Does Operative or Nonoperative Treatment Achieve Better Results in A3 and A4 Spinal Fractures Without Neurological Deficit? Systematic Literature Review With Meta-Analysis

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Abstract
Study Design: Systematic literature review with meta-analysis.
Objective: Thoracolumbar (TL) fractures can be treated conservatively or surgically. Especially, the treatment strategy for incomplete and complete TL burst fractures (A3 and A4, AOSpine classification) in neurologically intact patients remains controversial. The aim of this work was to collate the clinical evidence on the respective treatment modalities.
Methods: Searches were performed in PubMed and the Web of Science. Clinical and radiological outcome data were collected. For studies comparing operative with nonoperative treatment, the standardized mean differences (SMD) for disability and pain were calculated and methodological quality and risk of bias were assessed.
Results: From 1929 initial matches, 12 were eligible. Four of these compared surgical with conservative treatment. A comparative analysis of radiological results was not possible due to a lack of uniform reporting. Differences in clinical outcomes at follow-up were small, both between studies and between treatment groups. The SMD was 0.00 (95% CI —0.072, 0.72) for disability and —0.05 (95% CI —0.91, 0.81) for pain. Methodological quality was high in most studies and no evidence of publication bias was revealed.
Conclusions: We did not find differences in disability or pain outcomes between operative and nonoperative treatment of A3 and A4 TL fractures in neurologically intact patients. Notwithstanding, the available scores have been developed and validated for degenerative diseases; thus, their suitability in trauma may be questionable. Specific and uniform outcome parameters need to be defined and enforced for the evaluation of TL trauma.

Keywords
thoracolumbar burst fractures, A3 and A4 spinal fractures, AOSpine classification, neurologically intact patients, conservative therapy, surgical therapy, functional outcome, meta-analysis

Introduction
Burst fractures of the thoracolumbar spine account for approximately 45% of all major thoracolumbar injuries. At least half of the patients with thoracolumbar burst fractures maintain full neurological function.¹ In spite of the high incidence of thoracolumbar burst fractures without neurological deficit and the extensive reporting on this topic in the literature, the optimal treatment strategies for this type of injury remain controversial.
Many reviews have compiled information to compare different treatment modalities. Since 2000, reviews and meta-analyses on surgical strategies have been published on fusion versus nonfusion, minimally invasive surgery versus open surgery, anterior versus posterior approach, early versus late treatment, or looked at a specific treatment type in itself, for example, pedicle screw fixation or surgical treatment in general. Fewer reviews have been published about conservative treatment options, for example, on the usefulness of orthoses.

Likewise, the amount of reviews with the aim of directly comparing operative to non-operative treatment is scarce. Gnanenthiram et al published a meta-analysis in 2012, which identified 4 comparative primary studies published in 1998, 2001, 2003, and 2006. A Cochrane review, published in 2006 and updated in 2013, focused on randomized clinical trials (RCTs). In the update, 2 primary studies were deemed eligible, which were also included in the aforementioned meta-analysis. Another systematic review by Thomas et al in 2006 identified 21 studies of which only half were considered having a quality score of 50% or more. The 7 studies that achieved a quality score of greater than 50% dated from 1993 to 2004 and were presented in greater detail while the majority of the lower quality studies dated from the 1990s.

Ghobrial et al published a review on adverse events related to operative or nonoperative treatment in 2014. In contrast to our review, they excluded noncomparative studies and 63% of the operatively treated patients had a neurological deficit.

None of the aforementioned reviews comparing surgical with nonsurgical treatment narrowed the target population to AOSpine classification, published by Magerl et al in 1994, which got substituted with the present classification in 2013. The AOSpine classification, the A3 type represents an incomplete burst fracture with involvement of the posterior wall but only one endplate, while the A4 fracture, a complete burst fracture, is characterized by an involvement of the posterior wall and both endplates.

General consensus exists that in less severe fractures (A0-A2) conservative treatment has the best risk/benefit ratio and that very severe fractures (B and C type) as well as patients with neurological compromise should be treated surgically. However, no such consensus exists in patients with incomplete (A3) and complete (A4) thoracolumbar burst fractures without neurological deficit.

The most recent comprehensive systematic review with the aim of determining whether surgical or nonsurgical treatment achieves better results in these fracture types has been performed nearly 10 years ago.

Therefore, the purpose of our review was to generate the best available evidence on the clinical outcomes achieved with current operative and nonoperative treatment modalities in A3 and A4 fractures in neurologically intact patients by performing a meta-analysis.
Table 2. Inclusion and Exclusion Criteria.

| Inclusion criteria |
|--------------------|
| A3 and A4 thoracolumbar fractures (T10-L3) (AO spine injury classification) or, in the case of a mixed study population, with stratified analysis presenting results of patients with A3 and A4 fractures alone |
| Skeletally mature patients |
| Neurologically intact patients or, in the case of a mixed study population, with stratified analysis presenting results of neurologically intact patients alone |
| Intervention group size: $\geq 20$ analyzed patients |
| Any type of conservative treatment OR |
| Any type of surgical treatment except |
| - Kyphoplasty |
| - Vertebroplasty |
| - Augmentation |
| - Vertebral body stenting |
| - Isolated anterior approach |

Exclusion criteria

| Fractures other than A3 and A4 according to the AO spine injury classification |
| Fractures caused by |
| - Diminished bone mineral density (BMD) (eg, osteoporosis or osteopenia, "geriatric fractures," fractures in postmenopausal women) |
| - Neoplastic disease (eg, mention of cancer, metastases, "pathological fracture") |

Patients lost to FU. This was completed via a standardized data extraction form.

Whenever comparative studies presented results of several groups and not all groups to the minimum group size of 20 patients, only the group that contained a minimum of 20 patients was included in this analysis.

In case of missing information concerning parameters of interest, for example, outcome mean values at last FU or standard deviations, authors of the respective publications were contacted by email with the request to provide the missing information.

**Data Synthesis**

With regard to all measured indices of (a) disability and (b) pain, the pooled estimate of standardized mean difference (SMD) and 95% confidence intervals (CIs) were calculated by combining the SMD of each individual study that compared operative and nonoperative outcomes based on the mean, standard deviation, and sample size. SMD for disability was calculated based on the Roland Morris Disability Questionnaire (RMDQ) and the Low Back Outcome Score (LBOS), while pain was calculated based on pain visual analog scale (pain VAS) results. Missing values for standard deviation were imputed based on values from other studies in the analysis. Heterogeneity among studies was estimated by chi-square test and Cochran Q score (reported as $I^2$). An $I^2$ of 0% denotes no heterogeneity while an $I^2$ of 100% denotes maximum heterogeneity. The statistical significance level for heterogeneity was set at $P < .05$. In the presence of high heterogeneity, the random effects model was used. An SMD $< 0$ favored operative treatment when compared with nonoperative treatment. Publication bias was assessed by Egger’s regression and visual inspection of the funnel plots. The results of the meta-analyses were graphically presented as forest plots. The analysis was performed in the statistical software STATA version 13 (STATA Corp, College Station, TX, USA).

The mean values of clinical outcome parameters that were available for a minimum of 125 patients in both surgical and conservative treatment groups were depicted graphically to give an overview about results that also include the noncomparative studies.

**Assessment of Methodological Quality**

The quality of all studies was evaluated using a quality assessment tool previously used in similar publications. This tool is based on guidelines suggested by the Cochrane Collaboration Back Review Group and the University of British Columbia Department of Epidemiology “Evaluating Therapeutic Interventions” criteria. It contains 13 questions, which can be scored with “yes,” “no,” “unsure,” or “not applicable.” In prospective studies, 0 to 7 check marks denote a study of poor quality and 8 to 13 check marks indicate a study of good quality. In retrospective studies, 0 to 5 check marks denote a study of poor quality and 6 to 10 check marks indicate a study of good quality. A list of the respective items is given in Table 3.
Risk of bias of studies directly comparing conservative to surgical treatment was evaluated with the Newcastle-Ottawa Quality Assessment Scale (NOS). This methodological rating scale was originally developed to rate the risk of bias in non-randomized comparative studies. It rates the methodological quality of the 3 domains “selection,” “comparability,” and “outcome.” The maximum attainable ratings are 4 stars for selection, 2 stars for comparability, and 3 stars for outcome. Rather than defining absolute values denoting the methodological quality level, the authors advise to present the ratings as a visual comparison combined with the target outcomes of each study included in a review. This allows readers to make their own decision on the validity of respective outcomes.

**Ethical Aspects**

No institutional review board approval is needed for systematic literature reviews and meta-analyses.

**Results**

**Eligible Literature**

The searches in PubMed and the Web of Science resulted in a total of 1929 matches (Figure 1).

After screening of titles and abstracts by two independent reviewers, 142 primary studies were considered potentially relevant. After full text assessment, 11 articles were deemed eligible. Additionally, 26 reviews and meta-analyses were screened for further potentially eligible references, which led to the identification of another primary study.

Overall, 4 studies directly compared surgical with conservative treatment. One of them was an RCT. Six additional comparative studies had a different focus, and 3 studies compared different types of surgical treatment. Another 2 studies compared the outcome of patients with different degrees of injury severity, and 1 study, designed as an RCT, compared 2 types of conservative treatment.

Finally, 2 case series were identified. One presented results of surgical treatment and the other analyzed results of patients treated nonoperatively.

A total of 656 patients were included within these studies. No overlapping patient populations were identified. Overall, studies presented a high heterogeneity with regard to inclusion and exclusion criteria and the level of detail reported, particularly in the parameters used to evaluate treatment success. A summary of study characteristics for baseline data is given in Table 4 and for clinical outcome data in Table 5 and for radiological outcome data in Table 6.

The major reasons for exclusion after full text screening were (a) the use of a different classification to describe the fracture type, which did not allow to determine whether the fractures could have been classified as A3 or A4 acc. to AOSpine; (b) populations consisting of a mix of fracture types in which A3 and A4 were indeed contained, however not analyzed separate from other fracture types; (c) populations including patients with a neurological deficit; and (d) group size below threshold.

**Outcomes**

A wide range of different clinical outcome parameters were presented in the eligible publications: Most frequently reported was the pain VAS (7 studies), followed by the Roland Morris Disability Questionnaire (RMDQ) and Oswestry Disability Index (ODI) (6 studies each) and Short Form–36 (SF-36) (4 studies). The VAS functional spine score, LBOS, and patient satisfaction were reported in 3 studies each; the Hannover Spine score (FFbH-R), was reported in 2 studies, whereas the McGill Pain Questionnaire (MPQ), and an unspecified Quality of Life (QoL) scale were reported in 1 study each.

Nearly all publications presented results in which both A3 and A4 fractures were contained without stratification. Only Andress et al presented results stratified for fracture type and Koller et al presented results and fracture type for each individual patient. Based on the lack of stratified results, we were unable to evaluate results of A3 and A4 fractures separately.

SMDs were calculated for all studies directly comparing operative with nonoperative treatment. All 4 of these studies reported on disability but only 3 reported on pain. Heterogeneity assessment of the studies combined to calculate the SMD for disability revealed an $I^2$ of 86.3% ($P = .000$),
| Author (Year) | Study Design | Inclusion and Exclusion Criteria | Treatment | Demographic Characteristics | Injury Characteristics (Grade, Level) |
|--------------|--------------|----------------------------------|-----------|-----------------------------|--------------------------------------|
| Wood (2003)  | RCT          | **Inclusion criteria:**<br>Isolated burst fracture within the thoracolumbar region (T10 to L2) demonstrated on anteroposterior and lateral radiographs<br>Computed tomography scan revealing a burst-type fracture with retrupulsion of vertebral body bone posteriorly into the spinal canal<br>No new neurological abnormality of the lower extremities or abnormality of bowel or bladder function<br>Presentation less than 3 wk after the time of the injury<br>An age between 18 and 66 years<br>No medical illnesses that would preclude an operative intervention<br>No ongoing cancer, infection, bleeding disorder, or skin disease<br>An understanding of the English language. Concomitant stable compression fractures elsewhere in the spine were permitted if they did not require specific treatment.<br>**Exclusion criteria:**<br>Closed-head injury (a score of <14 points on the Glasgow coma scale on admission)<br>Open vertebral fracture<br>Neurological deficit related to the fracture<br>Loss of structural Integrity within the posterior osteoligamentous complex (such as facet fracture, dislocation or flexion-distraction ligament disruption)<br>Senile, osteopenic, or insufficiency fracture. A laminar fracture was neither an exclusionary criterion nor a contraindication for nonoperative treatment<br>No absolute degree of kyphosis, canal encroachment by bone, or anterior loss of height was a criterion for exclusion. | Operative: Short-segment (2- to 5-level) posterolateral spinal arthrodesis with pedicle screw-hook instrumentation and ICBG or Anterior 2-level fibular and rib-strut construct arthrodesis with local autogenous bone-grafting and instrumentation.<br>Nonoperative: Body cast with manual kyphosis reduction through anterior force, worn for 8-12 wk, followed by thoracolumbosacral orthosis for 8 wk or Thoracolumbosacral orthosis with the spine in hyperextension to reduce the kyphosis and subsequent molded plaster cast that was then converted to an encompassing plastic jacket, worn for 24 h/d except for showering for 12-16 wk | Operative: Mean age: 43.3 y Male: 16 (66.7%) Female: 8 (33.3%) | Operative: T11: 1 (4.2%) T12: 4 (16.7%) L1: 13 (54.2%) L2: 6 (25.0%) | Nonoperative: Nonoperative: |
| Landi (2014) | Retrospective cohort | **Inclusion criteria:**<br>Magerl type A.3, involving only one level<br>McCormack score 6 or less<br>Spinal canal invasion 25% or less acc. to Hashimoto<br>Disco-ligamentous integrity confirmed on MRI<br>Neurologically intact (ASIA E) | Operative: Percutaneous short stabilization: One level above and one below or Rigid brace for 2 mo followed by semirigid brace for another 2 mo | ND | A3.1:10 (40%) A3.2: 5 (20%) A3.3: 10 (40%) |
| Post (2009)  | Retrospective cohort | **Inclusion criteria:**<br>Age 18-60 years at the time of injury<br>A3 thoracolumbar (T7-L5) spinal fracture according to the Comprehensive Classification as diagnosed on radiographs and CT scans | Operative: Short fixation (for A3 fractures: called MSPI by other authors) involving 1 or two segments (depending on fx type, ie, with 2 damaged endplates: 2 segmental fixation; with 1 damaged endplate: 1-segmental fixation) | Operative: Mean age: 37.2 ± 11.8 y (18-56 y) Male: 26 (68%) Female: 12 (32%) | Operative: A3.1 15 (40%) A3.2 18 (47%) A3.3 5 (13%) | (continued)
| Author (Year) | Study Design | Inclusion and Exclusion Criteria | Treatment | Demographic Characteristics | Injury Characteristics (Grade, Level) |
|---------------|--------------|----------------------------------|-----------|----------------------------|--------------------------------------|
| Shen (2001)   | Prospective cohort | Neurologically intact with normal anal tone and no motor deficits, radioculopathy, or lower extremity spasms | Operative: Three-level fixation: Pedicle screws in the level above, in the fractured vertebrae, and in the level below the fractured vertebrae (3 levels, 6 screws). | Operative: Mean age: 42 y (20-64 y) Male: 18 (54.5%) Female: 15 (45.5%) | Levels: T1: 0 (0%) T12: 10 (30.5%) L1: 14 (42%) L2: 9 (27.5%) |
|               | III          | Single-level closed burst fracture involving T11, T12, L1, or L2 No dislocations, with pedicles and facet joints appearing intact, although the pedicles may have fractured from the vertebral body Nonosteoopenic, nonpathologic adult 18 to 65 y of age No other major organ system or musculoskeletal injuries. Other radiographic parameters such as posterior column involvement, kyphosis angle, and degree of canal compromise were not used as inclusion or exclusion criteria. | Nonoperative: Bed rest with activity allowed (including ambulation) as tolerated by pain with hyperextension brace fitted in slight hyperextension with the patient standing. Brace worn 24 h/d (except when bathing) for 3 months (according to instructions, but no monitoring of compliance undertaken) | Nonoperative: Mean age: 44 y (19-64 y) Male: 23 (49%) Female: 24 (51%) | Nonoperative: T1: 1 (2%) T12: 11 (23%) L1: 23 (49%) L2: 12 (26%) |
| Wei (2010)    | RCT          | Single-level closed burst fractures AO-ASIF type A3.1 and A3.2 involving T11–L2 No neurologic impairment Age 20-60 y Nonpathologic adult. Both pedicles intact without any cortical wall defect At least one of the endplate is intact or close to intact Sagittal index (SI) > 15° or loss of anterior body height >50% | MSPI (mono-segmental pedicle instrumentation): Screws inserted into the vertebrae adjacent to the injured endplate (if the broken endplate was the superior and the adjacent vertebra was the upper, or if the broken endplate was the inferior and the adjacent vertebra was the lower). | MSPI Mean age: 39.3 ± 14 y Male: 30 (71.5%) Female: 12 (28.5%) | MSPI A3.1: 25 A3.2: 22 pts Levels: T1: 5 (10.7%) T12: 8 (17.0%) L1: 18 (38.30%) L2: 16 (34.0%) |
|               | Ib           | Exclusion criteria: | | | |
|               |              | Other associated injuries, such as skull and brain injury, cervical whiplash injury, and fracture of the calcaneous, forearm, costal arches, and so on | SSPI (short-segment pedicle instrumentation): Pedicle screws in one level above and one level below the injured vertebra. | SSPI Mean age: 42.0 ± 13 y Male: 33 (76.8%) Female: 10 (23.2%) | SSPI A3.1: 21 pts A3.2: 17 pts Levels: T1: 6 (12.5%) |

(continued)
| Author (Year) | Study Design | Inclusion and Exclusion Criteria | Treatment | Demographic Characteristics | Injury Characteristics |
|--------------|--------------|----------------------------------|-----------|----------------------------|------------------------|
| Li (2012)    | Retrospective cohort | Inclusion: Thoracolumbar burst fracture examined through 3-dimensional CT to investigate pedicle and vertebral displacement. | MSPI (monosegmental pedicle instrumentation): Screws inserted into the vertebrae adjacent to the injured endplate (if the broken endplate was the superior and the adjacent vertebra was the upper, or if the broken endplate was the inferior and the adjacent vertebra was the lower). | MSPI: Mean age: 41.3 y (29-54 y) Male: 18 (60%) Female: 12 (40%) | In total: T11 + T12: 16 (19%) L1: 39 (46%) L2: 30 (35%) |
|              | III          | Exclusion: Oversized bone in the spinal canal Neurological deficit |            |                            |                        |
| Bailey (2014)| RCT          | Inclusion: Isolated AO-A3 burst fracture (vertebral body compression with retropulsion of the posterior vertebral body into the canal and excludes posterior element injury) between T10 and L3 | NO orthosis (NO): Immediate mobilization as tolerated with restrictions to limit bending and rotating through the trunk. Return to normal activities encouraged after 8 weeks. | NO: Mean age: 39.8 ± 15.3 y Male: 69.4% Female: 30.6% |                             |
|              | Ib           | Exclusion: Kyphotic deformity lower than 35° Neurologically intact 16 to 60 y of age Recruited within 3 days of injury | Early mobilization with “off-the-shell” adjustable thoracolumbosacral orthosis (TLSO): Strict bed rest until fitted with a TLSO and mobilization in the brace. The TLSO worn at all times except when lying flat in bed for a total of 10 wk with start of weaning from the brace at 8 weeks. | TLSO: Mean age: 40.5 ± 14.8 y Male: 70.2% Female: 29.8% |                             |
|              |              | Exclusion: Patients who could not wear a brace (ie, pregnancy/body mass index >40 kg/m²) Mobilized with or without a brace before recruitment Suffered a pathologic or open fracture Alcohol or drug abusers Previous injury or surgery to the thoracolumbar region Unable to complete the outcome questionnaires |            |                            |                        |
| Author (Year)     | Study Design | Inclusion and Exclusion Criteria | Treatment | Demographic Characteristics | Injury Characteristics |
|------------------|--------------|----------------------------------|-----------|-----------------------------|------------------------|
| Proietti (2014)  | Retrospective cohort III | Inclusion criteria: Single-level A3 fracture between T11 and L5 Age 18-65 years No neurological involvement Exclusion criteria: Pathological or osteoporotic fracture Multilevel fracture Previous surgery at site of fracture | All patients (groups A + B): Short stabilization: One level above and one below | Total (groups A + B): Mean age: 51.2 y (20–65 y) Male: 38 (63.5%) Female: 22 (36.5%) Group A, n = 39: SI value >10° ≤15° Group B, n = 21 SI >15° | Magerl classification A3.1 = 28 (47%) A3.2 = 8 (13%) A3.3 = 24 (40%) Levels: T11: 5 (8.3%) T12:17 (28.3%) L1: 17 (28.3%) L2: 8 (13.5%) L3: 9 (15%) L4: 3 (5%) L5: 1 (1.6%) |
| Schmid (2011)    | Prospective cohort III | Inclusion criteria: Burst fractures (type A3 according to Magerl) of the thoracolumbar junction (T12-L2) No neurological deficits (Frankel/ASIA E) Age <60 years Exclusion criteria: Fractures above T12 or below L2 Fractures with intact posterior wall (A1 and A2 acc. to Magerl) Neurological deficits (Frankel/ASIA A–D) Pathological or osteoporotic fractures Incomplete radiological or clinical follow-up Nonresident patients | Short segmental posterior fixation with angular stable pedicle screw systems Plus posterolateral fusion Plus unilateral TLIF with monocortical strut grafts and cancellous bone (ICBG) Implant removal at a mean of 15.1 ± 3.7 months The analysis was performed separately for 2 patient groups, but only group B (“TLIF group”) was large enough to be eligible for this review, group A is not considered here | Mean age: 32.7 ± 11.3 y Male: 16 (76%) Female: 5 (24%) | Magerl A3 T12: 7 (33.5%) L1: 11 (52.5%) L2: 3 (14.0%) |
| Jeong (2013)     | Retrospective cohort III | Inclusion criteria: Thoracic and lumbar burst fractures A fractured posterior vertebral surface dislocated into the spinal canal No neurological deficit A minimum of 1-year follow-up Indirect decompression using the ligamentotaxis technique Short-segment implants (1 level above and 1 level below the fracture) Exclusion criteria: Complete tear of the PLL as seen on MRI Any neurological deficit. | Pedicle screws 1 level above and 1 level below the fracture level The analysis was performed separately for 2 patient groups, but only one group (“high grade fracture group”) was large enough to be eligible for this review, so the other group is not considered here | Mean age: 38.8 y (16-61 y) Male: 15 (65%) Female: 8 (35%) | McCormack ≥ 7 27 levels in 23 pts |
| Koller (2008)    | Retrospective case series IV | Inclusion criteria: Single-level thoracolumbar (T11–L2) or lumbar (L3–5) compression or burst fracture Absence of neurological injury (Frankel A-D) | Manual kyphosis reduction through anterior force, then 3 months of brace (24 h/d) | Mean age: 49.1 ± 15.7 y Male: 15 (71.5%) Female: 6 (28.5%) | A3.1: 52.4% (n = 11) A3.1.1: 9 A3.1.2: 2 |
| Author (Year) | Study Design | Inclusion and Exclusion Criteria | Treatment | Demographic Characteristics | Injury Characteristics (Grade, Level) |
|--------------|--------------|----------------------------------|-----------|-----------------------------|-------------------------------------|
| Andress (2002) Retrospective case series IV | | Inclusion criteria: Burst-compression fracture at the thoraco-lumbar spine (T11-L2) which involved the middle column but left the posterior column intact (type A 3 according to Magerl) No neurological deficit No pathologic fracture Exclusive dorsal stabilization with the AO internal fixator (Synthes Cooperation, Bochum, Germany) in combination with or without transpedicular bone grafting Single level injury Complete documentation of the case including a pre-operative spinal CT Conventional biplanar X-rays of the thoracolumbar spine pre- and postoperatively, at the time of implant removal and at follow-up Minimal time period between surgery and follow-up examination: 36 mo Implant removal 9-15 mo after surgery. | Internal fixator either with or without transpedicular spongiosa grafting with fixed-angle pedicle screw instrumentation and pedicle screws above and below the fractured vertebral body In cases where the kyphotic angle was large or where the fractured vertebral body was completely destroyed: transpedicular inter- and intracorporal autologous bone grafting after transpedicular discectomy Transpedicular spongiosa grafting: 29 pts (58%) No grafting: 21 pts (42%) | Mean age: 46.2 y (22-77 y) Mean age: 51.3 y (22-77 y) Male: 27 (54%) Female: 21 (46%) | Magerl A3: A3.1: 19 (38%) A3.2: 17 (34%) A3.3: 14 (28%) Levels: L1: 27 (54%) L2: 12 (24%) L3: 2 (9.5%) L4: 3 (14.3%) |
### Table 5. Study Characteristics—Clinical Outcome.

| Author (Year) | Study design | LoE | Study Characteristics—Clinical Outcome. |
|---------------|--------------|-----|----------------------------------------|
| Wood (2003)   | RCT          | II  | **Operative:** Short-segment (2- to 5-level) posterolateral spinal arthrodesis with pedicle screw-hook instrumentation and ICBG or Anterior 2-level fibular and rib-strut construct arthrodesis with local autogenous bone-grafting and instrumentation. |
|               |              |     | **Operative:** | FU (SD and Range) | n/N (% FU) | Clinical Outcomes at Follow-up: Mean ± SD; Median (Range) [As Available] | Perioperative Outcomes and Return to Activity: Time to return to regular work: | Adverse Events (Complications/Reoperations): |
|               |              |     | **Operative:** | 42.9 mo (SD: 14.8, range 24-72 mo) | 24/26 (92%) | VAS (0-10): 3.3 (0-7.5); ODI: 20.75 (0-48); RMDQ: 8.16 (0-19); SF-36: 39; Pain: 59 | 10 (42%) at 6 mo Plus 4 (17%) between 6 and 24 mo | 19 complications in 16 patients: Wound dehiscence (2) Instrumentation/bone failure (2) Wound infection (deep) (1) Pseudarthrosis (1) Neuropaxia (1) Ketonacidosis (1) Instrumentation break (2) Urinary tract infection (2) Seroma (1) Instrumentation removal (6) Impairments of neurological function (0) |
|               |              |     | **Operative:** | 45.8 mo (SD: 21.9, range 24-118 mo) | 23/27 (85%) | VAS (0-10): 1.9 (0-9); ODI: 10.7 (0-52); RMDQ: 3.9 (0-24); SF-36: 72; Pain: 72 | 17 (74%) at 6 mo Plus 2 (9%) at 24 mo | 2 complications in 2 patients: Urinary tract infection (1) Skin blisters (1) |
| Landi (2014)  | Retrospective cohort | III | **Operative:** Percutaneous short stabilization: one level above and one below |
|               |              |     | **Operative:** | 12 mo | ND | RMDQ: 1.4 (0-4); ODI: 14% (4-36%); VAS (0-10): 0; Patient satisfaction/quality of life (1-10): 9.4 | | Blood loss: 10 cm³ OR time: 80 min Time for back to work: 29 days Time to normal activity: 31 days |
|               |              |     | **Nonoperative:** | 12 mo | ND | RMDQ: 3.4 (0-7); ODI: 22% (5%-40%); VAS (0-10): 1.5; Patient satisfaction/quality of life (1-10): 8 | | Time for back to work: 117 days Time to normal activity: 87.1 days |
| Post (2009)   | Retrospective cohort | III | **Operative:** Short fixation (for A3 fractures: called MSPI by other authors) involving 1 or 2 segments (depending on fix type, ie, with 2 damaged endplates: 2 segmental fixation; with 1 damaged endplate: 1-segmental fixation) |
|               |              |     | **Operative:** | 5.7y (SD: 2.9, range 2.5-10.6 y) | 38/46 (83%) | RMDQ: 3.3 ± 1.1; VAS Spine Score: 82.6 ± 21.9; | | No further surgery for late onset pain or late onset neurological deficit |

(continued)
| Author (Year) | Study design | Treatment | FU (SD and Range) | Clinical Outcomes at Follow-up | Perioperative Outcomes and Return to Activity | Adverse Events (Complications/Reoperations) |
|--------------|--------------|-----------|------------------|-------------------------------|-----------------------------------------------|-------------------------------------------|
| Shen (2001)  | Prospective cohort III | Operative: Three-level fixation: Pedicle screws in the level above, in the fractured vertebrae, and in the level below the fractured vertebrae (3 levels, 6 screws). Nonoperative: Bed rest with activity allowed (including ambulation) as tolerated by pain with hyperextension brace fitted in slight hyperextension with the patient standing. Brace worn 24 h/d (except when bathing) for 3 months. (according to instructions, but no monitoring of compliance undertaken) | Nonoperative: 4.8 y (SD: 2.9, range 2.1-10.4 y) 25/30 (83%) Operative: 24 mo ND 33/33 (100%) | Nonoperative: RMDQ: 3.1 ± 3.7; 1.0 (0-12) VAS Spine Score: 80.8 ± 19.4; 84.0 (31-100) Operative: VAS (0-10): 1.8 ± 1.3 LBOS: 61 ± 11 Patient satisfaction (1-4) (1 = highest level of satisfaction): 10:18:3:2 | Operative: No further surgery for late onset pain or late onset neurological deficit | |
| Wei (2010)  | RCT Ib | MSPI (monosegmental pedicle instrumentation): Screws inserted into the vertebrae adjacent to the injured endplate (if the broken endplate was the superior and the adjacent vertebra was the upper, or if the broken endplate was the inferior and the adjacent vertebra was the lower). SSPI (short-segment pedicle instrumentation): Pedicle screws in one level above and one level below the injured vertebra. | MSPI: ND (only complete population) No. of pts: ND, assume 47/47 (100%) MSPI: LBOS: 74.9 ± 8.7 ODI: 34.1 ± 9.7 SSPI: ND (only complete population) No. of pts: ND, Assume 38/38 (100%) SSPI: LBOS: 60.2 ± 9.6 ODI: 37.6 ± 11.5 | MSPI: Blood loss: 157 ± 49 mL (92-275 mL), OR time: 87 ± 24 min (61-123 min) SSPI: Blood loss: 460 ± 134 mL (240-810 mL), OR time: 138 ± 29 min (93-170 min). | MSPI: Correction loss of 10°, including 1 screw loosening (3) Screw dislodgement requiring reoperation (1) SSPI: Correction loss of 10°, including 1 screw breakage* (2) Screw breakage after trauma not requiring reoperation* (1) Possibly same patient, wording unclear Neurological deteriorations after surgery (0) Urinary infection (4) Superficial infection (1) | |
| Li (2012)  | Retrospective cohort III | MSPI (monosegmental pedicle instrumentation): Screws inserted into the vertebrae adjacent to the injured endplate (if the broken endplate was the superior and the adjacent vertebra was the upper, or if the broken endplate was the | MSPI: VAS: 1.4 ± 0.8 SSPI: VAS: 1.4 ± 1.0 (range: 0-2) | MSPI: Blood loss: 180 ± 62 mL OR time: 90 ± 25 min | MSPI: Wound seroma (1) | |

(continued)
**Table 5. (continued)**

| Author (Year) | Study design | FU (SD and Range) | Clinical Outcomes at Follow-up | Perioperative Outcomes and Return to Activity | Adverse Events (Complications/Reoperations) |
|---------------|--------------|-------------------|--------------------------------|---------------------------------------------|---------------------------------------------|
| **LoE**       | Treatment    | n/N (% FU)        | Mean ± SD; Median (Range) [As Available] | Blood loss: 203 ± 88 mL; OR time: 101 ± 28 min | Screw removal due to breakage (1); Adjacent segment degeneration (1) |
| Bailey (2014) | RCT Ib       | SSPI: 34.6 mo (range 12-64 mo) | SSPI: VAS: 1.1 ± 0.6 | No at 24 mo: RMDQ: 4.4 ± 5.33 (0-23); VAS: 2.03 ± 2.04 (0-7) | No: Hospital stay (mean ± SD) 2.6 ± 2.7 days |
|               |              | NA (30/30, retrospective, only pts w/ FU) |                      | NO at 12 mo: RMDQ: 5.33 ± 5.81 (0-17); VAS: 2.22 ± 1.89 (0-7) | TLO: Hospital stay (mean ± SD) 2.5 ± 2.9 days |
|               |              |                   |                              | NO at 24 mo: RMDQ: 3.03 ± 4.8 (0-24); VAS: 1.58 ± 1.87 (0-8) | TLO: Surgical interventions (2) |
|               |              |                   |                              | TLO at 24 mo: RMDQ: 3.2 ± 4.65 (0-14); VAS: 1.58 ± 1.87 (0-8) | (A) Surgery before initial hospital discharge:  |
|               |              |                   |                              | TLO at 12 mo: RMDQ: 3.2 ± 4.65 (0-14); VAS: 1.58 ± 1.87 (0-8) | - due to severe radicular pain not present when supine (1) |
|               |              |                   |                              |                              | - due to severe mechanical back pain necessitating surgical stabilization (1) |
|               |              |                   |                              |                              | (B) Surgery after initial hospital discharge:  |
|               |              |                   |                              |                              | - oesteotomy 8 months after fracture (1) |
|               |              |                   |                              |                              | |
| Proietti (2014) | Retrospective cohort III | Total population (group A + group B) | SF36 PCS: 83.2% (range 67.5%-95.4%) | Hospital stay: 49 days (3-7 days) | No complaints (21); Mild complaints (0); Severe complaints (0) |
|               |              | Group A: SI > 10° ≤ 15° | SF36 MCS: 79.9% (range 63.2%-83.5%) | Superficial dehiscence at 6 wk (1) | |
|               |              | Group B: SI > 15° | SF36 PCS: 73.5% (range 57.6%-85.3%) | Implant removal due to deep infection at 1 mo (1) | |
|               |              | SF36 MCS: 68.8% (range 53.2%-75.6%) | SF36 MCS: 68.8% (range 53.2%-75.6%) | Hardware failure at 5 years (1) | |
| Schmid (2011) | Prospective cohort III | Total population (group A + group B) | SF36 PCS: 83.2% (range 67.5%-95.4%) | Superficial dehiscence at 6 wk (1) | No complaints (15); Mild complaints (5); Severe complaints (1) |
|               |              | SF36 MCS: 79.9% (range 63.2%-83.5%) | SF36 MCS: 68.8% (range 53.2%-75.6%) | Implant removal due to deep infection at 1 mo (1) | |
|               |              | SF36 MCS: 68.8% (range 53.2%-75.6%) | SF36 MCS: 68.8% (range 53.2%-75.6%) | Hardware failure at 5 years (1) | |

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Inferior and the adjacent vertebra was the lower. SSPI (short-segment pedicle instrumentation): Pedicle screws in one level above and one level below the injured vertebra. BAILEY: No orthosis (NO): Immediate mobilization as tolerated with restrictions to limit bending and rotating through the trunk. Return to normal activities encouraged after 8 wk. Early mobilization with “off-the-shelf” adjustable thoraolumbosacral orthosis (TLSO): Strict bed rest until fitted with a TLSO and mobilization in the brace. The TLSO worn at all times except when lying flat in bed for a total of 10 wk with start of weaning from the brace at 8 wk. PROIETTI: All patients (group A* + group B**): Short stabilization: one level above and one below. Group A: SI > 10° ≤ 15°; Group B: SI > 15°. SCHMID: Short segmental posterior fixation with angular stable pedicle screw systems. Plus posterior lateral fusion. Plus unilateral TLIF with monocortical strut grafts and cancellous bone (ICBG) implant removal at a mean of 15.1 ± 3.7 mo. Analysis performed separately for two patient groups, but only one (“TLIF group”) was large enough to be eligible for this review, so the other group is not mentioned here.
| Author (Year) | Study design | LoE | Treatment | FU (SD and Range) | Clinical Outcomes at Follow-up | Perioperative Outcomes and Return to Activity | Adverse Events |
|--------------|--------------|-----|-----------|-------------------|-------------------------------|------------------------------------------|----------------|
| Jeong (2013) | Retrospective cohort | III | Pedicle screws 1 level above and 1 level below the fracture level | 27.6 mo (range 12-66 mo) | VAS: 4.6 (3-6) | ND | Donor-site related complaints |
|              |              |     | NA (23/23, retrospective, only pts w/ FU) |       | ODI: 19.6 (6-27) |       | No complaints (15) |
|              |              |     | NA (23/23, retrospective, only pts w/ FU) |       | ND Metal failure* (4) |       | Mild complaints (4) |
|              |              |     | NA (23/23, retrospective, only pts w/ FU) |       | Posttraumatic kyphosis (5) |       | Severe complaints (2) |
|              |              |     | NA (23/23, retrospective, only pts w/ FU) |       | Adjacent spine disease (6) |       | |
|              |              |     | NA (23/23, retrospective, only pts w/ FU) |       | *Pedicle screw pull-out or breakage |       | |
| Koller (2008) | Retrospective case series | IV | Manual kyphosis reduction through anterior force, then 3 months of brace (24 h/d) | 112.8 mo (SD:47 mo) | Mean ± SD | ND | Pulmonary artery embolism during immobilization in cast (1) |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | RMDQ: 3.2 ± 5.0 |       | Symptomatic lumbar posttraumatic kyphotic deformity following burst fracture of L4 (1) |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | LBOS: 49.5 ± 17.6 |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | VAS Spine Score: 74 ± 15 |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | SF-36 PCS: 47.1 ± 9.3 |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | SF-36 MCS: 49.4 ± 10.3 |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | Median (25%-75% quartile) |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | RMDQ: 1 (0-3) |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | LBOS: 54 (41-62) |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | VAS Spine Score: 75 (64-84) |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | SF-36 PCS: 48.3 (43.9-54.1) |       | |
|              |              |     | NA (21/21, retrospective, only pts w/ FU) |       | SF-36 MCS: 53.3 (44.7-57.5) |       | |
| Andress (2002) | Retrospective case series | IV | Internal fixator either with or without transpedicular spongiosa grafting with fixed-angle pedicle screw instrumentation and pedicle screws above and below the fractured vertebral body | 68 mo (range 36-103 mo) | Activity score (1-7): 4.92 points | ND | Harvest site pain in 2/29 (6.9%) |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | FFBH-R: 81.7 ± 14.4 points |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | With bone graft or without (mean ± SD) |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | FFBH-R for pts w/ bone graft: 82.4 ± 14.2 |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | FFBH-R for pts w/o bone graft: 80.7 ± 15.1 |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | FFBH-R stratified according to fx type (mean ± SD) |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | A 3.1: 81.1 ± 16.4 |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | A 3.2: 80.6 ± 15.4 |       | |
|              |              |     | NA (50/50, retrospective, only pts w/ FU) |       | A 3.3: 84.3 ± 9.5 |       | |

Abbreviations: ND, not documented; w/, with; w/o, without; pt, patient; pts, patients; NA, not applicable; fx, fracture; SI, Sagittal Index; RMDQ, Roland Morris Disability Questionnaire; VAS (0-10), visual analogue scale for pain; VAS spine score: VAS spine score\textsuperscript{25}; LBOS, Low Back Outcome Score\textsuperscript{26}; ODI, Oswestry Disability Index\textsuperscript{40}; FFBH-R, Hannover Spine Score\textsuperscript{43}; MPQ, McGill Pain Questionnaire\textsuperscript{44}; SF-36 PCS: Short Form–36 Physical Health Summary Scale\textsuperscript{41}; SF-36 MCS: Short Form–36 Mental Health Summary Scale.\textsuperscript{41}
| Author (Year) | Study Design | LoE | Treatment | FU (SD and Range) | Radiological Outcomes at Follow-up | Measurement Method to Determine Kyphosis |
|--------------|--------------|-----|-----------|-------------------|-----------------------------------|------------------------------------------|
| Wood (2003)  | RCT          | II  | Operative: | 42.9 mo (SD: 14.8, range 24-72 mo) 24/26 (92%) | Operative: Mean kyphosis angle at admission: 10.1° (≤10° to 32°) Mean kyphosis angle at discharge: 5° (–10° to 25°) Mean kyphosis angle at last FU: 13° (–3° to 42°) | Kyphosis and loss of the anterior height of the vertebral body were calculated according to the method of Atlas et al.
|              |              |     | Operative: |                  | Nonoperative: Mean kyphosis angle at admission: 11.3° (–12° to 30°) Mean kyphosis angle at discharge: 8.8° (–5.5° to 22°) Mean kyphosis angle at last FU: 13.8° (–3° to 28°) | |
| Landi (2014) | Retrospective cohort | III | Operative: | 12 mo ND 25/25 (100%) | Operative and Nonoperative: Sagittal kyphotic angle measurement was manually performed, directly on lateral plane X-ray images, using as reference the upper and lower edges of vertebral bodies L1–L5 and S1 upper edge. | |
| Post (2009)  | Retrospective cohort | III | Operative: | 5.7 y (SD: 2.9, range 2.5-10.6 y) 38/46 (83%) | Operative and Nonoperative: NA | |

(continued)
### Table 6. (continued)

| Author (Year) | Study Design | Treatment | FU (SD and Range) | Radiological Outcomes at Follow-up | Measurement Method to Determine Kyphosis |
|---------------|--------------|-----------|------------------|-----------------------------------|------------------------------------------|
| Shen (2001)  | Prospective cohort III | Operative: Three level fixation: pedicle screws in the level above, in the fractured vertebrae, and in the level below the fractured vertebrae (3 levels, 6 screws). | Operative: 24 mo ND 33/33 (100%) | Operative: Mean kyphosis angle at injury: 23° ± 6° (12°-33°) Mean kyphosis angle at 2 y: 12° ± 8° (21°-25°) Initial kyphosis correction: 17° ± 8° Mean initial retropulsion of midsagittal canal diameter: 32% | Sagittal plane kyphosis was measured, as described by Knight et al.\(^{46}\) from the inferior endplate of the vertebral body above the fracture to the inferior endplate of the fractured body |
| Wei (2010)   | RCT Ib       | MSPI (monosegmental pedicle instrumentation): Screws inserted into the vertebrae adjacent to the injured endplate (if the broken endplate was the superior and the adjacent vertebra was the upper, or if the broken endplate was the inferior and the adjacent vertebra was the lower). SSPI (short-segment pedicle instrumentation): Pedicule screws in one level above and one level below the injured vertebra. | MSPI: ND (only complete population) No. of pts: ND, assume 47/47 (100%) | MSPI: Preop SI: 13.1° ± 5.4° Postop SI: 4.5° ± 2.7° SI at FU: 7.1° ± 4.2° Preop LSC: 6.8 ± 1 LSC at FU: 2.9 ± 1.1 SSPI: Preop SI: 11° ± 6.5° Postop SI: 2.3° ± 1.6° SI at FU: 4.8° ± 2.9° Preop LSC: 6.5 ± 0.7 LSC at FU: 2.7 ± 0.6 | Sagittal index determined on plain radiographs according to Farcy et al.\(^{52}\) |
|              |              | Complete population: 27.8 mo (SD: 7.0, range 19-52 mo) ND, assume 95/95 (100%) | | | |

ND, assume 47/47 (100%)
| Author (Year) | Study Design | LoE | Treatment | FU (SD and Range) | Radiological Outcomes at Follow-up | Measurement Method to Determine Kyphosis |
|--------------|--------------|-----|-----------|-------------------|----------------------------------|------------------------------------------|
| Li (2012)    | Retrospective cohort | III | MSPI (monosegmental pedicle instrumentation): Screws inserted into the vertebrae adjacent to the injured endplate (if the broken endplate was the superior and the adjacent vertebra was the upper, or if the broken endplate was the inferior and the adjacent vertebra was the lower). SSPI (short-segment pedicle instrumentation): Pedicle screws in one level above and one level below the injured vertebra. | MSPI: 13.2 mo (range 12-26 mo) NA (30/30, retrospective, only pts w/ FU) | MSPI: Kyphotic angles: Before surgery, 17.3° ± 9.3° 1 wk after surgery: 6.5° ± 6.5° Latest FU: 9.5° ± 6.4° | “The vertebral kyphotic angle was measured” |
| Bailey (2014) | RCT | Ib | No orthosis (NO): Immediate mobilization as tolerated with restrictions to limit bending and rotating through the trunk. Return to normal activities encouraged after 8 wk. Early mobilization with “off-the-shelf” adjustable thoracolumbosacral orthosis (TSLO): Strict bed rest until fitted with a TLSO and mobilization in the brace. The TLSO worn at all times except when lying flat in bed for a total of 10 wk with start of weaning from the brace at 8 wk. | NO: 24 mo ND 36/49 (73%) 12 mo: 40/49 (82%) TSLO: 24 mo ND 32/47 (68%) 12 mo: ND 41/47 (87%) | NO group kyphosis angle: Admission: 14° ± 6° Discharge: 20° ± 8° 12 mo: 21° ± 9° 24 mo: 21° ± 9° TLSO group kyphosis angle: Admission: 15° ± 8° Discharge: 18° ± 7° 12 mo: 22° ± 5° 24 mo: 22° ± 5° | Kyphosis was measured based on the Cobb technique, as the angle succumbed between the perpendicular to the superior and inferior end plate of the vertebral body above and below the fractured level, respectively |
| Proietti (2014) | retrospective cohort | III | All patients (group A* + group B**): Short stabilization: one level above and one level below | Total population (group A + group B) Minimum 12 mo (range 12-48 mo) 60/63 (95%) | Group A: SI at 1 y: 9.3° (10°-15°) Correction loss 2.1° Group B: SI at 1 y: 15.4° (13°-22°) Correction loss 3.7° | Sagittal index: Sagittal index (SI) in accordance to Farcy’s criteria 52 Definition: The measurement of segmental kyphosis at the level of a given mobile segment (1 vertebra and 1 disc) adjusted for the baseline sagittal contour at that level. The sagittal index is derived by subtracting the baseline values from the measured segmental kyphosis at the injured level. Farcy et al used the following baseline estimates for the intact sagittal curve: 5° in the thoracic spine, 0° in the thoracolumbar junction, and 10° in the lumbar spine. Segmental kyphosis at the fracture level was defined as a positive value. Subtracting the baseline values from the segmental kyphosis was used to derive the sagittal index. |
| Schmid (2011) | prospective cohort | III | Short segmental posterior fixation with angular stable pedicle screw systems | 20.2 mo (SD: 6.1) | Initial monosegmental angle: -16.0° ± 10.0° Initial spinal canal narrowing: 34.3% ± 16.4% | Monosegmental angles were measured as endplate angles between both end plates adjacent to the fused segment in a lateral projection. The narrowing of the spinal canal was measured on |
| Author (Year)               | Study Design | Treatment                                                                 | FU (SD and Range) | Radiological Outcomes at Follow-up | Measurement Method to Determine Kyphosis |
|---------------------------|--------------|---------------------------------------------------------------------------|-------------------|-----------------------------------|----------------------------------------|
| Jeong (2013) Retrospective cohort | III          | Pedicle screws 1 level above and 1 level below the fracture level          | 27.6 mo (range 12-66 mo) NA (23/23, retrospective, only pts w/ FU) | Postoperative monosegmental angle: $-0.8^\circ \pm 6.8^\circ$ Monosegmental surgical correction: $15.1^\circ \pm 8.3^\circ$ Postoperative spinal canal narrowing: $9.3\% \pm 9.3\%$ Monosegmental angle at final FU: $-5.6^\circ \pm 7.6^\circ$ Postoperative loss of correction $4.9^\circ \pm 8.3^\circ$ | axial CT scans and described in percentages with the width of the adjacent intact vertebra serving as a 100% reference |
| Koller (2008) Retrospective case series | IV           | Manual kyphosis reduction through anterior force, then 3 months of brace (24 h/d) | 112.8 mo (SD: 47 mo) NA (21/21, retrospective, only pts w/ FU) | Regional kyphosis angle at FU: $4.7^\circ \pm 10.9^\circ$ Segmental kyphosis angle at FU: $12.1^\circ \pm 6.3^\circ$ | The Cobb’s angle and the anterior vertical compression ratio were calculated according to Jiang et al$^{45}$ |
| Andress (2002) Retrospective case series | IV           | Internal fixator either with or without transpedicular spongiosa grafting with fixed-angle pedicle screw instrumentation and pedicle screws above and below the fractured vertebral body In cases where the kyphotic angle was large or where the fractured vertebral body was completely destroyed: transpedicular inter- and intracorporal autologous bone grafting after transpedicular discectomy Transpedicular spongiosa grafting: 29 pts (58%) No grafting: 21 pts (42%) | 68 mo (range 36-103 mo) NA (50/50, retrospective, only pts w/ FU) | SI at FU stratified acc. to fx type (mean ± SD) A 3.1 $0.82\% \pm 0.15$ A 3.2 $0.79\% \pm 0.12$ A 3.3 $0.81\% \pm 0.13$ Sagittal plane kyphosis at FU stratified according to fx type (mean ± SD) A 3.1 $-15.5\% \pm 6.5$ A 3.2 $-19.0\% \pm 7.1$ A 3.3 $-14.0\% \pm 6.6$ | Using the ratio of the heights of the anterior and posterior vertebral wall (on lateral views of the injured vertebral body) we calculated the sagittal index (SI). Sagittal plane kyphosis (SPK): angle between the superior end plate of the vertebral body above the fracture and the inferior end plate of the fractured body |

Abbreviations: ND, not documented; w/, with, w/o, without, pt, patient; pts, patients; NA, not applicable; fx, fracture, FU, follow-up; SI: Sagittal Index, LSC: Load Sharing Classification.$^{53}$
whereas for the studies combined to calculate the SMD for pain, the $I^2$ was 93.0% ($P = .000$). Based on the high heterogeneity, a random effects model was used to calculate the SMD. Estimation of the SMD for disability was based on RMDQ and LBOS scores, while for pain it was based on the pain VAS.

For disability, the overall SMD was $0$ (95% CI $-0.72, 0.72$) (Figure 2) and for pain it was $-0.26$ (95% CI $-1.47, 0.95$) (Figure 3). An SMD of less than $0$ favors operative treatment whereas SMD values greater than $0$ favor nonoperative treatment.

Egger’s regression did not reveal any evidence of publication bias with coefficients of $-8.75$ for studies pooled for disability SMD ($P = .553$) and $-11.81$ for studies pooled for pain ($P = .591$).

In addition to the meta-analysis performed with studies directly comparing operative with nonoperative treatment, clinical outcome parameters that were available for a minimum of 125 patients for each of the target treatment modalities were analyzed descriptively for all studies. This was done for RMDQ and pain VAS. Since some of these studies comprised more than 1 patient group, results are presented per treatment group rather than per study (Figures 4 and 5).

Generally, the differences in the respective outcome parameter results at FU were small, both between studies and between treatment groups. Nine of 13 treatment groups that presented pain VAS reported mean values between 1 and 2 at FU, with the most extreme values coming from operatively treated patients. The best pain VAS results were published by Landi et al. for the surgical treatment group, where none of the patients reported any pain at FU. They had only included patients with a McCormack score of 6 or less and a maximum spinal canal invasion of 25%. The worst pain was reported by Jeong et al. who surgically treated patients with a McCormack score of 7 or higher and reported a mean pain VAS of 4.6 at FU for this group. Similar pain values were reported for patients with a Sagittal Index (SI) $>15°$, treated surgically by Proietti et al. At FU, they reported a mean pain VAS of 4.3.

Likewise, 8 of 10 treatment groups with RMDQ results reported mean values between 3 and 4.4 at FU, also with the most extreme values coming from operatively treated patients.
The best RMDQ results were reported by Landi et al.\textsuperscript{33} whose surgically treated patients reported a mean of 1.4 at FU while the worst RMDQ values were reported by Wood et al.\textsuperscript{15} whose surgically treated patients reported a mean of 8.2 at FU.

Only 3 studies provided information about the time after which their patients returned to normal work. Landi et al.\textsuperscript{33} reported that patients treated operatively were back to work after 29 days while patients undergoing nonoperative treatment needed 117 days. Wood et al.\textsuperscript{15} reported contrasting results: In the group treated operatively, 6 months after surgery 42\% of patients were back to work while in the nonoperatively treated patients this proportion was 74\%. After 2 years, 59\% of the operatively treated patients were back to work whereas this was the case for 83\% of the nonoperatively treated patients.\textsuperscript{15} Schmid et al.\textsuperscript{37} treated patients operatively and reported a mean time for back to work of 4.9 months.

Complication outcomes are listed in Table 5 and were clearly in favor of nonoperative treatment since the majority of possible complications are related to surgery. The most important local adverse events reported in nonoperatively treated patients were the need for surgery due to persisting complaints. Interestingly, surgery after initial conservative treatment was only reported in patients from one study.\textsuperscript{30} In this study, which comprised 96 nonoperatively treated patients, 5 patients required surgery while still in hospital; 2 for severe radicular pain, and 3 for mechanical back pain. Another patient from this study required an osteotomy 8 months after her fracture. In operatively treated patients, instrumentation failure and donor site morbidity were the most significant adverse events. None of the included studies reported a neurological deterioration in any of their patients.

Most studies reported radiological outcomes with the target to describe the magnitude of kyphosis. However, a wide range of methods was used to measure it. Three studies provided no exact\textsuperscript{34} or an unclear\textsuperscript{33,37} description. Another 3 studies used the SI.\textsuperscript{36,38,39} The Cobb angle was presented in 3 studies.\textsuperscript{30-32} One of these studies additionally presented the anterior vertical compression ratio\textsuperscript{31} as described by Jiang et al.\textsuperscript{45} One study each\textsuperscript{14,15} used kyphosis measurement methods as described by Knight et al.\textsuperscript{46} and Atlas et al.\textsuperscript{47} respectively. One study measured the segmental kyphosis angle (SKA).\textsuperscript{32} another study measured the sagittal plane kyphosis (SPK).\textsuperscript{39} The lack of uniform reporting made it impossible to pool the radiological results, which are listed in Table 6.

**Quality Assessment**

The quality assessment scores ranged from 4 to 11 on the 13-point scale. Two studies were rated low quality\textsuperscript{33,37} with scores of 5 and 4, respectively, 1 study scored 9,\textsuperscript{32} 4 studies scored 10,\textsuperscript{34,35,38,39} and 5 studies scored 11.\textsuperscript{14,15,30,31,36}

Risk of bias in the studies comparing conservative to surgical treatment was evaluated with the NOS.\textsuperscript{29} The highest risk of bias was found in the domain “comparability” since none of the studies had matched the treatment groups or controlled for potential confounders in the analysis. The lowest risk of bias was seen in the domain “outcome” since FU was sufficiently long with an acceptable rate of drop-outs.

**Discussion**

In this systematic review and meta-analysis, we attempted to generate the best available evidence to support either operative
or non-operative management of AO A3 and A4 thoracolumbar burst fractures in patients without neurological deficit.

Since we identified a number of primary studies that compared operative with nonoperative treatment, we were able to pool the respective results to generate SMDs for disability and pain. No difference between the operative and nonoperative management was revealed for any of these parameters. This finding is also supported by the results reported in the studies not comparing operative to nonoperative treatment, even though no analytical statistics could be performed with these results.

Two RCTs that just missed inclusion in this review are worth mentioning: In 2015, Wood et al. published long-term results of the same patient cohort that is included in this review and was not included here because the number of patients available for analysis had fallen below our group size limit. However, the long-term results confirmed the earlier findings, which were strongly in favor of nonoperative treatment, becoming even more pronounced in the 20-year follow-up. The other RCT that just missed inclusion was published by Sibenga et al in 2006 and was clearly in favor of operative treatment. Its group size was below our limit and some patients with fractures other than A3 or A4 had been included.

Generally, the differences in clinical outcomes of the included publications were small, both between studies and between treatment groups. In the vast majority of treatment groups, pain VAS results ranged from 1 to 2 on a 0 to 10 scale and RMDQ results ranged from 3 to 4.4.

In the context of chronic low back pain, the minimally important change (MIC) of RMDQ has been suggested to be defined as 5.49 For back pain VAS on a scale of 0 to 100, values of 15 (see Ostelo et al.49) and 18 and 19 (see Hagg et al.50) have been suggested. Assuming that the MIC is similar for trauma patients, hardly any of the treatment groups included in this review present clinically relevant differences.

Previous attempts to synthesize the available clinical evidence have produced similar results: The systematic literature review conducted by Thomas et al.19 in 2006 included 21 studies with a total of 564 patients but a recognized overall low quality. The authors concluded that in spite of the wealth of published studies on thoracolumbar burst fractures, methodological limitations were pervasive such that at the time, the available evidence to justify the additional risks of surgery in neurologically intact patients with thoracolumbar junction burst fractures was minimal.

In 2012, a meta-analysis published by Gnanenthiram et al.12 based their main analysis on 2 randomized trials that yielded contrasting results and comprised heterogeneous patient populations. They concluded that “operative management of thoracolumbar burst fractures without neurologic deficit may improve residual kyphosis, but does not appear to improve pain or function at an average of 4 years after injury and is associated with higher complication rates and costs.”

Abdou et al.18 performed a Cochrane review in 2013, which included the same 2 trials with a total of 79 participants on which Gnanenthiram et al.12 had published a meta-analysis in the year before. Abdou et al.18 summarized that the contradictory evidence provided by 2 small and potentially biased randomized controlled trials was insufficient to conclude whether surgical or nonsurgical treatment yielded superior pain and functional outcomes for people with thoracolumbar burst fractures without neurological deficit. However, they acknowledged that surgery was associated with more early complications and the need for subsequent surgery, as well as with greater initial health care costs.

In the absence of any evidence that would clearly favor one of the treatment options with regard to clinical outcome, on one hand, considerations on complication incidence, cost of intervention and time until full recovery gain importance. On the other hand, surgical treatment may well be considered for patients with unsatisfactory clinical outcomes after conservative treatment and further studies are needed to identify subgroups of patients who would benefit from early surgery.

The occurrence of complications in the studies included in this review is clearly in favor of nonoperative treatment. The most important local adverse events reported in nonoperatively treated patients were the need for surgery due to persisting complaints, while in the operatively treated patients, this concerned instrumentation and donor site morbidity.

These findings are well in line with results reported by other researchers. In 2014, Ghoebrial et al.20 published a review specifically targeted at adverse events in the operative and nonoperative management of thoracolumbar burst fractures. They found significant differences in the incidence of infection (5.5% vs 0%, P = .0009) and instrumentation failure leading to revision surgery (4.4% vs 0%, P = .004). The incidence of all other types of complications as well as the overall complication rate was always higher in the operatively treated patients, but this never reached statistical significance.

The time required to go back to work reported in the studies included in our review is inconclusive due to contradicting results of the individual studies.

The major limitation of this review is the heterogeneity of included studies, which was present in various aspects such as FU time, study population, treatment modalities, and outcome parameters. The FU times ranged from 1 year to 10 years. However, since the clinical results were fairly uniform independent of FU time, we believe this had only a minor influence. On the other hand, the heterogeneity concerning the study populations was striking and certainly limited the comparability of studies in general. Nonetheless, the effect on clinical outcomes was primarily visible in the studies that had the most extreme differences in in- and exclusion criteria. For instance, Landi et al.33 only included patients with a McCormack score of ≤6 and reported a mean pain VAS of 0 at FU, while Jeong et al.31 report a mean VAS of 4.6 at FU in patients with a McCormack score of ≥7. This highlights how heterogeneous patient populations hamper the comparability among trials. The aforementioned differences in the included populations also show that the focus on AO A3/A4 fractures alone as an inclusion criterion may not be sufficient to define a uniform population for a systematic review. And yet, given that the
12 primary studies found eligible for this review were derived from 1929 initial matches in the literature databases, stricter inclusion criteria might have led to even less eligible studies.

A further important source of heterogeneity was the lack of uniformity amongst treatments. For instance, all studies analyzing non-operative treatment used different treatment modalities. The same applied to the studies analyzing operative treatment, but several studies used short segment stabilization or mono segmental stabilization techniques with pedicle screws.33-35,38

Another limitation of our review is the choice of target outcome parameters. We focused on the most common clinical outcome scores, but all of these were initially developed and validated for patients with chronic low back pain caused by degenerative diseases. Hence, these scores may not be suitable instruments to measure the success of spinal interventions after trauma. However, since no such instruments exist yet, we did not have an alternative.

Additionally, it was not possible to evaluate the radiological outcomes due to the lack of uniform reporting. However, several studies have demonstrated superior radiological results after operative treatment.14,16,33 Nonetheless, the clinical relevance of radiological outcome in itself is unclear - no studies are known to us that demonstrate an unequivocal association of radiological and clinical outcomes after A3 and A4 fractures. On the other hand, many physicians are familiar with reports of patients who initially underwent conservative treatment and later in life present with significant global alignment and/or severe adjacent level issues requiring far more substantial surgery than initial surgical treatment would have involved. Further long-term studies employing uniform radiological outcome measures in combination with appropriate clinical scores are needed to address this important topic.

Finally, for calculation of the disability SMD, we pooled the functional scores RMDQ and LBOS. Even though the very concept of SMD relies on pooling different scores that are aimed at measuring the same outcome for the purpose of synthesizing evidence from different studies, pooling of these 2 scores is precarious. Both scores measure pain and the ability to perform activities of daily living, but while RMDQ measures pain aspect purely in terms of duration, LBOS measures pain in terms of intensity.

Although previous studies have shown a possible benefit of surgical treatment of A3 and A4 fractures with regard to radiographic outcomes, a structured analysis of radiological outcomes was not possible in this review due to the wide range of different measurement techniques employed.

Furthermore, this review demonstrated that so far, the majority of studies have not differentiated between incomplete (A3) and complete (A4) burst fractures, leaving potential outcome differences between the 2 entities undetected. The new AOSpine classification aims to overcome this drawback by emphasizing this difference with a clear distinction between these fracture types in the classification labels.

In the future, it will be important for the spine community to define and enforce the use of specific and uniform outcome parameters that should be applied in all studies evaluating thoracolumbar trauma.

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