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DIAGNOSTICS

Sequential Damage Assessment of the Different Components of the Posterior Ligamentous Complex After Magnetic Resonance Imaging Interpretation

Prospective Study 74 Traumatic Fractures

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Study Design. Prospective cohort study.

Objective. To study whether there is a sequential pattern in the posterior ligamentous complex (PLC) rupture caused by deforming traumatic forces by analyzing magnetic resonance (MR) images in a consecutive prospective cohort of patients with traumatic vertebral fracture.

Summary of Background Data. PLC plays an important role in vertebral stability. However, the sequence in which the different components of the PLC tear, in the face of traumatic forces, has not been yet described.

Methods. Prospective study of 74 consecutive vertebral acute traumatic fractures analyzed using radiography and magnetic resonance imaging (MRI) (FS-T2-w/short-tau inversion-recovery [STIR] sequences). Fracture morphology was classified according to the AO classification. Integrity of each PLC component—facet capsules, interspinous ligament (ISL), supraspinous ligament (SSL), and ligamentum flavum (LF)—was assessed and classified as intact, edema, or disruption. ISL edema was further subdivided depending on the extension (>50%/<50%). We analyzed the association between MRI signal and the AO progressive scale of morphological damage.

Results. AO type A1/A2 fractures associated with only facet distraction. A3 fractures showed additional ISL edema, usually less than 50%, with neither SSL nor LF disruption. Type B1 fractures associated with facet distraction, ISL edema or disruption, and low rate of SSL/LF disruptions; B2 fractures increased SS/LF disruption rates. Type C fractures associated with facet fracture or dislocation and ISL, SSL, or LF complete rupture. We found high association ($P < 0.001$) between AO progressive scale and MRI signal. MRI analysis showed that posterior distraction forces begin in the facets and extend throughout the ISL, starting at its posterosuperior margin (finally disinserting the SSL superiorly) and traveling diagonally toward anteroinferior border, finally tearing the LF.

Conclusion. MR images correlated with AO progressive scale of morphological damage, which showed a progressive orderly rupture sequence among the different PLC components as traumatic forces increased.

Key words: vertebral fracture, posterior ligamentous complex, magnetic resonance imaging, PLC rupture. **Spine 2012;37: E662–E667**

We are aware of the importance of the posterior ligamentous complex (PLC) integrity in vertebral fracture stability. Holdsworth[1] has reported the role of interspinous ligament (ISL) and supraspinous ligament (SSL) injuries in posterior spinal column instability. Subsequent biomechanical studies demonstrated the predominant role of the posterior column and its ligaments in the percentage of tensional loads they support regarding flexion deforming forces.[2–5] Thus, it is commonly agreed that PLC injury accompanied by collapse of the anterior/medial osseous column leads to progressive kyphosis and mechanical instability.

Classic anatomical researchers have studied the arrangement of ISL fibers, obtaining different conclusions.[6] The different schemas proposed regarding fiber orientation manage to justify 2 possible action mechanisms of the complex. The horizontal arrangement theory[7] defends the importance of axial load distribution of the abdominal press muscles,[8] whereas those describing oblique fiber arrangement defend its role as a restrictor of flexion tensile forces.[5,6,9] The most recent articles seem to clarify that the ISL comprises 3 well-defined layers, with oblique orientation from anterior to posterior and from caudal to cranial.[6,9] The ventral layer intimately bound to the ligamentum flavum (LF), arranged with a slight posteroinferior concavity curve, is more elastic, thus enabling a certain flexibility in flexion. The intermediate layer is arranged like an

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Italic "S" that tenses on flexion, with little elasticity due to its collagen tissue composition. And the dorsal layer with a short oblique arrangement is transitional until it intertwines with the inextensible cord ligament, forming the SSL, a prolongation of the intramuscular fascia.[6]

When experiencing flexion tension forces, the area with greatest resistance lies between the intervertebral disc and the capsular ligaments. Biomechanical studies indicate that there is an inflexion point (maximum load), whereby there is PLC rupture, which starts in the ISL and the SSL.[4,5] Nevertheless, controversy still exists regarding the sequence and how the different components of the PLC (ISL, SSL, LF, and facet capsules [FC]) are torn in relation to sequential damage of the lesional forces.

In recent years, magnetic resonance imaging (MRI) has been proposed as the key tool to detect lesions in the soft spinal tissues (discs, articular capsules, and ligaments).[10–12] Also, described anatomical findings have been corroborated with MRI.[6]

The purpose of our article is to study whether there is a sequential pattern in the PLC rupture in the face of deforming traumatic forces, *via* MRI analysis in a consecutive prospective cohort of patients with traumatic vertebral fracture.

MATERIALS AND METHODS

A prospective study of all patients with acute vertebral fractures admitted to a single hospital consecutively from April 2008 to April 2010 was conducted. All the patients were informed of their inclusion in the study, which followed the Declaration of Helsinki principles.

Inclusion criteria were patients experiencing acute traumatic dorsolumbar fracture, excluding pathological fractures, that is, infectious, tumoral, or osteoporotic (age limits: women, 55 yr; men, 60 yr).

Fractures were suspected after clinical and radiographical examination. All patients underwent an MRI scan within the first 5 days. Patients on whom MRI was performed after day 5 were excluded because of lack of consistency between signal intensity and real ligament integrity. The MR images were obtained with a 1.5-tesla system using turbo spin-echo pulsed sequences, boosted with T1-weighted and T2-weighted fat suppression (FS) on sagittal and axial planes. In addition, short-tau inversion-recovery (STIR) pulsed sequences were obtained on the sagittal plane and T2-weighted FS turbo spin-echo sequences on the coronal plane. These images were used to define the morphological fracture pattern, the state of the intervertebral discs, and especially the PLC integrity. Diagnosis of complex rupture was performed according to the criteria of Lee *et al*[13]: rupture was diagnosed with a loss of ligament continuity (clear rupture of the "black stripe") of the "linear" ligaments (SSL and LF) in T2-weighted FS and STIR sequences; ISL and FC injuries were diagnosed by increased anomalous signal (hyperintensity) in T2-weighted FS/STIR sequences.

The integrity of each PLC component (FC, ISL, SSL, and LF) was assessed using the MR images, as intact, edema, and rupture. ISL edema was subdivided according to its intrasubstance extension as more than or less than 50%.

The morphological pattern of each fracture was diagnosed using radiography and MRI following the AO classification (Magerl *et al*[14]). The classification described previously proposes 3 well-defined basic subtypes (A, B, and C), outlining a progressive scale of morphological damage as per progression of lesional forces.

Finally, the association between the MR signal and the AO progressive scale of morphological damage was analyzed. Statistical analyses were carried out using SPSS software (version 11.5; SAS Institute Inc., Cary, NC). The comparison between variables was performed using the χ^2 test with a significance level of 5% ($P < 0.05$).

A total of 74 consecutive patients with acute traumatic vertebral fractures were recruited after meeting the inclusion criteria. Of these patients, 37.8% fractures (28) were located at the dorsal area D3–D9, 54.1% (40) on the dorsolumbar hinge T10–L2, and 8.1% (6) at the lumbar L3–L5. The levels affected with greater frequency were D12 (12 fractures) and L1 (17 fractures). Mean patient age was 38.9 ± 13.6 years. Eight fractures (10.8%) were diagnosed as contusions (vertebral body edema in the MR image). The rest was distributed as per AO classification: A1, 24 fractures (32.4%); A2, 5 fractures (6.8%); A3, 13 fractures (17.6%); B1, 14 fractures (18.9%); B2, 6 fractures (8.1%); C1, 1 fracture (1.4%); and C2, 3 fractures (4.1%).

RESULTS

Table 1 shows distribution of individualized MRI findings per PLC component. It was noted that the ISL and FC could show 3 signal patterns: intact, edema, and rupture. However, the ligaments SSL and LF were shown ruptured or intact.

Another finding after MRI analysis showed that complete rupture of ISL was not essential for the SSL to rupture, although it was for the LF to rupture by distraction.

The results of the relation between fracture morphological patterns as per AO classification and PLC MRI findings with fat saturation protocol shown subsequently. Statistically described findings showed high association ($P < 0.001$) (Table 2) except in the subdivision of the IE edema extension.

TABLE 1. Distribution of Magnetic Resonance Imaging Findings for Each Posterior Ligamentous Complex Component

	Intact		Edema		Rupture	
Ligaments	N	%	N	%	N	%
FC	34	46	35	47	5	7
ISL <50%			11			
ISL >50%			9			
ISL	43	58	20	27	11	15
SSL	61	8			13	18
LF	63	85			11	15

FC indicates facet capsules; ISL, interspinous ligament; SSL, supraspinous ligament; LF, ligamentum flavum.

TABLE 2. Data of the 74 Fractures Showing the Distribution of MRI Findings (FS T2-Weighted/STIR Sequences) Among the Different Fracture Patterns*

	FC Alterations	ISL Edema	ISL Edema <50%	ISL Edema >50%	ISL Rupture	SSL Rupture	LF Rupture	N
Contusions	12.5%	0	0	0	0	0	0	8
AO A1	25%	(2) 8%	100%	0	0	0	0	24
AO A2	60%	0	0	0	0	0	0	5
AO A3	84%	(6) 46%	83%	17%	0	0	0	13
AO B1	79%	(10) 71%	50%	50%	21%	36%	29%	14
AO B2	67%	(1) 16%	0	100%	83%	67%	67%	6
AO B3	...	...	...	...	...	...	...	0
AO C1	100%	0	0	0	100%	100%	100%	1
AO C2	100%	(1) 33%	0	100%	66%	100%	67%	3
AO C3	...	...	...	...	...	...	...	0
P	0.000	0.000	0.1	0.1	0.000	0.000	0.000	

**AO classification (Magerl et al[14]). The comparison between variables was performed using the χ^2 test.*

FC indicates facet capsules; ISL, interspinous ligament; SSL, supraspinous ligament; LF, ligamentum flavum; N, number of cases.

AO Fractures Type A

In osseous contusion fractures shown as vertebral body edemas in the MR image without the signal of plate fracture and in AO fractures type A1/A2 (due to low-intensity compression/axial forces), the characteristic image pattern showed an intact PLC or at most an isolated distraction of articular capsules (intra-articular fluid) (Figure 1). The higher the AO classification degree, the higher the prevalence of intracapsular signal alteration. However, both facets were not always altered in the same way (sometimes only unilateral distraction was noticed); nevertheless, higher AO grades showed a higher percentage of bilateral facet distraction. In 2 A1 cases, an increased signal in ISL that was more than 50% of its extension was noted.

AO fractures type A3 are due to axial forces causing partial or total vertebral body burst. In these, there is a greater percentage of intracapsular signal hyperintensity (capsular distraction) cases. Moreover, almost half the cases were associated with ISL edema (signal hyperintensity in T2-weighted FS/STIR) almost always less than 50% of its extension and usually located in the dorsocranial area (ligament medial and dorsal layers). No alteration of the SSL or LF signal was observed (Figure 2).

AO Fractures Type B

AO type B1 fractures are due to moderate flexion-distraction forces that cross through the disc. These were related to images with intra-articular fluid (distraction of FC); hyperintensity of ISL signal: edema to a large extent or intrasubstance rupture; and a certain percentage of cases with black stripe discontinuity of SSL and/or LF ligaments (rupture) (Figure 3). In type B2 fractures where flexion and distraction forces cross the vertebral body from posterior to anterior, there was a predominance of ISL ruptures and the percentage of "cord" ligament injury (SSL, LF) increased (Figure 4).

AO Fractures Type C

AO type C fractures are due to complex high-intensity forces in flexion-distraction and rotation. In all cases, facet distortion was observed as a facet fracture or dislocation, likewise showing anatomical discontinuity (complete rupture) of 1 or all complex ligaments (ISL, SSL, and LF). In these, signal alteration in the MR image comprised the entire complex (Figures 5 and 6).

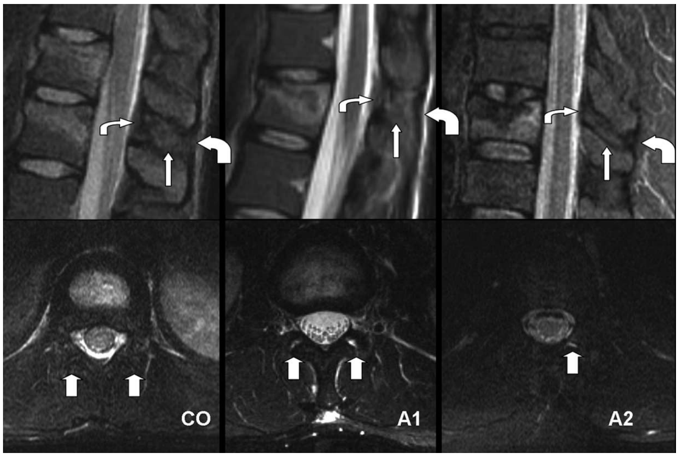

Figure 1. CO: contusion. All posterior ligamentous complex components are intact (facet capsules—wide straight arrows; interspinous ligament—thin straight arrows; supraspinous ligament—wide-angled arrows; and ligamentum flavum—thin-angled arrows). A1: intact ligaments, bilateral intra-articular hyperintensity signal (wide straight arrows); A2: intact ligaments, unilateral intra-articular hyperintensity signal (wide straight arrow).

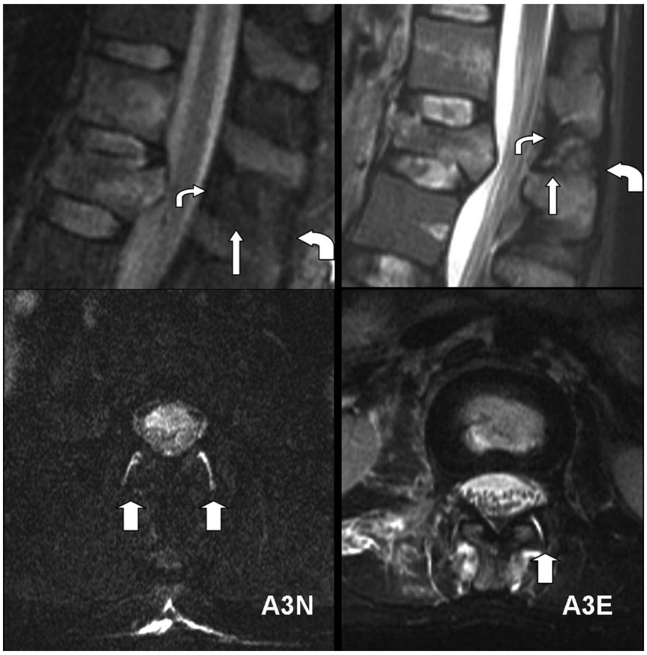

Figure 2. A3N (normal): Intact ligaments (ISL,SSL,LF), bilateral intraarticular hiperintensity signal (wide-straight arrow) A3E (edema): ISL edema in Italic-S (thin-straight arrow). Intact SSL (wide-angled arrow) and LF (thin-angled arrow). Unilateral intraarticular hiperintensity signal (wide-straight arrow).

DISCUSSION

In this study, we have described a possible mechanical rupture sequence of the different PLC components by means of MRI analysis with fat saturation. The results described earlier seem to agree with the anatomical and biomechanical properties published by other authors for each complex component.

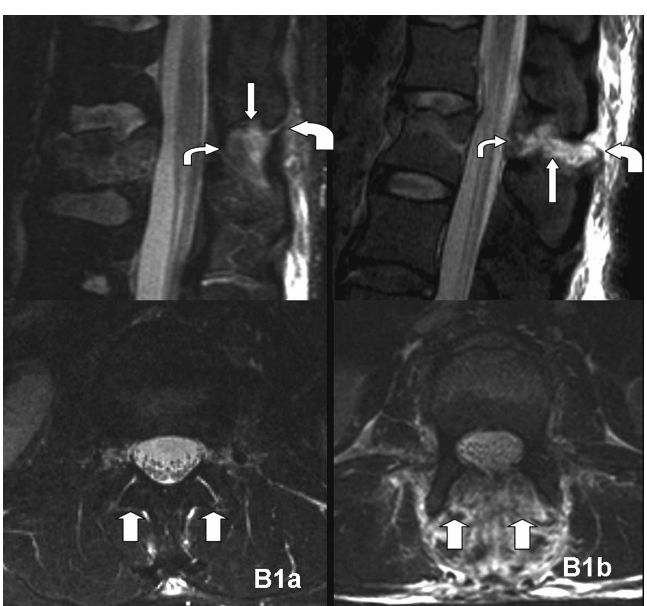

Figure 3. B1a: Interspinous ligament (ISL) edema with posterosuperior partial rupture (thin straight arrow), supraspinous ligament (SSL) disinsertion (wide-angled arrow), and normal ligamentum flavum (LF) (thin-angled arrow) bilateral intra-articular hyperintensity signal (wide straight arrows). B1b: ISL (thin straight arrow), SSL (wide-angled arrow), and LF rupture (thin-angled arrow). Facet dislocation (wide straight arrows).

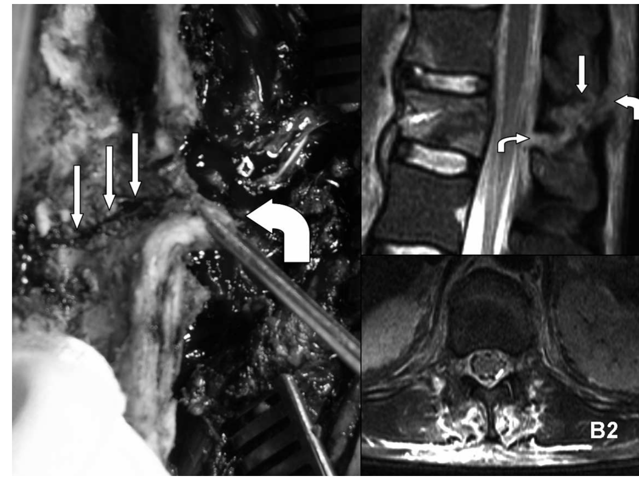

Figure 4. B2: Complete interspinous ligament rupture (thin straight arrows), with supraspinous ligament disinsertion (wide-angled arrows), and anteroinferior ligamentum flavum detachment (thin-angled arrow).

To stage the progressive lesional damage of forces occurring in dorsolumbar traumas, we used the AO classification.[14] The authors based their classification on the 3 basic functions of a stable spine as described by Whitesides.[15] Depending on where the center of rotation of the spine segment is located when an injury occurs, 3 basic patterns are described. Compression, distraction, and torsion (A B, and C) outline a progressive morphological damage scale as lesion forces increase. Thus, when lesional forces are low energy, the anterior spinal column[16] experiences a contusion without repercussion in posterior elements. As the energy increases, an anterior compression fracture occurs (AO A1) or an axial "split" (AO A2) with a posterior distractor moment, which may distend the articular capsules. This finding is more prevalent and more bilateral, the higher the deforming force. Capsules described earlier have been proven highly elastic and resistant to the flexor moment[7,17]; however, they experience tension from deforming force commencement,[4] that is, they are the first to defend the complex from flexion aggressions.

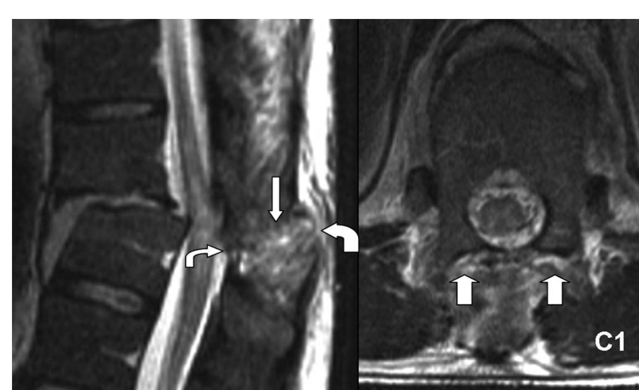

Figure 5. C1: Complete interspinous ligament rupture (thin straight arrow), supraspinous ligament rupture—disinsertion (wide-angled arrow), and ligamentum flavum rupture (thin-angled arrow). Facet dislocation (wide straight arrows).

Figure 6. C2: Complete interspinous ligament (thin straight arrows), supraspinous ligament (wide-angled arrows), and ligamentum flavum rupture (thin-angled arrow). Bilateral intra-articular hyperintensity signal (wide straight arrows).

If the tensional force progresses and loads become more axial, communition of the vertebral body (AO A3) occurs likewise, with articular distraction visualized as intracapsular fluid. These findings are accompanied in almost half of the cases by ISL edema, which is almost always less than 50% of ligament extension, starting in its posterocranial insertion. At this point of flexion, the "cord" ligaments (SSL/LF) are not compromised. The ISL has the advantage of being far from the rotation center, and it does not start functioning until halfway through the flexor movement.[4] Yet, it has been biomechanically proven as the component least resistant to flexion forces.[4,18] Anatomically, the described ligament has 3 differentiated layers, with the dorsal and intermediate being the least elastic and most exposed to rupture due to tension forces.[9,19] Therefore, it seems logical that the ISL is the first PLC vulnerable structure after experiencing traumatic flexion damage.

As the flexor moment intensity increases (AO fractures type B), the posterior area distracts until the MR image shows detachment of the SSL cranial insertion from the spinous process ("black stripe" discontinuity in T2-weighted FS and STIR sequences).[13] SSL is a cord ligament comprising collagen fibers[9] and resistant to flexion forces.[18] Despite having the rotation center farthest from the complex, it has been proven that together with the ISL posterosuperior area, it is the first area to experience damage from tension forces.[4,5] Moreover, after a maximum load point, the ISL-SSL intersection inserted in the upper spinous process fails and tears. This maximum force varies according to the ligament and injury level.[18] The MR image projected at this distraction moment coincides with the complex anatomy. The distraction forces move from cranial and dorsal to caudal and ventral following the anatomy of the ISL fibers. Fibers described earlier are arranged like an italic "S" in the middle when the ligament is relaxed; on tensing under distraction forces, they become straight[6,9] (Figure 7). The lesional vector is conveyed along this path. Thus, the static post-traumatic image observed in the MR image sometimes reflects edema

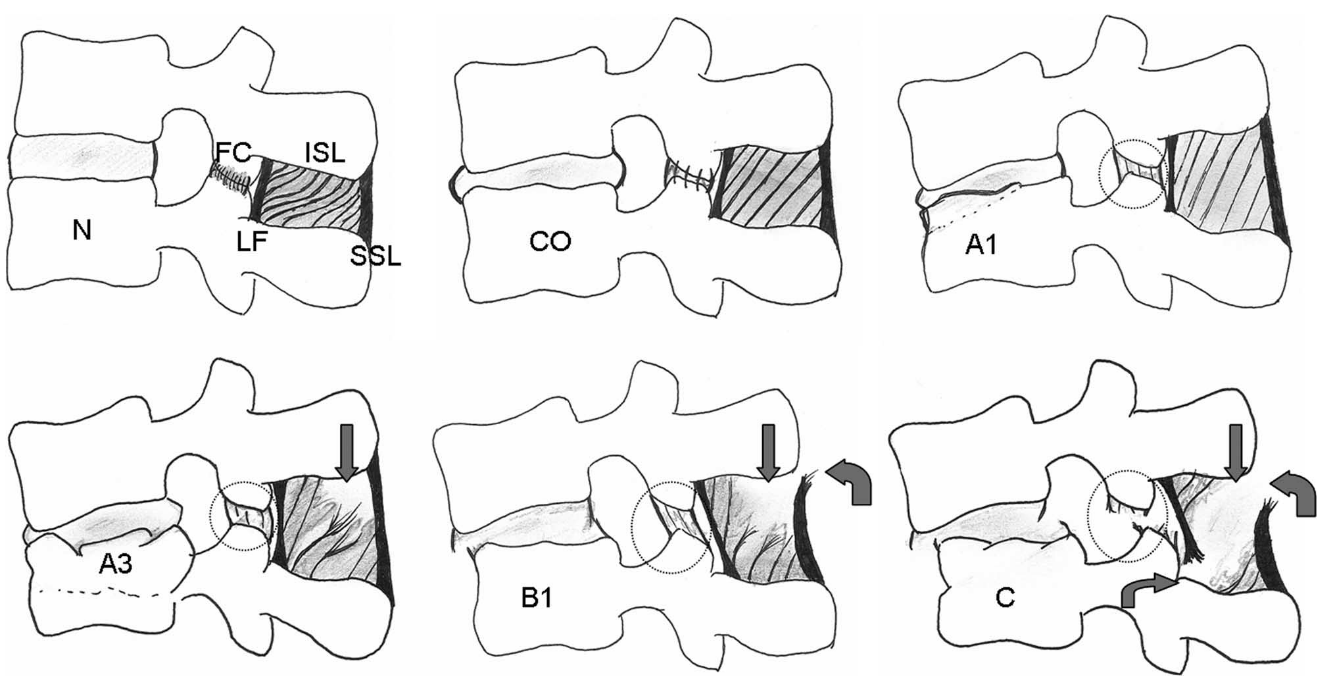

Figure 7. Diagram representing sequential damage of the different components of the posterior ligamentous complex under traumatic progressive forces. FC indicates facet capsules (doted circle); ISL, interspinous ligament (thin straight arrows); LF, ligamentum flavum (thin-angled arrow); SSL, supraspinous ligament (wide-angled arrows); N, normal/physiological vertebrae status; CO, contusion; A, B, C, subtypes of the AO classification.

highlighted by fat saturation as a line of signal hyperintensity, which travels the cranial-dorsal angle to the most ventral and caudal ISL layer sinusoidally (Figure 6, A3E [edema]).

If the flexor moment is maximum (AO types B2 and C), the most resistant and elastic area of the ISL ends up rupturing,[6,7,9,17,18] which is the ventral layer that overlaps with the LF. It is biomechanically proven that the LF vertical fibers resist flexor moments more efficiently,[8,17] and although the last ligament to be fatigued, it finally succumbs by its caudal insertion, as demonstrated in the MR image by a discontinuity of the black stripe in that area. At this stage, we generally find complete ISL rupture, SSL rupture, and sometimes facet fracture (capsular ligaments have the highest mechanical solicitation in rotation—type C fractures).[5] This is the last component to break because they are structures closest to the disc and rotation center,[4,18] yet the most resistant.[7,17]

The images analyzed belong to a group of consecutive patients and were collected prospectively. The results obtained coincide with published biomechanical and anatomical data. Nonetheless, we accept the limitations of the theory proposed in this article. The images are static and initially a larger study group would be necessary, followed by a biomechanical study on specimens to corroborate the described theory. Nevertheless, it is a novel study, attempting for the first time in literature to individualize *via* images the progressive damage of each PLC component, that was until now treated as a whole[20] in the diagnosis and management of acute vertebral fractures. This anatomical PLC rupture sequence might achieve clinical importance if additional research defines a clear-cut picture in PLC disruption that can demonstrate which PLC injury-stage clinicians should consider the complex incompetent and requiring surgical repair.

In conclusion, there is a close relation between the AO progressive scale of morphological damage and the MR signal, which shows a progressive orderly rupture sequence among the different PLC components as traumatic forces increase (Figure 7).

The posterior distraction forces seem to start causing capsular distraction, and as they increase, they injure the ISL (starting at its dorsocranial area), which ends up disinserting the SSL of the upper spinous process. Then the force travels diagonally toward the ventral-caudal margin, which ends up rupturing the LF from its inferior margin.

➢ Key Points

- ❑ MR images show a progressive orderly rupture sequence among the different PLC components as traumatic forces increase.
- ❑ Flexion-distraction forces begin in the FC and extend throughout the ISL. Then disinsertion of the SSL occurs and finally the LF tears.
- ❑ The SSL can be found disrupted in association with only partial ISL disruptions. LF distraction ruptures always occur after ISL complete ruptures.
- ❑ ISL can show any of the 3 signal patterns (intact, edema, or disruption); SSL and LF are found either intact or disrupted.

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References

1. Holdsworth FW. Fractures, dislocations and fracture-dislocations of the spine. *J Bone Joint Surg [Br]* 1963;45:6–20.
2. Oxland TE, Panjabi MM, Southern EP, et al. An anatomic basis for spinal instability: a porcine trauma model. *J Orthop Res* 1991;9:452–62.
3. James KS, Wenger KH, Schlegel JD, et al. Biomechanical evaluation of the stability of thoracolumbar burst fractures. *Spine* 1994;19:1731–40.
4. Adams MA, Hutton WC, Stott JRR. The resistance to flexion of the lumbar intervertebral joint. *Spine* 1980;5:245–53.
5. Panjabi MM, Goel VK, Takata K. Physiologic strains in the lumbar spinal ligaments. An in vitro biomechanical study. *Spine* 1982;7:192–203.
6. Scapinelli R, Stecco C, Pozzuoli A, et al. The lumbar interspinous ligaments in humans: anatomical study and review of the literature. *Cells Tissues Organs* 2006;183:1–11.
7. Hukins DW, Kirby MC, Sikoryn TA, et al. Comparison of structure, mechanical properties, and functions of lumbar spinal ligaments. *Spine* 1990;15:787–95.
8. Aspden RM, Bornstein NH, Hukins DWL. Collagen organisation in the interspinous ligament and its relationship to tissue function. *J Anat* 1987;155:141–51.
9. Heylings DJA. Supraspinous and interspinous ligaments of the human lumbar spine. *J Anat* 1978;125:127–31.
10. Lee HM, Kim HS, Kim DJ, et al. Reliability of magnetic resonance imaging in detecting posterior complex injury in thoracolumbar spinal fractures. *Spine* 2000;25:2079–84.
11. Öner FC, van der Rijt R, Ramos LMP, et al. Correlation of MR images of disc injuries with anatomic sections in experimental thoracolumbar spine fractures. *Eur Spine J* 1999;8:194–98.
12. Terk MR, Hume-Neal M, Fraipont M, et al. Injury of the posterior ligament complex in patients with acute spinal trauma: evaluation by MR imaging. *Am J Roentgenol* 1997;168:1481–86.
13. Lee JY, Vaccaro AR, Schweitzer KM, et al. Assessment of injury to the thoracolumbar posterior ligamentous complex in the setting of normal-appearing plain radiograph. *Spine J* 2007;7:422–7.
14. Magerl F, Aebi M, Gertzbein SD, et al. A comprehensive classification of thoracic and lumbar injuries. *Eur Spine J* 1994;3:184–201.
15. Whitesides TE Jr. Traumatic kyphosis of the thoracolumbar spine. *Clin Orthop Relat Res* 1977;128:78–92.
16. Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. *Spine* 1983;8:817–31.
17. Chazal J, Tanguy A, Bourges M, et al. Biomechanical properties of spinal ligaments and a histological study of the supraspinal ligament in traction. *J Biomech* 1985;18:167–76.
18. Myklebust JB, Pintar F, Yoganandan N, et al. Tensile strength of spinal ligaments. *Spine* 1988;13:526–31.
19. Fujiwara A, Tamai K, An H, et al. The interspinous ligament of the lumbar spine. Magnetic resonance images and their clinical significance. *Spine* 2000;25:358–63.
20. Vaccaro AR, Lehman RA Jr, Hurlbert RJ, et al. A new classification of thoracolumbar injuries: the importance of injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. *Spine* 2005;30:2325–33.