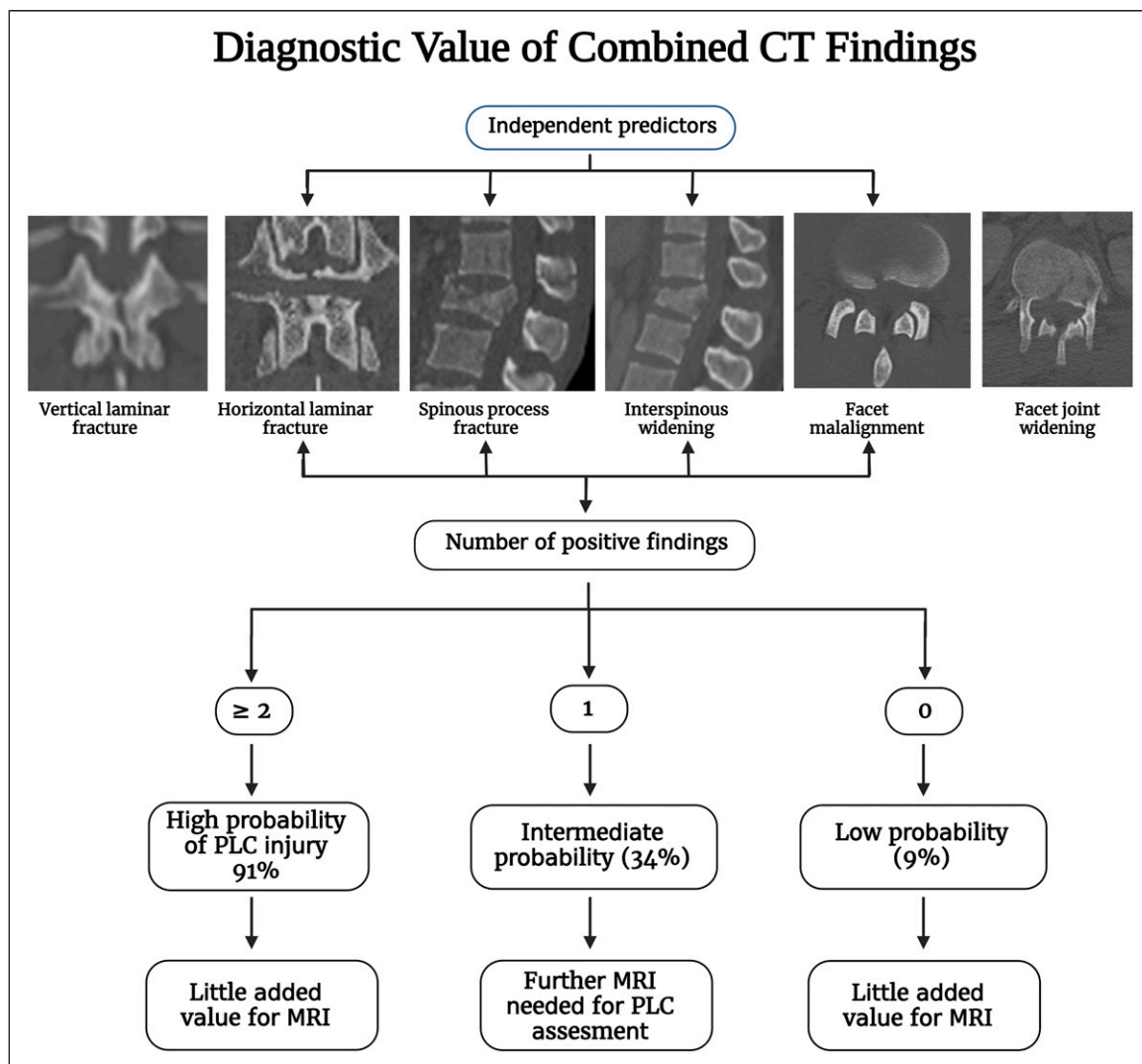


Figure 15. Diagnostic value of combined computed tomography findings for thoracolumbar posterior ligamentous complex assessment.

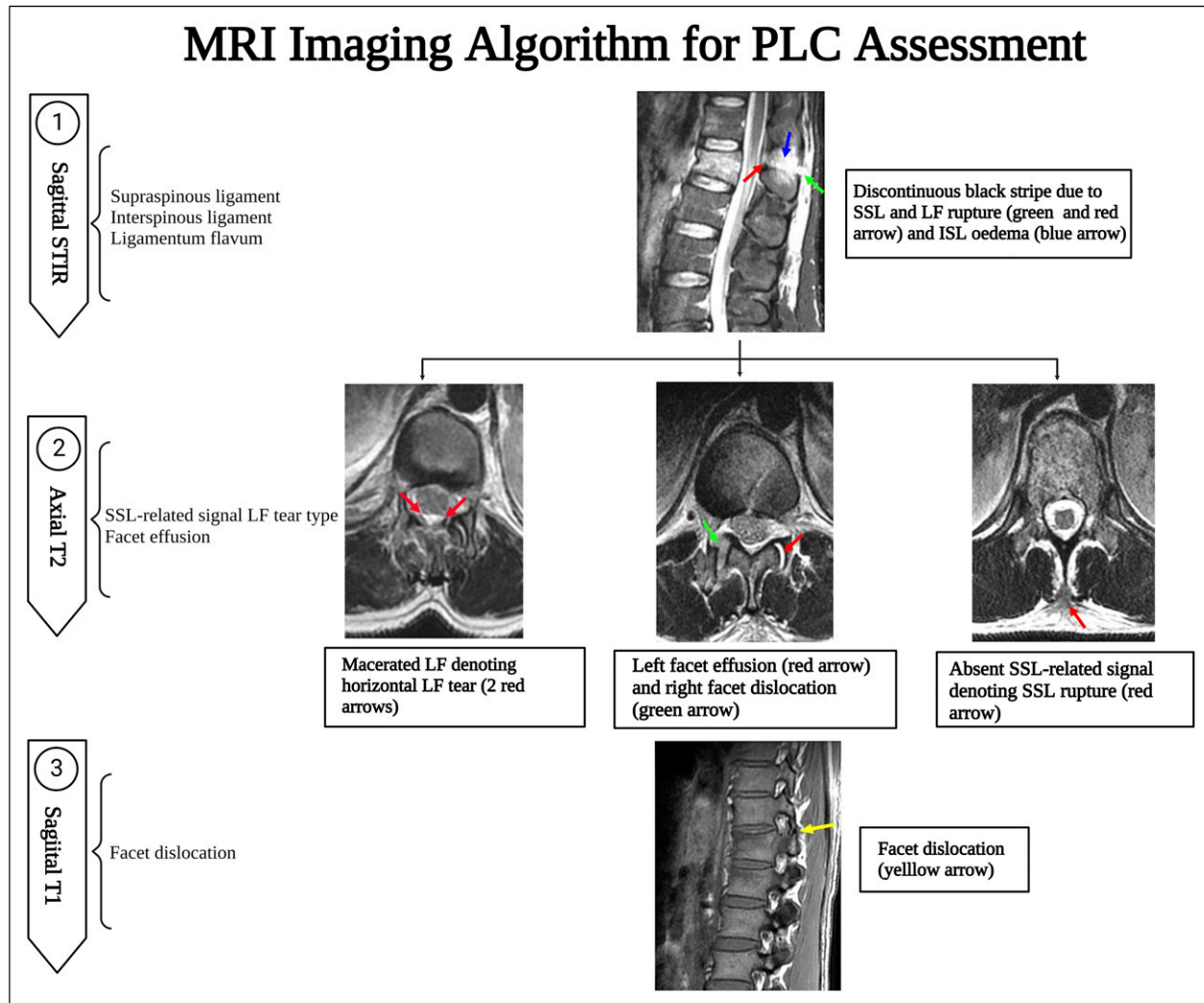


Figure 16. Magnetic resonance imaging algorithm for thoracolumbar posterior ligamentous complex assessment.

change TLF classification or treatment decisions in up to 30% of cases.^{22,24}

Pitfalls of Interpretations of PLC Injury in CT

Osteoporosis. Osteoporosis may reduce the accuracy of CT in detecting HLF or SPF. Furthermore, osteoporosis may cause osseous injuries out of proportion to PLC injury, lowering the PPV of CT findings for PLC injury.³² For instance, in osteoporotic patients, SPF can occur even with low-energy trauma and hence are less predictive of PLC injury. However, the impact of osteoporosis on CT accuracy is difficult to assess because not all patients have DEXA scans in the trauma setting.⁶

Multiple Injuries. In case of multiple contiguous injuries, HLF or SPF may occur proximal to the most severe fracture level depending on the injury vector and thus go unnoticed (Figures

14A-D). Non-contiguous fractures should be assessed independently because PLC injury at a second level may be treated separately or lead to instrumentation extension.

Supine CT vs. Standing X-Ray. Supine CT may be less sensitive than standing X-ray for detecting ISW and facet subluxation due to reduced bone displacement in the supine position. This may explain why even a subtle subluxation of the facet joints on CT may be highly predictive of PLC injury.⁷

Interpretation Morphology vs Mechanism Based. Because CT interpretation of PLC necessitates a thorough understanding of 3D imaging anatomy and pathomechanics, it may vary depending on experience and training.³⁴ Furthermore, in addition to the morphological interpretation of CT findings, interpretation based on the presumed mechanism of injury is critical.^{34,48} The distinction between HLF and VLF is a perfect example based on their

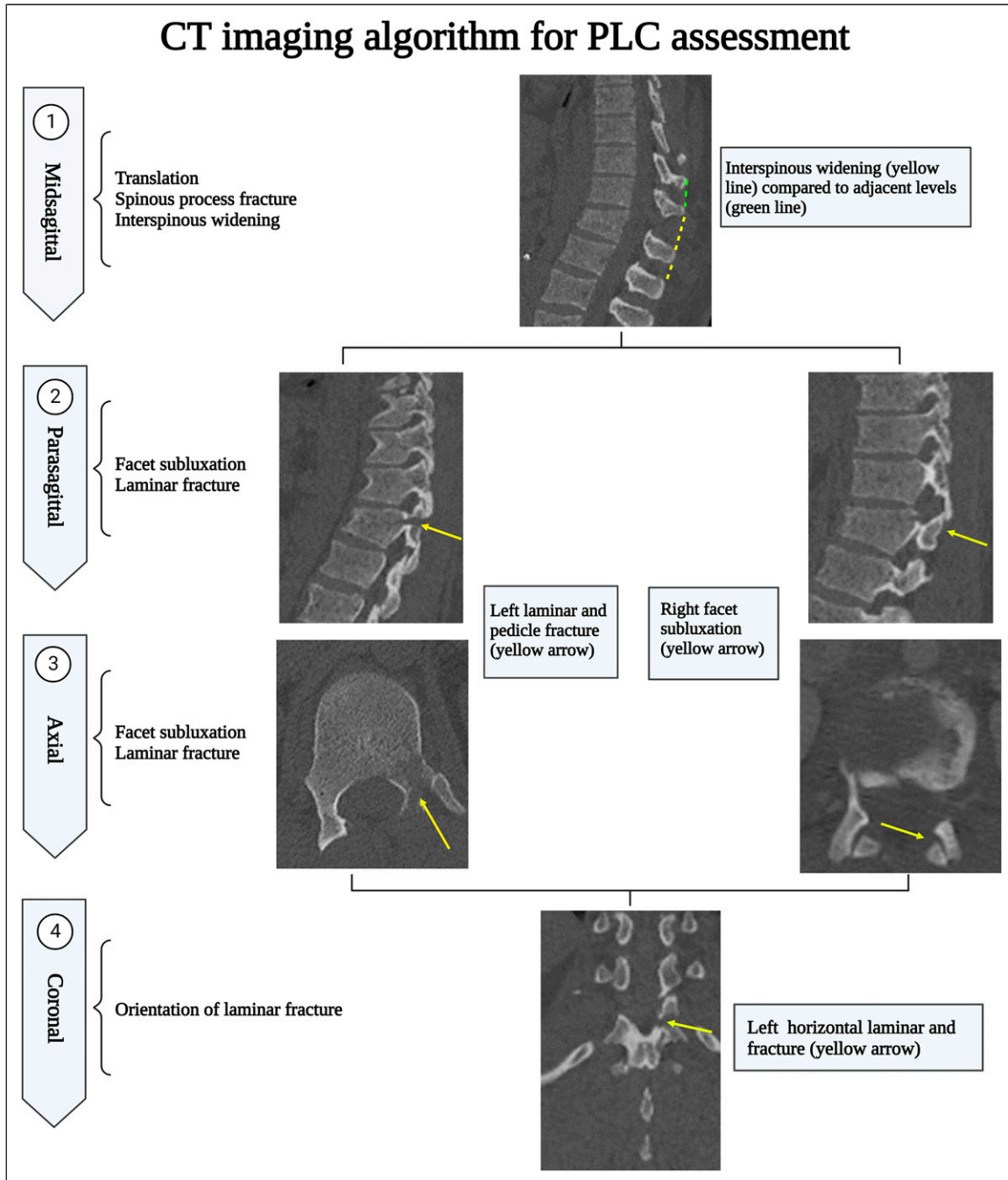


Figure 17. Computed tomography imaging algorithm for thoracolumbar posterior ligamentous complex assessment.

distinct pathomechanics: flexion-distraction vs axial compression.

because of the lumbar lordosis and inherent stability of this region.⁴⁰

Interregional Variations. Most studies evaluating CT accuracy for detecting PLC injury include a mixed cohort of thoracic and lumbar fractures without accounting for anatomical and biomechanical variations of the regions.^{52,53} Aly et al have shown that CT may be highly accurate (95%) in detecting PLC injury in lower lumbar fractures (L3-L5)

Suggested Step-by-step Algorithm for MRI and CT Assessment of PLC Injury

MRI Assessment of PLC Injury. A suggested algorithm for MRI PLC assessment is provided in Figure 16. Assessing the four PLC structures in all imaging sequences and planes

may be time-consuming, which could explain the low reliability. As a result, focusing on the key PLC components and the most sensitive sequences is critical for developing a simple, yet efficient algorithm for MRI interpretation.²⁶ SSL and LF are the key PLC structures because of their biomechanical importance as well as the high accuracy of MRI. In contrast, ISL and FC are less critical because of limited biomechanical importance or poor specificity of MRI, respectively.²⁴ The sagittal STIR is the most useful in screening for SSL, ISL, and LF injuries, which are sagittally oriented due to their high sensitivity to oedema (Figure 16).²⁶ T2 axial is the second most crucial sequence as it can incorporate the discontinuous black stripe in sagittal STIR with the absence of SSL associated with diffusely macerated LF.⁷ In most cases, these two sequences adequately evaluate PLC damage. T1 axial /sagittal is the most sensitive to detect malalignment of facet joints due to its superb ability to detect anatomical details.²⁴ However, facet malignment is difficult to assess in MRI and may be the least reliable and sensitive finding of PLC injury.

CT Assessment of PLC Injury

A suggested algorithm for MRI PLC assessment is provided in Figure 17. A CT algorithm focuses on the CT findings independently associated with PLC injury and the best plane for detecting them. The midsagittal CT plane is the most useful in screening for VBT, ISW, and SPF. Then a parasagittal plane helps screen laminar fracture and facet misalignment. However, in case of a laminar fracture, coronal reconstruction images are the best to display the fracture line orientation to distinguish VLF from HLF, which is clinically significant.³⁴ Facet subluxations are the most likely to be overlooked; hence all image planes should be checked for malalignment of any facet articular surfaces. Finally, axial CT may be the most useful to measure FJW because of its orientation.²³ FJW and VLF are the most likely findings to identify PLC injury falsely and, therefore, should be distinguished from HLF and other types of facet malalignment.¹²

Limitations

The systematic review was limited by data heterogeneity, precluding a meta-analysis from being performed. Another limitation of data heterogeneity is the inconsistent definitions of reference standards because some studies used operative findings to define PLC injury while others used MRI findings or surgeon consensus. Moreover, there is still a need for studies that provide a higher level of evidence to help guide decision-making utilizing available imaging options. While only English articles were included, which may have limited the global generalizability of these studies, there is no evidence of systematic biases due to language restrictions in medical meta-analyses. Finally, the proposed CT and MRI

algorithms were developed based on the authors' own experience. As a result, before being widely implemented in clinical practice, those algorithms should be validated in a multicenter prospective agreement study.

Conclusion

We developed a systematic imaging algorithm for detecting PLC injury in CT and MRI. The pitfalls of image interpretation, as well as pearls for avoiding them, were thoroughly discussed. Furthermore, the predictive value of various CT findings and their morphological variations were discussed based on the available literature. A consensus-based definition of CT findings and a more detailed analysis of their predictive value for PLC injury are required. The implementation of those CT and MRI algorithm will potentially improve the accuracy and reliability of PLC assessment. However, before being widely implemented in clinical practice, those algorithms should be validated in a multicenter prospective reliability study.

Declaration of Conflicting Interests

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