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Traumatic Lumbar Spondylolisthesis: A Systematic Review and Case Series

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Abstract

Study Design: Systematic review and case series.

Objectives: Any acute injury to the posterior elements of the lumbar spine resulting in listhesis is considered a traumatic spondylolisthesis. This rare injury caused by high-energy trauma is variably described in the literature as fracture-dislocation, where only case reports and series have been published. Our objectives were to propose evidence-based treatment recommendations and a new classification system for this injury.

Methods: A systematic review of literature from PubMed, EMBASE, and Cochrane without time frame limitations was performed, which included 77 level IV and V articles and 9 patients as case series in the analysis.

Results: A total of 125 cases were reviewed with mean age of 30.5 years. Half of the cases resulted from a vehicular accident. Back pain presented in 82%, while 50% had neurologic deficits. Operative treatment was performed in 93.6% (posterior decompression [PD] = 4%; posterior spinal fusion [PSF] = 43.2%; interbody fusion [IB] = 46.4%) with overall fusion rates of 74%. Binomial regression analysis for achieving solid fusion showed a 28.6× higher odds for IB compared to PSF ($P = .008$, $r^2 = 0.633$). Subanalysis of cases with disc injuries revealed higher fusion outcomes for IB (87%) compared to PSF (46%; $P = .006$), while there were no significant differences for patients without disc injury. Pain and neurological symptoms improved significantly on final follow-up ($P < .001$). Overall complication rate was 22%.

Conclusion: Operative management with reduction, decompression for neurologic deficits, instrumentation, and fusion is recommended for traumatic spondylolisthesis. Interbody fusion is recommended to achieve better fusion outcomes especially with preoperatively identified disc lesions.

Keywords
traumatic spondylolisthesis, lumbar spine, fracture, dislocation, fracture-dislocation, classification, surgical treatment, outcomes

Introduction

Due to the inherent stability of the lumbar spine, traumatic spondylolisthesis is a rare injury caused by a complex high-energy mechanism. It is defined as any acute injury of the posterior elements associated with vertebral body listhesis resulting in instability, pain with or without neurologic deficit. Isolated lumbar dislocations or combined fracture-dislocations are also associated with traumatic spondylolisthesis. It was first described by Watson-Jones in the 1940s and later incorporated into classifications by Wiltse.[1,2] Despite the broad definition of this injury, only case reports and series have been published to describe the pathology and treatment recommendations.[3-7]

We present a systematic review on the presentation and treatment of this rare traumatic condition. Data from published studies was analyzed, together with cases managed at our institution to create management recommendations. We sought to answer the following questions: (1) What are the common presentations of traumatic spondylolisthesis? (2) How are these lesions treated and what are their outcomes? (3) What are the complications of operative treatment? A new classification system was also proposed to adequately describe the injury

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spectrum for traumatic lumbar spondylolisthesis and guide treatment.

Methodology

Study Design

Systematic review and retrospective review of a case series was approved by the University of Louisville Institutional Review Board.

Search Strategy

A systematic review was performed using the PubMed, Medline, EMBASE, and Cochrane Databases in December 2017 following PRISMA guidelines[8] with no time frame limitations and including only articles in English. The search strategy involved keywords with their expansions and medical subject headings, combined with a Boolean search strategy: "spondylolisthesis," "fracture dislocation," "lumbar," "trauma," "injuries." Terms excluded were "spondyloptosis," "degenerative," "isthmic," "cervical," and "thoracic." Generated reference lists were reviewed using the same search criteria set by the authors.

Selection Criteria

Cases with lumbar spondylolisthesis secondary to trauma were included using the following criteria: (1) no age restrictions; (2) lumbar or lumbosacral spondylolisthesis attributed to a traumatic event; (3) preoperative data including examination findings, neurologic status, listhesis direction, and listhesis grade was reported; (4) adequate description of fractures or dislocation; (5) treatment outlined in article; and (6) postoperative data including outcomes, follow-up period, and complications was described.

Exclusion criteria were (1) spondyloptosis; (2) spondylolisthesis from degenerative, isthmic, congenital, or other nontraumatic causes; (3) fractures not associated with a traumatic event; and (4) chronic spondylolysis.

Study Quality Assessment

The levels of evidence for each study included in the review were assigned based on the criteria published in *The Journal of Bone & Joint Surgery–American Volume*.[9] Individual studies were assessed for risk of bias based on the Risk of Bias in Nonrandomized Studies (ROBINS-I) tool developed by members of the Cochrane Bias Methods Group and the Cochrane Non-Randomized Studies Methods Group.[10] The overall quality of evidence was based on the guidelines set by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Working Group.[11,12]

Data Extraction

Data retrieved from the reports included demographic and preoperative data (back pain, neurologic deficits, and presence of multiple injuries). Neurologic findings were converted to American Spinal Injury Association (ASIA) grades.[13] Sensory findings were recorded as 0 = no sensation, 1 = impaired sensation, and 2 = intact, while bladder and bowel findings were noted as (+) symptoms or none. Data collected from radiographs, computed tomography (CT), and magnetic resonance images (MRI) included extent and direction of listhesis.[14,15] Cases were classified based on identified injuries using a new system proposed by the senior author (Figure 1). Data from the postoperative course was collected, including time to surgery, treatment type and approach, follow-up period, use of brace, and complications. Fusion status, ambulation, pain, and neurologic deficits were also obtained.

Case Series

A retrospective chart review was done of cases treated by the Norton Leatherman Spine group at the University of Louisville Hospital and Norton Hospital from 2010 to present. Data from cases was coded similarly to the cases from the systematic review.

Statistical Analysis

Cases were analyzed using IBM SPSS for Macintosh, v25 (IBM, Armonk, NY). Comparisons of continuous normally distributed variables were done using *t* tests or analysis of variance. Nonparametric data was compared using χ^2 or Wilcoxon test. A binomial regression analysis was also performed to identify any association between preoperative variables with treatment outcomes. Statistical significance was set at $P < .05$.

Results

Study Characteristics

The search yielded 1157 unique articles. Initial abstract review by 2 authors (MLPV and LYC) identified 177 articles, with 77 articles eligible for inclusion for full-text review (Figure 2). The reviewers considered case reports as expert opinion that were Level V studies. All included articles were Level IV case series and Level V case report studies. From the 77 eligible articles, 116 cases were included in the database along with 9 patients obtained from the retrospective case series review (Table 1).

Risk of Bias Assessment

The reviewing authors (MLPV and LYC) performed bias assessment on the included studies. Inconsistencies with risk assessment were reconciled through discussion among all 3 authors. Based on the ROBINS-I tool, each study was assessed for individual domain bias due to confounding, selection of participants, classification of intervention, deviations from intended interventions, missing data, measurement of outcome, and selection of reported results. All articles had serious risk of bias judgments in either one or more domains, which the

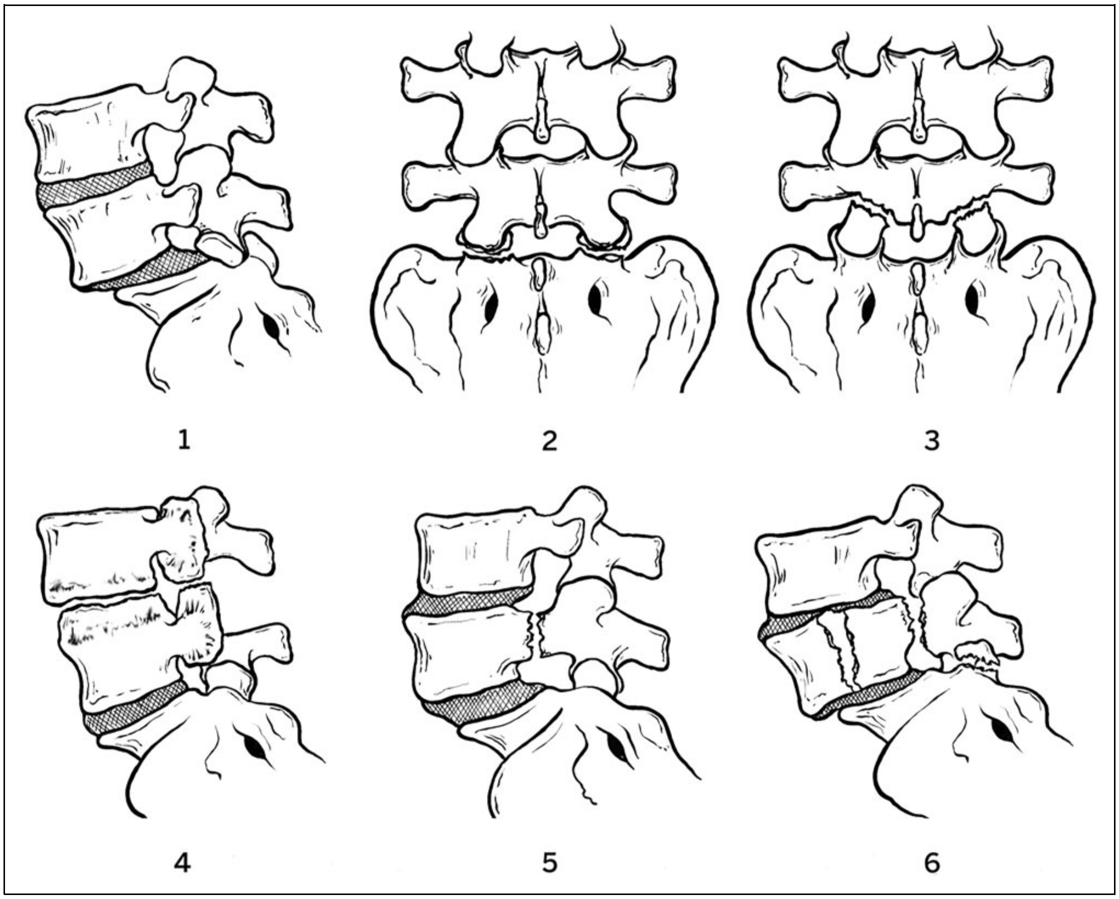

Figure 1. Traumatic lumbar spondylolisthesis classification based on anatomic injury (Dimar JR 2nd). Type 1: unilateral or bilateral facet jump/dislocation; Type 2: unilateral or bilateral facet fracture; Type 3: acute unilateral or bilateral pars fracture; Type 4: acute fracture to previous fusion mass; Type 5: bilateral pedicle fracture; Type 6: complex fracture dislocation with vertebral body involvement.

reviewers attributed to the nature of Level IV case series and Level V case report studies. Individual studies included in the analysis had an overall serious risk for bias (Table 1).

Question 1: What are the common presentations of traumatic lumbar spondylolisthesis? From the 116 cases from the literature and 9 from our series, the mean age at injury was 30.5 years, with the majority being male (Table 1). The most common cause were road traffic accidents (53%) followed by severe crushing injuries (36%) and falls (11%). The most commonly injured level was the lumbosacral junction (74%), usually presenting as low-grade anterolisthesis (Table 2). Pain was the major presenting symptom (82%), with only half of cases (50%) presenting with neurologic injury (motor or sensory deficits from injury or compression to lumbar nerve roots, or disturbances in bladder and bowel control), and a small percentage (10%) reporting cauda equina syndrome (Tables 2 and 3). Consistent with the high-energy trauma, extraspinal injuries were present in 65%.

Using a new classification system based on increasing complexity of injury patterns, traumatic spondylolisthesis commonly involved a pure facet dislocation (Type I, 25%), facet fracture (Type II, 26%), or a complex fracture involving the vertebral body (Type VI, 27%). Only a third of the reported cases demonstrated injuries to the intervertebral disc. The use of MRI, which only started in the 1990s, as well a normal neurologic examination in half of these patients, may have led to underreporting of disc injuries in the literature.

Question 2: How are these lesions treated and what are the outcomes? Most authors consider traumatic spondylolisthesis as an unstable injury requiring spinal stabilization. In our review, only 8 patients were treated nonoperatively. Almost all nonoperative cases had medical contraindications for surgery, and majority were treated during a period when pedicle screw instrumentation was not widely used. Stabilization and decompression, if required, was done through a posterior approach in 78% of cases, while a combined anterior-posterior (AP) procedure was done in 15% (Table 1). Posterior spinal fusion (PSF), including cases describing posterior instrumentation with posterolateral fusion or posterior fusion, was done in 43% (Figure 3). A similar number of cases (46%) had posterior instrumentation with or without posterior fusion and an interbody fusion (IB) done either through a posterior approach or a combined AP procedure (Figure 4).

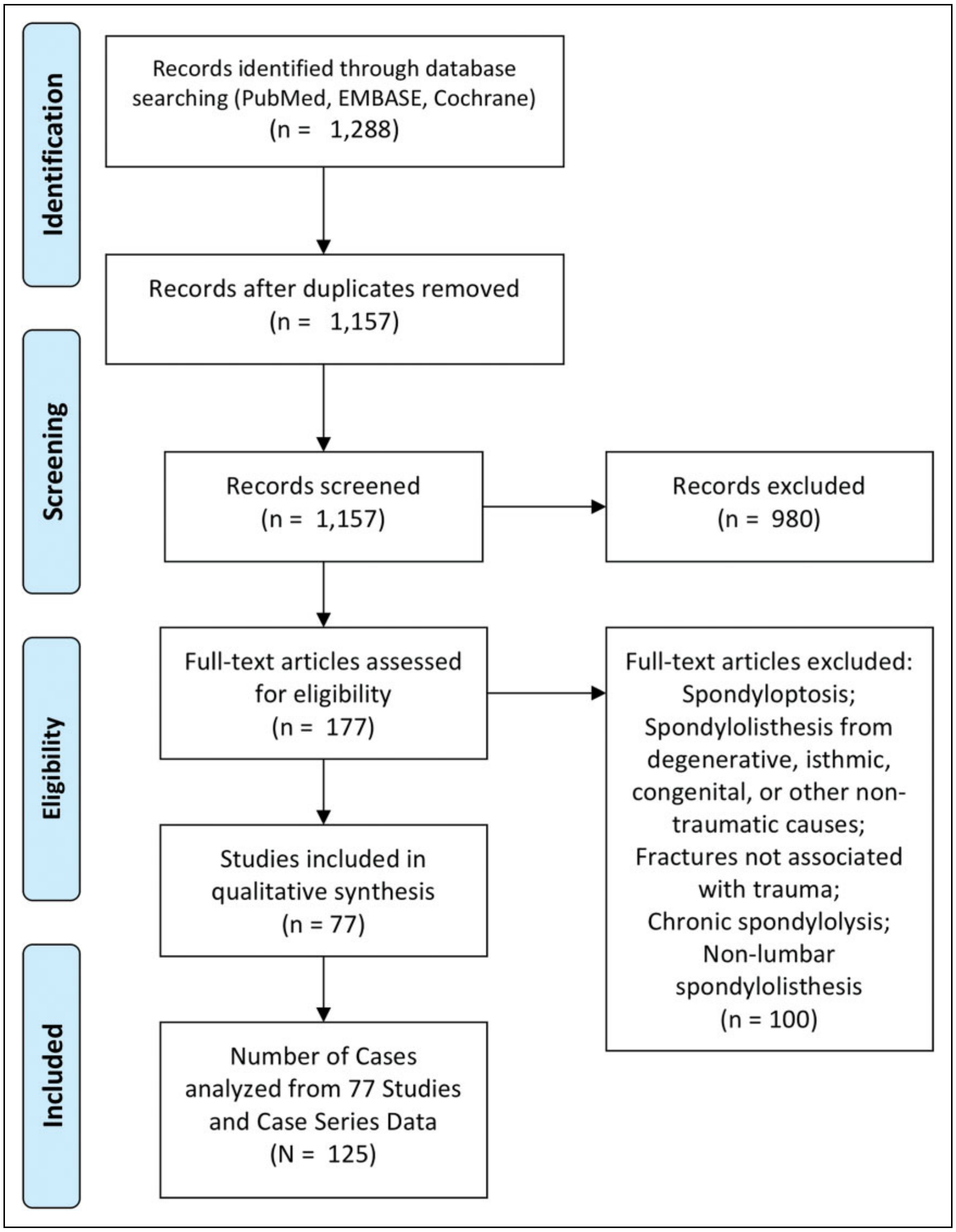

Figure 2. Overview of search strategy based on PRISMA guidelines.

The mean number of days from injury to the surgical procedure was 29 days, but this was skewed by delayed surgeries due to medical comorbidities or missed injuries (Table 2). Most surgical procedures were performed within 24 hours from injury (26%), with 60% done within a week. The mean follow-up was 27.2 months. Bracing was done in 40% of the cases for an average of 3 months, with longer duration lasting 6 months in nonoperative cases. The majority of the cases who were not prescribed with bracing had an interbody fusion (Table 2).

There is general improvement in outcomes with operative treatment of traumatic spondylolisthesis (Table 3). The overall fusion rate was at 74%, with the highest fusion rates in patients with IB Fusion (IB = 88% vs PSF = 69%, $P = .012$). Majority of the patients were ambulatory postoperatively (94%), despite having minimal neurologic deficits in some patients. There was a statistically significant improvement in pain and neurologic deficits postoperatively compared to preoperative exam ($P < .001$). Only 20% of patients had residual pain and 25% had persistent neurologic deficits, which included either weakness, numbness, or disturbances in bladder and bowel control.

Binomial logistic regression analysis was done to determine factors that are associated with the primary outcomes of fusion, ambulation, pain, and neurologic deficits between PSF (N = 54) and IB fusion (N = 58), which are the primary procedures considered in traumatic spondylolisthesis. Factors entered in the model included preoperative back pain, preoperative neurologic involvement (ASIA scores, sensory impairment,

Table 1. Summary of Cases Included in Review.

Year	Author	N	Age, Mean (Range)	Injury Type, n (%)	Listhesis Direction, n (%)	Treatment Approach, n (%)	Treatment Type, n (%)	Level of Evidence[a]	Overall Risk for Bias[b]
1956	Van Demark[56]	1	14	Crush	Anterior	Posterior	PSF	V	Serious
1957	Robertson[57]	1	48	Crush	Posterior	NO	NO	V	Serious
1957	Robson[58]	1	26	Crush	Anterior	NO	NO	V	Serious
1964	Aufranc[59]	1	21	RTA	Anterior	Posterior	PSF	V	Serious
1968	Dewey[60]	2	32 (31-33)	Crush 1; RTA 1	Anterior	NO-1; Posterior-1	NO-1; PD-1	IV	Serious
1972	Chaca[61]	1	27	RTA	Posterior	Posterior	PSF	V	Serious
1973	Henderson[62]	2	17.5 (15-20)	Fall 1; RTA 1	Anterior	Posterior	PSF	IV	Serious
1977	Newell[63]	1	41	Fall	Anterior	NO	NO	V	Serious
1981	Das De[64]	4	31 (19-54)	Crush	Anterior	Posterior	PSF 2; PD 2	IV	Serious
1982	Sciberras[65]	1	24	Crush	Anterior	Posterior	PSF	V	Serious
1983	Edvardsen[66]	1	22	Crush	Anterior	Anterior	IB	V	Serious
1983	Nicholson[67]	1	28	RTA	Posterior	Posterior	PSF	V	Serious
1984	Herron[41]	1	22	Crush	Anterior	Posterior	PSF	V	Serious
1984	Otani[68]	2	22.5 (22-23)	Crush 1; RTA 1	Anterior	Combined 2	IB	IV	Serious
1984	Suomalainen[69]	1	17	RTA	Anterior	Posterior	PSF	V	Serious
1985	Schnaid[70]	1	36	Crush	Anterior	Posterior	PSF	V	Serious
1988	Cope[71]	1	34	Fall	Anterior	NO	NO	V	Serious
1991	Carl[72]	2	28.5 (21-36)	Crush 1; Fall 1	Anterior	Posterior	PSF	IV	Serious
1991	Ebraheim[38]	1	18	RTA	Anterior	Posterior	PD	V	Serious
1991	Garin[73]	1	14	RTA	Anterior	Posterior	PSF	V	Serious
1991	Posel[74]	1	70	RTA	Anterior	Posterior	PSF	V	Serious
1992	Connolly[37]	4	20.25 (16-26)	Crush	Anterior	Posterior	PSF	IV	Serious
1992	Eyres[75]	1	21	RTA	Anterior	Posterior	PSF	V	Serious
1992	Osman[76]	1	41	Crush	Anterior	Combined	IB	V	Serious
1993	Barquet[77]	1	24	Crush	Anterior	Posterior	PSF	V	Serious
1993	Lee[78]	1	32	Fall	Anterior	Posterior	PD	V	Serious
1995	Beguiristain[79]	1	5	Crush	Anterior	NO	NO	V	Serious
1997	Steinitz[80]	1	36	RTA	Posterior	Combined	IB	V	Serious
1998	Aihara[7]	2	23.5 (22-25)	Crush	Anterior	Combined	IB	IV	Serious
1998	Roche[40]	1	25	RTA	Anterior	Posterior	IB	V	Serious
1999	Carlson[45]	1	15	RTA	Anterior	Combined	IB	V	Serious
1999	Fabris[6]	3	26.3 (26-27)	RTA	Anterior	Posterior	PSF 1; IB 2	IV	Serious
1999	Hodges[23]	1	31	Crush	Anterior	Combined	IB	V	Serious
1999	Murata[81]	1	19	RTA	Anterior	Posterior	PSF	V	Serious
2001	Verlaan[47]	1	17	Crush	Anterior	Posterior	IB	V	Serious
2003	Lamm[22]	1	21	RTA	Anterior	Combined	IB	V	Serious
2003	Smith[82]	1	44	Crush	Anterior	Posterior	PSF	V	Serious
2003	Tohme-Noun[42]	1	55	RTA	Anterior	Posterior	IB	V	Serious
2004	Miyamoto[83]	1	20	RTA	Anterior	NO	NO	V	Serious
2004	Stuart[21]	1	25	RTA	Anterior	Posterior	PSF	V	Serious
2004	Tsirikos[5]	2	29 (16-42)	RTA	Anterior	Combined	IB	IV	Serious
2004	Vialle[29]	4	36.75 (14-54)	Crush 1; RTA 3	Anterior	Posterior 3; Combined 1	PSF 2; IB 2	IV	Serious
2005	Ahmed[84]	1	34	RTA	Posterior	Posterior	IB	V	Serious
2005	Hidalgo-Ovejero[85]	1	24	Crush	Anterior	Posterior	IB	V	Serious
2005	Robertson[49]	4	39 (19-56)	Crush 2; RTA 2	Anterior	Posterior	PSF 3; IB 1	IV	Serious
2005	Song[86]	1	47	RTA	Anterior	Posterior	IB	V	Serious
2005	Vialle[39]	1	27	RTA	Lateral	Posterior	PSF	V	Serious
2006	Cho[50]	1	26	RTA	Anterior	Combined	IB	V	Serious
2006	Ghaiem-Hasakhani[87]	1	22	RTA	Anterior	Posterior	PSF	V	Serious
2006	Reinhold[88]	1	37	Crush	Anterior	Combined	IB	V	Serious
2007	El Assuity[46]	1	19	Fall	Anterior	Combined	IB	V	Serious
2007	Vialle[4]	11	34.8 (14-55)	Crush 1; Fall 2; RTA 8	Anterior 9; Lateral 2	Posterior 8; Combined 3	PSF 4; IB 7	IV	Serious

(continued)

Table 1. (continued)

Year	Author	N	Age, Mean (Range)	Injury Type, n (%)	Listhesis Direction, n (%)	Treatment Approach, n (%)	Treatment Type, n (%)	Level of Evidence[a]	Overall Risk for Bias[b]
2008	De Iure[89]	1	34	RTA	Lateral	Posterior	IB	V	Serious
2008	Deniz[28]	1	44	RTA	Anterior	Posterior	IB	V	Serious
2008	Reddy[27]	2	35 (23-47)	Crush 1; RTA 1	Anterior	Posterior	PSF	IV	Serious
2008	Szentirmai[34]	1	14	RTA	Anterior	Posterior	PSF	V	Serious
2009	Lim[35]	3	48.3 (41-56)	Crush 2; Fall 1	Anterior	Posterior	PSF 1; IB 2	IV	Serious
2010	Blecher[32]	1	20	Crush	Anterior	Posterior	IB	V	Serious
2010	Hidalgo-Ovejero[90]	1	40	Crush	Anterior	Posterior	PSF	V	Serious
2011	Fang[53]	1	26	RTA	Anterior	Posterior	IB	V	Serious
2011	Soultanis[51]	1	19	RTA	Anterior	Posterior	PSF	V	Serious
2011	Xu[20]	1	23	Crush	Anterior	Posterior	IB	V	Serious
2012	Catana[17]	2	31 (26-36)	RTA	Anterior	Posterior	IB	IV	Serious
2012	Im[19]	1	37	Crush	Anterior	Posterior	IB	V	Serious
2012	Shinohara[18]	1	18	RTA	Anterior	Posterior	IB	V	Serious
2013	Guo[91]	1	66	Crush	Anterior	Posterior	IB	V	Serious
2013	Nakao[44]	1	47	Crush	Lateral	Posterior	PSF	V	Serious
2013	Rodrigues[92]	1	15	Crush	Anterior	Combined	IB	V	Serious
2013	Tang[25]	1	41	Crush	Anterior	Posterior	IB	V	Serious
2014	Onu[24]	1	20	RTA	Posterior	Posterior	PSF	V	Serious
2014	Padalkar[48]	1	25	Crush	Anterior	Posterior	IB	V	Serious
2014	Tang[26]	5	38.4 (31-46)	Crush 1; RTA 4	Anterior	Posterior	IB	IV	Serious
2015	Robbins[3]	2	36 (23-49)	Crush 1; RTA 1	Anterior 1; Posterior 1	Posterior	IB	IV	Serious
2015	Tang[52]	1	38	RTA	Anterior	Posterior	IB	V	Serious
2015	Yang[93]	1	11	Crush	Anterior	Posterior	PSF	V	Serious
2015	Yazdi[31]	1	16	Fall	Anterior	Posterior	PSF	V	Serious
2016	Zenonos[30]	1	36	RTA	Anterior	Posterior	PSF	V	Serious
	Case Series	9	31.1 (13-58)	Crush 1; Fall 3; RTA 5	Anterior 9	NO 1; Posterior 7; Combined 1	NO 1; PSF 5; IB 3		
		Case 1	18	RTA	Anterior	Posterior	PSF		
		Case 2	19	RTA	Anterior	Posterior	IB		
		Case 3	30	RTA	Anterior	Posterior	PSF		
		Case 4	18	Crush	Anterior	Posterior	PSF		
		Case 5	58	Fall	Anterior	Posterior	PSF		
		Case 6	39	Fall	Anterior	Combined	IB		
		Case 7	13	Fall	Anterior	Posterior	IB		
		Case 8	34	RTA	Anterior	Posterior	PSF		
		Case 9	51	RTA	Anterior	NO	NO		
Total	77 included articles with present case series	N = 125	30.53 (5-70); male = 89 (71.2%); female = 36 (28.8%)	Crush = 45 (36%); fall = 14 (11.2%); RTA = 66 (52.8%)	Anterior = 110 (88.0%); posterior = 7 (5.6%); lateral = 5 (4.0%)	NO = 8 (6.4%); posterior = 97 (77.6%); anterior = 1 (0.8%); combined = 19 (15.2%)	NO = 8 (6.4%); PD = 5 (4.0%); PSF = 54 (43.2%); IB = 58 (46.4%)		

Abbreviations: RTA, road traffic accident; NO, nonoperative; PD, posterior decompression; PSF, posterior spinal instrumentation + fusion; IB, interbody fusion with supplemental posterior instrumentation ± fusion.

[a]Level of evidence: I, randomized controlled trial; II, prospective cohort study; III, case-control or retrospective cohort study; IV, case series with no control group; V, expert opinion or case reports.

[b]Overall risk for bias: *Low*, comparable to a well-performed randomized trial; *Moderate*, nonrandomized study but cannot be considered comparable to a well-performed randomized trial; *Serious*, has some important problems; *Critical*, too problematic to provide any useful evidence and should not be included in any synthesis; *No information*, no information to base a judgement about risk of bias.

bladder and bowel disturbances), multiple injuries, listhesis grade, fracture classification, lumbosacral compared to non-lumbosacral level of injury, the presence of disc lesions, and treatment type between PSF and IB fusion. Only the regression model for fusion outcomes was significant with $r^2 = 0.633$ and $P < .001$. Among all the factors for fusion, only the treatment type was significant at $P = .008$ (95% confidence interval = 2.409-338.934), where IB fusion had 28.6× higher odds for

Table 2. Preoperative and Postoperative Characteristics of Patient Cases Stratified Based on Treatment Type.

Preoperative Data (N = 125)		N (%)	NO (n, %)	PD (n, %)	PSF (n, %)	IB (n, %)
Levels involved (N = 125)	T12-L1	1 (0.8%)				1 (0.8%)
	L1-L2	7 (5.6%)			5 (4.1%)	2 (1.6%)
	L2-L3	3 (2.4%)	1 (0.8%)		2 (1.6%)	
	L3-L4	9 (7.2%)			7 (5.7%)	2 (1.6%)
	L4-L5	9 (7.2%)			2 (1.6%)	7 (5.7%)
	L5-S1	93 (74.4%)	7 (5.7%)	5 (4.1%)	37 (30.3%)	44 (36.1%)
Cauda equina		13 (10.4%)			3 (2.4%)	10 (8%)
Multiply injured		81 (64.8%)	5 (4%)	3 (2.4%)	40 (32%)	33 (26.4%)
Disc lesion (N = 43)		43 (34.4%)	1 (2.3%)	1 (2.3%)	11 (25.6%)	30 (69.8%)
Listhesis—low grade (N = 112)	Grade 0	2 (1.6%)			1 (0.9%)	1 (0.9%)
	Grade 1	30 (24%)	3 (2.7%)	1 (0.9%)	15 (13.4%)	11 (9.8%)
	Grade 2	49 (39.2%)	3 (2.7%)	1 (0.9%)	16 (14.3%)	29 (25.9%)
Listhesis—high grade	Grade 3	18 (14.4%)	2 (1.8%)		9 (8%)	7 (6.3%)
	Grade 4	13 (10.4%)			5 (4.5%)	8 (7.1%)
Dimar classification	1 Facet dislocation	31 (24.8%)	1 (3.2%)	2 (6.5%)	9 (29%)	19 (61.3%)
	2 Facet fracture	33 (26.4%)	1 (3%)	1 (3%)	14 (42.4%)	17 (51.5%)
	3 Pars fracture	10 (8.0%)		1 (10%)	4 (40%)	5 (50%)
	4 Fusion mass fracture	0 (0%)				
	5 Pedicle fracture	13 (10.4%)	2 (15.4%)		7 (53.8%)	4 (30.8%)
	6 Complex + Body fracture	34 (27.2%)	3 (8.8%)		20 (58.8%)	11 (32.4%)
Postoperative Data		N (%)	NO (n, %)	PD (n, %)	PSF (n, %)	IB (n, %)
Time to surgery, days (N = 107, mean ± SD)		29.47 ± 64.64 (0-420)		22 ± 27 (0-60)	19 ± 36 (0-150)	41 ± 85 (0-420)
Follow-up period, months (N = 122, mean ± SD)		27.2 ± 26.4 (1-120)	22.06 ± 31.68 (1-96)	64 ± 64.75 (4-120)	28.41 ± 27.09 (1-120)	24.20 ± 18.74 (3-84)
Brace[a,b]	Bracing done	50 (40%)	7 (5.6%)	3 (2.4%)	27 (21.6%)	13 (10.4%)
	No brace	75 (60%)	1 (0.8%)	2 (1.6%)	27 (21.6%)	45 (36.0%)
	Brace period (months) (N = 49, mean ± SD)	3.24 ± 3.29 (0.5-24)	5.93 ± 8.15 (0.5-24)	1.67 ± 0.58 (1-2)	2.84 ± 1.07 (1.25-6)	2.96 ± 1.62 (1-6)
Complications[c]	Complications	28 (22.4%)	3 (2.4%)	4 (3.2%)	12 (9.6%)	9 (7.2%)
	No complications	97 (77.6%)	5 (4%)	1 (0.8%)	42 (33.6%)	49 (39.2%)
	Presentation, months (N = 28, mean ± SD)	13.3 ± 23.6 (0-96)	13.3 ± 10.5 (3-24)	3.0 ± 6.0 (0-12)	23.1 ± 33.1 (0.3-96)	4.9 ± 7.2 (0-21)

Abbreviations: NO, nonoperative; PD, posterior decompression; PSF, posterior spinal instrumentation + fusion; IB, interbody fusion with supplemental posterior instrumentation ± fusion.
[a]Significant difference with bracing use between treatment types using Pearson χ^2 test ($\chi^2[3] = 18.078$, $P < .001$).
[b]Significant difference between PSF and IB fusion with the Pearson χ^2 test ($\chi^2[1] = 9.269$, $P = .002$).
[c]Significant difference with presence of complications between treatment types using Pearson χ^2 test ($\chi^2[6] = 17.023$, $P = .009$).

Table 3. Outcome Data Stratified Based on Treatment Type.

Outcomes (N = 125)		Preoperative Total (n, %)	Postoperative Total (n, %)	NO (n, %)	PD (n, %)	PSF (n, %)	IB (n, %)
Fusion (N = 124)[a,b]	Fusion		92 (73.6%)	3 (37.5%)	1 (25%)	37 (68.5%)	51 (87.9%)
	No fusion		32 (25.6%)	5 (62.5%)	3 (75%)	17 (31.5%)	7 (12.1%)
Ambulation (N = 124)	Ambulatory		118 (94.4%)	7 (87.5%)	4 (100%)	51 (94.4%)	56 (96.6%)
	Nonambulatory		6 (4.8%)	1 (12.5%)		3 (5.6%)	2 (3.4%)
Pain[c]	(+) Pain	103 (82.4%)	25 (20.0%)	3 (37.5%)	1 (25%)	9 (16.7%)	12 (20.70%)
	No pain report		99 (80%)	5 (62.5%)	3 (75%)	45 (83.3%)	46 (79.30%)
Neurologic deficits overall[c]	(+) Deficits	63 (50.4%)	31 (24.8%)	2 (25%)	0	15 (27.8%)	14 (24.10%)
	Normal		93 (74.4%)	6 (75%)	4 (100%)	39 (72.2%)	44 (75.9%)
ASIA score[c]	A	2 (1.6%)	1 (0.8%)				1 (0.8%)
	B	3 (2.4%)	0 (0%)				
	C	36 (28.8%)	15 (8.0%)	1 (0.8%)		5 (4.0%)	4 (3.2%)
	D	15 (12.0%)	15 (12.0%)			8 (6.4%)	7 (5.6%)
	E	67 (53.6%)	96 (76.8%)	7 (5.6%)	4 (3.2%)	40 (32%)	45 (36%)
Sensory[c]	0	6 (4.8%)	1 (0.8%)				1 (0.8%)
	1	52 (41.6%)	26 (20.8%)	2 (1.6%)		13 (10.4%)	11 (8.8%)
	2	65 (52%)	95 (76.0%)	6 (4.8%)	4 (3.2%)	40 (32%)	45 (36%)
Bladder symptoms[c]	(+) Bladder	26 (20.8%)	4 (3.2%)			2 (3.70%)	2 (3.4%)
	None		120 (96%)	8 (100%)	4 (100%)	52 (96.3%)	56 (96.6%)
Bowel symptoms[c]	(+) Bowel	23 (18.4%)	5 (4.0%)			3 (5.6%)	2 (3.4%)
	None		119 (95.20%)	8 (100%)	4 (100%)	51 (94.4%)	56 (96.6%)

Abbreviations: NO, nonoperative; PD, posterior decompression; PSF, posterior spinal instrumentation + fusion; IB, interbody fusion with supplemental posterior instrumentation ± fusion.
[a]Significant difference in fusion outcomes between treatment types with Pearson χ^2 test ($\chi^2[3] = 17.306$, $P = .001$).
[b]Significant difference in fusion outcomes between PSF and IB based on Pearson χ^2 test ($\chi^2[1] = 6.259$, $P = .012$).
[c]Significant difference between preoperative and postoperative variables on related samples Wilcoxon signed ranks test, with $P < .001$ (Z scores: pain $Z = -8.556$; neurologic deficits overall $Z = -5.578$; ASIA score $Z = -6.026$; sensory $Z = -5.466$; bladder symptoms $Z = -4.690$; bowel symptoms $Z = -4.243$).

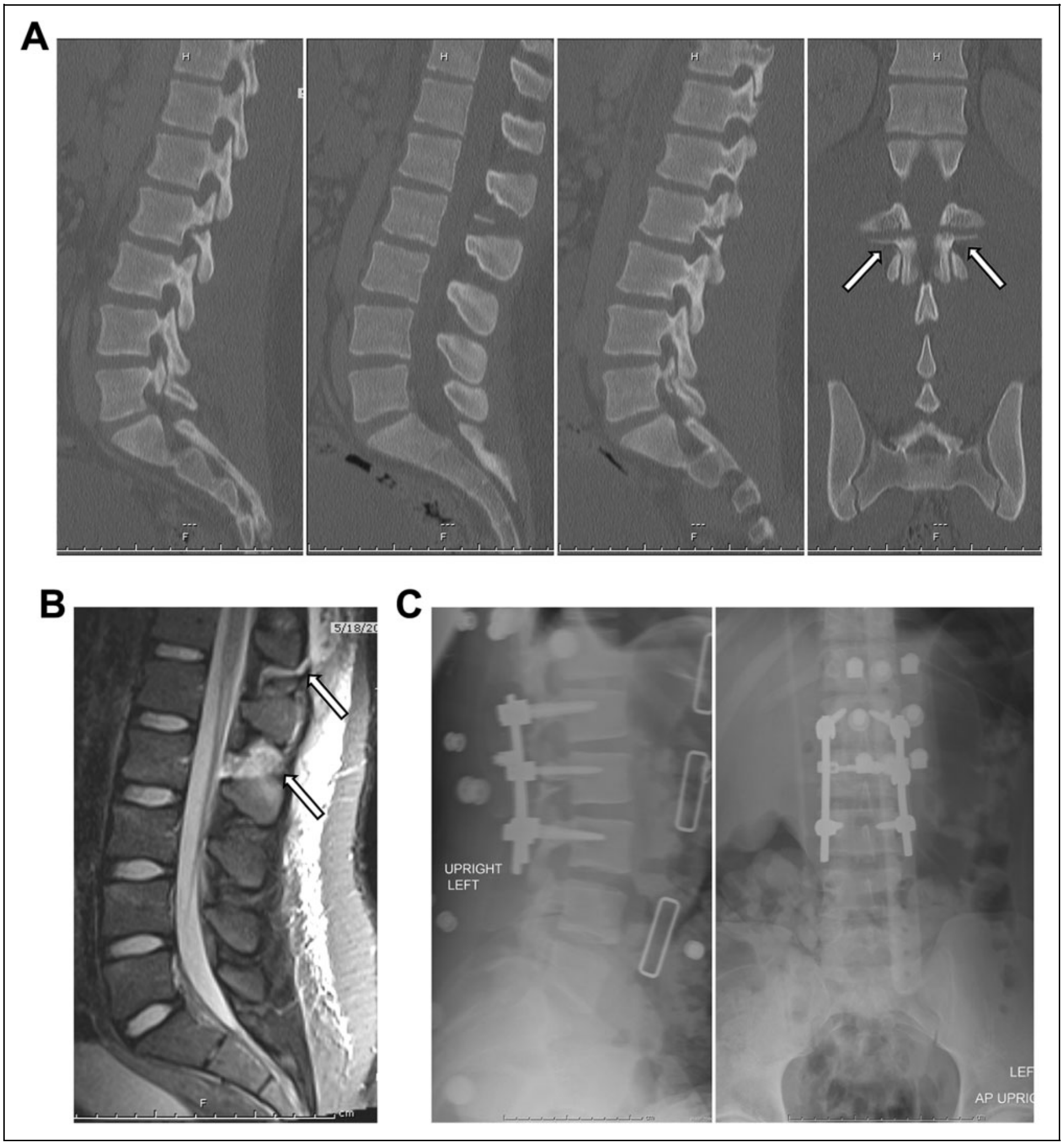

Figure 3. Patient 1 was an 18-year-old male who came in after a road traffic accident. He presented with severe back pain but was neurologically intact, and he had an associated left femur fracture. (A) CT image with acute bilateral pars fracture at L2 (Dimar classification Type 3). Grade 1 anterior listhesis on radiographs (not shown) reduces on supine position. Note the chronic spondylolysis at L5. (B) No disc injuries noted on T2-weighted MRI scan, but had acute injuries to the interspinous ligament at L1-L2 and L2-L3. (C) Posterior spinal instrumentation with posterolateral fusion was done from L1-L3 after reduction. Maintenance of instrumentation and fusion was documented, with no reported pain or deficits on last follow-up 4 years post injury.

developing fusion compared to PSF (Supplemental Table 1, available in the online version of the article).

There was substantial opinion across the reviewed literature on the individual treatment recommendation in the presence of disc injuries for traumatic spondylolisthesis. The subanalysis of patients with disc injuries resulted in significant differences between the PSF and IB fusion (Table 4). Fusion (87% vs 46%) and ambulation (100% vs 83%) were significantly better in IB fusion compared to PSF ($P < .05$). There was a significant improvement in pain and neurologic deficits postoperatively, but neither procedure was statistically better over the other. On the other hand, in patients without identified disc lesions, it was notable that there were no significant differences on postoperative fusion rates, ambulation, pain, and neurologic deficits between PSF and IB fusion (Table 5). Another subanalysis done for injury types based on the proposed classification showed significant difference between injury types only for pain ($P < .05$; Table 6). Although not statistically significant, lower fusion and ambulation rates, and worse neurologic deficits, were seen in more complex injury types (pedicle fracture and complex fracture).

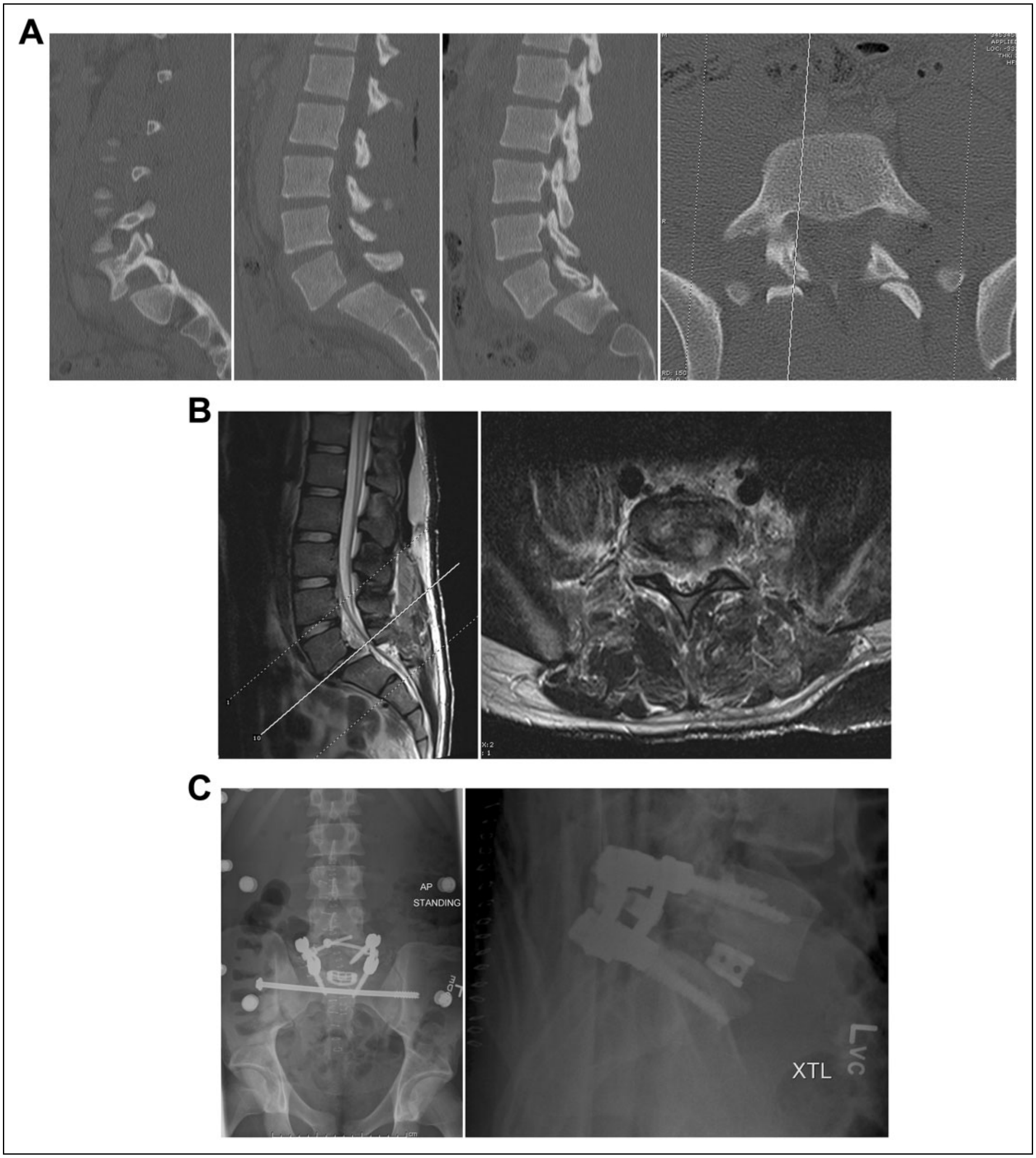

Figure 4. Patient 2 was a 19-year-old male involved in a road traffic accident who was neurologically intact with associated left scapula and right sacral fracture. (A) CT image showing L5-S1 bilateral facet dislocation (Dimar classification Type 1) with grade 3 anterior listhesis. (B) Disc injury seen on T2-weighted MRI scan. (C) Interbody fusion with supplemental posterior instrumentation and fusion was performed at L5-S1. On last follow-up at 1 year post injury, patient was ambulatory without complaints of pain and neurologic deficits, and had documented fusion.

Question 3: What are the complications of operative treatment? The overall postoperative complication rate was high at 22% with significant differences between treatment groups (Table 2). Posterior decompression alone had higher complication rates compared to PSF and IB fusion, while PSF and IB fusion were not significantly different from each other. Complications present on average at 13 months, with the following complications reported in decreasing order: (1) implant failure (n = 11/28) from PSF (n = 8) and IB fusion (n = 3) at 39%; (2) progression of listhesis at 18% secondary to nonoperative (n = 3) or posterior decompression (n = 2); (3) postoperative infection at 14% (n = 4); (4) worsening postoperative neurologic symptoms (n = 3); (5) progressive degenerative changes (n = 3); (6) general surgical comorbidities (n = 1); and (7) death from fat embolism (n = 1). Incomplete reduction was not considered a complication, but it was observed in 9 cases. Medical

Table 4. Outcome Subanalysis of Patients With Identified Disc Lesions Stratified Based on Posterior Spinal Instrumentation + Fusion (PSF) or Interbody Fusion With Supplemental Posterior Fixation ± Fusion (IB).

Outcomes (N = 41)		Preoperative Total (n, %)	Postoperative Total (n, %)	PSF (n, %)	IB (n, %)
Fusion[a]	Fusion		31 (75.6%)	5 (45.5%)	26 (86.7%)
	No fusion		10 (24.4%)	6 (54.5%)	4 (13.3%)
Ambulation[b]	Ambulatory		39 (95.1%)	9 (81.8%)	30 (100%)
	Nonambulatory		2 (4.9%)	2 (18.2%)	0 (0%)
Pain[c]	(+) Pain	38 (88.4%)	9 (22%)	2 (18.2%)	7 (23.3%)
	No pain report	5 (11.6%)	32 (78.0%)	9 (81.8%)	23 (76.7%)
Neurologic deficits overall[c]	(+) Deficits	29 (67.4%)	12 (29.3%)	5 (45.5%)	7 (23.3%)
	Normal	14 (32.6%)	29 (70.7%)	6 (54.5%)	23 (76.7%)

Abbreviations: PSF, posterior spinal instrumentation + fusion; IB, interbody fusion with supplemental posterior instrumentation ± fusion.
[a]Significant difference in fusion outcomes between PSF and IB based on Pearson χ^2 tests ($\chi^2[1] = 7.413$, $P = .006$).
[b]Significant difference in ambulation between PSF and IB based on Pearson χ^2 tests ($\chi^2[1] = 5.734$, $P = .017$).
[c]Significant difference between preoperative and postoperative variables on related samples Wilcoxon signed ranks test, with $P < .001$ (Z scores: pain $Z = -5.014$, neurologic deficits overall $Z = -4.00$).

Table 5. Outcome Subanalysis of Patients Without Disc Lesions Stratified Based on Posterior Spinal Instrumentation + Fusion (PSF) or Interbody Fusion With Supplemental Posterior Fixation ± Fusion (IB).

Outcomes (N = 71)		Preoperative Total (n, %)	Postoperative Total (n, %)	PSF (n, %)	IB (n, %)
Fusion[a]	Fusion		57 (80.3%)	32 (74.4%)	25 (89.3%)
	No fusion		14 (19.7%)	11 (25.6%)	3 (10.7%)
Ambulation[a]	Ambulatory		68 (95.8%)	42 (97.7%)	26 (92.9%)
	Nonambulatory		3 (4.2%)	1 (2.3%)	2 (7.1%)
Pain[a,b]	(+) Pain	54 (76.1%)	12 (16.9%)	7 (16.3%)	5 (17.9%)
	No pain report	17 (23.9%)	59 (83.1%)	36 (83.7%)	23 (82.1%)
Neurologic deficits overall[a,b]	(+) Deficits	29 (42%)	17 (23.9%)	10 (23.3%)	7 (25%)
	Normal	40 (58%)	54 (76.1%)	33 (76.7%)	21 (75%)

Abbreviations: PSF, posterior spinal instrumentation + fusion; IB, interbody fusion with supplemental posterior instrumentation ± fusion.
[a]No significant difference in outcomes between PSF and IB based on Pearson χ^2 tests ($P > .05$).
[b]Significant difference between preoperative and postoperative variables on related samples Wilcoxon signed ranks test, with $P < .001$ (Z scores: pain $Z = -6.33$, neurologic deficits overall $Z = -3.55$).

Table 6. Outcome Subanalysis of Patients Stratified Based on Proposed Classification.

Postoperative Outcomes (N = 121)		I— Facet Dislocation (n, %)	II—Facet Fracture (n, %)	III—Pars Fracture (n, %)	IV—Fusion Mass (n, %)	V—Pedicle Fracture (n, %)	VI—Complex Fracture (n, %)
Fusion	Fusion	24 (77.4%)	27 (81.8%)	8 (80%)		11 (84.6%)	20 (58.8%)
	No fusion	7 (22.6%)	6 (18.2%)	2 (20%)		2 (15.4%)	14 (41.2%)
Ambulation	Ambulatory	29 (93.5%)	33 (100%)	10 (100%)		13 (100%)	30 (88.2%)
	Nonambulatory	2 (6.5%)					4 (11.8%)
Pain[a]	(+) Pain	5 (16.1%)	7 (21.2%)			6 (46.2%)	4 (11.8%)
	No pain report	26 (83.9%)	26 (78.8%)	10 (100%)		7 (53.8%)	30 (88.2%)
Neurologic deficits overall	(+) Deficits	4 (12.9%)	8 (24.2%)	1 (10%)		5 (38.5%)	12 (35.3%)
	Normal	27 (87.1%)	25 (75.8%)	9 (90%)		8 (61.5%)	22 (64.7%)

[a]Significant difference in postoperative pain between groups based on Pearson χ^2 test ($\chi^2[4] = 10.293$, $P = .036$).

comorbidities and extraspinal injuries were not included with the surgical complications.

Evidence Summary

The overall quality of the body of evidence collected from the Level IV and V studies and used for outcomes analysis was considered low at baseline based on guidelines set by the GRADE Working Group. With serious risk of bias for each individual study, the inconsistent quality of data, indirectness of results, and publication bias, the overall quality of evidence was downgraded to "very low" (Supplemental Table 2, available in the online version of the article).[16]

Discussion

Considering the etymology of "spondylolisthesis," which is Greek for spine and forward slippage, the definition of traumatic lumbar spondylolisthesis already covers a wide spectrum of injuries involving the lumbar spine.[17] Based on this review, a consensus definition for traumatic lumbar spondylolisthesis describes any acute traumatic injury involving either bony or soft tissue posterior spinal elements accompanied with slippage of one vertebral body over another.

Pathomechanics

A high-energy injury mechanism is typically required to create the injuries seen in traumatic spondylolisthesis. The motion required to produce this injury is postulated to be either severe flexion, extension, or distraction combined with a rotatory force, though there is preference for hyperflexion injuries.[5,17-23] The hyperflexion mechanism usually results from seat-belt or lap-belt injuries during a motor vehicle accident.[17,24] The high-energy impact leads to failure of bony facets and/or soft tissue disruption resulting in anterolisthesis. The shift from a sagittal-oriented thoracolumbar facet joint to a coronal-oriented L5-S1 facet joint explains the predisposition to dislocation and listhesis.[5,25-28] Despite robust lower lumbar facets and stronger ligamentous attachments of the lower lumbar spine, disruption of these structures and the presence of sacral sloping leads to a higher prevalence of traumatic spondylolisthesis at L5-S1.[28-30] The direction of listhesis can also be explained by the facet orientation: disruption of the coronal facets allows for an anteroposterior listhesis, whereas disruption of sagittal-oriented facets allows for lateral listhesis.[27] Due to the injury mechanism, failure at the facet joints commonly presents as an anatomic finding.[4,7]

Evaluation

A considerable number of cases present initially with low back pain without neurologic deficits (Table 3). Most injuries occurring at the lower lumbar region are low-grade anterolisthesis. This finding combined with the normally wide spinal canal at L5-S1 may be the reason for the absence of extensive neurologic deficits.[30,31] A high index of suspicion is required during polytrauma evaluation when there are coexistent abdominal degloving injuries. Patients may present without neurologic symptoms, but instead have serious accompanying injuries from other systems that take precedence over the immediate treatment of the traumatic spondylolisthesis by the traumatologists.[32] Rarely a cauda equina syndrome may exist and should always be ruled out, and if present, immediate decompression should be carried out.[33,34] The ultimate goal of treatment of a polytrauma patient is to stabilize the traumatic spondylolisthesis emergently to prevent neurologic deterioration.[35,36]

Imaging

Images from standard radiographs, CT scan, and MRI scan help identify the direction and degree of listhesis.[18,37,38] It allows for a comprehensive evaluation of the soft tissue and bony anatomy, which is required for classification, prognostication, and surgical preparation. Transverse process fractures are considered sentinel fractures for traumatic lumbar spondylolisthesis[3,22,28,39,40] and quantify the degree of impact on the lumbar spine.[6,41] High-energy injuries are more likely to have concurrent neurological injuries and require a meticulous physical and neurological exam. We recommend that MRI images be obtained in all cases of traumatic spondylolisthesis to identify soft tissue injuries, and concurrent disc disruptions.[22,29] Should there be a contraindication to doing a lumbar MRI, the injury should be evaluated with a CT scan with or without a myelogram prior to surgical reduction.[29] Disc disruptions are universally present when there is a traumatic spondylolisthesis and most will require reduction and fusion.[5] Disc injuries should be treated with an adequate decompression to clear the spinal canal of potential disc material or bony fragments. Concurrent reconstruction of anterior column with an interbody fusion and implant support has been shown to result in improved fusions and outcomes (Table 4).[6] On the contrary, the presence of intact discs indicates a stable anterior column; thus, posterior pedicle screw instrumentation after reduction can provide stability while awaiting fracture union and spinal fusion.

Classification

The classification summarizes the various patterns of anatomic injuries seen in traumatic lumbar spondylolisthesis based on increasing injury complexity. It provides a more detailed description of all the various traumatic spondylolisthesis fracture patterns that can occur in the entire lumbar spine, compared to the classifications introduced by Aihara et al and Vialle et al, which are specific only to a certain injury type in the lumbosacral spine.[4,7] Type 1 injuries (facet dislocations), Type 2 (facet fractures), and Type 3 (pars fractures) are relatively low-grade injuries compared to Type 4 (fusion mass fractures), Type 5 (pedicle fractures), and Type 6 (complex fractures with vertebral body involvement; Figure 1, Table 2). By using this classification system, individual fracture patterns are better assessed, which can facilitate surgical decision making. Generally, less severe (Types 1-3) injuries and those with low-grade listhesis only require posterior instrumentation and fusion. Otherwise, if the injury involves the anterior column and/or pedicles (Types 4-6), or has a high-grade listhesis, we recommend posterior instrumentation and fusion involving additional levels superiorly or inferiorly as required for stability with possible anterior interbody fusion. Additionally, based on our subanalyses, the presence of disc injuries acts as a modifier to treatment that would require an interbody fusion if present (Table 4). Adequate decompression, reduction, and stable fixation should be emphasized in the operative treatment especially with the more severe lesions.[4,6] Constructs may on occasion require iliolumbar fixation to stabilize the severe injury types. Although not statistically significant, Type 5 and Type 6 lesions presented with higher postoperative neurologic deficits, and Type 6 complex fractures had lower fusion rates compared to the remaining groups (Table 6). Outcomes associated with the proposed classification system can be better assessed and validated once case variability is controlled for.

Operative Management, Outcomes, and Complications

Operative management is the mainstay of treatment for traumatic spondylolisthesis. Failure of nonoperative and nonfusion has been reported early in literature, with progression of the spondylolisthesis and secondary neurological impairment due to instability.[7,19,22,31,42-45] The time from injury to operative management is dictated by the neurology of the case and by associated injuries.[29] Although the timing of surgery is governed by the presence or progression of a neurologic deficit, ideally the deformity should be stabilized as soon as possible to mobilize the patient, since reduction becomes more difficult with time.[6] For those presenting with deficits, earlier surgical intervention should include a wide decompression of the spinal canal, neuroforamina, and removal of offending bony, soft tissue fragments, and any disc material to decrease risk of neurologic injury with listhesis reduction.[23,46]

Focusing on the 2 main surgical procedures for traumatic spondylolisthesis, there were no differences in outcomes for postoperative ambulation, pain, and neurologic status between PSF and IB fusion (Table 3). IB fusion had significantly better overall fusion outcomes compared to PSF (Table 3), which was also significant on our regression model with an odds ratio of 28.6× ($P = .008$) for IB fusion. By separating disc injury cases from those with intact discs, results from the subanalysis showed that disc injury plays an important role in fusion outcomes for traumatic spondylolisthesis. Fusion outcomes for cases without disc injuries are similar between PSF and IB fusion (Table 5), while it is significantly better with IB fusion once disc disruption is present (Table 4). The effect of the smaller number of patients with disc injuries may have been masked by the larger population of cases without disc injuries, which led to its nonsignificant contribution to our regression model for fusion. Posterior instrumentation and fusion is recommended for lesions with low-grade listhesis and intact discs since outcomes are comparable to IB fusion (Table 5).[18,20,47] Anterior column reconstruction using interbody cages with supplemental posterior instrumentation and fusion should be done for cases with identified disc lesions and those with high-grade listhesis (Figure 4).[6,7,28,46,48,49] Advantages of circumferential fusion and instrumentation include providing a higher degree of stability, immediate mobilization, and an improved chance of fusion.[17,22,35,50] Normal alignment should be restored following decompression of the spinal canal to improve outcomes. Improvement in neurological symptoms, ambulation, and pain are expected with successful operative treatment except for patients with complete neurological injury or the presence of nerve root disruption.[51]

Excluding neurological injuries, surgical complications were seen in 22% of all documented cases. The majority of cases are caused by implant failure from an isolated posterior spinal fusion,[35,39] and progression of listhesis from nonoperative and noninstrumented cases due to pseudarthrosis.[52,53] Questions remain regarding the disc status from these complications during time of treatment. These findings emphasize the need for a circumferential fusion as the best procedure, especially with documented disc lesions, with adequate decompression, reduction, and stabilization to ensure solid fusion and good outcomes.[28,46]

Limitations

The major limitation of this study is the lack of prospective randomized studies available for review and the studies included were only Levels IV and V. This is due to the widely recognized, inherent nature of spinal trauma that lends itself poorly to adequate long-term follow-up. Because of the low level of evidence, and serious risk for bias in the individual studies, it can be assumed that the strength of our recommendations for treatment are set as Grade C (poor-quality evidence) based on the North American Spine Society Grades of Recommendation.[54,55] Similarly, the recommendation strength is weak when the GRADE criteria is used (Supplemental Table 2, available in the online version of the article).[16] The authors' interpretation of the literature may be subject to bias and data was extrapolated from the systematic review to base the findings and recommendations on. Data presented in this review should be considered as a qualitative summary for the management of traumatic lumbar spondylolisthesis. The authors also did not include cases of traumatic spondyloptosis since these injuries are rare, the literature is sparse, and they can be expected to have worse neurologic symptoms and poor outcomes. Better recommendations are expected should there be a larger population studied, or if prospective studies with standardized data is collected.

Summary

The urgency of treatment for traumatic lumbar spondylolisthesis is dictated largely by the presence of neurologic symptoms. Careful imaging evaluation is required to determine injuries to the spinal unit, which will aid in the appropriate selection of surgical procedure. In conclusion, this review shows that decompression, reduction, and instrumentation with fusion is widely recommended in the literature. The authors also recommend circumferential fusion in most cases when there is disc disruption and instability.

Declaration of Conflicting Interests

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Supplemental Material

The supplemental material is available in the online version of the article.

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