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Surgical management of thoracolumbar junction fractures: An evidence-based algorithm

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A R T I C L E I N F O

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A B S T R A C T

Background: The management of thoracolumbar junction (TLJ) fractures, involving the restoring anatomical stability and biomechanics properties, still remains a challenge for neurosurgeons.Despite the high frequency of these injuries, specific treatment guidelines, set on biomechanical properties, have not yet been assumed. The present study is meant to propose an evidence-based treatment algorithm. The primary aim for the protocol validation was the assessment of postoperative neurological recovery. The secondary objectives concerned the evaluation of residual deformity and rate of hardware failure. Technical nuances of surgical approaches and drawbacks were further discussed.

Methods: Clinical and biomechanical data of patients harboring a single TLJ fracture, surgically managed between 2015 and 2020, were collected. Patients' cohorts were ranked into 4 groups according to Magerl's Type, McCormack Score, Vaccaro PLC point, Canal encroachment, and Farcy Sagittal Index. The outcome measures were the early/late Benzel-Larson Grade and postoperative kyphosis degree to estimate neurological status and residual deformity, respectively.

Results: 32 patients were retrieved, 7, 9, 8, and 8 included within group 1, 2, 3, and 4, respectively. Overall neurological outcomes significantly improved for all patients at every follow-up stage ($p < 0.0001$). Surgeries gained a complete restoration of post-traumatic kyphosis in the entire cohort ($p < 0.0001$), except for group 4 which experienced a later worsening of residual deformity.

Conclusions: The choice of the most appropriate surgical approach for TLJ fractures is dictated by morphological and biomechanical characteristics of fracture and the grade of neurological involvement. The proposed surgical management protocol was reliable and effective, although further validations are needed.

1. Introduction

The thoracolumbar junction (TLJ), referred to the T10-L2 vertebral segment, is still considered the most unstable spinal region since it accounts for up to 90% of adult traumatic fractures.[1,2] This high occurrence is explained by the increase in mechanical instability due to the transition from the rigid thoracic spine, stabilized by the sternum and rib joints, to the mobile lumbar column. Additionally, according to Denis' three-column theory, the center of gravity of axial load moves from the anterior to the posterior column at the level of TLJ, resulting in raised hemodynamic stress only supported by the sagittal oriented facets.[3–5]

Up-to-date data about TLJ fractures report an increasing incidence of 15,000/year, especially among young patients (median age 30 years old).[6–8]

In 70% of cases, the TLJ fractures result in immediate neurological damages and for over 250,000 patients/year permanent deficits persist.[6,9,10]

In the light of overt morbidity and mortality, an accurate assessment and management of TLJ fractures is vital. The great challenge for neurosurgeons remains the surgical fully re-establish TLJ morphology and biomechanics properties. Many concerns still burden the treatment of TLJ fractures. First, despite the various classifications proposed in the last

Abbreviations: AIS, Abbreviated Injury Scale; CT, Computed Tomography; ISS, Injury Severity Score; MRI, Magnetic Resonance Imaging; PLC, Posterior Ligamentous Complex; TLJ, Thoracolumbar Junction.

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50 years, an exhaustive classification system including both morphological and clinical features is still missing.[11–17] On the other hand, the literature lacks prospective and randomized multicenter trials, thus the scientific piece of evidence is largely based on retrospective case series that are insufficient to draw up appropriate guidelines. It derives that, still to date, it and doesn't exist any absolute or universally shared criteria for the TLJ fractures management

Herein, we reported our personal experience with the management of TLJ fractures and propose our evidence-based surgical algorithm, designed on pathomorphology and patients' neurological status. The primary goal of this study was to assess the early postoperative and long-term neurological outcomes. The secondary aim was to estimate the residual deformity and rate of biomechanical properties restoration.

Concerns, pitfalls, and alternative strategies for the surgical treatment of TLJ fractures were also discussed.

2. Methods

2.1. Study design

The present retrospective study was derived from data collected across two level I trauma centers hospitals from 2015 to 2020.

Eligible criteria were the age ranging between 15 and 70 years old, diagnosis of post-traumatic single TLJ fracture, and evidence for partial or complete neurological involvement. The Abbreviated Injury Scale (AIS) was applied for patients with multiple injuries and the overall Injury Severity Score (ISS) was estimated.[18,19]

Patients with face, extremity, or external involvement with concomitant AIS lower or equal than 2 and a maximum overall ISS of 12, were enrolled. Fractures conservatively treated or patients with head, neck, chest, or abdomen injuries, with an ISS greater than 12, were excluded from the study (Table 1).

2.2. Preoperative work-up

At admission, all patients enrolled underwent neurological assessment based on the Benzel-Larson grading system.[20] This scale evaluates the neurological symptoms and stratifies patients in VII grades, according to the myelopathic dysfunction (Table 2).

The preoperative imaging workup involved spinal roentgenogram, computed tomography (CT), and T1 and T2-weighted magnetic resonance imaging (MRI) scans. Fractures were classified according to Magerl's score [13]**.**

2.3. Analysis for failure of mechanical components

Anterior mechanical failure was assessed through CT reconstructions and the McCormack load sharing classification, ranging between 1 and 6.[15] It must be specified that the "kyphosis" was not considered, as it is a post-operative parameter achieved after interbody fusion. McCormack scores equal to or lower than 4 refer to an "adequate" vertebral body load sharing, while it is "inadequate" when McCormack scores range between 5 and 6.

Table 1
Eligibility criteria.

Body Region	AIS score
Head/Neck	0
Face	0–2
Chest	0
Abdomen	0
Extremity	0–2
External	0–2
ISS score:	0–12

AIS: Abbreviated Injury Scale; ISS: Injury Severity Score.

Table 2
Benzel-Larson Neurological Grading System[20].

Grade	Neurological Involvement
I	Complete functional neural transection: no motor or sensory function
II	Motor complete: no voluntary motor function, preservation of some sensation
III	Motor incomplete–nonfunctional: minimal nonfunctional voluntary motor function
IV	Motor incomplete–functional (nonambulatory): some functional motor control that is useful but not sufficient for independent walking
V	Motor incomplete–functional (limited ambulation): walking with assistance or unassisted but significant difficulty that limits patient mobility
VI	Motor incomplete–functional (unlimited ambulation): difficulty with micturition: significant motor radiculopathy; discoordinated gait
VII	Normal: neurologically intact or minimal deficits that cause no functional difficulties

Ref. [20].

Posterior mechanical failure was evaluated by MRI scans and reported as Vaccaro's posterior ligamentous complex (PLC) points.[17] The PLC score of 0 indicates the integrity of the posterior ligamentous complex, rather 2 or 3 points of PLC identifies a suspected or certain ligamentous disruption, respectively.

2.4. Evaluation of spinal canal encroachment

Spinal canal encroachment was assessed to estimate the residual post-traumatic canal size at the fracture level. All the measurements were performed on axial CT scans with the Picture Archiving and Communication System (PACS) radiology software.

According to Vaccaro et al, the cross-sectional area was calculated at three levels of interest: above, at, and below the level of the injured vertebra.[21] Canal encroachment was reported as the average percentage of cross-sectional area reduction compared to the level above and below .[21] Based on our experience, a canal encroachment greater than 40% was arbitrarily assumed to be as critical prognostic factor for potential risk of neurological involvement.

2.5. Assessment of post-traumatic kyphosis and instability

The evaluation of the post-traumatic segmental kyphosis deformity was reported as Farcy Sagittal Index. It consists in the measure of the kyphotic segmental deformity adjusted based on the normal sagittal contour at the injured level.[22] The formula applied was as follows: $Sagittal\ Index = \alpha + Cf$

α is the estimated angle between two parallel lines crossing through the inferior endplate of the overlying vertebra and the inferior endplate of the injured one. Cf is the correction factor for the normal sagittal contour. It is fixed at -5°, 0°, and $+10^{\circ}$ for the T10-T1, T12-L1, and L2 levels, respectively. A Sagittal Index greater than 20° was considered indicative of severe spinal instability.

2.6. Groups and surgical algorithm

Based on the aforementioned biomechanical key points, fractures were categorized into 4 Groups, differentiating patients with predominant or isolated posterior mechanical failure from those having a predominant or isolated anterior mechanical failure, from those holding both. Patients with a predominant or isolated posterior mechanical failure were further divided between those showing a large posttraumatic segmental kyphosis (greater than 20° evaluated by means of Sagittal Index) and those with a slight segmental kyphosis ($\geq 20^{\circ}$).

In all cases, the surgical treatment consisted in arthrodesis and fusion via open approaches.

The decision-making process for surgical decompression of the spinal canal involved the neurological status and percentage of spinal canal encroachment. Indications were the evidence for a neurological deficit and an encroachment ≥60%. This last was arbitrarily set based on our experience.

The average pre-operative Benzel-Larson Grade was calculated for each Group.

Group 1 involved patients diagnosed with anterior and posterior elements injury with distraction (Magerl Type B), McCormack score ranging between 1 and 4, Vaccaro PLC points ranging between 2 and 3, canal encroachment lower than 40%, and Sagittal Index greater than 20°.

Group 1 included fractures characterized by a predominant posterior mechanical failure with a concomitant large segmental kyphosis.

All patients underwent a segmental long posterior instrumented fusion, in a "two levels above – two levels" modality. Both non-hybrid constructs (pedicle screws and rods) and hybrid ones (pedicle screws below the fracture's level, laminar hooks above the fracture's level, and rods) were employed. Fusion is facilitated by the decortication of bony surfaces and removal of interspinous ligaments, while the placement on the crews of autologous bone graft promotes osteosynthesis and fusion.

The biomechanical advantages of posterior stabilization lie in the capability to achieve a three-column fixation via pedicle screws.

Group 2 comprised patients with vertebral body compression fractures (Magerl Type A), McCormack scores ranging between 5 and 6, Vaccaro PLC point of 0, canal encroachment greater than 40%, and Sagittal Index equal to or lower than 20°. These fractures had a predominant anterior mechanical failure and concomitant wide encroachment of the spinal canal.

All the patients involved in the Group 2 underwent a partial corpectomy and subsequent body height restoration by means of Harm's cage, via anterior approach, to sustain axial loads and achieve kyphotic correction. The cage is filled with autologous bone graft, obtained from the corpectomy, to exploit its osteogenic properties.

Group 3 is composed of patients diagnosed with both anterior and posterior elements' injury, with rotation (Magerl Type C), McCormack scores ranging between 5 and 6, Vaccaro PLC point of 2 or 3, canal encroachment greater than 40%, and Sagittal Index greater than 20°. For these cases, both anterior and posterior elements were disrupted with a concomitant wide encroachment of the spinal canal. They underwent a combined anterior and posterior approach. The anterior approach consisted of a partial corpectomy, and placement of an autologous bone-filled Harm's cage, while the posterior one was a segmental short-instrumented fusion.

Group 4 involved patients with anterior and posterior elements injury with distraction (Magerl Type B), McCormack score equal to or lower than 4, Vaccaro PLC point of 2 or 3, canal encroachment greater than 40%, and Sagittal Index lower than 20°. Group 4 resulted similar to Group 1, apart from the very slight residual kyphosis deformity. The patients included in Group 4 underwent a segmental short posterior instrumented fusion with a "one level above-one level below" modality. Non-hybrid segmental constructs (pedicle screws and rods) were employed.

Biomechanical groups and the proposed evidence-based surgical algorithm are summarized in Table 3 .

Table 3
Proposed evidence-based surgical algorithm.

Group	Magerl's Type	McCormack Score	Vaccaro PLC point	CE	FSI	Surgical Approach
1	B	<5	2–3	<40%	>20°	Long-PIF
2	A	5–6	0	>40%	≤20°	AIF
3	C	5–6	2–3	>40%	>20°	Combined A/PIF
4	B	<5	2–3	<40%	≤20°	Short-PIF

AIF: Anterior Instrumented Fusion; CE: Canal Encroachment; FSI: Farcy Sagittal Index; PIF: Posterior Instrumented Fusion; PLC: posterior ligamentous complex.

2.7. Follow-up protocol

The follow-up included a postoperative neurological evaluation, along with the same neuroimaging protocol performed preoperatively. Further endpoints of clinical and radiological evaluation were fixed up in the sixth month, first, second and third year.

2.8. Outcome measures and statistical analysis

The primary aim of our study was to evaluate postoperative neurological recovery. The immediate and long-term neurological outcomes were measured by the early and late Benzel-Larson grades, respectively. Early postoperative outcome was assessed at the sixth-month follow-up. It mirrors the correct execution and the prompt success of the surgery.

The late Benzel-Larson Grade was estimated at the first, second, and third-year follow-up. These reflect the mastery of the intervention in reaching a durable neurological recovery.

Between each Group, a coupled comparison between the preoperative, early, and late average Benzel-Larson Grades was performed by means of a *t*-test of paired samples. A p-value <0.05 was set as statistically significant.

For each Group, the overall trend of patients' neurological recovery was also obtained through the interpolation of the Benzel-Larson Grades measured during the follow-up stages.

The secondary goal of this study was to estimate the residual deformity. This parameter was measured by the Farcy Sagittal Index at all the follow-up stages, to assess if the surgical approaches had ensured a long-lasting restoration of the sagittal alignment.

Ultimately, at third-year follow-up, all patients underwent to the Prolo Economic and Functional Rating Scale to detect and analyze clinical outcomes and rate of life-threatening.[23]

3. Results

3.1. Demographic and biomechanical data

32 patients were enrolled. Group 1 included 7 cases diagnosed with a Type B fracture (3 B1.2 and 4 B2.3). In this Group, the average preoperative McCormack Score was 1.83 ± 1.52 (mean ± SD), Vaccaro PLC point 2.66 ± 0.1, canal encroachment 29.92 ± 9.3% and Farcy Sagittal Index 24.2 ± 1.37°. Group 2 received 9 patients with a Type A fracture (2 A2.2, 1 A2.3, 2 A3.2, and 4 A3.3). Group 2 had an average preoperative McCormack score of 5.47 ± 0.51, a Vaccaro PLC point of 0, a Canal encroachment of 72.26 ± 12.3%, and a Farcy Sagittal Index of 18.8 ± 1.16°. Group 3 comprised 8 patients with a Type C fracture (2C1.2 and 6C2.2). Here, the mean estimated McCormack score was of 5.63 ± 0.50, Vaccaro PLC point 2.90 ± 0.2, Canal encroachment 84.55 ± 6.3%, and Farcy Sagittal Index 23.4 ± 2.12°. Group 4 involved 8 patients diagnosed with a Type B fracture (3 B1.2 and 5 B2.3). In the latter Group, McCormack score was 2.4 ± 1.43, Vaccaro PLC point 2.80 ± 0.1, Canal encroachment 31.70 ± 8.7%, and Farcy Sagittal Index 18 ± 1.07° (Table 4).

3.2. Type of fractures and preoperative neurological assessment

Out of 32 fractures, the Magerl's types were as follow: 15 Type B (46%), 9 Type A (28%), and 8 Type C (25%). Subtypes were as follow: 2 A2.2, 1 A2.3, 2 A3.2, 4 A3.3, 6 B1.2, 9 B2.3, 2C1.2, and 6C2.2. Among the type A, 9%, 22%, 43%, and 26% reported a Benzel-Larson Grade of 2, 3, 4, and 5, respectively. Within Type B, 32% of patients had Grade 3, 59% Grade 4, and 9% Grade 5. For the type C, 9%, 45%, 9%, and 36% reported a Grade 1, 3, 4 and 5, respectively **(**Fig. 1**).**

3.3. Overall neurological outcome

All patients experienced an immediate postoperative neurological

Table 4
Biomechanical data.

Group	N° of pts		Magerl's Type	McCormack Score (mean ± SD)	Vaccaro PLC points (mean ± SD)	CE (mean ± SD)	FSI (mean ± SD)
1	7	3	B1.2	1.83 ± 1.52	2.66 ± 0.1	29.92 ± 9.3%	24.2 ± 1.37°
		4	B2.3				
2	9	2	A2.2	5.47 ± 0.51	0	72.26 ± 12.3%	18.8 ± 1.16°
		1	A2.3				
		2	A3.2				
		4	A3.3				
3	8	2	C1.2	5.63 ± 0.50	2.90 ± 0.2	84.55 ± 6.3%	23.4 ± 2.12°
		6	C2.2				
4	8	3	B1.2	2.4 ± 1.43	2.80 ± 0.1	31.70 ± 8.7%	18 ± 1.07°
		5	B2.3				

CE: Canal Encroachment; FSI: Farcy Sagittal Index; PLC: posterior ligamentous complex; Pts:Patients; SD: Standard Deviation.

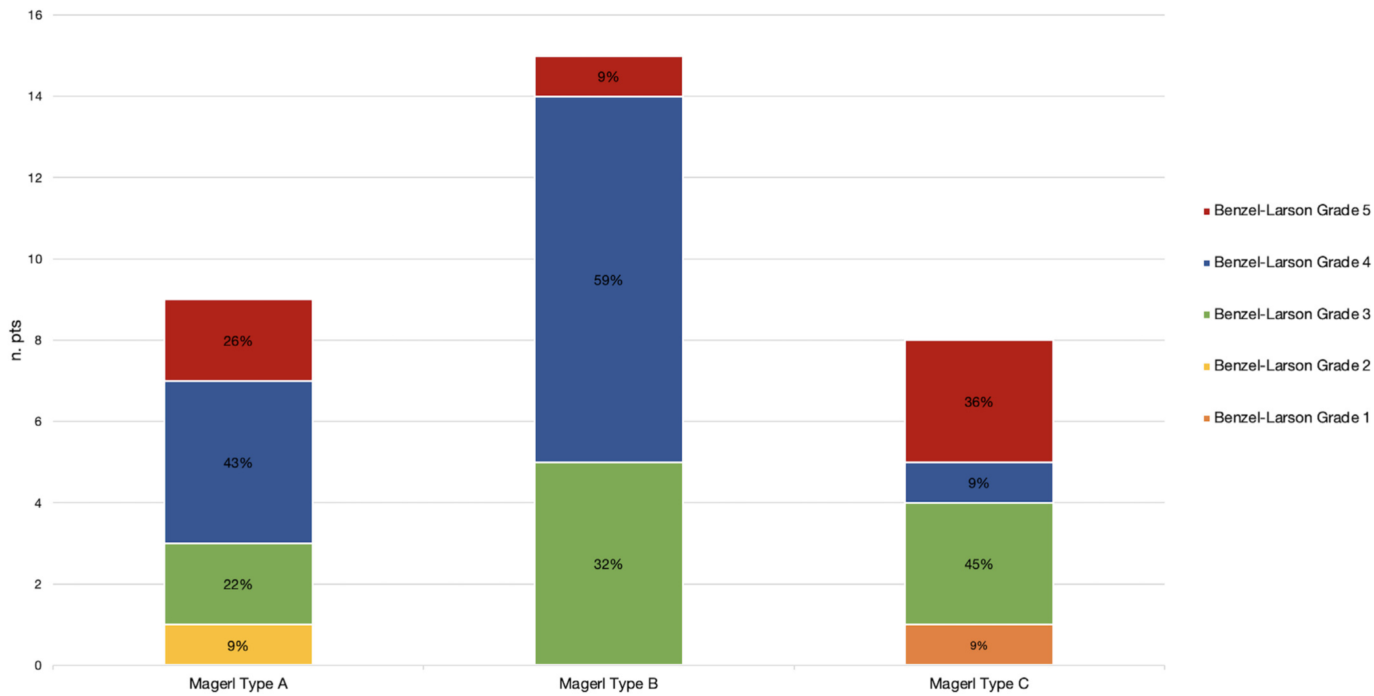

Fig. 1. Benzel-Larson grade according to Magerl's classification.

recovery. In Group 1, the average Benzel-Larson Grade was 3.83 ± 0.71 preoperatively and 5.75 ± 0.86 at six-month follow-up ($p < 0.0001$). In Group 2, the same value was 3.73 ± 1.55 preoperatively and 4.78 ± 2.01 at six-month follow-up ($p < 0.0001$). In Group 3, the mean estimated Benzel-Larson Grade was 3.72 ± 1.10 before surgery and 5.63 ± 1.12 in the sixth month ($p < 0.0001$). Group 4 had a preoperative average Benzel-Larson Grade of 3.7 ± 0.48 that became 6.7 ± 0.48 at six-month follow-up ($p < 0.0001$). At the six-month follow-up, the average estimated gain rate on Benzel-Larson Grade was 3.5, 2.5, 1.4, and 2.3 in Group 1, 2, 3, and Group 4, respectively. In all Groups no further improvement at first, second, and third-year follow-up was observed (Table 5).

Table 5
Overall neurological outcome.

Group	N° pts	Follow-up				
		Pre-op (mean ± SD)	6-mo (mean ± SD)	1-y *(mean ± SD)*	2-y *(mean ± SD)*	3-y *(mean ± SD)*
1	7	3.83 ± 0.71	5.75 ± 0.86	6.2 ± 0.50	6.0 ± 0.56	5.9 ± 0.62
		Range: 3-5	*Range:4-7*	*Range: 6-7*	*Range:6-7*	*Range:6-7*
t-test		$p < 0.0001$	NS	NS	NS	NS
2	9	3.73 ± 1.55	4.78 ± 2.01	5.0 ± 1.58	5.2 ± 1.53	5.3 ± 1.67
		Range: 1-6	*Range: 1-7*	*Range: 6-7*	*Range: 6-7*	*Range: 6-7*
t-test		$p < 0.0001$	*NS*	*NS*	*NS*	*NS*
3	8	3.72 ± 1.10	5.63 ± 1.12	5.8 ± 1.21	5.9 ± 1.14	6.2 ± 1.04
		Range: 2-5	*Range: 4-7*	*Range: 6-7*	*Range: 6-7*	*Range: 6-7*
t-test:		$p < 0.0001$	*NS*	*NS*	*NS*	
4	8	3.7 ± 0.48	6.7 ± 0.48	6.9 ± 0.52	6.8 ± 0.53	6.8 ± 0.64
		Range: 3-4	*Range: 6-7*	*Range: 6-7*	*Range: 6-7*	*Range: 6-7*
t-test		$p < 0.0001$	*NS*	*NS*	*NS*	*NS*

mo: Month; NS: No Statistical; pts: patients; y: year.

The overall trend of patients' neurological status, measured at the follow-up stages, displays a prompt postoperative improvement of neurological symptoms in all groups (Fig. 2).

3.4. Overall residual deformity and rate of hardware failure

Post-traumatic segmental kyphosis was estimated at 24.2°, 18.8°, 23.4°, and 18° in Groups 1, 2, 3, and 4, respectively. In all cases, surgery achieved an optimum sagittal alignment restoration as documented by the Farcy Sagittal Index at the sixth-month follow-up. It was set at 3.5°, 4.8°, 3.3°, and 10.2° in Groups 1, 2, 3, and 4 respectively ($p < 0.0001$). After three years, a slight decrease in Farcy Sagittal Index was observed in the first three Groups, even though this never resulted in statistically significant. In Group 4, a dramatic Farcy Index increase was found at first-year follow-up because 5 out of 8 patients experienced a hardware failure. Hardware failures consisted of 4 breakings of the screw and 1 screw's pullout. In these five patients, the estimated pre-operative Farcy Sagittal Index ranged between 12° and 20°. They underwent a re-operation to perform an elongation of the construct in a "two-levels above – two levels below" modality. In the same Group 4, Sagittal Index measured 10.2° and 9.8° at the second and third-year follow-up, respectively (Table 6).

The trend of kyphosis degree measurement graphically demonstrates the immediate restore of sagittal alignment at the 6-month follow-up, while the group 4 experienced a worsening at 1 year after surgery (Fig. 3).

3.5. Complication rate

Two cases experienced wound's infection. Both patients recovered within one month by means of the antibiotic therapy.

3.6. Life-threatening

At third-year follow-up, the average Prolo E and Prolo F were 4.00 and 3.83 in Group 1, 3.84 and 3.42 in Group 2, 2.09 and 2.63 in Group 3, and 2.88 and 3.03 in Group 4, respectively.

4. Discussion

In this study we presented an evidence-based surgical algorithm for the treatment of TLJ fractures reporting patients' neurological and biomechanical outcomes which result from its application.

The lack of evidence-based guidelines for the management of TLJ fractures directs to surgical choices only dictated by the surgeon's personal experience. This absence of a shared consensus potentially leads to an over- or under-treatment, resulting in overly invasive techniques, flatback syndrome or unresolved neurological symptoms, and risk of hardware failure.

A detailed preoperative multimodality assessment of the neurological status and biomechanical imbalances was crucial in the planning of our treatment algorithm.

First was the taxonomy of fractures. Magerl's classification system was proved to be the most suitable, providing information about pathomorphological features and kinetics. It is in the authors' opinion that, if completed with a subsequent outcome-based algorithm, Magerl's classification may be considered not only a descriptor but also a predictor.

Secondly, the failure of mechanical components, McCormack's score, percentage of canal encroachment, and Vaccaro's PLC points were analyzed. A predominant anterior mechanical failure (Group 2-McCormack score 5 or 6 and/or canal encroachment greater than 40% with a concomitant PLC point of 0) dictates an anterior approach. On the contrary, a predominant posterior mechanical failure (Groups 1 and 4-McCormack score ranging between 0 and 4 and/or canal encroachment lower than 40% with a concomitant PLC point of 2 or 3) clearly indicates the need for a posterior approach. Cases with a concomitant anterior and a posterior mechanical failure (Group 3-McCormack score 5 or 6 and/or canal encroachment greater than 40% with a concomitant PLC point of 2 or 3) unavoidably require a combined approach. Additionally, the assessment of post-traumatic kyphosis was performed by the Farcy Sagittal Index. TLJ hyper-kyphosis, frequent in fractures with a prevalent anterior mechanical failure, may be reduced manually by prone positioning. This maneuver accentuates the lumbar lordosis and reduces the kyphotic deformity.[24] Intraoperatively, the employment of in-situ contouring of the fixation rods may be necessary to achieve an effective correction of the sagittal collapse. Pre-contoured rods, placed into mono-axial screws, facilitate the rotation into sagittal orientation, thus

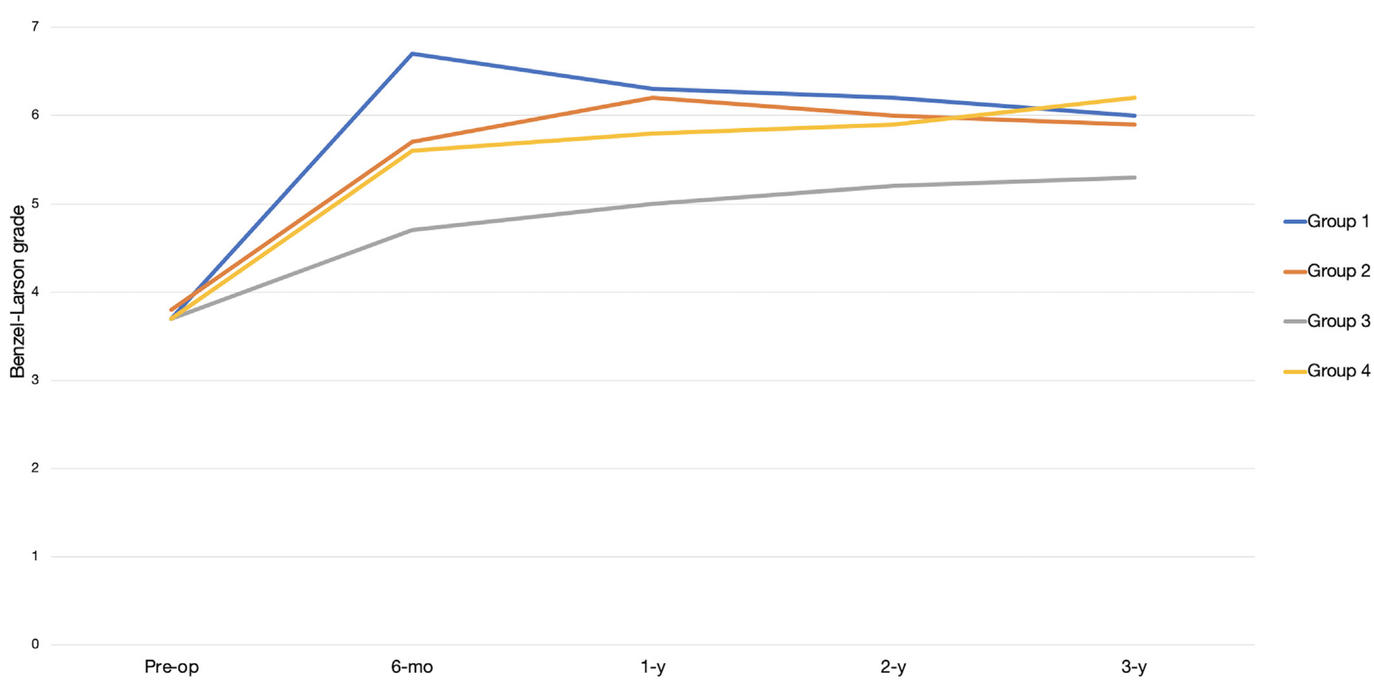

Fig. 2. Trend of Benzel-Larson Grades.

Table 6
Overall residual deformity and sagittal alignment restoration.

Group	N° pts	Follow-up				
		Pre-op (mean)	6-mo (mean ± SD)	1-y (mean ± SD	2-y (mean ± SD)	3-y (mean ± SD)
1	7	24.2°	3.5°	4.2°	4°	4.2°
t-test		p < 0.0001	NS	NS	NS	NS
2	9	18.8°	4.8°	5.2°	5.3°	5.4°
t-test		p < 0.0001	NS	NS	NS	NS
3	8	23.4°	3.3°	3.5°	3.8°	3.6°
t-test		p < 0.0001	NS	NS	NS	NS
4	8	18°	10.2°	19°	10.2°	9.8°
t-test		p < 0.0001	p < 0.0001	p < 0.0001	NS	NS

mo: Month; NS: No Statistical; Pts: patients; y: year.

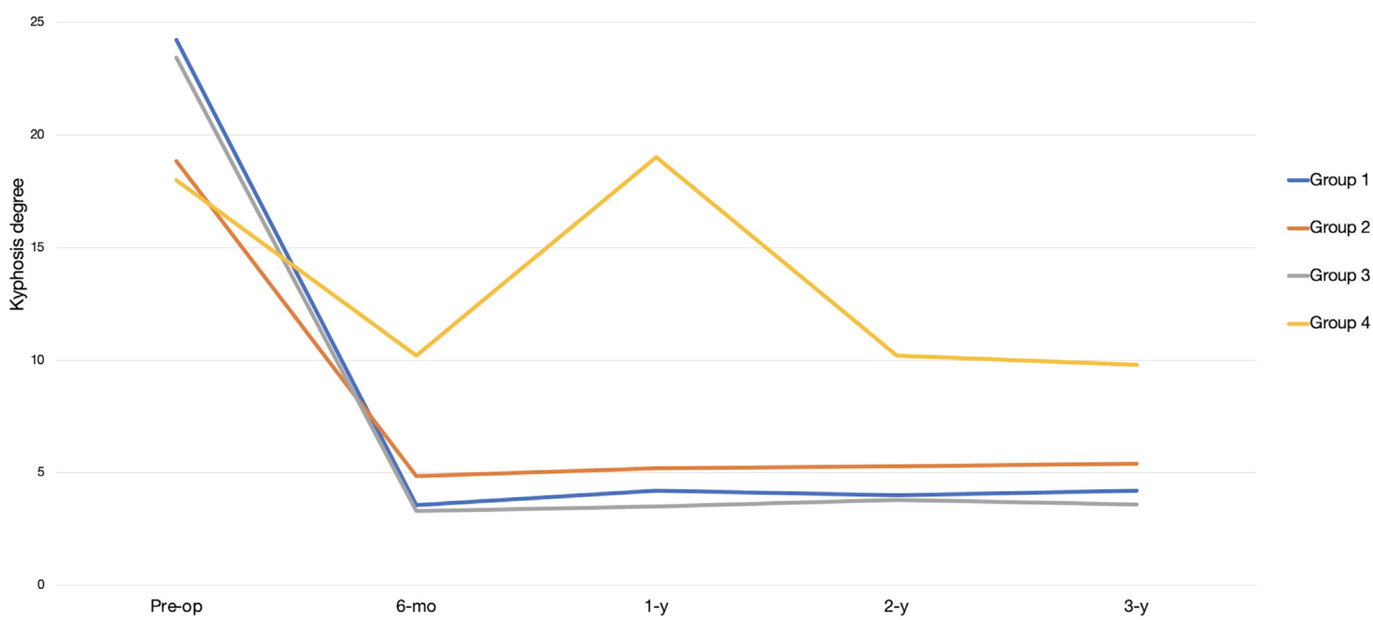

Fig. 3. Trend of Farcy Sagittal Index correction rate.

restoring lordosis. It must be stressed that the re-establishment of the anterior column integrity is mandatory before loading the posterior instrumentation.

The analysis of Sagittal Index also guides the surgeon in the selection of the type and the length of the posterior construct (Group 1 vs Group 4). Short-segment pedicle instrumentation offers some precious advantages. It gives the opportunity to apply simultaneous corrective forces at the injured level acting in axial compression or distraction, flexion or extension, and in rotational, coronal, and sagittal translation, gaining correction of sagittal, axial, and coronal imbalance.[25,26] The short-segment construct may be elongated by means of additional pedicle screws, two levels above-two levels below, or offset laminar hooks. Our data suggested that 12° of kyphosis defines the cut-off point between the need for "one level above-one level below" and "two levels above-two levels below" fixation, to avoid hardware failure.

Furthermore, the requisite for a concomitant spinal decompression is still debated. Despite pieces of evidence reporting the lack of efficacy of anterior decompression or laminectomy in cases of neurological impairment,[27–31] our experience led to conclude conversely that decompression of the spinal canal ought to be performed in cases of neurological deficits and significant spinal encroachment, mostly more than 60%. This approach theoretically increases the likelihood of neurological recovery and prevents the onset of posttraumatic myelopathy and syringomyelia.[32] The implementation of the proposed algorithm was successful in the reported series.

The first aim was fully achieved since all the cohorts experienced a post-operative improvement in the neurological state. Statistical and trend analysis of the Benzel-Larson Grades at follow-up stages proved the effectiveness of the choice of surgical approach to achieve an optimal overall neurological recovery within six months after surgery.

Even the secondary targets were met. In Groups 1, 2, and 3 surgical treatments guaranteed a resolution of the deformity and the restoration of biomechanical properties at the injured segment. The exception was only Group 4, in which at the 1-year follow-up an increase in Farcy Index was experienced. The high rate of hardware failure observed in those patients, having a Sagittal Index ranging between 12° and 20°, is probably due to the wrong employment of an excessively short posterior construct.

Of note, a persistent postoperative spinal deformity would be responsible for a fixed kyphosis or a flat-back deformity, leading to pain, vascular damage, instability, and neurological deterioration.[33–35] In 1999, Abel et al estimated the probability of long-lasting neurological deficits, post-traumatic syringomyelia, as proportional to the residual stenosis and kyphosis due to incorrect treatment of TLJ fractures.[36] Chiefs among these mechanisms are the direct impingement and obstruction of the subarachnoid space, the tethering of the cord at the fracture site, and the progressive cord ischemia due to direct compression.[36] These life-threatening complications necessitate a further late surgical revision to correct the residual kyphosis.

4.1. Conservative treatment and alternative approaches

Conservative treatment for TLJ fractures should be reserved to those patients who are neurologically intact and without radiological findings of biomechanical instability.[37–40]

In 2018, Spiegl and colleagues reported in a systematic literature review about conservative strategies based on more than 3000 articles. These included long-term bed rest, hyperextension body cast, thoracic-lumbar orthoses, pharmacotherapy via anti-inflammatories, opioids, and muscle relaxants. They concluded that orthotic treatment fits osteoporotic TLJ fractures, while drug therapies are appropriate for analgesic effects in patients with normal bone density.[41]

However, it must be stressed that the prolonged recumbency is burdened by an increased risk of complications, such as thrombosis, ulcers, and pneumonia.[37–40]

An ongoing randomized controlled trial, the Pragmatic Randomised Evaluation of Stable Thoracolumbar fracture treatment Outcomes (PRESTO), designed by three National Health Service hospitals, is estimating the feasibility of surgical treatment compared to conservative management in patients with a stable TLJ fracture and without spinal cord injury.[42] The results are still preliminary.

In the current scenario of advances in neurosurgical techniques, innovative and minimally invasive treatment strategies should be considered.

For the management of TLJ fractures, percutaneous screw fixation (PSF) was first reported in 2004 by Assaker et al[43] The PSF technique aimed to achieve spinal fusion via small skin incisions and through the implant of rods and screws, performed fluoroscopy- or navigation-assisted. Undeniable advantages of this technique are the sparing of tissue dissection, less surgical time and postoperative pain, lower bleeding, and decreased infection rate.[43–45] Drawbacks comprise high radiation exposure and proof of a steep learning curve for these procedures.[43–45]

In 2018, Sebaaly and colleagues conducted a literature review including the most recent evidence about surgical outcomes after PSF for TLJ fractures.[46] Based on their results, they proposed a surgical algorithm founded on the AO classification.[47] Patients presenting neurological signs or types C and B2 fractures, with ligamentous damage, are directed to open decompression and fusion. Among the neurologically intact ones, types A2, A4, and B1, as well as types A1 and A3 with local kyphosis $>20^\circ$ and anterior height $<50\%$, are suitable for PSF.[47] The complications reported for PPSF were vessel damage, cerebrospinal fluid leakage, break of the guide wire, and failed fixation.[45,48]

Additional hybrid techniques, such as percutaneous fixation combined with open decompression and debridement, have been tested for several thoracolumbar spinal pathologies.[49–51]

Nevertheless, the literature about their employment for the treatment of TLJ fractures is still scant. More randomized multicenter trials are still needed to draw up evidence-based guidelines for TLJ trauma management, including innovative minimally invasive treatments and new technologies.

A timely diagnosis, accurate preoperative evaluation, and solid choice of the surgical strategy are pivotal to achieve the best patient outcome, at the same time decreasing the risk of complications.

4.2. Study limitations

The present observational study has some limitations mainly related to the relatively small number of treated patients. Potential selection bias and misclassification or information bias are further issues related to the prospective nature of the study. Furthermore, in clinical practice, patients often report multiple lesions involving the chest and abdomen, as representing a contraindication to the prone position. The presence of concomitant thoracic and/or abdominal lesions also limits any early treatment, thus the reported algorithm may result only indicative.

5. Conclusions

The choice of the most appropriate surgical approach for a TLJ fracture ought to be based on the morphological and biomechanical characteristics of the fracture and the neurological involvement of the patient.

An anterior approach is indicated in patients with a prevailing anterior mechanical failure, whereas a posterior approach is preferable for posterior mechanical damages. A combined approach is required for concomitant anterior and posterior mechanical failures.

The post-traumatic grade of kyphosis deformity is at the base of the choice of the length of the construct in posterior instrumented fusions.

The proposed surgical management protocol proved to reliable and effective in the authors' experience, although further validations are needed.

Informed consent statement

Written informed consent has been obtained from the patient to publish this paper.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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