X-RAY AND CT SCAN PREDICTORS OF DAMAGE TO THE POSTERIOR LIGAMENTOUS COMPLEX IN FRACTURES OF THE VERTEBRAL BODIES OF THE THORACOLUMBAR JUNCTION

Systematic review and meta-analysis

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Objective of the review was to identify, basing on literature data, the most reliable X-ray and CT signs of damage to the posterior ligamentous complex (PLC) in fractures of the vertebral bodies of the thoracolumbar junction, initially interpreted as type A according to the AOSpine classification. The systematic review was carried out according to the recommendations of PRISMA. The search in PubMed, MEDLINE and Cochrane Library databases revealed 491 articles on relevant issues. Once the inclusion and exclusion criteria have been met, 7 original articles from peer-reviewed scientific journals for the last 10 years were selected for a systematic review, 6 of which were included in the meta-analysis. In all articles, the authors identified two groups of patients: with and without damage to the PLC. The PLC damages were confirmed by MRI and intraoperatively. Radiographic and CT spondylometric parameters were identified, which had statistically significant differences between the groups. To determine predictors of PLC damage, the values of these parameters were subjected to regression analysis. This was followed by a meta-analysis of random and fixed effects models depending on the homogeneity of the data. Statistical heterogeneity was assessed using the X-square test with the null hypothesis of the absence of significant differences in all studies, as well as the heterogeneity index – I^2. For the graphical display of the results, forest plots were built. Local kyphosis angle >25°, Cobb angle >16° and difference between interspinous distances >2.54 mm are CT scan predictors of PLC damage. The parameters characterizing the interspinous relationship were studied in no more than two studies, but at the same time they always had statistically significant differences between the groups with and without PLC injuries, therefore, they cannot be ignored during diagnosis. Anterior/posterior vertebral height ratio, anterior vertebral height ratio, sagittal index and suprajacent/subjacent parameters are not the predictors of PLC damage.

Key Words: spine, injury, posterior ligamentous complex, injury predictors, systematic review, meta-analysis.

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The role of posterior ligamentous complex (PLC) in stability of the spine is beyond question [1]. In case of injuries of the lower thoracic and lumbar spine, MRI enables to visualize PLC injuries to a high precision. Nevertheless, in a number of clinical situations with injuries originally treated as type A according to the AOSpine classification, MRI is not performed. According to the literature sources [2, 3], these circumstances can cause diagnostic errors in 30–41 % of cases in which type B injuries remain unidentified. To optimize the diagnosis process and eliminate tactical errors in the treatment of this category of patients, it would be advantageous to predict PLC damage using CT scan [4].

The objective is to identify, basing on literature data, the most reliable X-ray and CT signs of damage to the posterior ligamentous complex (PLC) in fractures of the vertebral bodies of the thoracolumbar junction, initially interpreted as type A according to the AOSpine classification.

Methodology of search and selection of publications. A systematic selection of literature was done according to the recommendations of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [5] in PubMed, MEDLINE, and Cochrane Library. Keywords: "posterior ligamentous complex injury", "prediction of posterior ligamentous complex injury", "correlation of posterior ligamentous complex injury", "assessment of posterior ligamentous complex injury". Moreover, the search was conducted using references and the similar article section of key articles.

Inclusion criteria for publications in the review:

– papers published from 2010 to 2021;

– injuries to the vertebral bodies of the thoracolumbar junction (T11–L2), interpreted as type A according to the AOSpine classification;

– comparative studies;

– X-ray or CT findings of injured spinal motion segments (SMS) with spondylometric parameters;

– availability of an MRI interpretation or intraoperative diagnosis for a control assessment of PLC integrity.

Exclusion criteria: multilevel spinal injury; pathologic vertebral fractures.

At the first selection stage, following the introduction of search queries, 491 articles were found in databases. After that, duplicate studies were removed, and as a result, 435 papers remained. At the second stage, the abstracts were analyzed, and 422 articles were deleted after using the above inclusion and exclusion criteria. At the third stage, full-text versions of published articles were studied. Then 6 more articles that do not meet the inclusion–exclusion criteria were eliminated. As a result, 7 original articles from peer-reviewed scientific journals over the past 10 years were selected for the review.

Analysis of selected articles. In terms of design, all 7 articles [6–12] were retrospective studies. The number of observations in them varied from 40 to 314. All patients underwent radiation diagnostics to identify the localization and nature of the injury. In four studies it was CT scan; in one case – plain X-ray; and in other two – X-ray and CT scan. All cases of vertebral fractures after radiation diagnosis were included in the studies and classified as type A injuries. After that, MRI scan was performed in six studies to identify the PLC integrity; in one case, PLC rupture was established intraoperatively. According to MRI data, the posterior ligamentous complex integrity was assessed using the Haba et al. method [13]. In all studies, MRI scan was performed in T1- and T2-weighted image modes, as well as in STIR mode. Following MRI scans (or after surgery), some patients had PLC ruptures. These injuries were reclassified to Type B. They made up Group 1 (with PLC rupture). The remaining patients who did not have PLC injuries on MRI imaging or surgery made up Group 2 (with intact PLC).

Database formation. The data extracted from the selected articles were recorded in Microsoft Excel software (Office 2019 for Mac) in the form of a table. The information in it was filled in by boxes: author and year of the study, study design, number of patients, fracture localization, types of diagnostic studies (X-ray, CT and MRI), evaluated ligaments of the posterior ligamentous complex on MRI: supraspinous ligament (SSL), interspinous ligament (ISL), ligamentum flavum (LF), and facet ligament (FL). Damage to any of these structures was considered as PLC injury. According to the data of selected publications, two groups of injuries were determined: 1 – with a rupture of PLC, 2 – with an intact PLC. Each group includes data on the number of observations, diagnostic techniques, as well as the values of the estimated spondylometric parameters.

The general characteristics of the articles included in the review by the number of observations, the design of the study, and diagnostic techniques are given in Table 1.

CT predictors of PLC injury. For both groups, the calculation and comparison of the spondylometric parameters of the injured SMS were performed. Moreover, the statistical significance of the differences between them was identified. We have analyzed only those parameters which were measured by the same technique for different authors. Additionally, for ease of presentation, parameters which are measured in the same way in different studies, but had various designations, are given one and the same abbreviation, as in the study by Jiang et al. [6] The latter contains the maximum number of parameters. The designations of the spondylometric and CT parameters, which are shown in each publication, and the measurement technique are given in Tables 2 and 3, as well as in Fig. 1, 2.

Analysis of the selected articles showed that in all studies, first of all, the authors determined statistically significantly different parameters in groups 1 and 2. For this, parametric and nonparametric techniques were applied to identify the significance of differences between groups depending on the type of distribution. Then regression analysis techniques were used to identify predictors of PLC injury. To define the value of each parameter at which it can be considered as PLC injury predictor, the relative risk was calculated.

The parameter values that had statistically significant differences between the groups, as well as the ranges at which these parameters can be regarded as predictors of PLC rupture, are given for each study in Tables 4 and 5.

Therefore, among statistically significant parameters, the most common are: LK – in four studies, CA – in three, supra- and interspinous distances (SSD, ISD) and their relations in variations (ISD ratio, ISDM, ISDM2, SSD (suprajacent/subjacent) – in three. The following parameters: AED, GA, GL, AEIEA, BFOFV, and CC were studied in no more than two studies. Nevertheless, there were always statistically significant differences between the groups with and without PLC injuries.

It is worth noting that after using regression techniques, some parameters with statistically significant differences between the groups were not predictors of PLC injury, and vice versa.

Meta-analysis. While performing the meta-analysis, we were guided by the methodological recommendations approved by the Order of the Center for Healthcare Quality Assessment and Control of the Ministry of Health of the Russian Federation as of December 29, 2017 No. 181-od. We used the certified Review Manager 5.4 (RevMan) software designed by the Cochrane Collaboration.

Six out of seven publications were included in the meta-analysis. A study by Radcliffe et al. [11] was not involved in the quantitative analysis due to the lack of all the necessary data. Then the methodological quality of each study was evaluated according to the Russian version of the Newcastle – Ottawa scale [15]. In the next stage, the statistical heterogeneity of the outcomes included in the meta-analysis was estimated using the Chi-squared criterion (χ^2) with the null hypothesis to the absence of significant differences in all studies. The threshold value of χ^2 criterion for assessing statistical significance was 0.10. Therefore, $p < 0.10$ indicates the presence of statistically significant

Table 1
General description of the publications included in the review

Authors	Year	Study design	Patients, n	Age of patients, y.o.	Diagnostic studies	Subject of assessment	Intact PLC, n	PLC rupture, n
Jiang et al. [6]	2018	Retrospective	60	50.73 ± 12.76	CT and MRI	SSL, ISL, LF, FL	33	27
Rajasekaran et al. [7]	2016	Retrospective	60	40.0 (15–66)	X-ray, CT and MRI	SSL, ISL, LF, FL	35	25
Chen et al. [8]	2016	Retrospective	105	40.70 ± 11.94	X-ray and MRI	ISL and SSL	44	61
Hiyama et al. [9]	2014	Retrospective	40	47.7 ± 15.8	CT and MRI	ISL and SSL	15	25
Mi et al. [10]	2017	Retrospective	84	47.4	CT and MRI	SSL, ISL, LF	48	36
Radcliff et al. [11]	2012	Retrospective	46	43.5	CT and MRI	SSL, ISL, LF	30	16
Hartmann et al. [12]	2019	Retrospective	314	51.8 (20–88)	X-ray and CT, surgery	PLC intraoperatively	225	89

heterogeneity, and at $p \geqslant 0.10$ there is no statistically significant heterogeneity.

The I^2 heterogeneity index was also calculated for the outcomes. The interpretation of the statistical heterogeneity assessment was performed using Cochrane Collaboration guidelines [16]:

– 0–40 % – insignificant heterogeneity;
– 30–60 % – moderate heterogeneity;
– 50–90 % – significant heterogeneity;
– 75–100 % – high heterogeneity.

Out of all the evaluated indicators, a high heterogeneity index was found for LK (I^2 = 84 %), CA (I2 = 75 %) and A/P ratio (I^2 = 76 %). In this regard, a random effects model was chosen for these indicators in the meta-analysis. If $p \geqslant 0.10$ in χ^2 test but I^2 heterogeneity index > 40 %, when choosing a mathematical model of meta-analysis, first of all, the results of statistical heterogeneity assessment according to χ^2 test were considered.

At the fifth stage, a meta-analysis was conducted on outcomes based on continuous data. We have applied data concerning the mean values, their standard deviation in two comparison groups (1st – rupture of PLC and 2nd – intact PLC) and the total number of patients in the corresponding comparison groups in all the studies involved in the meta-analysis. The mean bias was used as a generalized measure of the outcome. Since less than 10 studies were included in the meta-analysis, the publication bias was not assessed.

The meta-analysis included parameters which were found in more than one study, even if they did not have statistically significant differences between the groups in each of the studies. The values of the parameters included in the meta-analysis are given in Table 6.

The meta-analysis results are given below. The significance of the statistical heterogeneity of the results and the analysis of the combined data are shown in Table 7.

The forest plots were constructed to graphically display the results (Fig. 3–8).

Therefore, a meta-analysis of the combined data revealed the statistical significance of the differences between the two groups demonstrated by 3 parameters: LK, CA, and ISDM2.

The data needed to determine RR (relative risk) were obtained only for the LK parameter from four studies: Jiang et al. [6], Chen et al. [8], Hiyama et al. [9], and Mi et al. [10]. The parameter limit is LK > 25° as the strongest angle. Data for LK > 25° are given in two studies [6, 8]. In a study by Mi et al. [10], the data necessary for calculating RR are given for LK > 15°; in Hiyama et al. [9] – for LK > 20°. These data are integrated into the analysis, since if a PLC rupture happened in this sample at LK > 15° and LK > 20°, it would clearly also occur at LK > 25°.

The combined data indicate that for values of LK > 25°, the relative risk of an unfavorable outcome is RR = 1.40 (95 %), confidence interval (CI) [1.11; 1.78]. Correspondingly, it can be argued that LK value of more than 25° is a statistically significant ($p = 0.006$) predictor of an unfavorable outcome (PLC rupture). The statistical heterogeneity assessment of the study results revealed moderate heterogeneity: χ^2 with $p = 0.15$, $I^2 = 43$ % (Fig. 9).

For the other two parameters, which had a statistical significance of differences between the two groups, there were no data for determining RR in the publications. The average values for all studies are identified for them. They were for groups with intact PLC and with PLC rupture, respectively: CA – 13.1 and 16.5°, ISDM2 – 0.52 and 2.54 mm.

Discussion

The choice of surgical technique for fractures of the lower thoracic and lumbar spine vertebrae is often defined by the assessment of injury stability [17, 18]. Moreover, the role of PLC in ensuring stability is unquestionable [1]. The PLC, which protects the spine from excessive transmission, rotation, flexion and extension, consists of FC, ISL, SSL and LF [19, 20]. Some biomechanical studies have shown that the main PLC structure

Table 2
Spondylometric parameters shown in the literature review

Spondylometric parameters, measurement units	Measurement technique
AVH, PVH, mm — Anterior (posterior) vertebral body height	Anterior vertebral height (AVH) and posterior vertebral height (PVH) of the injured vertebra (Fig. 1)
UAVH, LAVH, mm — Anterior vertebral body height of the upper (lower) adjacent vertebra	Anterior vertebral height of cranial (UAVH) and caudal (LAVH) vertebra in relation to the fracture (Fig. 1)
A/P ratio, % — Anterior/posterior vertebral height ratio	The ratio of the anterior vertebral height of the injured vertebra to the posterior one: A/P ratio = AVH/PVH (Fig. 1)
AVH ratio, % — Anterior vertebral height ratio	The ratio of the anterior vertebral height to an average sum of the anterior heights of the cranial and caudal vertebrae: AVH ratio = AVH/(UAVH + LAVH)/2 (Fig. 1)
LK, deg. — Local kyphosis angle	Local kyphosis angle (Fig. 2)
RA, deg. — Region angle	Region kyphosis angle (Fig. 2)
GA, deg. — Gardner angle	Gardner angle (Fig. 2)
SI, deg. — Sagittal index GI, deg. — Gardner index	Sagittal (Gardner) index: SI (GI) = RA (GA) is a normal kyphotic contour, equal to 5°, 0°, -10° for thoracic, thoracolumbar and lumbar spine, respectively [14]
CA, deg. — Cobb angle	Cobb angle (Fig. 2)
ISD, UISD, LISD (мм) — Interspinous distance	Interspinous distances (Fig. 1)
ISD ratio (%), ISDM (mm), ISDM2, mm ILD, SSD, ISD (suprajacent/subjacent), %	Interspinous ratio ISD ratio = ISD/UISD + LISD; ISDM = ISD - (UISD + LISD)/2; ISDM2 = ISD - LISD (Fig. 1) ILD (suprajacent/subjacent) = ILD/ILD¹ SSD (suprajacent/subjacent) = SSD/SSD¹ ISD (suprajacent/subjacent) = ISD/ISD¹ (Fig. 2)
ISA, UISA, LISA, deg. — Interspinous angle	Interspinous angles formed by ISD, UISD, LISD (Fig. 1)
AEIEA, deg. — Anterior edge-inferior endplate angle	Angle between inferior and anterior endplates of a fractured vertebra [8]
AED, mm — anterior edge displacement	Vertebral displacement in the sagittal plane [8]
BFOFV, % — bony fragment in front of the fractured vertebra	A fractured fragment under the anterior longitudinal ligament [8]
STR, % — sagittal transverse ratio	The ratio of anteroposterior diameter of the spinal canal to the medial-lateral diameter at an injury level [11]
CC — canal compromise	The value of traumatic spinal canal stenosis [10]

Table 3
The list of investigated spondylometric parameters in publications included in the systematic review

Author	Parameters under study
Jiang et al. [6]	AVH, UAVH, LAVH, PVH, A/P ratio, AVH ratio, LK, RA, SI, GA, GI, CA, ISD, UISD, LISD, ISD ratio, ISDM, ISA, UISA, LISA
Rajasekaran et al. [7]	LK, CA, AVH ratio, PVH ratio, ISDM2
Chen et al. [8]	AEIEA, AED, CA, SI, LK, A/P ratio, AVH ratio, BFOFV
Hiyama et al. [9]	CA, LK, AVH ratio, AED, STR, ILD и SSD и ISD (suprajacent/subjacent)
Mi et al. [10]	CC, AVH ratio, PVH ratio, LK, CA
Radcliff et al. [11]	LK, SI, A/P ratio, AED, STR, ISD
Hartmann et al. [12]	LK, CA, A/P ratio, SSD (suprajacent/subjacent)

that keeps SMS stable is a supraspinal ligament [21, 22].

Classification proposed in 1994 by Magerl et al. [23] was based on several basic criteria, including the PLC integrity. In 2005, Vaccaro et al. [24–26] suggested the classification of TLICS, which for the first time highlighted the key role of PLC in terms of surgical treatment planning. The latest AOSpine classification for thoracolumbar spine fractures also included PLC injuries as a crucial criterion for type B injuries [27]. In the paper by Smith et al. [28] it was mentioned that injury to PLC not only causes trauma to be unstable, but also affects the choice of surgical technique. Dahdaleh et al. [29] concluded

Table 4
Values of spondylometric parameters with injured and uninjured PLC

Author	Statistically significant parameter	Groups		p value
		Intact PLC	PLC rupture	
Jiang et al. [6]	GA, deg.	11.98 ± 6.03	16.66 ± 6.02	0.004
	GI, deg.	16.83 ± 5.64	20.18 ± 6.53	0.037
	ISD, mm	28.91 ± 3.50	30.81 ± 3.26	0.035
	ISD ratio, %	49.30 ± 3.72	51.96 ± 4.70	0.017
	ISDM, mm	-0.44 ± 2.18	1.11 ± 2.67	0.016
Rajasekaran et al. [7]	CA, deg.	18.44 ± 7.03	22.96 ± 7.18	0.019
	ISDM2, mm	1.62 ± 1.16	3.10 ± 2.24	0.005
Chen et al. [8]	AEIEA, deg.	76.65 ± 5.58	71.56 ± 6.79	0.049
	AEIEA < 70°, n (%)	9.00 (8.60)	26.00 (24.80)	0.017
	AED, mm	9.34 ± 3.36	9.89 ± 3.12	0.034
	LK, deg.	15.55 ± 5.28	23.8 ± 5.88	0.021
	LK > 25°, n (%)	8.00 (7.60)	23.00 (21.90)	0.030
	BFOFV, %	18.10 (19.00)	40.00 (42.00)	0.009
Hiyama et al. [9]	CA, deg.	12.60 ± 6.20	18.40 ± 8.00	0.027
	LK, deg.	13.20 ± 5.00	17.90 ± 7.60	0.024
	LK > 20°, n (%)	1.00 (7.00)	14.00 (56.00)	0.002
	LK > 15°, n (%)	6.00 (4.00)	18.00 (72.00)	0.048
	SSD (suprajacent/subjacent), %	88.0 ± 24.3	118.80 ± 53.40	0.015
Mi et al. [10]	CC	0.11 ± 0.08	0.28 ± 0.15	<0.001
	LK, deg.	9.30 ± 5.17	18.93 ± 5.37	<0.001
Radcliff et al. [11]	AED > 3.5 mm	No data available	No data available	0.029
Hartmann et al. [12]	LK, deg.	11.10 ± 6.00	18.00 ± 7.40	<0.05
	CA	10.38 ± 7.81	16.85 ± 5.99	<0.05
	A/P ratio	0.73 ± 0.14	0.63 ± 0.24	<0.05

Fig 1
Measurement scheme of vertebral body height in injured and adjacent vertebrae, interspinous distances and interspinous angles

that fractures associated with PLC injury are an undoubted indication for surgical stabilization of injured SMS.

The STSG (Spine Trauma Study Group) has concluded to the effect that fracture morphology, spinal cord function and PLC integrity are the most significant criteria for defining surgical techniques. Different injury variants were presented, in which PLC ruptures were evidence for isolated posterior stabilization, or in combination with anterior corporodesis of the injured SMS [30].

Patients with compression fractures of the lower thoracic and lumbar vertebrae and undiagnosed PLC injury operated through anterior approaches have a risk of destabilization of the instrumentation system and kyphotic deformity with the need for subsequent posterior fixation [31]. Chen et al. [32] report that PLC injury is a criterion of indications for posterior fixation after anterolateral decompression and anterior stabilization. Thus, in practice, an assessment of PLC injury is required to define the surgical approach. PLC examination methods vary from physical to MRI scan [33].

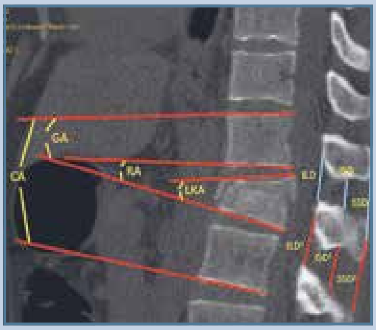

Fig 2
Measurement scheme of CA, GA, RA, LKA and interspinous ratio

Touch examination of interspinous space has low sensitivity [34]. Radiological methods of examination are essential for detecting fractures and assessing the severity of injury. Plain X-ray is a more convenient and cost-effective technique for diagnosing injuries compared to CT scan. It gives indirect evidence of PLC injury. Nevertheless, the value in predicting PLC injury has not yet built a consensus [35, 36]. In a study by Petersilge et al. [36] no significant correlation was found between the radiological type of fractures and PLC injury. CT scan is a more accurate diagnostic method for spinal injury. Currently it is considered to be the gold standard [37]. Some studies have indicated that up to 2/3 of the fractures found on CT imaging were missed during X-ray [38].

Yet the value of CT scan for the diagnosis of PLC rupture is controversial. A study by Barcelos et al. [39] has demonstrated that CT scan is reliable for assessing PLC injury in fractures of thoracolumbar spine. Vaccaro et al. [40] have shown that differences over PLC integrity in CT imaging occur more often among neurologically intact patients who have PLC injuries; according to Hitchon et al. [41], they make up about 18 %.

The results of a multicenter study performed in 2019 with the participation of seven centers from Africa, Europe, Asia and South America showed that CT parameters of injuries, previously considered predictors of PLC injuries, have considerable variability. Thus, the authors suggest performing MRI in all questionable cases [42].

Leferink et al. [2] retrospectively analyzed 160 patients with 49 type B fractures who were diagnosed before surgery using CT imaging. Intraoperatively, the authors found that approximately 30 % of type B fractures were misdiagnosed. Schnake et al. [3] observed that 41.9 % of 93 cases of type B injuries in a group of 361 patients were not recognized.

In a study by Schweitzer et al. [43] the STSG members concluded that diastasis in the facet joint on CT scan was the most reliable indicator of PLC disorder (kappa = 0.395). According to Ganjeifat et al. [44] in case of injury PLC demonstrated a reliable association with diastasis of the facet joints, as well as with an increase in interspinous distance and spinous process fracture.

Table 5

Spondylometric parameters as predictors of PLC injuries (according to publications)

Authors	Predictors of PLC rupture
Jiang et al. [6]	SI > 20°, GI > 24°, LK > 26°, ISD ratio > 56 %
Rajasekaran et al. [7]	CA > 20°, ISDM2 > 2 mm
Chen et al. [8]	AEIEA < 70°, BFOFV, LK > 25°
Hiyama et al. [9]	LK > 20°
Mi et al. [10]	CC > 0,19, LK > 14°
Radcliff et al. [11]	AED > 3.5 mm
Hartmann et al. [12]	CA + LK > 29°, CA² > 170°, LK/SI > 25°

Table 6

Spondylometric parameters according to the papers included in the meta-analysis

Parameters	Groups under study		p value
	Intact PLC	PLC rupture	
A/P ratio, %			
Jiang et al. [6]	58.37 ± 12.12	59.00 ± 9.62	0.829
Chen et al. [8]	57.53 ± 10.07	55.17 ± 10.68	0.255
Hartmann et al. [12]	73.00 ± 14.00	63.00 ± 24.00	0.050
AVH ratio, %			
Jiang et al. [6]	62.50 ± 13.03	65.73 ± 9.00	0.263
Hiyama et al. [9]	70.00 ± 14.00	63.10 ± 16.50	0.096
Mi et al. [10]	74.00 ± 13.00	71.00 ± 16.00	0.465
Rajasekaran et al. [7]	38.60 ± 13.70	40.73 ± 13.96	0.559
Chen et al. [8]	59.82 ± 91.36	56.27 ± 11.34	0.090
SI, deg.			
Jiang et al. [6]	12.84 ± 4.58	14.02 ± 6.92	0.433
Chen et al. [8]	16.77 ± 6.65	17.64 ± 6.31	0.497
LK, deg.			
Jiang et al. [6]	21.36 ± 6.70	20.66 ± 6.24	0.678
Hiyama et al. [9]	13.20 ± 5.00	17.90 ± 7.60	0.024
Mi et al. [10]	9.30 ± 5.17	18.93 ± 5.37	0.001
Rajasekaran et al. [7]	14.76 ± 7.64	18.38 ± 7.43	0.071
Chen et al. [8]	15.55 ± 5.28	23.98 ± 5.88	0.021
Hartmann et al. [12]	11.10 ± 6.00	18.00 ± 7.40	0.050
CA, deg.			
Jiang et al. [6]	10.81 ± 7.05	12.54 ± 7.54	0.362
Hiyama et al. [9]	12.60 ± 6.20	18.40 ± 8.00	0.027
Mi et al. [10]	11.20 ± 5.61	12.53 ± 8.26	0.384
Rajasekaran et al. [7]	18.44 ± 7.03	22.96 ± 7.18	0.019
Chen et al. [8]	15.26 ± 6.59	15.73 ± 8.05	0.751
Hartmann et al. [12]	10.38 ± 7.81	16.85 ± 5.99	0.050
ISDM2, mm			
Jiang et al. [6]	-2.67 ± 0.20	-0.56 ± 0.54	Recalculation
Rajasekaran et al. [7]	1.62 ± 1.16	3.10 ± 2.24	0.005

Table 7

Meta-analysis results for spondylometric parameters

Parameters	Studies, n	Heterogeneity	Mean difference	95 % CI	p
AVH ratio	5	Insignificant χ^2 with p = 0.34, I^2 = 12 %	0.09	[-3.27; 3.45]	0.96000
A/P ratio	3	High χ^2 with p = 0.02, I^2 = 76 %	3.87	[-1.88; 9.62]	0.19000
Cobb angle	6	Significant χ^2 with p = 0.0001, I^2 = 75 %	-3.41	[-5.86; -0.96]	0.00600
ISDM2	2	Moderate χ^2 with p = 0.21, I^2 = 37 %	-2.08	[-2.29; -1.87]	<0.00001
LK	6	High χ^2 with p < 0.00001, I^2 = 84 %	-5.67	[-8.39; -2.96]	<0.00010
SI	2	Insignificant χ^2 with p = 0.88, I^2 = 0 %	-1.00	[-2.94; 0.95]	0.31000

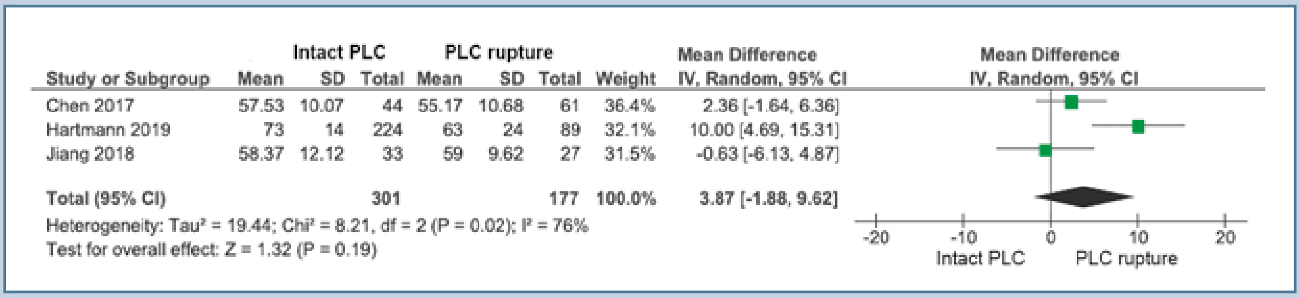

Fig 3
Forest plot of A/P ratio

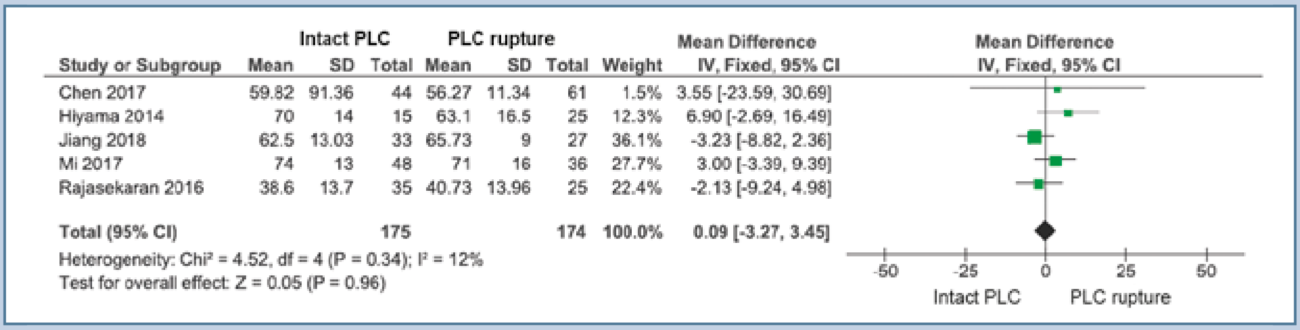

Fig 4
Forest plot of AVH ratio

Khurama et al. [45] found that translation of the vertebral body, fracture of the pedicle or arch, extension of interspinous distance and spinous process fracture, as a rule, are associated with injured PLC. Furthermore, the presence of two or more of these four CT parameters was much more possible to indicate injury to the PLC. Nevertheless, the above-mentioned CT signs (displacement, fracture of the vertebral arch pedicle, spinous process fracture, diastasis in the facet joint and pronounced increase in the interspinous distance) are rather unmistakable. They are the most likely

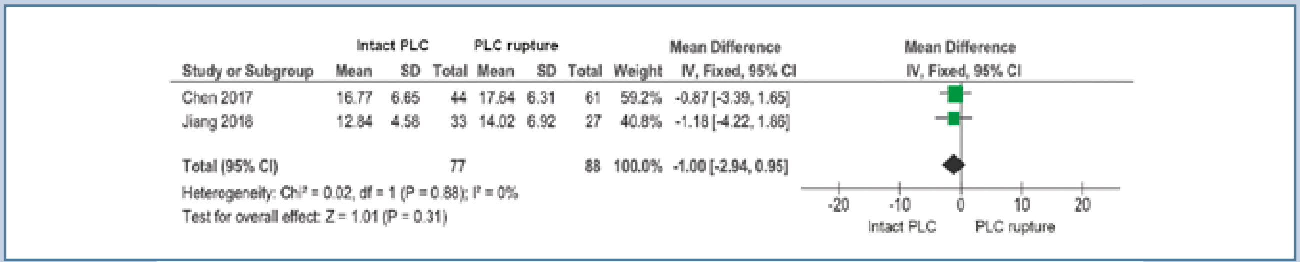

Fig 5
Forest plot of SI

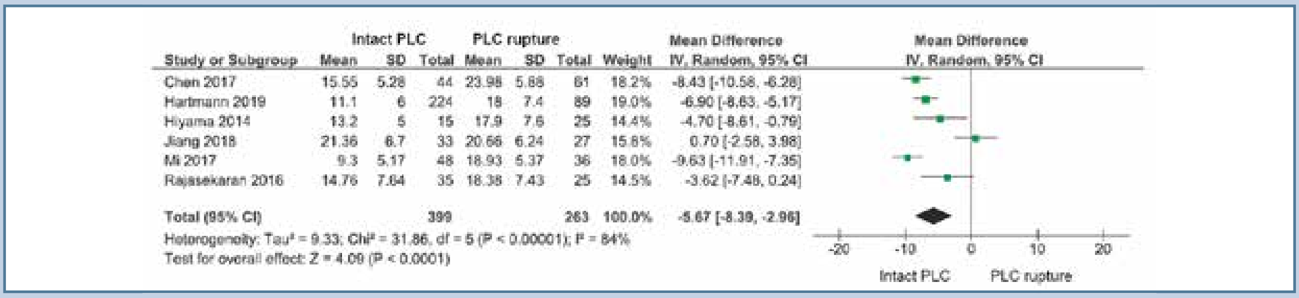

Fig 6
Forest plot of LK

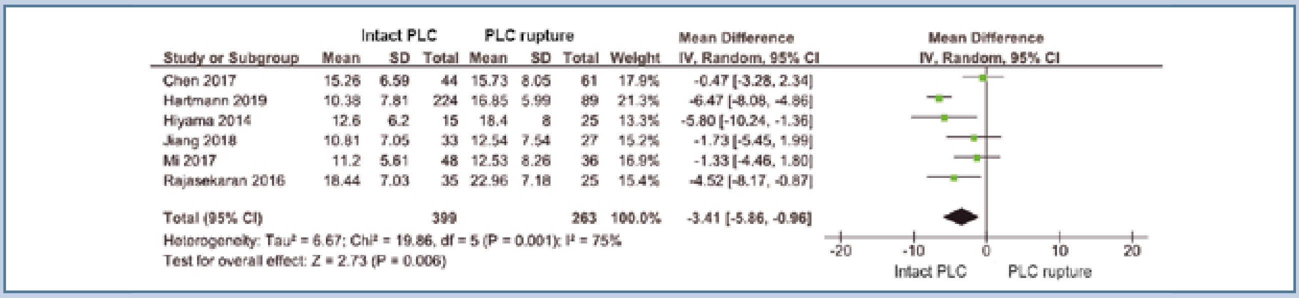

Fig 7
Forest plot of CA

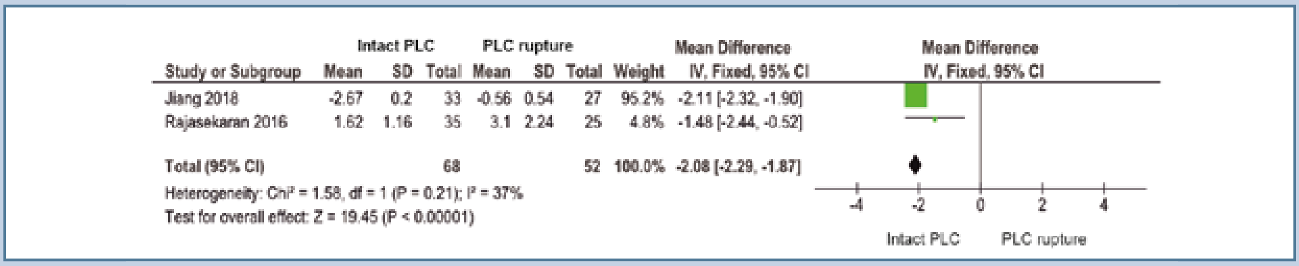

Fig 8
Forest plot of ISDM2

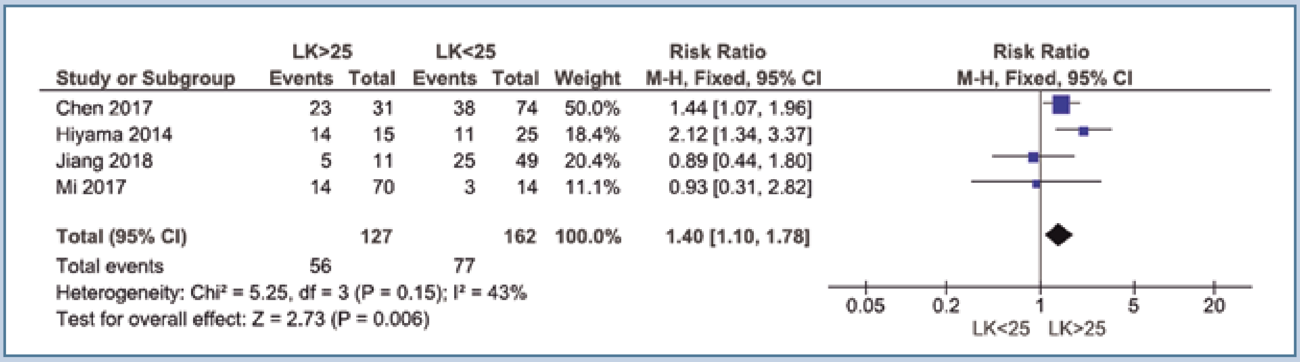

Fig 9
Forest plot of relative risk LK> 25°

CT signs of PLC injury, in which MRI is not necessary, especially in neurologically intact patients. For fractures of type A according to the AOSpine classification, when only anterior and middle columns of SMS are injured, there may be no such signs. This does not exclude injury to PLC. Fat suppressed imaging may be useful in such cases [13, 33, 34, 46–50].

Vaccaro et al. [40] and Rihn et al. [51] conducted a prospective study to identify the MRI accuracy in the diagnosis of PLC injury in patients with lower thoracic and lumbar spine fractures and compared these results with intraoperative data. In a study by Vaccaro et al., sensitivity to injury of various PLC components ranged from 79 to 90 %, and specificity – from 53 to 65 %. In a study by Rihn et al., MRI sensitivity for various PLC elements ranged from 80.4 to 100.0 %, specificity – from 57.9 to 80.5 %. In other words, MRI imaging has a relatively low specificity, which can result in overdiagnosis of PLC injuries. Similar information was received in the study by Mehta et al. [52]. The sensitivity and specificity of MRI for the diagnosis of PLC injury were lower than those previously described in the literature. The authors concluded that MRI must not be used in isolation to define treatment strategies. It should be considered that patients may have contraindications to MRI (pacemakers or other incompatible implants). The patients with multiple trauma may not be hemodynamically stable enough during the examination. They may need intubation and monitoring using devices that are not compatible with MRI [53, 54].

Ultrasound diagnostics is another testing tool for detecting PLC injuries in patients with thoracolumbar spine fractures [55]. A meta-analysis dedicated to the ultrasound diagnosis of PLC injury showed that ultrasound has high accuracy. Therefore, ultrasound can be regarded as a useful alternative to MRI when the latter is unavailable or contraindicated or when its findings are inconclusive [56].

Schroeder et al. [57] analyzed the reliability and perceived importance of PLC injury in type A fractures among 529 spine surgeons worldwide. The results of this study demonstrated that there is little reliability in defining the PLC integrity in type A fractures (kappa = 0.11). While the biomechanical importance of the PLC has not been in doubt, the inability to reliably identify the PLC integrity may limit the usefulness of M1 modifier in the AOSpine classification.

Conclusions

Local kyphosis angle more than 25°, Cobb angle more than 16° and difference between interspinous distances more than 2.54 mm are CT scan predictors of the PLC injury. The parameters describing interspinous relationships (ISD, ISD ratio, ISDM, AED, GA, GI, AEIEA, BFOFV, and CC) have been studied in no more than two studies. Meanwhile, they always had statistically significant differences between the injured and uninjured PLC groups. Thus, they should not be ignored in the diagnosis. Anterior/posterior vertebral height ratio (A/P ratio), Anterior vertebral height ratio (AVH ratio), Sagittal index (SI), and suprajacent/subjacent (SSD) parameters are not predictors of the PLC injury.

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