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REVIEW

Incomplete burst fractures of the thoracolumbar spine: a review of literature

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Abstract

Purpose The purpose of this review was to analyze the biomechanical basis of incomplete burst fractures of the thoracolumbar spine, summarize the available treatment options with evidence from the literature, and to propose a method to differentiate fracture severity.

Methods The injury pattern, classification, and treatment strategies of incomplete burst fractures of the thoracolumbal spine have been described following a review of the literature. All level I–III studies, studies with long-term results and comparative studies were included and summarized.

Results Details of five randomized control trials were included. Additionally, three comparative studies and two studies with long-term outcomes were detailed in this review. The fracture severity reported in the included studies varied tremendously. Most classification used did not adequately describe the complexity of fracture configuration. A wide variety of treatment strategies were outlined, ranging from non-operative therapy to aggressive surgical intervention with combined anterior-posterior approaches. Thus, the treatment of incomplete burst fractures of the thoracolumbar spine is quite diverse and remains controversial.

Conclusions Incomplete burst fractures can differ tremendously regarding the degree of instability they confer to the thoracolumbar spine. Based on a detailed review of the literature, it is clear that good results can be obtained with both non-operative and operative strategies to treat these injuries. In the authors' opinion, the intervertebral disc plays a key role in determining the long-term clinical and radiological outcome. Thus, an incorporation of the intervertebral disc pathology into the existing classification systems would be a valuable prognostic factor.

Keywords Incomplete burst fracture · Thoracolumbar spine · Intervertebral disc lesion · Operative treatment · Non-operative treatment

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Introduction

Incomplete burst fractures of the thoracolumbar spine are common injuries. Almost half of vertebral body fractures are reported to be burst fractures, of which 21% of those are incomplete burst fractures [1, 2]. The majority of these fractures (70%) occur at the thoracolumbar junction (Th11-L2) [1]. Additionally, 13% of the fractures are located at the thoracic spine (Th1-10) and 18% at the lumbar spine (L3–5) [1]. The etiology for this injury varies according to patient age. In young patients, falls from a great height are the most common cause of vertebral body fractures, but road, traffic accidents and sporting trauma are also frequently reported [1]. In an aged population, incomplete burst fractures can be seen after simple falls or even in the absence of trauma [3].

The treatment options for incomplete burst fractures range from non-operative management to isolated anterior or posterior stabilization or even combined anterior and posterior stabilization [4–6]. The approaches are also variable, including minimally invasive or open surgery, as well as short or long segmental fixation. Several studies have been performed which have focused on the clinical and radiological outcomes according to the treatment strategy being used [7–16]. However, to date no distinct superiority has been found clinically or radiologically with any specific treatment strategy. The aim of this review is to analyze the biomechanical basis of incomplete burst fractures of the thoracolumbar spine, summarize the available treatment options with evidence from the literature, and to propose a method to differentiate fracture severity.

The classification of thoracolumbar vertebral fractures

Magerl et al. [17] introduced the AO comprehensive fracture classification in 1994 after analyzing a total of 1445 thoracolumbar vertebral fractures. Fractures of the compression type were classified as type A fractures. Type A1 and A2 fractures affected the anterior column sparing the posterior cortex. Type A3 fractures were burst fractures that involved additionally the posterior cortex. Those fractures, where only one intervertebral segment was affected, were subclassified as incomplete burst fractures, type A3.1.

The degree of vertebral body involvement was classified by McCormack et al. [18]. This "Load sharing" classification is defined by three parameters, the percentage of comminution on the sagittal plane, the grade of apposition of fracture fragments, and the degree of posttraumatic kyphotic deformity. High scores were associated with implant failure after posterior-only stabilization. Recently, the Magerl classification was redone in collaboration with leading international AO spine members defining the "AOSpine Injury Classification System" and later the "AOSpine Thoracolumbar Spine Injury Classification System" including additional modifiers [19, 20]. A surgical algorithm was developed based on the fracture type [21]. Interestingly, incomplete burst fractures were reclassified as type A3 fractures in the recent classifications. Burst fractures affecting both intervertebral segments were classified as A4 fractures.

Bone quality

Notably, the above-mentioned classifications do not take into account reduced bone quality, as occurs with osteoporotic fractures and intervertebral disc lesions. An osteoporotic fracture (OF) classification was recently introduced to account for this patient group [22]. This score is defined by the fracture morphology and patient-specific variables, such as mobility, pain situation, and Dexa-score. The fracture morphology consists of 6 types. Interestingly, both OF 2 fractures and OF 3 fractures are incomplete burst fractures. Whereas OF 2 fracture consist of an only minor dorsal cortex lesion of less than 20%, OF 3 fractures are defined by a dorsal cortex involvement of more than 20%.

Intervertebral disc involvement

Three classifications consider intervertebral disc lesions. Oner et al. [23] performed an MRI in 63 patients 18–24 months after traumatic vertebral body fracture who were treated either conservatively or with posterior stabilization. The authors described six morphological patterns of the affected intervertebral discs, ranging from normal type 1 to degenerated disc type 6. Pfirrmann et al. [24] analyzed the degree of intervertebral disc degeneration based on literature and re-evaluated their algorithm by performing MRIs in 60 patients with substantial to excellent intra- and interobserver agreement. Additionally, Sander et al. [25] published a study investigating post-traumatic intervertebral disc lesions based on 204 MRIs after traumatic vertebral body fracture of the thoracolumbar junction. The authors defined four intervertebral disc types ranging from uninjured (grade 0) to displaced (grade 3) (Fig. 2). Interestingly, the authors found progressive disc degeneration during the first year after trauma. More than 50% of initially uninjured intervertebral discs converted to a grade 3 disc lesion, whereas no regeneration potential was visible during the first year after trauma [26].

Injury pattern

Incomplete burst fractures can occur by a variety of mechanisms. The severity of the fracture pattern not only determines the degree of potential instability but also the type of stabilization required (Fig. 1). Both the severity of the bony lesions and the associated intervertebral disc situation are not specified in the AO spine classification. The stability of the anterior column is affected by the fracture morphology and an understanding of this is crucial for deciding the appropriate treatment. McCormack et al. [18] reported high implant failure rates after posterior-only stabilization in patients with severe vertebral body defects after suffering incomplete or complete burst fractures. The authors pointed out that implant failure was dependent on the percentage of comminution, the degree of fragment apposition, as well as the extent of deformity correction. Based on these results, an additional anterior approach is necessary in patients with McCormack scores of 6 and more. In contrasts, patients with only minor defects might be candidates of posterior-only or conservative treatment strategies.

Post-traumatic intervertebral disc pathology

Additionally, the degree of posttraumatic intervertebral disc pathology seems to play an important role. Whereas

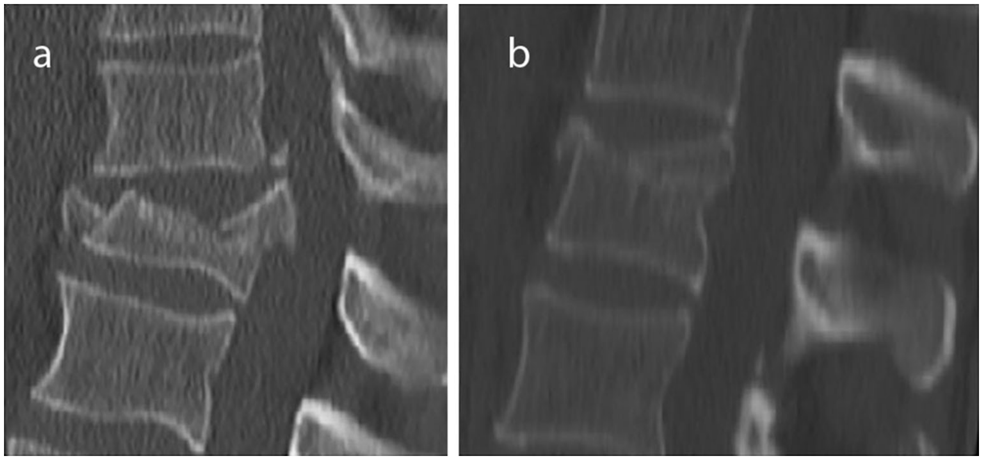

Fig. 1 Both sagittal reconstructions demonstrate examples of incomplete burst fractures (type A3) of the first lumbar vertebral body (**a**, **b**). **a** Depicts an instable fracture morphology with a McCormack score of 8 which is highly suggestive of intervertebral disc lesion; **b** show a minimal displace fracture which can be treated conservatively with a McCormack score of 3 and only minor indirect signs of a traumatic intervertebral disc pathology

some incomplete burst fractures present with rupture of the annulus fibrosus and/or incrementation of disc material in the fracture gaps (Fig. 1), other incomplete burst fractures are associated with no vertebral discs pathology (Fig. 2) [23]. This is of even greater importance considering the insufficient capacity of intervertebral disc regeneration in adults [26, 27]. Altogether, the risk of traumatic intervertebral disc lesion decreases during the process of aging. Two main reasons are responsible for this phenomenon: firstly, the sclerotic changes of the intervertebral disc during the aging process lead to less disc flexibility and elasticity [28, 29]; secondly, reduction of the bone quality as occurs with osteoporosis decreases bony stability and decreases the threshold to withstand force prior to fracture occurrence [3, 30]. Prior to the advent of MRI, visualization of the intervertebral disc was not possible in most cases; however, now it is clearly visible [23]. Reinhold et al. [14] reported of relevant reduction loss of the bisegmental Cobb's angle after implant removal in a multicenter study by the German trauma association. Several authors have also reported a reduction loss of the Cobb's angle, which was postulated to be mainly caused by intervertebral disc space narrowing [31–34]. A relationship exists between intervertebral disc space narrowing and extension of the fracture to the disc space [35].

There are limited data available regarding the extents of traumatic disc lesion that gives rise to chronic disc pathology and results in inferior clinical results when treated conservatively or with posterior stabilization. Additionally, there is a lack of knowledge about the best time point to investigate for traumatic intervertebral disc pathologies. Furthermore, the degree of posttraumatic kyphotic malalignment is a question for debate; the recommended range lies between 10° and 30° [5, 9, 36, 37]. Gertzbein [37] found an increased incidence of significant back pain in patients with >30° kyphotic deformity. From a biomechanical point of view, it seems logical to accept only minimal regional kyphotic malalignment to avoid maximum stress at adjacent segments and to maintain muscle balance during daily activity. However, thus far no studies have been able to demonstrate an association between mild to moderate regional posttraumatic kyphosis and impaired clinical outcome [8, 11, 12, 14, 38, 39]. Only a small proportion of studies were able to identify minimal correlations between moderate regional radiologic alignment of <20° regional kyphosis and clinical outcome [15, 40]. Furthermore, fracture location influences the

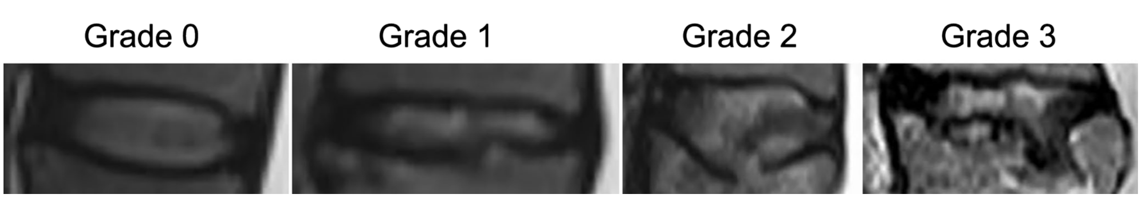

Fig. 2 T2-sequences of traumatic intervertebral disc lesions ranging from uninjured (grade 0) to infarction of the disc into the vertebral endplate (grade 3) according to Sander et al. [25]. Grade 1 lesions are intervertebral discs with disc edema. Grade 2 pathologies represent disc ruptures with intradiscal bleeding

amount of kyphotic malposition that can be tolerated, which is based on the variability of the physiological alignment between the thoracic and lumbar spine.

Non-operative treatment

Unfortunately, there is no standardized conservative therapy in most aspects of vertebral fracture management.

Although, the effectiveness of corsets or braces has been well analyzed. Three independent randomized control trials reported no benefit to wearing corsets as a part of conservative treatment [41–43]. No improvement of any radiologic parameters was seen. In contrast, inferior clinical results were recorded after the use of plaster of paris casts compared to brace therapy [42]. However, there may be a benefit of using braces to improve muscle strength in patients suffering osteoporotic fractures by supporting muscle function [42]. Additionally, early mobilization and extension exercises seem to be beneficial [44–46]. However, no evidence exists regarding further specific physiotherapeutic strategies and the duration of treatment. Additionally, no standards exist pertaining to other therapies such as manipulation, acupuncture, and ultrasound after surgical stabilization.

Follow-up

Clinical and radiologic follow-up are essential in non-operative therapy. Radiologic control examinations should be performed in standing position to visualize the degree of reduction loss [47]. Additionally, full spine radiography is of increasing interest to analyze sagittal alignment [48–52]. Conventional radiographs are recommended after mobilization about 3–4 days after trauma to rule out high increase of malalignment [53]. Following this, it is not clear at what time point clinical and radiologic control examinations are necessary and how long it should be continued.

Surgical treatment

Indication for surgery

The indications for surgery are controversial. Whereas, some authors believe there is no indication for surgery in patients without neurologic deficits [54], others are of the opinion that surgery is indicated with a posttraumatic kyphotic malalignment ranging from 10° to 15° [5], scoliotic malposition of >5°–10° [5], associated disc lesions, and/or incomplete burst fractures type McCormack six or higher [18, 55]. Additionally, the bone quality and the trauma mechanism may play a role in deciding to consider surgery and determine the surgical technique which might be utilized.

Generally, the potential for reduction is significantly greater with posterior stabilization [4, 15]. Therefore, an initial posterior stabilization is performed in the majority of patients treated surgically [4]. This can be done in combination with an additional ventral osseous stabilization using cement augmentation techniques such as kyphoplasty, in patients without traumatic intervertebral disc lesions [56]. Several authors use this technique in geriatric patients with reduced bone quality only [57–59], whereas others perform an additional cement augmentation of the fractured vertebral body in younger adults as well [56].

Posterior stabilization

Nowadays, posterior stabilizations are mainly performed with pedicle screws. However, older studies used long segment pedicle screw-hook constructs [8, 9]. The majority of authors prefer short- or mono-segment stabilization at the thoracolumbar junction and the lumbar spine, whereas long segmental stabilization is recommended at the thoracic spine [4, 5, 36, 60]. Some authors advocate an additional posterolateral fusion, whereas others propose isolated stabilization [61, 62]. Both polyaxial and monaxial screws have been used. However, short segment posterior stabilization with monoaxial screws exhibits significant higher stability in flexion and extension than polyaxial screws in a biomechanical setting [63, 64]. Furthermore, the addition of intermediate screws (index screws) significantly increases the stability of short segment constructs [63]. Similarly, patients treated with short segment stabilization with monoaxial screws resulted in a significant less loss of reduction compared to polyaxial screws during the first 6 weeks after instrumentation [55].

Additionally, open and minimally invasive approaches have been described. Minimally invasive techniques have been reported to be associated with less bleeding, less muscle damage, and similar reduction potential [65, 66]. The majority of minimal invasive screws being used are polyaxial screws. However, monoaxial minimal invasive implants are available. Furthermore, the oftentimes smaller rod diameter used for minimally invasive instrumentations needs to be considered (5 versus 5.5 mm); smaller rod diameter is associated with decreased construct stiffness [67] and a higher risk of reduction loss. This can be addressed using stiffer materials such as cobalt-chrome to compensate the rod stability.

Finally, cement augmentation is also an area of controversy. It has been shown that screw hold can be significantly improved in osteoporotic bone stock with cement augmentation although this benefit is not found in healthy bone situations [68]. Thus, some authors perform Dexa-

Scan prior to surgery [69]. However, in clinical practice this is often not feasible. Others use cement if they discover reduced bone quality while preparing the pedicle [70]. Recently, authors found a good correlation between Hounsfield units measured by computer tomography (CT) and bone mineral density [71, 72]. In such a way, the risk of screw loosening might be predicted by posttraumatic CT. In contrast, Spiegl et al. [55] reported significant higher rates of fracture reduction loss 6 weeks after posterior stabilization without cement augmentation in patients 60 years of age or older compared to those with cement augmented screws implantation.

Anterior stabilization

Based on the decreased potential to restore alignment using anterior stabilization alone, authors view the indication for an isolated anterior approach as being associated traumatic intervertebral disc pathology and only slight kyphotic malposition [15]. Anterior spondylodesis can be done mono- or bisegmentally. To perform a monosegmental spondylodesis sufficiently healthy bone stock of the fractured vertebral body is required, ranging from 33 to 50% [6]. Most authors combine an anterior vertebral body replacement device with an additional plate or rod-screw construct to gain sufficient stability [6, 73]. In the majority of cases iliac bone crest grafts or cages of different materials, such as titanium, PEEK, or tantalum are used as an anterior implant. The rate of partial or complete bony fusion of iliac bone crest grafts has been reported to be as low as 42% in the short term, raising to up to more than 90% in the long term, particularly after posterior implant removal [14, 74]. However, the approach to the iliac crest is associated with a considerable morbidity leading to continuous discomfort in a high percentage for the patients. Up to 71% of the patients complain of pain at this region. Additionally, bony fusion of the graft is associated with a demonstrable reduction loss [74–78]. The use of cages instead of bone graft has been attempted but is associated with cage subsidence into the vertebral bodies, particularly in patients with reduced bone quality [79]. This can be successfully reduced by careful endplate preparation and/or cement augmentation of the accompanied vertebral bodies [79, 80]. The anterior approach can be performed in an open technique or thoracoscopically assisted. Generally, thoracoscopic approaches are more demanding and are reported to have an extensive learning curve [73, 81]. However, the thoracoscopic-assisted approach is associated with less approach-related morbidity and seems to be well tolerated even in a geriatric population [6, 73, 79].

Combined anterior–posterior stabilization

An additional anterior support after posterior reduction and stabilization is indicated in patients with increased risk of loss of reduction after posterior-only stabilization or in those patients with posttraumatic intervertebral disc pathology [18, 34]. The diagnosis of associated traumatic intervertebral disc pathology is an area of controversy. Some authors recommend an MRI in all trauma cases [82–84]. However, 1 year after trauma more than half of initially uninjured discs demonstrate related disc pathology [26]. To detect the ongoing processes of disc degeneration, some authors recommend an MRI four to 6 weeks after posterior stabilization [55]. Additional anterior column reconstruction can be done several weeks afterwards without risk of loss of reduction if no laminectomy was required at the index surgery. Therefore, it is recommended that posterior stabilization be carried out with monoaxial screws, and augmented with cement in patients with impaired bone quality [55].

Again, anterior spondylodesis can be done monosegmentally or bisegmentally based on the degree of fracture involvement. In contrast, an intraosseous stabilization such as kyphoplasty in combination with a posterior stabilization is sufficient in the majority of osteoporotic or osteopenic patients without associated intervertebral disc lesions, leading to promising clinical short-term outcomes after 1 year [13]. Some authors are also proposing this technique in a younger population without traumatic intervertebral disc lesion [56].

Literature review

Non-operative treatment

Two studies analyzed the long-term outcome of thoracolumbar burst fractures treated non-operatively. Moller et al. [85] followed 27 patients with 23–41 year follow-up. All patients were initially treated with bracing. Twenty-one patients (78%) had no or only minimal back pain at the latest follow-up. Only six patients complained of severe back pain. A mild progression of kyphotic malalignment of 3° was detected without indirect signs of accompanied intervertebral disc lesions on conventional radiographs. Further, Weinstein et al. [38] re-evaluated 42 patients with burst fractures of the thoracolumbar junction and the lumbar spine after an average follow up of 20 years. The majority of patients were treated with a brace and bed rest for up to 8 weeks. The average pain rating at the latest follow-up was 3.5 on a visual analogue scale of 1–10. The vast majority (88%) of patients was able to work at their pre-injury occupation and all patients were satisfied with their treatment. However, the follow-up rate was 51% and the average bi-segmental kyphosis was reported to be >20°. However, no correlations between malposition and clinical outcome were found.

Comparative studies dealing with incomplete burst fractures

Three studies compared therapy strategies in patients suffering from incomplete thoracolumbar burst fractures (Table 1). Two of those studies are retrospective level IV studies [36, 86]. Liu et al. [36] compared monosegmental versus short segmental stabilization and posterolateral fusion in patients with traumatic incomplete burst fractures (including incomplete burst-split fractures). There was significant higher blood loss after short segmental stabilization. At the latest follow-up, authors found no clinical and radiological differences. Li et al. [86] introduced a vertebral body augmentation technique implanted using a subpedicle approach and compared it to the same technique with additional posterior stabilization. The authors found no differences in clinical and radiological outcomes and recommended the augmentation technique without additional posterior stabilization based on the significant shorter operating time. Spiegl et al. [15] performed a prospective cohort study comparing anterior versus anterior–posterior approach with a follow-up of at least 6 years. The authors found no differences in clinical outcomes but significant less kyphotic malposition after combined anterior–posterior approach.

Randomized controlled trials

Five randomized control trials have been performed focusing on the treatment of vertebral fractures at the thoracolumbar spine (Table 2). No superiority of one strategy could be consistently shown (Table 3). All five studies are presented in the following two paragraphs.

Non-operative versus operative treatment

Two randomized control trials compared conservative and operative treatment strategies. Wood et al. [8] performed a randomized control trial comparing conservative treatment and operative stabilization by an anterior or posterior approach of burst fractures of the thoracolumbar junction. The authors found similar local kyphosis, pain levels, and return to work rates without significant differences after a follow-up of 16 years [39]. Siebenga et al. [11] performed a multicenter randomized control study comparing conservative treatment with short segment posterior stabilization in patients with acute compression fractures type A. Thirty-four patients were included: 16 were treated conservatively and 18 operatively. About one-third of the patients had incomplete burst fractures. Surgical therapy included transpedicular autogene spongiosa graft or dorsolateral fusion. Two patients were lost to follow-up, one in each study group. MRI was not routinely performed. Implant removal was performed in all but 2 patients after 9–12 months. After 2 years, the authors found significant higher kyphotic malposition (19° versus 8°), significant higher pain scores and higher functional disability scores (RMDQ-24) in the non-operative group. No difference in the number of complications was reported.

Comparison of operative treatment strategies

Three randomized control trials compared different operative techniques with each other. Wood et al. [9] compared posterior versus anterior instrumentation and fusion in patients with burst fractures. Twenty patients were treated anteriorly with subtotal corporectomy and allografts implantation and anterior plate osteosynthesis. Eighteen patients were treated posteriorly by 3–4 level stabilization using hook-pedicle screw constructs and posterolateral fusion. The authors found no differences in the clinical and radiological outcome but a higher complication rate after

Table 1 List of comparative studies including incomplete burst fractures only

Study	Fracture Type [17, 18]	Location	Therapy strategies	Number of patients	Follow-up (months)	Results
Li [86]	A3.1 and A3.2 McCorm >5	T11-L2	Post + subped subped	Post + subped: 38 subped: 42	Min: [a] Ave: 47	Subped: reduced operating time
Liu [36]	A3.1 and A3.2 McCorm >3	T12-L2	Post: 1 level Post: 2 levels	1 level: 33 2 levels: 30	Min: 24 Ave: 50	No differences
Spiegl [15]	A3.1 McCorm >5	T10-L2	Ant Ant-post	Ant: 9 Ant-post: 10	Min: 60 Mean: 77	Ant-post: superior reduction

T thoracal, *L* lumbar, *subped* subpedicle augmentation, *post* posterior stabilization, *min* minimum, *ave* average, *ant* anterior fusion, *ant-post* combined anterior–posterior stabilization/fusion

[a] Not reported

Table 2 Summary of randomized control trials (methods)

Study	Fracture type [18, 19]	Location	Therapy strategies	Surgical techniques	Number of patients	Follow-up (months)	Loss of follow-up
Wood 2003 [8][a]	A3 + A4	T10-L2	Cons	Post: hook-screw (3–4 lev)	Cons: 27	Min: 24	6 (11.3%)
			Surg (ant or post)	Ant: Fib span + plate	Surg: 26	Ave: 44	
Wood 2005 [9]	A3 + A4	T10-L2	Post	Post: hook-screw (3–4 lev)	Post: 21	Min: 24	5 (11.6%)
			Ant	Ant: fib span + plate	Ant: 22	Ave: 43.5	
Siebenga [11]	24[a] A4	T10-L4	Cons	Monoaxial screws (2 lev)	Cons: 18	Min: 24	2 (5.9%)
	10[a] A3		Surg (post)		Surg: 16	Mean: 52	
Korovessis [12]	A3 + McCormack <7	L2-4	Post	Post: polyax screws (2 lev)	Post: 20	Min: 27	0
			Ant-post	Ant: aut spongiosa	Ant-post: 20	Ave: 47	
Wood 2015 [39][a]	A3 + A4	T10-L2	Cons	Post: hook-screw (3–4 lev)	Cons: 27	Min: 204	10 (18.9%)
			Surg (ant or post)	Ant: fib span+plate	Surg: 26	Mean: 223	
Wang [61]	A3 + A4	T12-L4	Post fusion	Polyax screws (2 lev)	Fusion: 30	Min: 24	0
			Post n-fusion	Fusion: aut bone graft	N-fusion: 28	Ave: 41	

T thoracal, *L* lumbar, *cons* conservative therapy, *vs* versus, *surg* surgical therapy, *ant* anterior stabilization or fusion, *post* posterior stabilization or fusion, *lev* level, *fib* fibular graft, *min* minimum, *ave* average, *polyax* polyaxial, *aut* autogenous, *ant-post* combined anterior-posterior stabilization, *n-fusion* non-fusion, *aut* autogenous

[a] Same patient collective

posterior fusion. Korovessis et al. [12] performed a randomized control trial comparing anterior–posterior approach with a posterior-only approach in patients with mid-lumbar burst fractures. Forty patients were included. There were no clinical differences between both study groups after a follow-up of 45 months. However, the posterior-only strategy was associated with significant higher reduction loss. Last but not least, Wang et al. [61] compared the outcome after posterior short segmental stabilization with or without fusion, including 58 patients and an average follow-up of 41 months. The authors found no differences in clinical outcome and kyphotic malalignment but reported higher complication rates after additional segmental fusion.

Discussion

The main finding of this review was that the treatment of incomplete burst fractures of the thoracolumbar spine is quite diverse and remains controversial. Whereas Siebenga et al. [11] reported improved outcomes after posterior stabilization compared to non-operative treatment, Wood et al. [39] did not find any differences between non-operative and operative treatment except higher complication rates after surgical approach [8]. Similarly, Abudou et al. [87] concluded in their systemic review that there are insufficient data to demonstrate superiority of non-operative versus operative treatment of thoracolumbar burst fractures without neurologic deficit. However, surgery is likely to be associated with a higher early complication rate and higher healthcare cost. Nonetheless, it is important to consider in analyzing these studies the technology that was available at the particular time (i.e., screw-hook constructs) which in many cases is inferior to modern pedicle screws fixation [88].

Notably, no study has demonstrated any clinical superiority comparing operative treatment strategies. However, based on the radiological results, there seems to be improved long-term reconstruction of regional alignment after combined anterior–posterior approach compared to both posterior and anterior only stabilization [12, 15]. Furthermore, short segmental posterior stabilization with fusion was associated with a significant higher complication rate without proving any clinical or radiological superiority compared to posterior stabilization without fusion [61]. Therefore, the need of additional dorsolateral fusion in patients treated with posterior-only stabilization has to be discussed critically. Lastly, monosegmental posterior stabilization showed similar clinical outcomes but was associated with less intraoperative blood loss compared to short segmental stabilization [36]. By sparing one intervertebral segment, a monosegmental approach might be preferable in incomplete burst fractures with sufficient

Table 3 Results of randomized control trials

Study	Pain (VAS)	Pain: *p* value	Kyphosis (°)	Kyphosis: *p* value	Number of complications	Complications: *p* value
Wood 2003 [8][a]	Cons: 1.9 Surg: 3.3	0.18	Cons: 13.8 Surg: 13.0	0.6	Cons: 2 Surg: 19	[b]
Wood 2005 [9]	Post: 3.6 Ant: 3.1	0.28	Post: 12.5 Ant: 11.1	>0.05	Post: 17 Ant: 3	[b]
Siebenga [11]	Cons: 2.8 Surg: 1.3	0.033	Cons: 19.5 Surg: 8.4	<0.0001	Cons: 3 Surg: 5	>0.05
Korovessis [12]	Post: 3.6 Ant-post: 4.3	>0.05	Post: 14.3 Ant-post: 11.8	>0.05	Post: 4 Ant-post: 5	>0.05
Wood 2015 [39][a]	Cons: 1.5 Surg: 4.0	0.003	Cons: 19 Surg: 13	>0.05	[b]	[b]
Wang [61]	[b]	[b]	Fusion: 11.5 N-fusion: 9.8	>0.05	Fusion: 12 N-fusion: 3	[b]

VAS visual analog scale, *cons* conservative therapy, *surg* surgical therapy, *post* posterior stabilization/fusion, *ant* anterior stabilization/fusion, *ant-post* combined anterior-posterior stabilization/fusion, *n-fusion* non-fusion

[a] Same patient collective

[b] Not reported

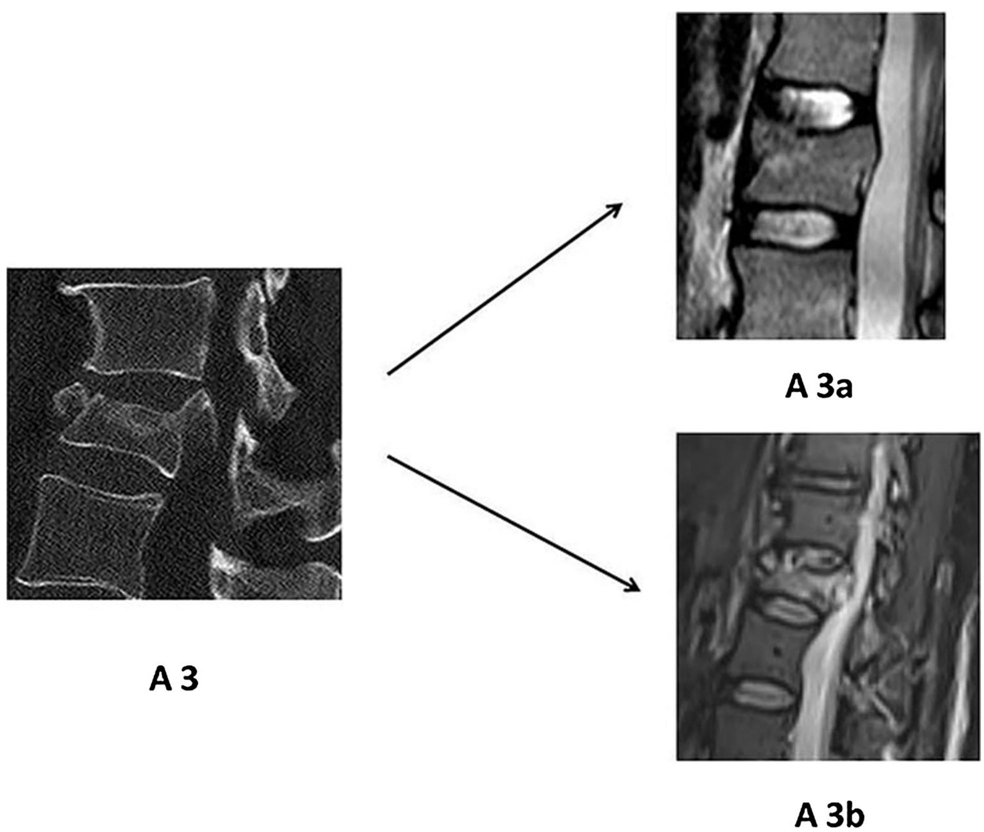

Fig. 3 To depict the fracture severity of incomplete burst fractures, incomplete burst fractures can be differentiated between those without relevant intervertebral disc lesions (grade Sander 0 or 1, Fig. 2) defined as type A3 a lesions and those with disc lesion or disruption (grade Sander 2 or 3), type A3 b

healthy bone stock and intact pedicles to provide sufficient screw hold in the fractured vertebral body.

Generally, the evidence about the treatment of vertebral body fractures is low. The majority of studies included patients with several different fracture types, increasing the risk of selection bias. To increase evidence for superiority or inferiority of some therapy strategies compared to others, it is necessary to improve the study qualities including longer follow-up intervals, higher patient numbers and standardized conservative and operative techniques. Additionally, the patient selection has to be more precise. More studies including exclusively incomplete burst fractures are warranted. However, the fracture severity including the grade of instability varies majorly between those fractures. In our opinion, the best way to gain studies with comparable injury pattern is a modified classification considering the severity of ventral column destruction as well as the degree of intervertebral disc pathology. However, intervertebral disc pathologies correlate well with the grade of fragment apposition. Thus, to keep it simple, a modification of the new AO classification including post-traumatic intervertebral disc status might be sufficient. The modified classification is postulated in Fig. 3.

Conclusion

Incomplete burst fractures can differ tremendously regarding the degree of instability that confer to the thoracolumbar spine. As detailed in this review, good results are possible with both non-operative and operative strategies. To define fracture severity correctly, the "AO Spine Thoracolumbar Spine Injury Classification System" is very helpful including important information such as the patient's neurology. Nonetheless, several further criteria need to be considered. These include fracture location, degree of kyphotic malposition, degree of spinal canal stenosis, degree of vertebral disc lesion, and bone quality. In addition, the patient's general condition and demands, as well as the patient's wishes for treatment, need to be taken into account. In the authors' opinion, the intervertebral disc plays a key part for the clinical and radiological outcome. Thus, an incorporation of the intervertebral disc pathology into the classification might be valuable. Generally, the treatment strategy needs to be adjusted to each patient individually.

Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

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