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ORIGINAL PAPER

Prediction of posterior ligamentous complex injury in thoracolumbar fractures using non-MRI imaging techniques

Shanmuganathan Rajasekaran [1] · **Anupama Maheswaran** [1] · **Siddharth N. Aiyer** [1] · **Rishi Kanna** [1] · **Srikanth Reddy Dumpa** [1] · **Ajoy Prasad Shetty** [1]

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Abstract
Purpose We aimed to formulate a radiological index based on plain radiographs and computer tomography (CT) to reliably detect posterior ligamentous complex (PLC) injury without need for MRI.
Methods Sixty out of 148 consecutive thoracolumbar fractures with doubtful PLC were assessed with MRI, CT and radiographs. PLC injury was assessed with the following radiological parameters: superior-inferior end plate angle (SIEA), vertebral body height (BH), local kyphosis (LK), inter-spinous distance (ISD) and inter-pedicular distance (IPD) and correlated with MRI findings of PLC injury. Statistical analysis was performed to identify the predictive values for the parameters to identify PLC damage.
Results MRI identified PLC injury in 25/60 cases. The ISD and LK were found to be significant predictors of PLC injury. On radiographs the mean LK with PLC damage was 25.86° compared to 21.02° with an intact PLC ($p = 0.006$). The ISD difference was 6.70 mm in cases with PLC damage compared to 2.86 mm with an intact PLC ($p = 0.011$). In CT images, the mean LK with PLC damage was 22.96° compared to 18.44° with an intact PLC ($p = 0.019$). The ISD difference was 3.10 mm with PLC damage compared to 1.62 mm without PLC damage ($p = 0.005$).
Conclusions On plain radiographs the presence of LK greater than 20 °(CI 64–95) and ISD difference greater than 2 mm (CI 70–97) can predict PLC injury. These guidelines may be utilised in the emergency room especially when the associated cost, availability and time delay in performing MRI are a concern.

Keywords Posterior ligamentous complex · Thoracolumbar fractures · Interspinous distance · Local kyphosis · Spinal deformity

✉ Shanmuganathan Rajasekaran
sr@gangahospital.com

1 Department of Spine Surgery, Ganga Hospital, 313, Mettupalayam Road, Coimbatore, India

Introduction

The treatment strategies of thoracolumbar fractures are largely based on the classification systems which have undergone periodic change with the better understanding of the biomechanics of the spine [1–5]. Most of the recent classification systems have stressed on the importance of assessing the integrity of the posterior ligament complex (PLC) for assessment of instability [6–9] as these injuries are unstable and can result in late onset progression of deformity with poor functional outcomes [6, 7].

PLC injury as an independent factor in consideration of treatment, was first instituted by Vaccaro et al. in the thoracolumbar injury classification [8, 9]. The recent AO spine thoracolumbar fracture classification has also incorporated tension band failures as a part of type B injuries [10, 11]. MRI is the modality of choice for the imaging and confirmation of PLC injury [12–15]. Hyperintense signal changes on short tau inversion recovery (STIR) images can accurately identify PLC injury complex [5, 12, 15]. Use of an MRI in the primary assessment of a thorocolumbar fracture is not a routine standard of care in most trauma centres for reasons of availability, increased cost and difficulties of an MRI in acute trauma settings and in the presence of polytrauma [16–19].

In the absence of an MRI the chances of a missed PLC injury with a poor clinical result remain high. We probed the possibility of identifying a PLC damage reliably using plain radiographs and CT scan parameters so that the assessment and treatment can be optimised even in the absence of an MRI.

Methods

The study was approved by the institutional review board and performed in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Plain radiographs, CT scans and MRI of 148 consecutive patients with thoracolumbar fractures (T11–L2) admitted to a tertiary care spine unit between January 2013 and March 2015 were analysed in the study. Exclusion criteria were (a) pathological fractures, (b) multilevel contiguous and non-contiguous injuries, (c) fractures with obvious spinous process split indicating tension band failure, and (d) fractures with translation injuries or dislocations (Fig. 1) which imply an obvious PLC injury [15]. After exclusion of the above, a total of 60 cases were selected for final analysis.

MRI was used as a reference standard to assess the presence or absence of PLC injury. The PLC complex includes the following structures: supraspinous and interspinous ligaments, facet capsules and ligamentum flavum. T_2weighted images were assessed for the presence of hyperintense signal changes in the PLC complex and hyperintense signal change in the fat suppressed images (Fig. 2). The PLC complex integrity was ascertained on independent evaluation of the MRI by a radiologist and a spine surgeon using a 1.5 T MRI (Magnetom Symphony Seimens, Germany).The inter-observer reliability was found to be good (K - 0.80). Discrepancies were settled by mutual consent. Plain radiographs and mid-sagittal CT scans were assessed for the following parameters:

(1) *Superior inferior end plate angle* (SIEA): The angle formed between the lines drawn along the superior and inferior end plate of the fractured vertebra (Fig. 3).
(2) *Vertebral body height* (BH): The vertebral body height was measured at two locations; first along the anterior vertebral body margin between the anteriosuperior corner and the anteroinferior corner of the fractured vertebral body and second along the posterior vertebral body margin between the posteriosuperior corner and the posteroinferior corner of the fractured vertebral body. The loss in body height was assessed by comparing the fractured body height with the mean dimensions of the uninvolved superior and inferior vertebral body (Fig. 3).
(3) *Local kyphotic deformity* (LK): The angle formed between the lines drawn along the superior end plate of the cephalad and the inferior end plate of the caudal uninvolved vertebra (Fig. 3).
(4) *Interspinous distance* (ISD): The distance between the spinous process of the cephalad normal vertebra and the fractured vertebra measured at the midpoint of the spinous process; this distance was compared with the caudal uninvolved segment (Fig. 3).
(5) *Interpedicular distance* (IPD): This was measured as the distance between the medial borders of the two pedicles of the fractured vertebra. This was compared to mean of the uninvolved adjacent segment cephalad and caudal to the fractured segment. Measurements were done on PACS using VEPRO software. These parameters were analysed to predict PLC injury when compared with MRI diagnosed PLC injury.

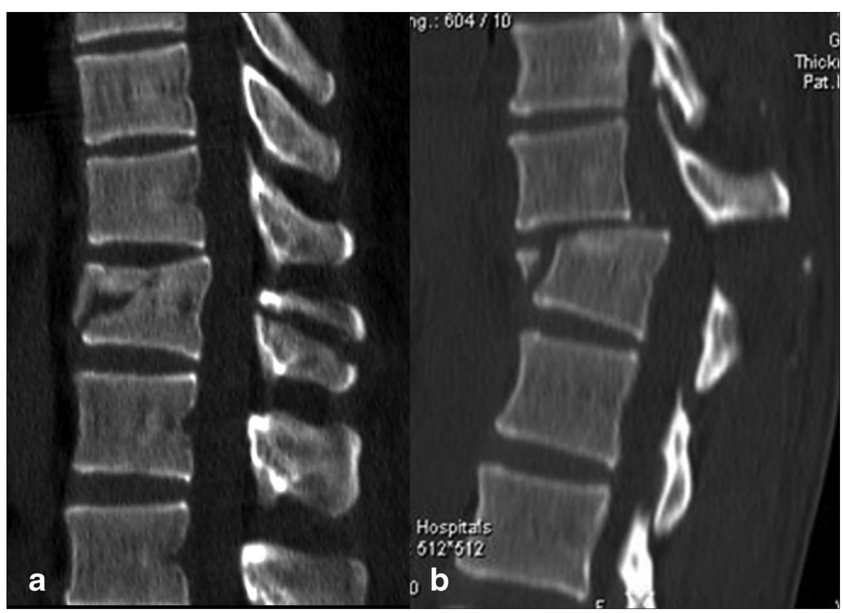

Fig. 1 Exclusion criteria. (**a**) CT image showing obvious PLC injury indicated by spinous process split fracture. (**b**) CT image showing obvious PLC damage indicated by translational injury

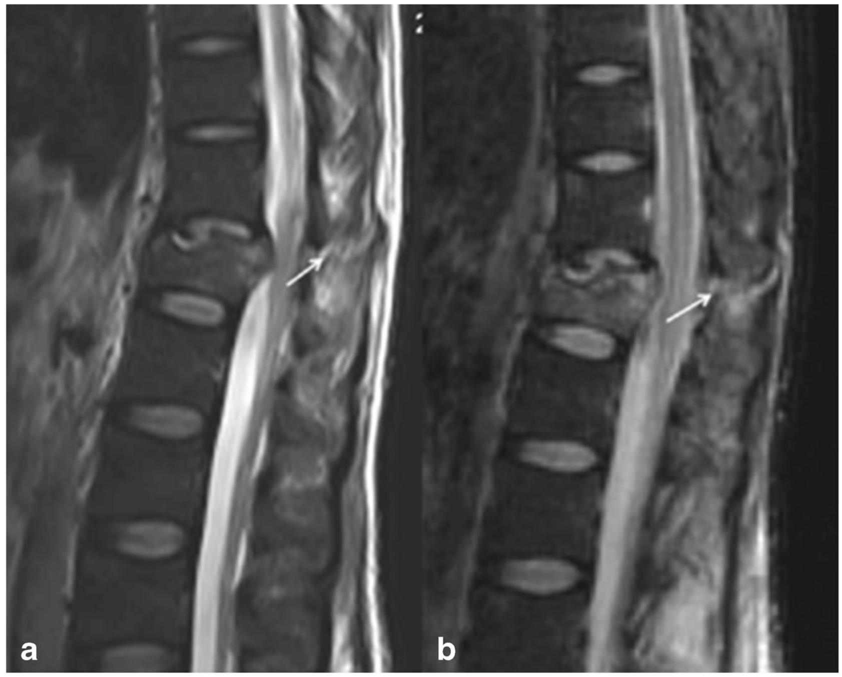

Fig. 2 MRI images. (**a**) T_2 weighted sagittal section image showing hyperintense signal (*white arrow*) change extending across from the ligamentum flavum, interspinous ligaments and supraspinous ligaments. (**b**) Fat suppressed (STIR) images showing disruption of the PLC complex (*white arrow*) including ligamentum flavum, interspinous ligaments and supraspinous ligaments

Statistical analysis

The five variables LK, SIEA, BH (at anterior and posterior locations), IPD and ISD were statistically tested for their individual contribution to the assessment of PLC status. Significant variables, at $p < 0.05$, were chosen for further analysis. Sensitivity, specificity, and positive predictive value (PPV) at various cut-offs were calculated along with percentage of failures within and at various small ranges to measure chance of failure. An ROC curve was then utilised to calculate the approximate probability of PLC damage at different ranges of measurement values for each of the parameter studied. A combinatorial analysis was also performed, where either of the factors (deformity or ISD) was present and for when both the factors were simultaneously present.

Results

A total of 148 consecutive thoracolumbar spine fractures (T11-L2) were seen during the study period. There were 124 males and 24 females. The mean age was 40 years (range 15–66 years). There were 40 cases with translational injuries/fracture dislocations; 39 cases with multilevel injuries and nine cases with obvious spinous process fractures. After exclusion 60 cases were included in the final analysis. MRI identified 25 cases with features of PLC injury. Among the five parameters assessed LK and ISD were found to have a positive correlation in identification of PLC injury on both plain radiograph and CT scan (Tables 1 and 2).

Analysis of plain radiographs for LK and ISD

The mean LK for the PLC injured group was 25.86° when compared to mean LK of 21.02° in the PLC intact group ($p = 0.006$). The mean ISD for the PLC injured group was 6.7 mm compared a to mean ISD of 2.86 mm for the PLC intact group ($p = 0.01$). Assessing LK and ISD as individual factors the sensitivity for LK of 20 ° had a sensitivity of 85 % and a specificity of 33 % to identify PLC injury. With progressive increase of LK angle to 30° showed an increase in specificity to 97 % and sensitivity of 35 %. Considering ISD as an individual factor, an increase of 2 mm compared to the uninvolved distal segment was associated with a sensitivity of 90 % and specificity of 36 %. When considering presence of both factors of LK greater than 20° and ISD greater than 2 mm, sensitivity was 75 % and specificity was 53 %.

Analysis of CT scan for LK and ISD

The mean LK for the PLC injured group was 22.96° when compared to mean LK of 18.44° in the PLC intact group ($p = 0.01$). The mean ISD for the PLC injured group was 3.10 compared to mean ISD of 1.62 mm for the PLC intact group ($p = 0.005$). Assessing LK of 20 degrees, as an individual factor had a sensitivity of 76 % and a specificity of 54 % to identify PLC injury. With progressive increase of LK angle to 30° showed an increase in specificity to 97 %. Considering ISD as an individual factor, an increase of 2 mm compared to the uninvolved distal segment was associated with a sensitivity of 60 % and specificity of 57 %. When considering presence of both factors of LK greater than 25° and ISD greater

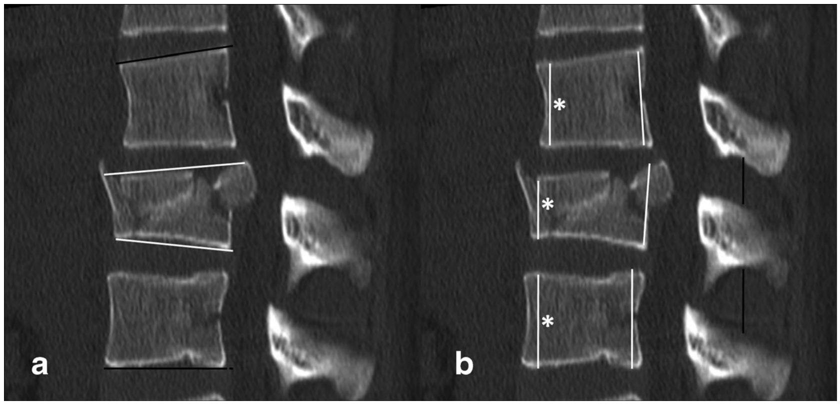

Fig. 3 (**a**) Mid-sagittal cut of the CT spine showing the superior inferior end plate angle (SIEA) subtended between *white lines* and local kyphosis (LK) angle subtended between *black lines*. (**b**) Mid sagittal cut showing the anterior body height measured by (*white lines with asterix*) and posterior body height measured by (*white lines*). The interspinous distance measured by *black lines*. (Note similar measurement were performed on the plain radiographs as well)

than 2.5 mm the specificity was 97 %. The plot for the percentage of cases with PLC injury against the various ranges of LK and ISD intervals when measured on CT images, indicated an increase at LK of 20° and ISD of 2 mm (Fig. 4).

Discussion

Thoracolumbar fractures constitute 50–60 % of all spinal injuries and incidence rates for thoracolumbar fractures have been quoted as 30–60/1,00,000 population [20, 21]. Thoracolumbar fractures are the most frequent spinal fractures noted in clinical practice and 60 % of these injuries affect the transitional zone from T10-L2 [22]. These injuries are results of high velocity injuries such as motor vehicle accidents and fall from heights [20–23] and have concomitant injuries in other regions in up to 50 % of cases [23].

Surgeons all over the world have strived for a classification system that will help them provide a common language of description, assess instability and provide treatment guidelines for thoracolumbar fractures [1–4, 9, 11]. The recent classification published by the Spine Trauma Study Group and AO Spine Thoracolumbar Injury Classification provides importance to the integrity of the PLC complex [9, 11]. PLC injury makes the injury unstable and its integrity has a bearing on the final plan of treatment in thoracolumbar fractures [6, 7, 9]. Smith et al. have noted that the PLC damage is an important factor to consider in thoracolumbar fractures because of the

Table 1 Results for the variables when assessed on plain radiographs

Measurement	PLC injury	Number	Mean	Std. Deviation	P-value
SIEA angle (degrees)	No	35	17.99	8.43	0.057
	Yes	25	22.62	8.51	
LK deformity angle (degrees)	No	35	21.02	5.85	*** 0.006**
	Yes	25	25.86	6.02	
BH anterior	No	35	53.4	13.0	0.244
	Yes	25	49.2	12.7	
BH posterior	No	35	15.1	10.9	0.190
	Yes	25	11.5	8.9	
IPD (mm)	No	35	18.9	16.0	0.955
	Yes	25	19.1	13.5	
ISD (mm)	No	35	2.86	1.98	*** 0.011**
	Yes	25	6.70	6.01	

PLC posterior ligament complex, *SIEA* superior inferior end plate angle, *LK* local kyphotic deformity, *BH* body height, *IPD* interpedicular distance, *SSD* supra spinous distance, *ISD* interspinous distance

Angles are measured in degrees, distance in millimetres, and body height has been expressed as a percentage of reduction compared to adjacent uninvolved segment.

* Statistical significance at $p < 0.05$

Table 2 Results for the variables when assessed on CT images

Measurement	PLC injury	Number	Mean	Std. Deviation	P-value
SIEA angle (degrees)	No	35	14.76	7.64	0.071
	Yes	25	18.38	7.43	
LK Deformity angle (degrees)	No	35	18.44	7.03	*** 0.019**
	Yes	25	22.96	7.18	
BH anterior	No	35	38.6	13.70	0.559
	Yes	25	40.73	13.96	
BH posterior	No	35	11.37	9.38	0.361
	Yes	25	9.66	4.79	
IPD (mm)	No	35	19.01	10.98	0.887
	Yes	25	19.42	10.91	
ISD (mm)	No	35	1.62	1.16	*** 0.005**
	Yes	25	3.10	2.24	

PLC posterior ligament complex, *SIEA* superior inferior end plate angle, *LK* local kyphotic deformity, *BH* body height, *IPD* interpedicular distance, *SSD* supra spinous distance, *ISD* interspinous distance

Angles are measured in degrees, distance in millimetres, and body height has been expressed as a percentage of reduction compared to adjacent uninvolved segment.

* Statistical significance at $p < 0.05$

biomechanical stresses affecting this transition zone [7]. The disruption of the posterior ligamentous structures not only makes the injury unstable but also has an implication in deciding the need for surgical stabilisation and may influence the surgical approach [6]. PLC is a relatively avascular structure and is considered to have low healing potential; thus injury to the PLC complex may be better treated with surgical intervention [7]. This growing understanding of the importance of PLC, has resulted in its incorporation into recent classification systems, and accurate identification of a PLC injury is necessary to formulate appropriate treatment strategies.

In a survey conducted among the spine trauma study group members vertebral body translation, diastases of facets on CT scan and interspinous widening greater than 7 mm were rated highest by members to indicate PLC damage [15]. In absence of such plain radiographic/CT scan findings, identification of PLC injury becomes difficult and MRI is considered to be essential for PLC assessment [13].

MRI has shown to be highly sensitive for detection of PLC injury [4, 5, 24–26]. Lee reported on reliability of MRI to identify PLC injury and concluded that MRI is highly sensitive, specific and accurate investigation for identifying PLC injury [24]. Crosby et al. compared inter-observer variation between surgeon, radiologist and resident trainees in identifying PLC injury using MRI and found it to be an accurate investigation irrespective of years of training [12].

Rihn et al. noted that MRI was highly sensitive but had a poor positive predictive value suggesting a high number of false positives. They concluded that surgical decisions purely based on MRI assessment of PLC may lead to unnecessary surgical procedures [26]. In a critical appraisal of literature on assessment of PLC damage, authors concluded that MRI has a tendency to overestimate PLC damage and have raised concerns over MRI being used as a reference standard for diagnosis of PLC damage [27].

Though MRI can be considered to be highly sensitive for identification of PLC injury, use of MRI as a standard of care in patients with thoracolumbar injuries, especially without a neurological involvement, is not universal. Routine use of MRI in the acutely injured patient has many drawbacks and limitations [16]. The cost of an MRI and availability are major logistical problems. The time required to complete the imaging sequence compared to CT scan is considerably longer, thus precluding the routine use of MRI in the assessment of PLC especially in the unstable patient [16].

Computer tomography is now considered the investigation of choice in the diagnosis of spine fractures [17–19]. Brown evaluated 3,537 cases of blunt spinal trauma with spiral computer tomography and noted that 99.3 % of all spinal fractures were accurately identified [18]. Wurmb reported on diagnostic work-up time in patients with multiple injuries and concluded that mulitslice helical CT shortens time to diagnosis and may be considered first line diagnostic modality in polytrauma patients [17]. Considering that CT scans are accurate in identifying spine fractures, a predictive index for PLC injury on CT scans would be valuable.

We analysed five variables on CT scan and plain radiographs and found statistically significant values for predicting PLC injury for LK and ISD using both investigational modalities. When considering LK as an individual factor the sensitivity for LK of 20 ° was 76 % for CT scans and 85 % on plain

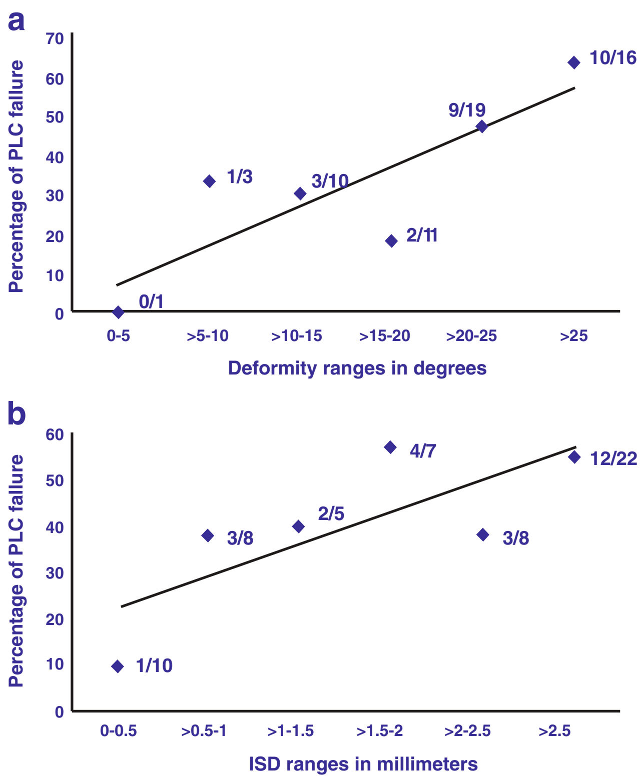

Fig. 4 (**a**) Analysis of CT images for local kyphotic deformity. The graph shows the percentages of PLC failures within various deformity ranges. *Marked diamond* plots show data labels indicating number of PLC failures/total number of cases within respective ranges. The *curve* shows an increase in percentage of PLC injuries beyond 20° of local kyphotic deformity. (**b**) Graphical plot for analysis of CT images for interspinous distance. The graph shows the percentages of PLC failures within various ranges of increased interspinous distance compared to the uninvolved distal segment. *Marked diamond* plots show data labels indicating number of PLC failures/total number of cases within respective ranges. The *curve* shows an increase in percentage of PLC injuries beyond ISD greater than 2 mm compared to distal uninvolved segment

radiographs. The local kyphotic deformity variable is affected in both AO type A3 and A4 fractures where PLC may be intact and in cases with posterior tension band failures as seen in AO type B1 and B2 injuries. AO type A3 and A4 may have significant fracture of the vertebral body which may account for increased deformity angle. When considering a cut off of 20 °, these fractures form the false positives resulting in lower sensitivity.

Considering ISD as an individual variable the sensitivity for ISD of 2 mm from the uninvolved adjacent segment was 60 % on CT scan and 90 % for radiographs. Any widening on the ISD would typically be associated with AO B1 and B2 injuries with PLC damage. AO A3 and A4 injuries with intact PLC are less likely to show widening of the ISD. Considering this fact, ISD would be specific to identifying PLC injury. The specificity of ISD of 2 mm was 57 % for CT scan and 36 % for plain radiographs. When the ISD increased to 3 mm the specificity increased to 83 % for CT scan and 56 % for plain radiographs. This specificity increases to over 90 % at ISD over 4 mm.

Variations were noted in the measurements for BH, ISD and IPD comparing radiographs and CT images. However as these variables are relative measurements, measured in comparison with the adjacent uninvolved segments, the differences were not apparent in the final results. These variations can be ascribed to more accurate delineation of bony structure detail on CT images and difficulty in accurately delineating the borders of the posterior elements on plain radiographs. From this study, it appears that findings on plain radiographs may be sufficient to satisfactorily predict PLC damage; however, CT does offer improved visualisation of posterior elements such that more accurate assessment of the interspinous widening can be performed. Under these circumstances, identification of a 2-mm discrepancy between the interspinous distances on CT scan may be better justified.

There are some limitations to this study; manual measurements have the element of human error and an automated software tool may improve the results. Also, it will be useful if these predictive values can be validated with intra-operative confirmation in a larger cohort in a future study.

Conclusion

Our study has been successful in formulating a predictive radiological index to identify PLC damage. On plain radiographs the presence of kyphosis greater than 20 ° has a sensitivity of 85 % (confidence interval 64–95), and interspinous distance difference greater than 2 mm has a sensitivity of 90 % (confidence interval 70–97). We suggest that emergency room assessment which shows deformity greater than 20° and ISD greater than 2 mm on plain radiographs or CT images may be considered indicators of probable PLC injury. These guidelines may be utilised in the emergency room decision making especially when the associated cost, availability and time delay in performing MRI are a concern in a patients with polytrauma.

Compliance with ethical standards

Funding Ganga Orthopaedic Research & Education Foundation, Coimbatore.

Conflict of interest None

Disclosures None

Ethical considerations All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

1. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. Eur Spine J 3(4):184–201
2. Hwee Weng Dennis H, Hwan Tak H (2011) A review of thoracolumbar spine fracture classifications. J Orthop Trauma 1: 235406
3. Sethi MK, Schoenfeld AJ, Bono CM, Harris MB (2009) The evolution of thoracolumbar injury classification systems. Spine J 9(9): 780–788
4. Dai LY, Jiang SD, Wang XY, Jiang LS (2007) A review of the management of thoracolumbar burst fractures. Surg Neurol 67(3): 221–231
5. Hiyama A, Watanabe M, Katoh H, Sato M, Nagai T, Mochida J (2015) Relationships between posterior ligamentous complex injury and radiographic parameters in patients with thoracolumbar burst fractures. Injury 46(2):392–398
6. Kepler CK, Felte RF, Rihn JA (2012) Current Concepts: Classification of Thoracolumbar Fractures. Seminars Spine Surg 24(4):210–215, WB Saunders
7. Smith HE, Anderson DG, Vaccaro AR, Albert TJ, Hilibrand AS, Harrop JS, Ratliff JK (2010) Anatomy, biomechanics, and classification of thoracolumbar injuries. Seminars Spine Surg 22(1):2–7, WB Saunders
8. Vaccaro AR, Lim MR, Hurlbert RJ, Lehman RA Jr, Harrop J, Fisher DC, Group STS et al (2006) Surgical decision making for unstable thoracolumbar spine injuries: results of a consensus panel review by the Spine Trauma Study Group. J Spinal Disord Tech 19(1):1–10
9. Vaccaro AR, Lehman RA Jr, Hurlbert RJ, Anderson PA, Harris M, Hedlund R et al (2005) A new classification of thoracolumbar injuries: the importance of injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. Spine 30(20):2325–2333
10. Reinhold M, Audigé L, Schnake KJ, Bellabarba C, Dai LY, Oner FC (2013) AO spine injury classification system: a revision proposal for the thoracic and lumbar spine. Eur Spine J 22(10):2184–2201
11. Vaccaro AR, Oner C, Kepler CK, Dvorak M, Schnake K, Bellabarba C et al (2013) AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers. Spine 38(23):2028–2037
12. Crosby CG, Even JL, Song Y, Block JJ, Devin CJ (2011) Diagnostic abilities of magnetic resonance imaging in traumatic injury to the posterior ligamentous complex: the effect of years in training. Spine J 11(8):747–753
13. Lee JY, Vaccaro AR, Schweitzer KM, Lim MR, Baron EM, Rampersaud R et al (2007) Assessment of injury to the thoracolumbar posterior ligamentous complex in the setting of normal-appearing plain radiography. Spine J 7(4):422–427
14. Morais DF, de Melo Neto JS, Meguins LC, Mussi SE, Ferraz Filho L JR, Tognola WA (2014) Clinical applicability of magnetic resonance imaging in acute spinal cord trauma. Eur Spine J 23(7): 1457–1463
15. Vaccaro AR, Lee JY, Schweitzer KM, Lim MR, Baron EM, Öner FC et al (2006) Assessment of injury to the posterior ligamentous complex in thoracolumbar spine trauma. Spine J 6(5):524–528
16. Salgado Á, Pizones J, Sánchez-Mariscal F, Álvarez P, Zúñiga L, Izquierdo E (2013) MRI reliability in classifying thoracolumbar fractures according to AO classification. Orthopedics 36(1): e75–e78
17. Wurmb TE, Frühwald P, Hopfner W, Keil T, Kredel M, Brederlau J, Kuhnigk H (2009) Whole-body multislice computed tomography as the first line diagnostic tool in patients with multiple injuries: the focus on time. J Trauma Acute Care Surg 66(3):658–665
18. Brown CV, Antevil JL, Sise MJ, Sack DI (2005) Spiral computed tomography for the diagnosis of cervical, thoracic, and lumbar spine fractures: its time has come. J Trauma Acute Care Surg 58(5):890–896
19. Hessmann MH, Hofmann A, Kreitner K, Lott C, Rommens PM (2006) The benefit of multislice CT in the emergency room management of polytraumatized patients. Acta Chir Belg 106(5):500
20. Hu R, Mustard CA, Burns C (1996) Epidemiology of incident spinal fracture in a complete population. Spine 21(4):492–499
21. Jansson KÅ, Blomqvist P, Svedmark P, Granath F, Buskens E, Larsson M, Adami J (2010) Thoracolumbar vertebral fractures in Sweden: an analysis of 13,496 patients admitted to hospital. Eur J Epidemiol 25(6):431–437
22. Rajasekaran S, Kanna RM, Shetty AP (2015) Management of thoracolumbar spine trauma: An overview. Indian J Orthop 49(1):72
23. Reinhold M, Knop C, Beisse R, Audigé L, Kandziora F, Pizanis A, Bühren V (2010) Operative treatment of 733 patients with acute thoracolumbar spinal injuries: comprehensive results from the second, prospective, internet-based multicenter study of the Spine Study Group of the German Association of Trauma Surgery. Eur Spine J 19(10):1657–1676
24. Lee HM, Kim HS, Kim DJ, Suk KS, Park JO, Kim NH (2000) Reliability of magnetic resonance imaging in detecting posterior ligament complex injury in thoracolumbar spinal fractures. Spine 25(16):2079–2084
25. Haba H, Taneichi H, Kotani Y, Terae S, Abe S, Yoshikawa H et al (2003) Diagnostic accuracy of magnetic resonance imaging for detecting posterior ligamentous complex injury associated with thoracic and lumbar fractures. J Neurosurg Spine 99(1): 20–26
26. Rihn JA, Yang N, Fisher C, Saravanja D, Smith H, Morrison WB, Vaccaro AR (2010) Using magnetic resonance imaging to accurately assess injury to the posterior ligamentous complex of the spine: a prospective comparison of the surgeon and radiologist: Clinical article. J Neurosurg Spine 12(4):391–396
27. Van Middendorp JJ, Patel AA, Schuetz M, Joaquim AF (2013) The precision, accuracy and validity of detecting posterior ligamentous complex injuries of the thoracic and lumbar spine: a critical appraisal of the literature. Eur Spine J 22(3):461–474