MRI study of post-traumatic incompetence of posterior ligamentous complex: importance of the supraspinous ligament. Prospective study of 74 traumatic fractures

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Abstract

Purpose Posterior ligamentous complex (PLC) components have an orderly sequence of rupture. However, it is still unclear how many structures have to be damaged to consider it disrupted. We aim to establish imaging criteria, which can define the complex as competent or incompetent. **Methods** Prospective study of 74 consecutive vertebral acute traumatic fractures, using X-rays and MRI scan (FS-T2-w/STIR sequences). We analyzed the association between MRI signal (intact, edema, disruption) of each PLC component—facet capsules (FC), interspinous ligaments (ISL), supraspinous ligaments (SSL) and ligamentum flavum (LF)—and the variables: AO/TLICS classification, treatment, surgical findings, interspinous diastasis index (IDI), local kyphosis (LVK) and ISS (TLICS) score. χ^2 test and *U* Mann–Whitney were used for statistics.

Results MR images of ISL edema correlated surgically with intact ligaments or laxity, and were associated with 87.5 % of facet distraction, LVK: 11.6°, IDI: 1.2. Images of ISL, SSL or LF disruptions showed in all cases ruptures under surgical examination. Images of SSL disruption associated with LVK: 14.5°, IDI: 1.8. Images of ISL disruption associated with SSL/LF rupture, LVK: 16°, and IDI: 2; while LF disruption showed LVK: 18°, IDI: 1.9. When comparing “competent PLC” (images of facet distraction and ISL edema) with “incompetent PLC” (images of SSL disruption $\pm$ ISL or LF disruption) the latest

showed more severe scores in every variable ($p < 0.001$), except neurologic status.

Conclusion Following PLC rupture sequence, ISL edema with facet distraction seems not to be enough to define a posterior tension band incompetence. It is the further step of SSL rupture what gives the key to PLC incompetence.

Keywords Vertebral fracture · Posterior ligamentous complex · Magnetic resonance imaging · PLC rupture · Supraspinous ligament · Vertebral instability

Introduction

Both destruction of the bone component and soft tissue damage, particularly posterior ligamentous complex (PLC) injury [1], define vertebral fracture instability.

Bone injury diagnosis can be carried out with considerable precision using X-ray and CT scan [2, 3]. Nevertheless, difficulties still exist for diagnosing ligamentous lesions with these examination tools [4], and indirect indicators need to be used to suspect ligamentous damage: gap between spinous processes, local kyphosis, facet diastasis or more than 50 % of anterior body compression [5]. In recent years, MRI [6, 7] has proven it offers the best definition of soft tissue, and validity studies of said test have shown excellent results [6–9].

A recent study performed by means of MRI, has shown a sequential orderly rupture of the different PLC components as traumatic forces increase [10]. It seems that distraction of facet capsules (FC) and edema of the interspinous ligament (ISL) appear before the rupture of the supraspinous (SSL), interspinous (ISL) and flavum (LF) ligaments and acts as the boundary between AO type A and B/C fractures (Fig. 1). PLC integrity has acquired so much

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Fig. 1 Sequential damage of the different components of the PLC as traumatic forces increase, following AO classification. FC facet capsules (circle); ISL: interspinous ligament (white arrows); SSL supraspinous ligament (black-straight arrows); LF: ligamentum flavum (black-angled arrows). N: normal/physiological vertebrae status; A1: FC distraction; A3: FC distraction + ISL edema; B1: FC distraction + ISL edema + SSL disruption; C: Rupture of the four PLC components

importance that it has been introduced as a severity factor in itself in recently proposed classifications (TLISS [11], TLICS [12]). These authors propose categorization of the complex damage as intact, indeterminate and disrupted. However, said categories define PLC as a whole leaving unresolved doubts.

It is still unknown how many PLC components must be damaged to consider the complex disrupted, in other words, in which moment of the damage sequence posterior instability arises. There are no clear criteria to diagnose the complex rupture with imaging. The term ‘indeterminate’, of the TLICS classification, generates doubts about whether the complex is still competent or incompetent and requiring repair to recover posterior spinous stability [13]. Furthermore, this lack of precision means the MRI validity results for detecting complex lesions [4, 14] have reduced in comparison with previous reports [6–9].

This paper studies, in depth, the rupture of the different PLC components by means of MRI analysis on a consecutive cohort of patients with acute vertebral fracture. The aim is to establish imaging criteria in the diagnosis of the PLC rupture, which can define the complex as competent or incompetent. The hypothesis is that in the progressive

sequence of PLC rupture, the rupture of the SSL acts as the spark that leads to PLC incompetence.

Materials and methods

A prospective study was conducted on all the consecutive patients with acute thoracolumbar vertebral fracture admitted at our institution between April 2008 and December 2010. Every patient was aware of their inclusion in the study and purpose thereof, which followed the Declaration of Helsinki principles. Pathological fractures were excluded: tumoral, infectious and osteoporotic (men over 60 and women over 55 were excluded).

Data collection

All patients were examined via simple anteroposterior and lateral X-ray, and MRI with fat-saturation protocol. Turbo spin-echo (TSE) pulsed sequences were used, boosted on T1 and T2 with axial and sagittal fat suppression (FS) sequences, using a 1.5 Tesla system. In addition, STIR (short-tau inversion-recovery) pulsed sequences were used on sagittal plane, and T2-w FS TSE sequences on coronal plane. All images were blinded examined and analyzed by a senior musculoskeletal radiologist and an experienced spine surgeon, before treatment decision was taken.

With pre-operation X-ray the following parameters were measured: local vertebral kyphosis (LVK) as the angle formed between the fractured upper vertebra plate and its lower plate; interspinous diastasis index (IDI), such as the ratio between the distance between the spinous processes of the affected vertebra and the immediate cranial vertebra, and the mean of the distances of the interspinous spaces of the adjacent cranial and caudal vertebrae.

Via MRI each PLC component signal was analyzed (SSL, ISL, LF, FC) as intact, edema and disruption. Any alteration of the signal (hyperintensity) was considered edema particularly in T2-w FS/STIR; except continuity solutions (‘black-stripe’ disappearance) which were considered disruptions [15].

All fractures were classified as per AO classification [1] and then TLICS [12], which included identification of each morphological fracture pattern, neurologic status and PLC consideration.

The ISS (injury severity score) of each fracture, according to the TLISS [11] classification, was collected. The treatment decision for every fracture was taken based on instability criteria. Both classification management guides (AO and TLICS) were taken into account, as was the ISS. These decisions also considered additional circumstances like: patient co-morbidities, multiple injuries, age, neurological involvement, bone quality, number of

levels affected, etc. In patients who were operated, we endeavoured to also differentiate every PLC component at surgery by intact, laxity or disrupted. This was done analogous to classification via MRI per component to be able to compare both variables. A dynamic manual stretching test was performed during surgery to evaluate the elasticity and instability of the posterior complex.

Data analysis

Each PLC component was individually analyzed following the described progressive PLC sequence of rupture [10], studying its MRI signal findings. Afterwards, signals were related with multiple variables: association with other PLC components damage, AO classification, TLICS classification, treatment performed, surgical findings, LVK, IDI and ISS.

Two groups of PLC compound signals were created: competent PLC and incompetent PLC, establishing the rupture of the SSL as the boundary between them as assumed by the hypothesis. Both groups were compared in search of differences. Competence was presupposed when a traumatic altered PLC was still able to maintain its physiological functions, which arbitrarily was defined as being associated with better/more stable parameters of the measured variables. Incompetence was defined as a ruptured PLC associated with worse/more severe parameters.

Statistical analyses were conducted using SPSS software (version 11.5, SAS Institute Inc, Cary, NC, USA). The means were shown next to the standard deviations. Comparisons were done with *U* Mann–Whitney for quantitative variables. The χ^2 test was used to analyse categorical variables. A significance level of 5 % ($p < 0.05$) was considered.

Demographic data

The global cohort presented 74 acute vertebral fractures which met inclusion criteria. Patients mean age was 38.9 ± 13.6 . Most fractures were located at the thoracolumbar junction (54.1 %). Tables 1 and 2 show distribution of fractures as per their respective AO and TLICS classifications. 48.6 % patients were treated conservatively, against 51.3 % who underwent surgery, the majority by single instrumented posterior approach (84.2 %) the rest via instrumented double approach.

Results

Results are described following the sequence of progressive PLC injury (Fig. 1).

Table 1 Distribution of fractures according to AO (Magerl et al. [1])

	Number of cases	Percentage
BME	8	10.8
AO A1	24	32.4
AO A2	5	6.8
AO A3	13	17.6
AO B1	14	18.9
AO B2	6	8.1
AO C1	1	1.4
AO C2	3	4.1

BME bone marrow edema or contusion

Table 2 Description of fractures according to TLICS (Vaccaro et al. [12])

TLICS	Number of cases	Percentage
Morphology		
Compression	38	51.4
Burst	18	24.3
Translational	3	4.1
Distraction	15	20.3
Neurologic status		
Intact	65	87.8
Incomplete injury	9	12.2
PLC consideration		
Intact	42	56.8
Indeterminate	16	21.6
Disrupted	16	21.6

Does isolated diastasis of facet joints imply PLC incompetence by itself?

Thirteen fractures were obtained where the only PLC image finding was joint fluid appearing facet joints. Relation with other variables studied is shown in Table 3, showing mild severity parameters. At this sequence stage, it seems that PLC is stable and competent.

Does the interspinous ligament edema imply PLC incompetence?

Twenty fractures were obtained with ISL edema in the MRI, and 85 % associated fluid from facet joint distraction. 4 (20 %) also had the SSL disrupted; however, none of the 20 fractures associated a disrupted LF.

We analyzed 16 fractures with ISL edema without associated rupture of SSL or LF. 87.5 % (14) associated facet joint opening with intracapsular fluid (Fig. 2). Six were in the thoraco-lumbar junction, four in the lumbar area and the rest in the dorsal area. In ten the edema had less than 50 % extension and in 6 the extension was greater

Table 3 Description of the relation between PLC components and study variables

	FC diastasis	ISL edema	ISL disruption	SSL disruption	LF disruption
AO					
A	1BME	2 A1	–	–	–
	4 A1	6 A3			
	3 A2				
	5 A3				
B	–	7 B1	3 B1	5 B1	4 B1
		1 B2	5 B2	4 B	4 B2
C	–	–	1 C1	1 C1	1 C1
			2 C2	3 C2	2 C2
TLICS					
Fracture morphology	7 Comp	5 Comp	1 Burst	2 Burst	1 Burst
	6 Burst	7 Burst	2 Tras	3 Tras	2 Tras
		4 Distr	8 Distr	8 Distr	8 Distr
Neurologic status	–		3 injuries	3 injuries	4 injuries
PLC consideration	13 Intact	0 Intact	0 Intact	0 Intact	0 Intact
	0 Indet	15 Indet	0 Indet	0 Indet	1 Indet
	0 Disrup	1 Disrup	11 Disrup	13 Disrup	10 Disrup
Treatment					
Conservative	13	7	–	–	
Surgical	–	9	11	13	11
Surgical findings	–	2 Intact	0 Intact	0 Intact	0 Intact
		7 Laxity	0 Laxity	0 Laxity	0 Laxity
		0 Disrup	11 Disrup	13 Disrup	11 Disrup
LVK	9.9° ± 5.2°	11.6° ± 5.1°	16.1° ± 6.2°	14.5° ± 6.3°	17.9° ± 6°
IDI	1	1.2	1.99	1.89	1.95
ISS	1.73	3.6 ± 0.5	7.5 ± 1.4	7 ± 1.5	7.7 ± 1.5

FC facet capsules, ISL interspinous ligament, SSL supraspinous ligament, LF ligamentum flavum, LVK local vertebral kyphosis, IDI interspinous diastasis index, ISS injury severity score (TLICS), BME bone marrow edema/contusion, Comp compression, Distr distraction, Tras translational/rotational, indet. indeterminate, Disrup disrupted

than 50 %. The relation of these 16 fractures with the different variables studied is shown in Table 3. Results show moderate severity figures, thus at this stage this injury, even if associated with FC distraction, allows the PLC to be stable and competent.

Does disruption of the supraspinous ligament imply complex incompetence?

Intact SSL ligaments (61) associated in 72 % of cases with intact ISL and 28 % with ISL edema. 13 fractures showed SSL disruption: 30 % associated with ISL edema (in which laxity was surgically found) (Fig. 3), and 70 % associated with ISL complete disruption ($p = 0.000$). In 38 % of disrupted SSL, the LF was intact. The relation of the study variables with these 13 SSL disruptions is shown in Table 3. It is associated with severity criteria and initially, at this stage of damage, PLC appears to be unstable and incompetent.

Does disruption of the interspinous ligament imply complex incompetence?

Complete rupture of ISL associated with facet joint alteration in 81.9 % of cases, in 81 % with SSL disruption and in 91 % with LF disruption; while ISL edema associated with joint diastasis in 85 % of cases, 20 % associated SSL disruption, but not LF disruption, this comparison is statistically significant ($p = 0.000$). 11 fractures had a disrupted ISL, Table 3 shows its relation with the study variables. Its association with severity criteria makes PLC look, at this stage, unstable and incompetent.

Does disruption of ligamentum flavum imply complex incompetence?

Of intact LF (63), 59 % were associated with intact ISL and 31 % with ISL edema. 11 fractures showed disrupted LF, 100 % associated to disrupted ISL, ($p = 0.000$) (Fig. 4).

Fig. 2 Compression fracture showing MRI signals of ISL edema (*superior white arrow*) without SSL (*black-straight arrow*) or LF (*black-angled arrow*) rupture. It is associated with facet joint distraction and intracapsular fluid (inferior circle), IDI = 1, LKV = 12°, ISS = 3 (compression + indeterminate PLC)

Whenever the LF was disrupted due to a flexion distraction mechanism, so was the SSL. However, the SSL does not necessarily tear before the LF does; LF-only ruptures are common in direct disruptions of posterior arch without SSL injury (as in AO type C injuries). Table 3 shows the details of the 11 LF disruptions. Its association with severity criteria shows that, at this stage of injury, PLC can be clearly considered unstable and incompetent.

Surgical findings

The complete disruption signal of ISL, SSL, and LF in the MRI corresponded in all cases to disruption during surgical examination (Fig. 4). ISL showed total thickness disruption. The SSL was torn from its insertion in the upper spinous. To see the ligamentum flavum, the previous ligaments had to be split and partial or total laminectomies had to be performed. Its disruption was shown as focal discontinuity of the ligament.

The ISL edema signal corresponded to intact or laxity after ligament surgical examination, those ligaments were never found disrupted. Laxity usually shows hyperaemic ligaments which on mechanical distraction show greater elasticity than that of adjacent levels.

Comparison between competent and incompetent ligaments

A combined MR image of: intracapsular FC fluid and ISL edema was considered to define a competent PLC. A combined MR image of SSL disruption $\pm$ ISL or LF disruption was considered to define an incompetent PLC. Incompetent PLC showed criteria of greater severity/instability than competent: greater morphological damage according to AO, greater severity according to TLICS criteria, surgical treatment predominance, higher interspinous diastasis index, greater local kyphosis and worse ISS. All the variables showed statistical significance ($p < 0.001$), except neurologic status ($p = 0.07$); (Table 4).

Fig. 3 Incomplete burst fracture showing MRI signal of FC distraction (circle), ISL edema (white arrows) and SSL detachment from the superior spinous process (black-straight arrow). LF (black-angled arrow) is intact. This is verified surgically with a detached/disrupted SSL (black-straight arrow) and laxity of ISL (inferior white arrow). IDI = 1.3, LKV = 20°, ISS = 5 (burst + disrupted PLC)

Fig. 4 The complete disruption signal of ISL (white arrow), SSL (black-straight arrow), and LF (black-angled arrow) in the MRI corresponded in all cases to disruption during surgical examination

Discussion

This prospective clinical study shows, after analyzing MR images, that integrity of the supraspinous ligament is critical in post-traumatic posterior complex incompetence. An MRI signal of ISL edema combined with facet diastasis but without SSL disruption corresponds to more benign fracture parameters and a competent complex. An MR image of isolated SSL disruption, with or without ISL and LF disruption, associates with more severe fracture parameters and a predictable complex incompetence.

Biomechanical studies award different distributions of force along the columns comprising the spinal axis [16]. The percentage of forces that posterior column supports depends on the direction the different columns are experimentally sectioned. Thus, PLC is attributed greater importance in stability if columns are sectioned from anterior to posterior (mechanism closest to the clinical scene) and less if inverted [17].

The truth is PLC integrity plays an important role in fracture stability [18]. The difficulty lies in accurate diagnosis of its lesion. Prior to MRI, diagnosis of PLC damage

Table 4 Comparison between stable and unstable PLC considering MRI findings (FS T2-w/STIR sequences)

	Stable (competent)	Unstable (incompetent)	P
Number	58	16	
Localization	45 % T 48 % TL 7 % L	12.5 % T 75 % TL 12.5 % L	0.06
AO classification type	55 % A1; 9 % A2; 22 % A3; 12 % B1; 2 % B2; 0 % C	0 % A; 44 % B1; 31 % B2; 6 % C1; 19 % C2	0.000
Fracture morphology			
Compression	65 %	0 %	0.000
Burst	28 %	12 %	
Translational	0 %	19 %	
Distraction	7 %	69 %	
Neurologic status			
Intact	91.4 %	75 %	0.07
Damaged	8.6 %	25 %	
PLC consideration			
Intact	72 %	0 %	0.000
Indeterminate	26 %	6 %	
Disrupted	2 %	94 %	
Treatment			
Conservative	60 %	0 %	0.000
Surgical	40 %	100 %	
Surgical findings			
ISL			
Intact	62 %	0 %	0.000
Laxity	38 %	19 %	
Rupture	0 %	81 %	
SSL			
Intact	100 %	12.5 %	0.000
Rupture	0 %	87.5 %	
LF			
Intact	100 %	31 %	0.000
Rupture	0 %	69 %	0.000
IDI	1.1	1.8	0.001
LVK	8.6 ± 5.2	15.9 ± 6.9	0.000
ISS	2.1 ± 1.2	7.2 ± 1.5	0.000

χ^2 and U Mann–Whitney

Competent: facet distraction + ISL edema, *Incompetent*: SSL disruption ± ISL or LF disruption, *T* thoracic, *TL* thoracolumbar, *L* lumbar, *ISL* interspinous ligament, *SSL* supraspinous ligament, *LF* ligamentum flavum, *IDI* interspinous diastasis index, *LVK* local vertebral kyphosis, *ISS* injury severity score (TLICS)

was based on examination, X-ray and CT scan. As reported by the STSG, the indirect factors which most orient to complex lesion are [5]: vertebral translation, interspinous space greater than in adjacent levels (over 2 mm according to Daffner [19]), facet joint diastasis seen in CT scan, local

kyphosis without vertebral injury (over 20° according to Nagel [20]), facet joint diastasis seen in X-ray, palpable interspinous gap, spinous avulsion and vertebral compression exceeding 50 % without lesion of posterior wall.

Today, MRI has become a basic tool for diagnosing disco-ligamentous lesions. Among other things, Öner [21] described four categories of PLC damage in MRI: absence of lesion, ISL edema without discontinuity, ISL elongation without discontinuity, clear PLC disruption and demonstrated the importance of its lesion in the recurrence of post-traumatic kyphosis after treatment [18]. However, the first to grade PLC lesions incorporating them in a therapeutic management algorithm was the group of Vaccaro et al. [12]. This method introduces the “indeterminate” complex concept as something neither clearly intact nor disrupted. This ‘grey’ area is not well defined in diagnosis, creating discrepancy among examiners [4]. Moreover, it lends a great specific weight in ISS calculation (two out of five points required by a fracture to be surgical) [11]. Thus, leaving the management of the most common fractures in clinical practice in a shadowy area, such as thoraco-lumbar junctional burst fractures without neurological damage and with PLC edema (totaling 4 points, leaving its recommendable treatment undefined).

Another controversy is MRI validity (sensitivity and specificity) as a diagnosis tool for PLC lesions. The first authors who studied image findings compared with surgical findings granted that MRI has great diagnostic power [6–9]. Recently, however, the overdiagnosis MRI offers on posterior complex disruption has been emphasized [4, 14]. It could be this PLC ‘indeterminate’ category what biases these studies. In order to calculate MRI validity, this category must be grouped either with the intact or disrupted complex consideration. If the “indeterminate” complex is included in the disrupted group, MRI sensitivity and above all specificity is reduced (increase in false positives) as a diagnosis tool for PLC lesions. In fact, in our study, most PLC originally considered “indeterminate” eventually had competent criteria, i.e. they would have been included for analysis in the intact group. The aforementioned authors themselves highlight the need for better definition of MRI PLC disruption criteria [4].

Recently Pizones et al. have described a progressive rupture sequence of the different PLC components as traumatic forces progress, beginning with FC diastasis, then ISL edema, progressing to SSL detachment/rupture and finally ISL and LF disruption [10]. However, no data were presented concerning in which moment of the damage sequence, posterior instability arises. With our present study, we pretended to clarify and define whether there is a clear cut between intact and disrupted PLC. On analyzing each PLC component separately with MRI fat-saturation protocol [15], we can demonstrate that an isolated

Fig. 5 Competent PLC: Burst fracture showing MRI signal of FC (circles) distraction (seen as intracapsular fluid–hyperintensity signal in T2-w FS/STIR- sequences), ISL edema following the S-shaped ISL

middle layer (white arrow), intact SSL (black-straight arrow) and intact LF (black-angled arrow). This injury is associated with stability parameters: IDI = 1.2, LKV = 13°, ISS = 3 (burst + intact PLC)

Fig. 6 Incompetent PLC: Translation fracture showing MRI signal of FC distraction (circle), SSL tear seen as “black-stripe” discontinuity (black-straight arrows), ISL rupture (white arrows) and LF disruption

(black-angled arrows). This injury is associated with instability parameters: IDI = 1.8, LKV = 19°, ISS = 8 (translation + disrupted PLC + nerve root injury)

distended joint (seen as intracapsular fluid-hyperintensity signal in T2-w FS/STIR- sequences) or in combination with ISL edema (hyperintensity signal in T2-w FS/STIR sequences) is associated with stable fracture parameters, and can be considered as a competent PLC (Fig. 5). When images show rupture of the SSL signal ('black-stripe' discontinuity) with or without a complete superimposed alteration of ISL (substance discontinuity with signal hyperintensity) and LF ('black-stripe' discontinuity) we found more aggressive injuries, thus PLC can be considered incompetent (Fig. 6). These latter are associated with fracture instability parameters: greater morphological damage according to AO classification, greater severity in TLICS criteria, predominance of surgical treatment, greater interspinous diastasis, greater local kyphosis and worse ISS.

MR ISL signal can be intact, edema or disrupted. While SSL and LF ligaments are disrupted or not disrupted, MR images are clear showing no intermediate stages. PLC lesions due to flexion-distraction forces are progressive, showing an orderly sequence in component ruptures [10]. In this chain of events, it seems that the supraspinous ligament represents the key to incompetence. Disruption of the SSL marks an inflection point, changing the complex from competent to incompetent, from whereon any added damage increases the degree of posterior column instability.

In the present study, the incompetent PLC group has associated a higher surgical repair index, where clinical incompetence of the different complex components has been verified visually and dynamically. Nevertheless, whether this PLC incompetence is self-repairing requires future analysis, i.e. it has yet to be demonstrated whether an incompetent complex is able to heal conservatively and enable lesion stabilization without the need for surgical repair.

Although we assume the study limitations (small sample size, no biomechanical laboratory support), we can define the rupture of the SSL as the clear-cut image of PLC incompetence. With the results obtained we could clear the term 'indeterminate' from the TLICS classification. A competent complex (articular distraction $\pm$ incomplete distension/lesion of ISL) could continue totally 0 points in the ISS calculation. An incompetent complex (SSL disruption $\pm$ complete ISL lesion and/or disruption of the LF by distraction) could total 3 points in the ISS. This could help in vertebral fracture decision making. Prospective studies will be necessary using these criteria to demonstrate their validity.

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Conflict of interest None.

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