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Original Article

Diagnostic accuracy of ultrasound for detecting posterior ligamentous complex injuries of the thoracic and lumbar spine: A systematic review and meta-analysis

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Abstract

Background: Posterior ligamentous complex injuries of the thoracolumbar (TL) spine represent a major consideration during surgical decision-making. However, X-ray and computed tomography imaging often does not identify those injuries and sometimes magnetic resonance imaging (MRI) is not available or is contraindicated. **Objective:** To determine the diagnostic accuracy of the ultrasound for detecting posterior ligamentous complex injuries in the TL spine. **Materials and Methods:** A systematic review was carried out through four international databases and proceedings of scientific meetings. The pooled sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, diagnostic odds ratio, and their 95% confidence intervals (CIs) were estimated, by using weighted averages according to the sample size of each study. Summary receiver operating characteristic was also estimated. **Results:** A total of four articles were included in the meta-analysis, yielding a summary estimate: Sensitivity, 0.89 (95% CI, 0.86-0.92); specificity, 1.00 (95% CI, 0.98-1.00); positive likelihood ratio, 224.49 (95% CI, 30.43-1656.26); negative likelihood ratio, 0.11 (95% CI, 0.05-0.19); and diagnostic odds ratio, 2,268.13 (95% CI, 265.84-19,351.24). There was no statistically significant heterogeneity among results of included studies. **Summary:** Receiver operating characteristic (±standard error) was 0.928 ± 0.047. **Conclusion and Recommendation:** The present meta-analysis showed that ultrasound has a high accuracy for diagnosing posterior ligamentous complex injuries in patients with flexion distraction, compression, or burst TL fractures. On the basis of present results, ultrasound may be considered as a useful alternative when magnetic resonance imaging (MRI) is unavailable or contraindicated, or when its results are inconclusive.

Key words: Burst fracture, instability, posterior ligamentous complex, ultrasound

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INTRODUCTION

Current treatment approach of thoracolumbar (TL) injuries is mainly based on classifications systems involving the comprehensive assessment of all components of the spine. Those classifications had evolved significantly over the last 80 years, since schemes that only considered osseous disruptions, towards more comprehensive that evaluate the others spinal components involved in maintaining the overall spinal stability.[1]

In 2005, the Spine Trauma Study Group purposed a new classification system called the Thoracolumbar Injury Classification and Severity (TLICS) Score, which reflects accepted features cited in the literature important in predicting spinal stability, future deformity, and progressive neurologic compromise.[2] This classification includes the delineation of injury morphology, the neurologic status of the patient, and the integrity of the posterior ligamentous complex (PLC). These variables are of paramount importance for decision-making between to proceed with surgical therapy or assume a most conservative treatment with external orthotics.

The PLC, also called posterior tension band, includes the supraspinous ligament (SSL), interspinous ligament (ISL), ligamentum flavum (LF), and the facet joint capsules (FJC). Those structures protect the spine against excessive flexion, rotation, translation, and distraction; therefore, the assessment of its anatomic integrity is of paramount importance for selecting the best treatment for TL injuries.[2-4]

Currently, the preferred modality for detecting PLC injuries is magnetic resonance imaging (MRI), which provides detail of soft tissue and neural tissue. Several studies have showed that its sensitivity ranges from 79 to 100% and its specificity from 51.5-100%.[5-7]

Spinal ultrasound (US) is another noninvasive test that could be helpful in detection of PLC injuries. Since 1980s' decade, it has been used for determining intraoperative completeness of fracture reduction, being considered a safe and accurate method that provides good anatomical detail.[8-12] There is also some evidence about its potential role for detecting injuries of the PLC after TL trauma, which may be very valuable, especially when performing a MRI is not possible.[13-15]

US is more versatile than MRI; and currently, portable equipment's are widely available, making possible to perform an examination in patients that cannot be transferred due clinical conditions to the imaging room or a center with MRI capability. Cost of an US examination is also lesser than MRI, which is a major advantage in poor resource settings. Furthermore, unlike MRI, US can demonstrate the fibrillar microanatomy of tendons, ligaments, and muscles; enhancing its clinical usefulness in the surgical decision-making.[13]

Several studies have assessed the clinical performance of US for assessing TL structures after trauma, including vertebral body height, and spinal canal diameter.[12-17] The present meta-analysis was specifically performed to investigate the ability of this modality for diagnosing PLC injuries in patients with TL spine trauma.

MATERIALS AND METHODS

A systematic review and meta-analysis were carried out to estimate the diagnostic accuracy of US for identifying PLC injuries.

Search strategy

The literature search was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline.[18] Identification of relevant articles was performed in April 2013 through PubMed, EMBASE, Scopus, and Google Scholar; without restrictions or filters with regard to language or year of publication. The search terms were: "ultrasound" OR "ultrasonography" (ALL FIELDS) AND "spine" OR "spinal" OR "ligament" OR "posterior ligamentous complex" AND "injury" OR "trauma" OR "traumatic" OR "fracture".

Eligibility criteria

The inclusion criteria were: All observational studies or clinical trials, with design prospective or retrospective; evaluating the diagnostic accuracy of US for identification of PLC injuries in adults' patients (older than 18-years-old) with traumatic thoracic or lumbar fractures.

The exclusion criteria were: Studies including pediatric patients, studies that did not report the status of PLC by operative or MRI findings, and those with less than 10 participants. There were also excluded those studies including patients with osteoporotic vertebral compression fractures, primary vertebral osseous tumors, multiple myeloma, solitary plasmocytoma of the spine, or spinal metastatic disease.

Main outcome

Presence of injuries of PLC structures as confirmed by MRI and/or operative findings.

Study selection and data extraction

The titles of the articles found in the search were assessed by two independent reviewers to identify all potentially relevant articles. Then a selection by abstract was done, and an attempt was made to get the full text. For study selection, the inclusion and exclusion criteria were assessed by two independent reviewers and any discrepancies were resolved by consensus.

Two reviewers gathered data regarding study type, definition of PLC injury, reader type, assessed ligaments, and ultrasound equipment. Additionally, the following values were extracted for each study: True-positives (TP), false-positives (FP), true-negatives (TN), and false-negatives (FN).

Assessment of methodological quality

The methodological quality was assessed by two independent reviewers using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [Appendix 1].[19] Only those studies with a QUADAS total score ≥9 on the 14-item tool were considered of high quality and were included to data abstraction.

Data synthesis and analysis

On the basis of raw data from each study; pooled sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio and their 95% confidence intervals (CI) were estimated by using weighted averages according to the sample size of each individual study. Variations of sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio from different studies were displayed by plots.

The summary of receiver operating characteristic was also estimated and the result of area under curve was classified according the criteria purposed by Swets in 1988.[20] Using this guidelines, when area under the curve is between 0.5 and 0.7, the accuracy is low; between 0.7 and 0.9, moderate; and for values greater than 0.9, is deemed high.

Assessment of heterogeneity

Heterogeneity assessment was performed by means of Cochran's Q test and I^2 index, with significance set at $P < 0.10$ and at >50%, respectively.[21,22] Both indexes were used because the Cochran's Q test only informs about the presence versus the absence of heterogeneity, but it does not report on the extent of such heterogeneity; while I^2 allows quantifying the degree of heterogeneity, being a complement to the Q test.[21-23]

When heterogeneity reached any of preconceived significance criteria, pooled sensitivities and specificities were estimated by the random effect model of DerSimonian-Laird method; on contrary, if it was not statistically significant, were estimated by the fixed effect model of Mantel-Haenszel method.

Sensitivity analysis

Because of the variations on the accuracy of a diagnostic method could be found according to the definition of the main outcome, in the present study was planned to perform a subgroup analysis if the ligamentous injury was established by MRI or operative findings.

All analyses were performed using the software MetaDisc, version 1.4, (Unidad de Bioestadística Clínica, Hospital Ramón y Cajal, Madrid; Spain).

RESULTS

A total of four articles assessing the diagnostic accuracy of US for detecting PLC injuries meet the preset eligibility criteria.[13,14,24,25] The results of the literature search are presented in the Figure 1 as a flowchart.

608 articles retrieved from databases
- **2** duplicates
- **574** excluded on the basis of title and/or abstract
  - **1** animal experiments
  - **16** case reports
  - **4** commentaries and letters
  - **4** reviews
  - **6** editorials
  - **519** not relevant*

32 full-text reviews
- **3** did not meet the selection criteria
  - **1** reference group did not corrrespond to our definitions
  - **1** no well defined reference standard according to guidelines
  - **1** no 2x2 contigency table could be made

4 studies included in meta-analysis

Figure 1: Flowchart of literature search and selection of studies. *Did not investigate the diagnostic accuracy of ultrasound (US) for detecting posterior ligamentous complex injuries of the thoracic and lumbar spine

All included studies collected data prospectively.[13,14,24,25] Not all studies analyzed the entirety of PLC. In the study by Moon *et al.*, SSL, ISL, and LF were comprehensively assessed by US, MRI, and operative inspection.[13] Gallardo *et al.*, and Vordemvenne, *et al.* also performed the examination of SSL and ISL, but no additional structures was examined.[14,24] Finally, in the study by von Scotti *et al.*, they reported the exploration of SSL and ISL integrity separately.[25] No studies report the description of FJC [Table 1].

All patients included in the present meta-analysis had fractures caused by flexion-distraction, compression or burst, while there were not cases of rotational injuries. In three studies, the exact mechanism of injury was reported, yielding a pooled prevalence of flexion-distraction injuries of 31.5%; while 68.5% were caused by predominantly axial compressive forces (compression or burst fractures).[13,25,14] In the remaining study, the authors did not report the mechanisms of injuries, but they made a comprehensive examination using by computed tomography looking for injuries of lateral elements, and those patients with rotational injuries were excluded, as well as single lineal fractures across the vertebral body.[24]

Methodological quality assessment

All studies had high methodological quality (range: 12-13.5). In all studies, the reader was independent and blinded regarding the interpretation of the reference standard (operative or MRI findings), which could be a potential source of major biases. The detailed results of methodological quality assessment of each study are presented in the [Table 2].

False-positive cases were mainly related with definition of ligamentous injury on the basis of the presence of hematoma, which explained 80% of those incorrect classifications.[13,14] In a single case, the absence of ligamentous injury was determined by MRI and did not have operative corroboration because patient was treated nonoperatively.[13]

Diagnostic accuracy

Meta-analysis of US for detecting PLC injuries of the thoracic and lumbar spine yielded the following summary estimate: Sensitivity, 0.89 (95% CI, 0.86-0.92); specificity, 1.00 (95% CI, 0.98-1.00); positive likelihood ratio, 224.49 (95% CI, 30.43-1,656.26); negative likelihood ratio, 0.11 (95% CI, 0.05-0.19); and diagnostic odds ratio, 2,268.13 (95% CI, 265.84-19,351.24) [Table 3].[13,14,24,25] The Cochran's Q test and I^2 index showed that there was no statistically significant heterogeneity among analyzed studies.

Plots of the sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio are shown in Figure 2.

Summary receiver operating characteristic (± standard error) was 0.928 ± 0.047, representing high diagnostic accuracy according to the Swets's classification [Figure 3].

Sensitivity analysis

Because of the variations in the accuracy, a diagnostic method could be found according to the definition of the main outcome;

Table 1: General characteristics of included studies

Author	Year	Country	Enrolled injuries	Design	Referent	Assessed ligaments	Ultrasound equipment	Reader type	QUADAS score
Moon *et al.*	2002	Korea	Flexion distraction, bursting fracture, compression	Prospective study	Operative and/ or MRI findings	SSL, ISL, and LF	An ultrasound scanner of HDI 3000 (ATL, Bothell Washington) with a 5-10 MHz linear transducer was used	An experienced musculoskeletal radiologist who was not involved in the treatment planning and surgery	13.5
Gallardo *et al.*	2007	Mexico	Rotational injuries were excluded	Prospective	Operative findings	SSL, ISL	A 2 MHz linear probe	A radiologist who had been blinded about operative decision-making and findings	12.5
Vordemvenne *et al.*	2009	Germany	Magerl A2, A3, B1, B2	Prospective validating cohort study	Operative and MRI findings	SSL, ISL	7.5 MHz linear probe (Siemens Inc. Sonoline) in B mode performing transverse and sagittal planes	Independent and previously-trained spine surgeon	12
von Scotti *et al.*	2010	Germany	Magerl A3, B1, B2	Prospective	Operative findings	SSL, ISL	7 MHz linear probe (General Electric Healthcare, Chalfont St. Giles, United Kingdom)	A radiologist who was not involved in the treatment planning and surgery	12.5

MRI: Magnetic resonance imaging, QUADAS: Quality assessment of diagnostic accuracy studies, SSL: Supraspinous ligament, ISL: Interspinous ligament, LF: Ligamentum flavum

Table 2: QUADAS methodological quality data

Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Moon *et al.*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	Y	Y	Y
Gallardo *et al.*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	Y	N	Y
Vordemvenne *et al.*	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N
von Scotti *et al.*	Y	Y	Y	Y	Y	Y	Y	Y	U	Y	Y	Y	Y	N

QUADAS: Quality Assessment of diagnostic accuracy studies included in systematic reviews (code item: Y: Yes, N: No, U: Unclear) Question order is described as Appendix 1

Table 3: Summary of sensitivity and specificity parameters in each individual study

Reference	*n*	Sensitivity (CI 95%)	Specificity (CI 95%)
Moon *et al.*	12	0.83 (0.36-1.00)	0.83 (0.36-1.00)
Gallardo *et al.*	14	0.88 (0.47-1.00)	1.00 (0.40-1.00)
Vordemvenne *et al.*	18	1.00 (0.48-1.00)	0.77 (0.46-0.95)
von Scotti *et al.*	22	0.83 (0.36-1.00)	0.94 (0.70-1.00)

CI: Confidence interval

in the present study, it was planned to perform a subgroup analysis if the ligamentous injury was established by MRI or operative findings.

The estimation of diagnostic accuracy using MRI findings as gold standard yielded the following summary estimate: Sensitivity, 0.90 (95% CI, 0.55-1.00); specificity, 0.79 (95% CI, 0.49-0.95); positive likelihood ratio, 3.63 (95% CI, 1.42-9.28); negative likelihood ratio, 0.18 (95% CI, 0.04-0.8); and diagnostic odds ratio, 24.24 (95% CI, 2.62-224.05). The Cochran's Q test

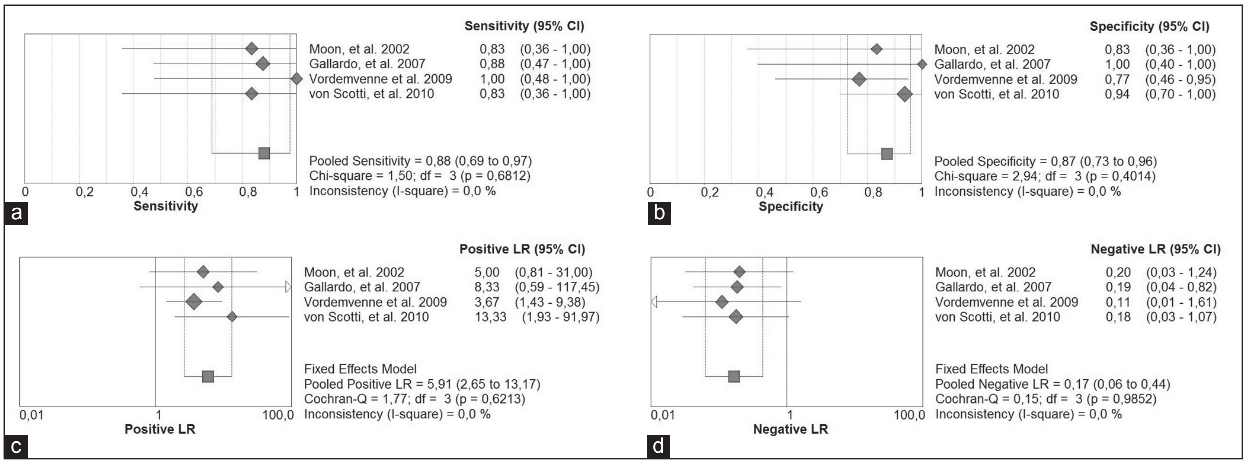

Figure 2: Plots of diagnostic accuracy measures; including sensitivity (a), specificity (b), positive likelihood ratio (c), and negative likelihood ratio (d)

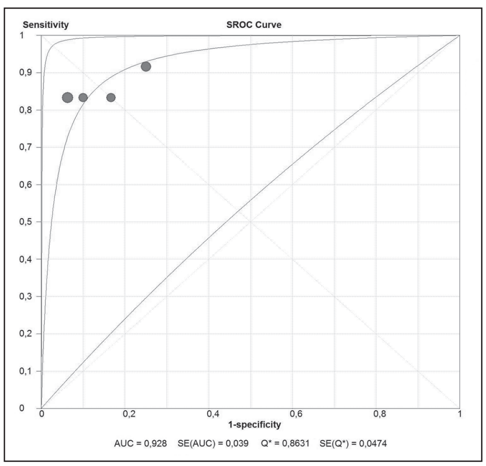

Figure 3: Plot of symmetric summary receiver operating characteristic

and I^2 index showed that there was no statistically significant heterogeneity among analyzed studies.

When only operative findings were considered, the pooled estimates were: Sensitivity, 0.91 (95% CI, 0.71-0.99); specificity, 0.89 (95% CI, 0.73-0.97); positive likelihood ratio, 4.98 (95% CI, 2.31-10.72); negative likelihood ratio, 0.17 (95% CI, 0.06-0.44); and diagnostic odds ratio, 46.69 (95% CI, 8.78-248.29). The Cochran's Q test and I^2 index showed that there was no statistically significant heterogeneity among analyzed studies. Summary receiver operating characteristic (±standard error) was 0.923 ± 0.052.

DISCUSSION

Ultrasonographic examination allows detecting injuries of PLC based on the presence of any disruption of the first continuous echogenic layer as a sign for a lesion of the subcutaneous fat and fascial structures, disruption of the continuous hypoechoic line between spinous processes as a sign for SSL and ISL lesions, identification of spinous process as echogenic demarcation with posterior acoustic shadow, detection of hypoechoic cysts as an indirect sign for hematoma and disruption, inhomogeneous arrangement of ligament and muscle fiber, or avulsed bony fragment.[13,14]

The present meta-analysis showed that using the aforementioned signs, US is a highly accurate imaging modality for identifying PLC injuries in patients who have suffered TL fractures. On the basis of the present results, US imaging is advisable for determining the competence of the PLC components and may help to determine the best way of treatment of those fractures in which its integrity is important for decision-making. All included studies were of high methodological quality, which minimize potential biases and enhance the reliability of the pooled data. The assessment of heterogeneity by the Cochran's Q test and I^2 index showed that it was not statistically significant in any analysis; suggesting that its diagnostic accuracy had also been consistently found in the included studies.

Currently, there is a variety of methods for evaluation of PLC injuries, leaving spinal surgeons with several options. However, MRI is by far, the modality of choice for assessing traumatic lesions involving the intervertebral disks and spinal ligaments.[26,27] In comparison with MRI, diagnostic accuracy parameters of US appear to be similar to previously described in the literature.[5-7,28] However, it has several limitations for delineating other spinal structures as vertebras and spinal cord, and thus, information about entire stability provided by US is incomplete. Hence, it should be considered as an additional tool in the work-up, more than a gold standard.

Additional advantages of US are its safety, portability, and wide availability; which make it an attractive alternative when MRI is not feasible, as in unstable patients with ventilator or cardiac support, severe trauma, and those with intolerance to decubitus. It can also be used in those with contraindications for MRI as claustrophobia, pacemarkers, deep brain stimulation systems, surgical clips, artificial cardiac valves, metallic auditory implants, metallic with steel, electronic devices, etc.[29]

Despite the strong results of the present meta-analysis, data must be carefully analyzed, due to eligibility criteria of each individual study, sample characteristics, and inherent limitations of US.[13,14,21,24,25] One of these drawbacks is the definition of PLC, because in most of the included studies only the ISL and LSS were considered.[14,24,25] Therefore, the analysis of the diagnostic performance of US for evaluating the LF and FJC cannot be adequately addressed in the present meta-analysis, impeding the complete generalization of its results to all elements of the PLC. These difficulties for visualization of those two structures have also been described by using MRI.[6] A prospective cohort study by Pizones *et al*. demonstrated that MRI specificity for injury diagnosis of FJC is only 52%, even using fat supressing-T2-weighted/sagittal short-tau inversion recovery sequences, confirming that its visualization on MRI is also unreliable.[30] In another study performed by Vaccaro *et al*, the intraoperative corroboration of LF injuries was achieved in 65% of those cases detected by MRI.[6] However; integrity of FJC does not appear to be a major concern, because according to current literature, it appears to have a subordinate role as predictor of instability by comparison with the remaining elements of the PLC.[3,26,31]

Respecting fracture morphology, the results yielded by the present study are derived from patients with flexion distraction, compression, and burst fractures (Magerl type A and B). It is explainable because these injury patterns are the most frequent and rotational injuries are deemed as very unstable; requiring surgical stabilization, independent of integrity of ligamentous structures which frequently are disrupted.[4] Therefore, the present study provides evidence about the performance of US in patients whom harbor injuries with morphological characteristics that generate controversies and disagreements during surgical decision-making.

Another limitation for generalization of the present results, was the inconsistence between definitions of reference standard, because in most of included studies was based on operative findings, but in one was based on MRI findings. Faces of this difficulty, there were used both definitions for the sensitivity analysis; confirming its good diagnostic accuracy even after excluding those cases without intraoperative corroboration.

A potential selection bias could be related with included cases in each study, because most of them underwent to operative treatment (89.4%). It suggests that they harbored more severe and unstable injuries, than those patients who were treated nonoperatively, and consequently, those injuries could be more easily identified by US. However, this bias cannot be solved before improving the sensitivity and specificity of the current noninvasive reference standard (MRI); or a different and more accurate modality became available.

Since diagnostic performance of each ultrasonographic sign of PLC injury has not been fully assessed, there is a concern about the value of indirect signs. In the present meta-analysis, 80% of false-positive cases were erroneously identified based on detection of a hematoma.[14] Soft tissues hematomas have also deemed as indicators of PLC injuries when detected on MRI, however, its sensitivity is ~80%.[32] Those findings suggest that if only direct signs are included, most false-positive cases could be avoided, improving the pooled estimated specificity. However, available data for the present analysis are not sufficient to assess this hypothesis.

CONCLUSIONS

Despite some limitations, the present meta-analysis showed that diagnostic accuracy of US for detecting PLC injuries is very good and therefore, may be considered as another useful aid for imaging evaluation of TL trauma. It is especially useful for assessing integrity of SSL and ISL, which are the most relevant for maintaining spinal stability after traumatic fractures.

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