

Review Article

Thoracolumbar Burst Fracture in Patients with Neurological Deficit: An Evidence-Based Systematic Review Comparing Anterior Versus Posterior Surgical Approach for Spinal Decompression and Fixation

Nicandro Figueiredo^{1*}, Nikola Vagic², Rajamagesh Duraisamy³, Wesley Arruda⁴, Krzysztof Wasilewski⁵, Hafez Ahmed⁶ and Zbigniew Brodzinski⁷

¹Spinal Neurosurgeon, Spinal Surgery Unit, Medcare Orthopaedics & Spine Hospital, Dubai (MOSH), UAE; Visiting-Professor, Medical School, Federal University of Mato Grosso (UFMT) and University of Cuiaba (UNIC), Cuiaba, MT, Brazil

²Orthopedic and Spinal Surgeon, Spinal Surgery Unit, Medcare Orthopaedics & Spine Hospital (MOSH), Dubai, UAE

³Radiologist, Department of Radiology, Medcare Orthopaedics & Spine Hospital (MOSH), Dubai, UAE

⁴Medical School, University of Varzea Grande (UNIVAG), Varzea Grande, MT, Brazil

⁵Vascular Surgeon, DrSulaiman Al Habib Hospital, Dubai, UAE

⁶Professor of Biochemistry, Medical School, Dubai Medical College, Dubai, UAE

⁷Spinal Surgeon, Department of Orthopedic Surgery, Emirates Specialty Hospital (ESH), Dubai, UAE

***Address for Correspondence:** Nicandro Figueiredo, Spine Surgery - Medcare Orthopaedic & Spine Hospital, Sheikh Zayed Road, exit 47; P. O. Box 215565, Dubai, UAE, Tel: +971 4 3768414; +971 501631015; E-mail: nicandro2@yahoo.com

Received: 09 July 2019; **Accepted:** 04 September 2019; **Published:** 06 September 2019

Citation of this article: Figueiredo, N., Vagic, N., Duraisamy, R., Arruda, W., Wasilewski, K., Ahmed, H., et al. (2019) Thoracolumbar Burst Fracture in Patients with Neurological Deficit: An Evidence-Based Systematic Review Comparing Anterior Versus Posterior Surgical Approach for Spinal Decompression and Fixation. *Int J Orth*, 2(2): 031-043.

Copyright: © 2019 Figueiredo, N., et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ABSTRACT

Design: Systematic review

Objective: To identify prospective comparative clinical studies of thoracolumbar (TL) burst fractures associated with neurological deficit, to find out which surgical approach is the most appropriate: anterior approach (AA) or posterior approach (PA) for decompression and fixation of unstable TL fractures.

Methods: Evidence-based systematic review of the literature in PubMed and Cochrane Data Base was conducted, comparing AA versus PA for the surgical treatment of TL fractures with neurological deficit. The search was restricted to articles written in English, published in the last 20 years (1998-2018).

Results: Three clinical studies comparing AA with PA for the surgical treatment of TL fractures in patients with neurological deficit were included (Level of Evidence I-III). One article was a randomized controlled trial (RCT), Evidence Level I; 1 a prospective, comparative study (Level II); and 1 a retrospective, comparative study (Level III). The RCT demonstrated that AA group had better neurological improvement and vertebral height restoration than the PA. The other 2 studies, reported similar neurological improvement. Nonetheless, PA group had shorter operation time and is associated with less blood loss than AA.

Conclusions: Level I of Medical Evidence, Recommendation Grade B, was provided with this systematic review which indicates that for decompression and fixation of the thoracolumbar fractures in patients with neurological deficit: 1) anterior approach (AA) was superior to posterior approach (PA) for neurological recovery; 2) AA was superior to PA for vertebral height restoration; 3) PA had shorter operation time and less intraoperative blood loss than AA.

Abbreviations

AA = Anterior Approach; ASIA = American Spinal Injury Association, CT = Computed Tomography, L = Lumbar, LOE = Level of Evidence, MRI = Magnetic Resonance Imaging, NASS = North American Spine Society, PA = Posterior Approach, PLC = Posterior, Ligamentous Complex, RCT = Randomized Controlled Trial, T = Thoracic, TL = Thoracolumbar, TLICS = Thoracolumbar injury classification system

Introduction

The majority of spinal fractures occur in the thoracolumbar (TL) region of the spine, segments T11-L2, which has some particular biomechanics features predisposing to this potential vulnerability, as the rigid thoracic region of the spine connects with the mobile lumbar segments at the TL junction of the spinal column. Thoracolumbar injuries are usually the result of high energy trauma, being the TL burst fractures, characterized by anterior vertebral body height loss, fracture of the posterior wall of the vertebral body and retropulsion of bone fragments into the spinal canal, accountable for around 10-20% of all traumatic spinal injuries [1-3]. The clinical features of burst fractures may include spinal pain, deformity, neurological deficits and sphincter disturbances, according to the region, type of fracture, and severity of the neurological compression [1,4,5].

The well-known anatomic discrepancy between the vertebral and spinal cord level is very important for the understanding of the neurological findings of patients with TL fractures [6]. Fractures at the spinal level T11-12 may affect the segments of the lumbar spinal cord, which are normally inside the spinal canal at that level. At the spinal level L1, the sacro-coccygeal segments of the spinal cord are inside the canal and can be injured. The patients with TL trauma can present with conus medullaris and/or cauda equina syndrome, according to the level and type of trauma [6-8].

Thoracolumbar burst fractures are usually caused by trauma that imply high axial compression forces, like falls from heights, motor vehicle accidents, and lesions caused by high-intensity sports [1,9-12].

About half of the patients are neurologically intact and the opinions are still largely divided regarding their best management, as both the nonsurgical and the surgical treatment strategies have been recommended [13]. The nonoperative approach involves physiotherapy, postural re-education, bed rest, analgesics, body cast, and use of orthoses. Operative management includes spinal fixation, with or without fusion, through various approaches, like posterior, anterior, or combined surgical approaches [14-16].

Many classification systems of spinal fractures to facilitate communication and encourage optimal treatment protocols have been described. The Thoracolumbar Injury Classification System (TLICS) evaluates the injury morphology, integrity of the posterior ligamentous complex (PLC), and neurological status. TLICS aims to guide treatment decision using a scoring system, which assigns point values based on those described parameters. It should be recommended nonsurgical treatment if the total score is less than 4 points; indeterminate if 4 points; or surgical treatment if more than 4 points [5,17]. The AO Spine Trauma Knowledge Forum, an international group of academic spine surgeons, developed and validated a classification system incorporating both fracture

morphology and clinical factors relevant for surgical decision making, such as the presence of neurological deficits [18]. The systematic review of Oner et al. [5] demonstrated that TLICS is the most useful classification system for surgical and nonsurgical decision-making with regard to thoracolumbar spine injuries.

In the majority of cases of TL fractures, the conservative management is satisfactory. Surgical management can be considered in symptomatic, unstable TL fractures, and those associated with neurological deficit [16,19-21]. Surgical intervention can decompress neural elements, restore vertebral body height, correct angular deformity and stabilize the spine. However, controversies still exist over the best specific approach to be used for the surgical treatment. Spinal surgeons can choose either anterior, posterior, or combined surgical approach for the TL spine region, using minimally invasive or open-traditional technique. Some authors recommend posterior approach (PA) for decompression and fixation, because of the excellent results obtained in terms of spinal stability, anatomical alignment, very familiar approach for most of the spinal surgeons, postoperative neurological improvement and low patient morbidity [22-25]. In contrast, advocates of the anterior approach (AA) cite direct and predictable decompression of the spinal canal, improvement in postoperative neurological function and no significant increase in surgical morbidity [26-28]. Both the AA and PA are associated with satisfactory results as well as some potential complications. Treatment of traumatic TL injury depends on many factors such as patient age, associated co-morbidities, surgeon's experience and preference, available instruments and spinal implants, extent of spinal canal compromise, sagittal index, anterior vertebral body height, degree of integrity of posterior elements and presence of neurological deficit [29]. All these parameters may affect the decision regarding the best surgical approach for a particular case, with each parameter being an indication for one or the other approach [22-29].

In cases of TL spine injury, the surgeon must decide whether the injury requires a surgical or conservative treatment, and TLICS can be helpful for this decision [5]. If an operation is required, the surgeon must decide whether the surgery can be optimally accomplished via anterior, posterior, or combined approach. In the absence of good scientific data to guide decision making, expert consensus opinions can be helpful. Vaccaro et al [17] published a paper based on a survey among the members of the Spine Trauma Study Group (STSG) to define the major characteristics of TL spine injuries that influence their surgical decision making. The best surgical approach and treatment of unstable TL spine injuries are still controversial due to the limited number of published comparative studies, as Evidence Level I to III. This lack of clear evidence-based consensus about the ideal surgical approach may result in uncertainty for the involved surgeons and patients being treated inappropriately or sub-optimally [5,30-35].

Objectives

The main purpose of this study is to systematically review the literature, in special the published controlled clinical trials (Evidence Level I-III), to clarify the differences between the AA and PA, aiming to help to guide the spinal surgeons in choosing the most appropriate surgical technique for the treatment of acute, traumatic TL unstable spinal fractures, in patients with spinal cord compression and neurological deficit.

Materials and Methods

Search strategy

An Evidence-based Systematic Review of the literature available in the PubMed Database (indexed for MEDLINE) [36] and Cochrane Central Register of Controlled Trials (Cochrane Library) [37] was conducted, initially by 2 independent reviewers, limited to clinical articles comparing anterior versus posterior approach for the surgical treatment of thoracolumbar spinal fractures in patients with associated neurological deficit; in English-language; adult-human population; published in the last 20 years (1998-2018), in order to reflect current practices and modern surgical techniques.

The following main search terms were used, combined or isolated to select the papers based on the titles and/or abstracts, and, if pre-selected, we reviewed the full article: “thoracolumbar fracture” (1,216), “thoracolumbar burst fracture” (372), “surgery for thoracolumbar burst fractures” (329), “thoracolumbar fracture with neurological deficit” (231), “thoracolumbar fracture with spinal cord injury” (173), “thoracolumbar fracture with conus medullaris syndrome” (67), “thoracolumbar fracture with incomplete neurological deficit” (31), “AO Spine type B thoracolumbar fracture” (8), and “anterior versus posterior surgery for thoracolumbar burst fracture with neurological deficit” (2) were used. Cross-reference articles were also searched and reviewed.

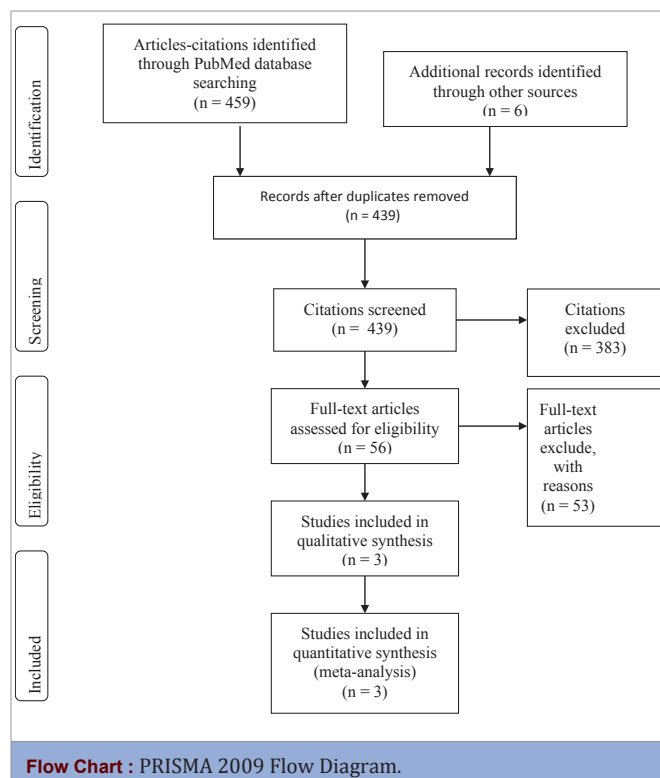
Selection criteria

Comparative prospective and retrospective studies describing patients with traumatic TLfractures with neurological deficit, comparing operative cases of patients’ submitted to anterior versus posterior surgical decompression and/or fixation were pulled and reviewed. The reviewers independently assessed the titles and abstracts of the identified reports. Any disagreements were resolved by discussion and consensus among the authors (Flow chart - appendix).

Articles that were duplicate reports were excluded. Articles in which the group of patients with neurological deficit could not be clearly retrieved for the proposed comparison between anterior versus posterior approach were excluded. Studies related to chronic spinal injury, fractures of other different regions of the spine, and other etiological factors, like pathologic or osteoporotic vertebral fractures, were also excluded of this systematic review. Relevant socio-demographic and clinical data, image studies, surgical technique, complications of the treatment, and patient outcome described by the included papers were analyzed and discussed. Descriptive statistics were compiled when appropriate.

Quality assessment

The articles were graded according to Levels of Evidence guidelines of Wright et al. [38], and of Kaiser et al. [39], adopted by the North American Spine Society (NASS), with levels varying from I through V as follows: Level I (well done randomized controlled studies or systematic reviews of such studies), Level II (prospective cohort studies, poor-quality randomized controlled trials, or systematic reviews of such studies), Level III (case-control studies, retrospective cohort studies, or systematic reviews of such studies), Level IV (case series with no, or historical, control group), and Level V (expert opinion) [38-40].



According to the Level of Evidence (LOE), the NASS guidelines also gives Recommendation Grades, as the highest-quality recommendation, Grade “A” (recommended), required 2 or more Level I studies with consistent findings. Fair evidence, either a single Level I study or consistent findings from multiple Level II or III studies, was given a Grade “B” (suggested). Poor-quality evidence would support a Grade “C” (option), including either a single Level II study or consistent findings from Level IV or V studies. Recommendations based on a single Level III or lower-level study or studies of equal strength that demonstrated conflicting results were given a Grade “I” (insufficient) designation [38-40].

Measurements and statistical analysis

Pre-operative and post-operative main outcomes, including motor and sensory neurological function (ASIA classification score) [41], vertebral height of the affected vertebrae, surgical time, blood loss and other parameters reported in the selected literature were averaged and the standard deviations calculated. Appropriate weighting with respect to sample size were applied in order to arrive at the final figures. This was also applied for the spinal fusion and complication rates. Statistical comparisons of the outcomes were evaluated separately for anterior and posterior approaches. Statistical Packages for Social Scientists (SPSS), version 24 (IBM SPSS, Inc., Chicago, Illinois, USA), was used for the statistical analysis.

Results

The search strategy identified initially 465 citations, reading the titles and abstracts of those articles, 56 papers were pre-selected and fully reviewed with only 3 papers satisfying the inclusion criteria for data extraction and systematic review (Flow chart - appendix) [42-44]. This study included those selected papers in order to make a homogeneous, appropriate and reliable comparison between AA and

PA for patients with TL fractures and neurological deficit associated with spinal cord compression (Table 1 and 2, Figures 1-6).

The reported results for a total population of 208 individuals described in the 3 included papers [42-44] were analyzed, of whom 63.5% were males and 36.5% females. For anterior approach (AA) group sample size was 111, while in posterior approach (PA) sample size was 97. In both types the L1 experienced the largest number of fractures (Table 1 and 2).

Stancic et al. [44] published a prospective, comparative study (Evidence Level II) in 2001, of 25 patients with TL fracture, submitted to surgical treatment. AA for spinal cord decompression and TL fixation was used in 52% (13/25), and the PA in 48% (12/25) of the patients. Both groups did not differ significantly in their age, gender or preoperative clinical data. The technique used at AA group was antero-lateral approach, subtotal corpectomy, decompression, insertion of iliac crest auto graft, followed by fixation using screws-plate instrumentation or screws-rod system. The technique used at

Table 1: Descriptive summary of all included studies regarding the use of anterior X posterior decompression-fixation for thoracolumbar burst fractures in patients with neurological deficit.

Authors	Level of Medical Evidence	Description	Conclusions
Stancic et al. [44]	II	Prospective, comparative study of 25 patients, admitted with unstable TL fracture, with incomplete (ASIA B-D) or without neurological deficit, submitted to surgical treatment. AA for spinal cord decompression and TL fixation was used in 52% (13/25), and the PA in 48% (12/25) of the patients, according to type of implants available in the operating theater. The median age was 36 years-old (range: 18-53) at the AA, and 35 years-old (range: 16-60) at PA group. Male/female distribution was 7/6 at the AA and 8/4 at the PA group. The fractured level was: T12 in 1, L1 in 10 and L2 in 2 patients of the AA group; and T12 in 2, L1 in 9 and L2 in 2 patients of the PA group. Both groups did not differ significantly in their age, gender or preoperative clinical data. Neurological (ASIA/IMSOP) improvement and functional outcome were similar in both the AA and the PA groups. At the AA group, the average surgical timing and intraoperative blood loss was 250 min and 1,362 ml, respectively, while at the PA group, the average surgical timing and intraoperative blood loss was 174 min and 750 ml, respectively, demonstrating a significantly lesser surgical timing and blood loss at the PA group.	This study supports that anterior approach is similar to posterior approach for neurological recovery. Nonetheless, posterior approach has shorter operation time and less intraoperative blood loss than anterior approach.
Hitchon et al. [43]	III	Retrospective, cohort study of 63 patients with TL fracture, submitted to surgical treatment. AA for spinal cord decompression and TL fixation was used in 60.3% (38/63), and the PA in 39.6% (25/63) of the patients. The mean age was 42 years-old (range: 18-70) at the AA, and 42 years-old (range: 22-64) at PA group. Male/female distribution was 26/38 at the AA and 19/25 at the PA group. The fractured level was: T11 in 1, T12 in 13, L1 in 18 and L2 in 6 patients of the AA group; and T11 in 1, T12 in 3, L1 in 12 and L2 in 9 patients of the PA group. At the AA group, the mean Frankel motor score system improved from 3.7 to 4.2 after surgery, while at the PA group, improved from 3.5 to 4.0 after surgery, not demonstrating significant difference.	This study supports that anterior approach is similar to posterior approach for neurological recovery.
Cui et al. [42]	I	Randomized Controlled Trial of 120 patients, with TL fracture, submitted to surgical treatment. AA for spinal cord decompression and TL fixation was used in 50% (60/120), and the PA in the remaining 50% (60/120) of the patients. The average age was 46.5 years-old (range: 23-57) at the AA, and 46 years-old (range: 22-58) at the PA group. Male/female distribution was 37/60 at the AA and 35/60 at the PA group. Both groups did not differ significantly in their age, gender or preoperative clinical data. At the AA group, the average motor score improved from 39.2 to 69.9 after surgery, while at the PA group, the average motor score improved from 39.9 to 52.8 after surgery, demonstrating a significantly better motor recovery at the AA group. At the AA group, the average sensory score improved from 44.9 to 72.5 after surgery, while at the PA group, the average sensory score improved from 45.3 to 61.2 after surgery, also demonstrating a significantly better sensory recovery at the AA group. At the AA group, the average surgical timing and intraoperative blood loss was 217 min and 498 ml, respectively, while at the PA group, the average surgical timing and intraoperative blood loss was 154 min and 275 ml, respectively, demonstrating a significantly lesser surgical timing and blood loss at the PA group. Vertebral height restoration of the affected vertebral body increased from 1.4 to 4.1 cm in the AA, and from 1.5 to 2.4 cm in the PA group, showing significantly superior anatomical correction of the fractured vertebral in the AA group.	This study supports that anterior approach is superior to posterior approach for neurological recovery and vertebral height restoration. Nonetheless, posterior approach has shorter operation time and less intraoperative blood loss than anterior approach.

Abbreviations: AA = Anterior Approach; PA = Posterior Approach; ASIA = American Spinal Injury Association; TL = Thoracolumbar.

Citation: Figueiredo, N., Vagic, N., Duraisamy, R., Arruda, W., Wasilewski, K., Ahmed, H., et al. (2019) Thoracolumbar Burst Fracture in Patients with Neurological Deficit: An Evidence-Based Systematic Review Comparing Anterior Versus Posterior Surgical Approach for Spinal Decompression and Fixation. *Int J Orth*, 2(2): 031-043.

Table 2: Quantitative summary of the included studies regarding the use of anterior X posterior decompression-fixation for thoracolumbar burst fractures in patients with neurological deficit.

Characteristics	Description (after systematic review)
Papers included	<ul style="list-style-type: none"> • 3 papers [42-44]
Level of medical evidence for therapeutic studies and study description	<ul style="list-style-type: none"> • Level I of medical evidence = randomized controlled trial = 33.3% (1) [42] • Level II of medical evidence = prospective, comparative study = 33.3% (1) [44] • Level III of medical evidence = retrospective, cohort study = 33.3% (1) [43]
Patients	<ul style="list-style-type: none"> • N = 208 patients
Surgical technique	<ul style="list-style-type: none"> • Anterior approach (AA) = 53.3% (111/208 patients) • Posterior approach (PA) = 46.6% (97/208 patients)
Patients per study	<ul style="list-style-type: none"> • Mean = 69.3 patients/study (25-120)
Age and gender	<ul style="list-style-type: none"> • Age in years (range) = 16–70 years-old • Gender distribution <ul style="list-style-type: none"> √ Total study population = 208 patients • Male = 63.5% (132/208) • Female = 36.5% (76/208) √ AA group = 111 <ul style="list-style-type: none"> • Male = 63.1% (70/111) • Female = 36.9% (41/111) √ PA group = 97 <ul style="list-style-type: none"> • Male = 63.9% (62/97) • Female = 36.1% (35/97) 1. Stancic et al. [44] study population = 25 patients <ul style="list-style-type: none"> • AA group = 13 <ul style="list-style-type: none"> √ Median age = 36 years (18-53 yr.-old) √ Male = 54% (7/13) √ Female = 46% (6/13) • PA group = 12 <ul style="list-style-type: none"> √ Median age = 35 years (16-60 yr.-old) √ Male = 67% (8/12) √ female = 33% (4/12) 2. Hitchon et al. [43] study population = 63 patients <ul style="list-style-type: none"> • AA group = 38 <ul style="list-style-type: none"> √ Median age = 42 years (18-70 yr.-old) √ Male = 68% (26/38) √ Female = 32% (12/38) • PA group = 25 <ul style="list-style-type: none"> √ Median age = 42 years (22-64 yr.-old) √ Male = 76% (19/25) √ Female = 24% (6/25) 3. Cui et al. [42] study population = 120 patients <ul style="list-style-type: none"> • AA = 60 <ul style="list-style-type: none"> √ Median age = 46.5 years (23-57 yr.-old) √ Male = 62% (37/60) √ Female = 38% (23/60) • PA = 60 <ul style="list-style-type: none"> √ Median age = 46 years (22-58 yr.-old) √ Male = 58% (35/60) √ Female = 42% (25/60)

Vertebral fracture level	<ul style="list-style-type: none"> • Anterior approach group = 53.3% (111/208) <ul style="list-style-type: none"> √ T11 = 19.8% (22/111) √ T12 = 23.4% (26/111) √ L1 = 41.4% (46/111) √ L2 = 3.5% (15/111) • Posterior approach group = 46.7% (97/208) <ul style="list-style-type: none"> √ T11 = 19.5% (19/97) √ T12 = 15.3% (17/97) √ L1 = 36.9% (41/97) √ L2 = 20.6% (20/97)
Motor score improvement (ASIA score) [41]	<ul style="list-style-type: none"> • Average motorscore improvement = 21.4/100 points (n = 120 patients) [42] • AA = 30/100 points (n = 60) • PA = 12.9/100 points (n = 60) <ul style="list-style-type: none"> √ Motor score improvement was 2.3 folds more in AA than PA group • Anterior approachescores <ul style="list-style-type: none"> √ Preoperative: 39.2 (±17.2) √ Postoperative: 69.2 (±23.1) Improvement = 30 points • Posterior approach <ul style="list-style-type: none"> √ Preoperative: 39.9 (±17.4) √ Postoperative: 52.8 (±24.8) Improvement = 12.9 points <ul style="list-style-type: none"> ○ Information available = 33.3% (1/3) of the studies (limitations) [42]
Sensory score (ASIA score) [41]	<ul style="list-style-type: none"> • Average sensory score improvement = 21.7/112 points (n = 120 patients) [42] • AA = 27.6/112 points (n = 60) • PA = 15.9/112 points (n = 60) <ul style="list-style-type: none"> √ Sensory score improvement was 1.7 folds more in AA than PA group • Anterior approach <ul style="list-style-type: none"> √ Preoperative: 44.9 (±16.1) √ Postoperative: 72.5 (±15.6) Improvement = 27.6 • Posterior approach <ul style="list-style-type: none"> √ Preoperative: 45.3 (±15.8) √ Postoperative: 61.2 (±15.9) Improvement = 16.2 <ul style="list-style-type: none"> ○ Information available = 33.3% (1/3) of the studies [42]
Vertebral height gain(cm)	<ul style="list-style-type: none"> • Average vertebral height gain= 1.8 cm (n = 120 patients) [42] • AA = 2.7 cm (n = 60) • PA = 0.9 cm (n = 60) <ul style="list-style-type: none"> √ Vertebral height restoration was 3 folds superior in AA than PA group • Anterior approach <ul style="list-style-type: none"> √ Preoperative: 1.4 cm (±0.6) √ Postoperative: 4.1 cm (±0.4) Averagevertebral height gain = 2.7 cm • Posterior approach <ul style="list-style-type: none"> √ Preoperative: 1.5 cm (±0.6) √ Postoperative: 2.4 cm (±0.8) Averagevertebral height gain = 0.9 cm <ul style="list-style-type: none"> ○ Information available = 33.3% (1/3) of the studies [42]
Surgical time (min)	<ul style="list-style-type: none"> • Average surgical time [42,44] • AA = 233.8 min • PA = 164.3 min <ul style="list-style-type: none"> √ Averagesurgical time was 1.42 times longer in AA than PA group • Anterior approach • Stancic et al: [40] <ul style="list-style-type: none"> √ Intraoperative: 250 min (200-295) • Cui et al: [8] <ul style="list-style-type: none"> √ Intraoperative: 217.6 min (±19.8) • Posterior approach • Stancic et al: [40] <ul style="list-style-type: none"> √ Intraoperative: 174 min (130-215) • Cui et al: [8] <ul style="list-style-type: none"> √ Intraoperative: 154.6 min (±16.3) ○ Information available = 66.6% (2/3) of the studies [42,44]

Citation: Figueiredo, N., Vagic, N., Duraisamy, R., Arruda, W., Wasilewski, K., Ahmed, H., et al. (2019) Thoracolumbar Burst Fracture in Patients with Neurological Deficit: An Evidence-Based Systematic Review Comparing Anterior Versus Posterior Surgical Approach for Spinal Decompression and Fixation. *Int J Orth*, 2(2): 031-043.

Intraoperative blood loss (ml)	<ul style="list-style-type: none"> • Average intraoperative blood loss [42,44] • AA = 930.3 ml • PA = 512.8 ml • Average intraoperative blood loss was 1.81 fold more in AA than PA group Anterior approach √ Stancic et al. [40] <ul style="list-style-type: none"> ○ Blood volume: 1362.0 ml (1150-1500) √ Cui et al. [8] <ul style="list-style-type: none"> ○ Blood volume : 498.60 ml (±24.7) • Posterior approach √ Stancic et al. [40] <ul style="list-style-type: none"> ○ Blood volume: 750.0 ml (500-1100) √ Cui et al. [8] <ul style="list-style-type: none"> ○ Blood volume: 275.6 ml (±18.5) ○ Information available = 66.6% (2/3) of the studies [42,44]
Surgical complications	<ul style="list-style-type: none"> • Average surgical complication rate = 11.4% (10/88) of the patients [42,44] √ AA = 7.8% (4/51) √ PA = 16.2% (6/37) • Stancic et al. [40] √ AA (n = 13) <ul style="list-style-type: none"> ○ Complication rate = 15.4% (2/13) √ PA (n = 12) <ul style="list-style-type: none"> ○ Complication rate 8.3% (1/12) • Hitchon et al. [21] √ AA (n = 38) <ul style="list-style-type: none"> ○ Complication rate = 5.2% (2/38) √ PA (n = 25) <ul style="list-style-type: none"> ○ Complication rate = 20% (5/25) ○ Information available = 66.6% (2/3) of the studies [42,44]

the PA group was posterior spinal exposure, indirect decompression, laminectomy, fixation using a combination of hook-rod and pedicle screws (Table 1 and 2).

Neurological (ASIA/IMSOP) [41] improvement and functional outcome were similar in both the AA and the PA groups. At the AA group, the average surgical timing and intraoperative blood loss was 250 min and 1,362 ml, respectively, while at the PA group it was 174 min and 750 ml, respectively, demonstrating a significantly lesser surgical timing and blood loss at the PA group (Table 1 and 2, Figures 4-6) [44].

Hitchon et al. [43] published a retrospective, cohort study (Evidence Level III) in 2006, of 63 patients with TL fracture, submitted to surgical treatment. Anterior approach for spinal cord decompression and TL fixation was used in 60.3% (38/63), and PA in 39.6% (25/63) of the patients. The surgical technique used at the AA group was antero-lateral approach, subtotal corpectomy, decompression, insertion of cage, bone allograft, and/or iliac crest autograft was performed to fill the space of the corpectomy, followed by lateral instrumentation using dual-rods and screws or plate system with screws. The technique used at the PA group was posterior spinal exposure, decompression using laminectomy and disimpaction, transpedicular or transect approach and/or ligamentotaxis, fixation using pedicle screws or pedicle screws with hooks (1 or 2 segments above and below), followed by bone graft for fusion (autograft and allograft) (Table 1 and 2).

Neurological status was assessed using the Frankel motor score system [45]. For ease of statistical analysis, the Frankel grade was converted into a numerical score in which A is equal to 1 (complete motor and sensory paralysis below the lesion), B is 2 (complete motor paralysis but some residual sensory perception), C is 3 (residual motor function but not of practical usefulness), D is 4 (useful but subnormal motor function below the lesion), and E is 5 (normal

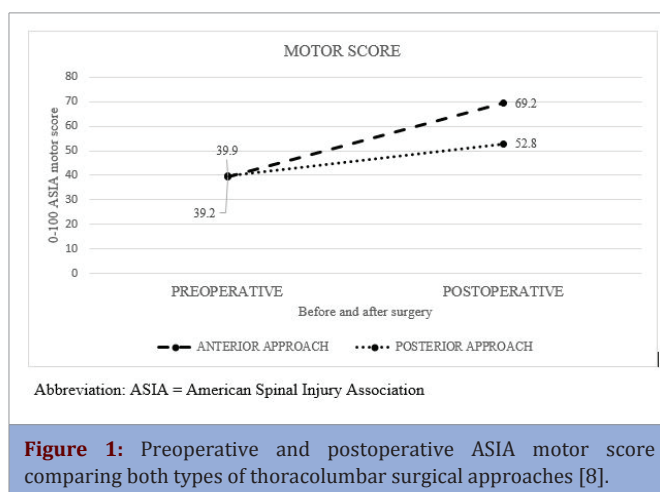


Figure 1: Preoperative and postoperative ASIA motor score comparing both types of thoracolumbar surgical approaches [8].

motor and sensory function). At the AA group, the mean Frankel score improved from 3.7 to 4.2 after surgery, while at the PA group, improved from 3.5 to 4.0 after surgery, not demonstrating significant difference (Table 1 and 2) [43].

Thoracolumbar average angular deformity at the fractured level was corrected from 11.9° to 2.0° after surgery in the AA group, and from 4.1° to 3.4° in the PA group, showing significantly better angular correction of the fractured vertebra in the AA group. In the AA group, average angulation was corrected by 9.9° between admission and discharge, and the correction persisted at 4.5° at follow up. In the PA group, however, average angulation decreased only 0.7° between admission and discharge, whereas it progressed to 9.8° at the final follow-up examination. At the follow-up evaluation, the average angulation in the PA group was significantly greater than that in the AA group (Table 1 and 2) [43].

At the AA group, 5% (2/38) of the patients' required repeated surgery that involved posterior instrumentation for fusion, while at the PA group, 20% (5/25) of the patients required repeated surgery. Four patients of the PA group required revision of the instrumentation, and in 1 patient an infection necessitated the removal of the hardware. Posterior approaches in cases of burst fractures needed decompression in many cases. This complication rate associated with posterior instrumentation has been underscored by other published data. There was no significant difference between the two approaches in the SF-36 questionnaire, duration of the procedure, cost of the implant, neither in the total cost of hospitalization (Table 1 and 2, Figure 6) [43].

Cui et al. [42] published a Randomized Controlled Trial (Evidence Level I) in 2015, of 120 patients with TL fracture, submitted to surgical treatment. Anterior approach for spinal cord decompression and TL fixation was used in 50% (60/120), and the PA in the remaining 50% (60/120) of the patients. Both groups did not differ significantly in their age, gender or preoperative clinical data. The surgical technique used at the AA group was antero-lateral approach, subtotal corpectomy, decompression, insertion of bone graft, followed by instrumentation (screw-rods). The technique used at the PA group

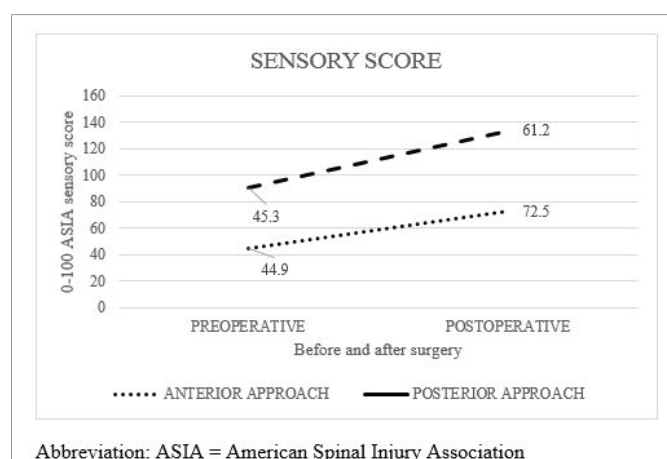


Figure 2: Preoperative and postoperative ASIA sensory score comparing both types of thoracolumbar surgical approaches [8].

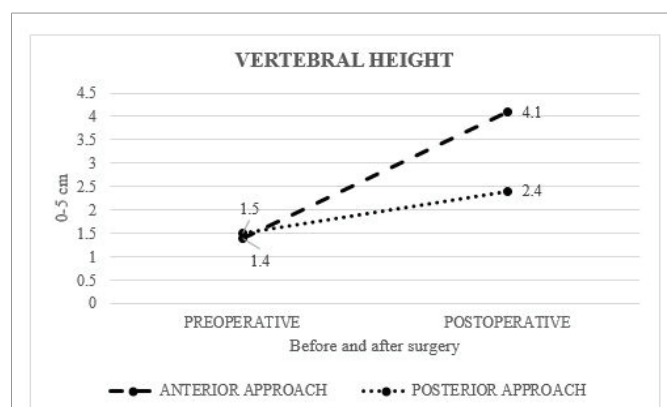


Figure 3: Vertebral height preoperative and postoperative comparing both types of thoracolumbar surgical approaches [8].

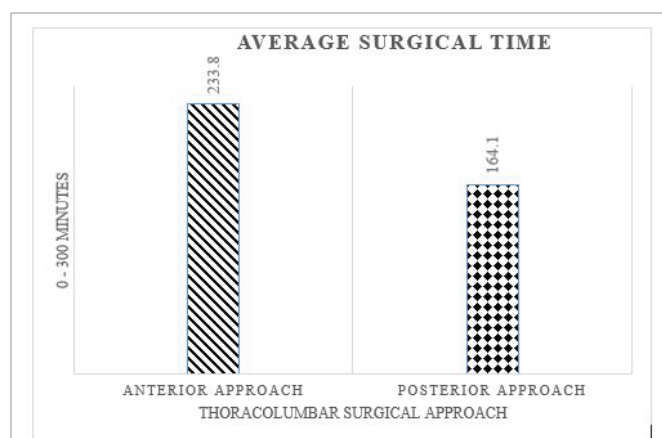


Figure 4: Average surgical time comparing both types of thoracolumbar surgical approaches [8,40].

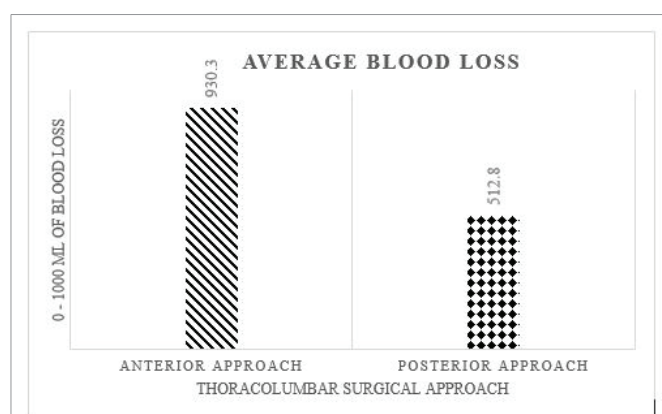


Figure 5: Average blood loss comparing both types of thoracolumbar surgical approaches [8,40].

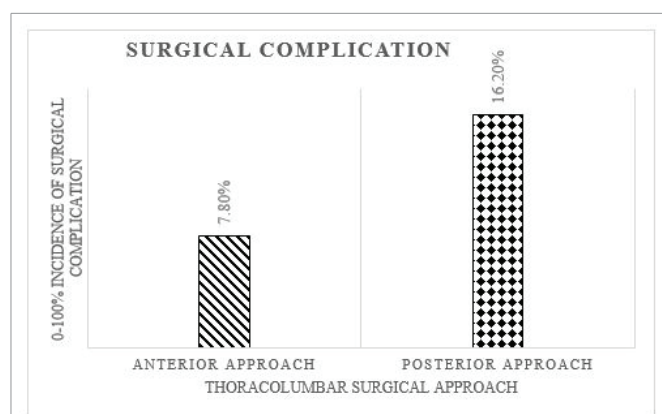


Figure 6: Surgical complications comparing both types of thoracolumbar surgical approaches [21,40].

was posterior spinal exposure, laminectomy for decompression and fixation using pedicle screws, 1 segment above and below (Table 1 and 2).

Neurological (ASIA) [41] functional outcome showed a

significant difference between the two surgical approaches. At the AA group, the average motor score improved from 39.2 to 69.9 after surgery, while at the PA group, improved from 39.9 to 52.8 after surgery, demonstrating a significantly better motor recovery at the AA group (AA group was 2.38 fold superior to PA). At the AA group, the average sensory score improved from 44.9 to 72.5 after surgery, while at the PA group, improved from 45.3 to 61.2 after surgery, also demonstrating a significantly better sensory recovery at the AA group (AA group was 1.74 fold superior to PA) (Table 1 and 2, Figure 1 and 2) [42].

Average vertebral height restoration of the affected vertebral body increased from 1.4 to 4.1 cm in the AA, and from 1.5 to 2.4 cm in the PA group, showing significantly superior anatomical correction of the fractured vertebral in the AA group (AA group had 3 fold more anatomical correction than PA) (Table 1 and 2, Figure 3) [42].

At the AA group, the average surgical timing and intraoperative blood loss was 217 min and 498 ml, respectively, while at the PA group, it was 154 min and 275 ml, respectively, demonstrating a significantly lesser surgical timing at the PA group (Table 1 and 2, Figure 4) [42].

Average intraoperative blood loss was 930 ml for the AA group, while for the PA group it was 512.8 ml, demonstrating a significantly lesser intraoperative bleeding (AA group had 1.81 fold more bleeding than PA) (Table 1 and 2, Figure 5) [42,44].

Discussion

Surgical intervention is usually indicated in the treatment of TL burst fractures when the patient presents with associated neurological deficit, pain, or spinal instability [43,46]. The main goal of surgical intervention is decompression of the neural elements, restoration of vertebral body height, correction of angular deformity, and stabilization. Such decompression and stabilization can be performed with anterior or posterior surgical approach, using minimally invasive or open technique, and both approaches have been associated with favorable results, as well as complications [22-28,42-44,47].

The antero-lateral through the retroperitoneal flank, diaphragm and/or transthoracic approach allows the surgeon to perform corpectomy and fusion, reconstructing the anterior and middle columns of the spine. Bone and disc fragments can be removed from the canal under direct vision. Following corpectomy, the vertebral column is reconstructed by inserting a bone graft and/or prosthesis, correcting angulation and loss in vertebral body height. When placing anterior instrumentation for immobilization and fusion, the hardware generally incorporates one vertebral body above and one below to the fracture [26-28,47,48].

When the posterior surgical route is used, access to the canal is gained by laminectomy and/or removal of the facet joints and pedicle, generally on one side, and neurological decompression is achieved by disimpaction. Posterior stabilization generally requires that the instrumentation be placed one or two levels above and below the site of injury [22-25].

The proper management of unstable TL burst fracture with neurological deficit remains challenging since the best surgical approach aims to decompress the spinal cord and/or cauda equina, increase the chance of neurological recovery, correct the localized deformity and perform a stable fixation, with acceptable risk of

complications. There are many clinical and review articles comparing anterior versus posterior surgical approach for TL spinal fractures, but most of those studies do not differentiate patients with and without neurological deficit, including and mixing all the cases in the same sample, nevertheless, the presence of spinal cord compression and neurological deficit are important factors for the decision about the operation and surgical technique [5,30-35].

The systematic review of Scheer et al [32] addressed the management of TL fractures, in patients with and without neurological deficit. They included 272 studies published from 1992 until 2014. The level of evidence (LOE) was assessed and the result was the following: 1.5% (4) of the studies were considered LOE I; 7% (19) were LOE II; 14% (38) LOE III; 77.2% (210) LOE IV; and 0.4% (1) LOE V. They concluded that the literature contains a high LOE to support the operative management of traumatic TL burst fractures. There is a lot of controversy whether to operate on neurologically intact patients and on the appropriate surgical approach. However, there was no RCT (LOE I) comparing AA versus PA in patients with neurologic deficit.

The meta-analysis of Xu et al [34] and the systematic review of Zhu et al [35] reviewed controlled studies (level I and II of evidence) comparing anterior versus posterior approaches for TL fractures, including patients with and without neurologic deficit. They concluded that there were no significant differences in terms of neurological recovery, return to work, complications and Cobb angle between the two groups. Nonetheless, the AA was associated with longer operative time and greater blood loss than the PA group. Therefore, the reviewed literature had a large degree of heterogeneity, including patients with and without neurological deficit, lack of randomized controlled trials (RCTs), small sample sizes, and a large number of patients lost follow-up.

The studies of Stancic et al. [44] published in 2001 (LOE II), and of Hitchon et al. [43] 2006 (Level III), showed that the neurological recovery was not significantly different comparing AA versus PA in both papers (Table 1 and 2). The article of Stancic et al. [44] and the RCT of Cui et al. [44] published in 2015 (Level I), showed a significantly lesser surgical timing and blood loss at the PA in comparison with AA group (Table 1 and 2, Figure 4 and 5). The study of Hitchon et al. [43] showed that the angular deformity at the fractured area was more successfully corrected and maintained using the AA in comparison with the PA. There was no significant difference between the two approaches in the neurological recovery, SF-36 questionnaire, duration of the procedure, cost of the implant, neither in the total cost of hospitalization (Table 1 and 2).

The RCT of Cui et al. [42], the most recent (2015) and the only with LOE I, demonstrated a significantly better neurological (motor and sensory score) recovery at the AA in comparison with the PA group. The vertebral height gain and anatomical correction after surgery was also significantly superior at the AA in comparison with the PA group (Table 1 and 2, Figure 1 and 2). None of the included comparative studies were using minimally invasive techniques.

In cases of acute TL burst fractures in which neurological deficit and angular deformity are present, the AA with anterior-column reconstruction appears to be more advantageous. The AA allows removal of retropulsed bone from the canal under direct vision as well as reconstruction of the anterior column with a strut graft and

Citation: Figueiredo, N., Vagic, N., Duraisamy, R., Arruda, W., Wasilewski, K., Ahmed, H., et al. (2019) Thoracolumbar Burst Fracture in Patients with Neurological Deficit: An Evidence-Based Systematic Review Comparing Anterior Versus Posterior Surgical Approach for Spinal Decompression and Fixation. *Int J Orth*, 2(2): 031-043.

PRISMA-P (PREFERRED REPORTING ITEMS FOR SYSTEMATIC REVIEW AND META-ANALYSIS PROTOCOLS) 2015 CHECKLIST: RECOMMENDED ITEMS TO ADDRESS IN A SYSTEMATIC REVIEW PROTOCOL*

Section and topic	Item No	Checklist item
ADMINISTRATIVE INFORMATION		
Title:		
Identification	1a	Identify the report as a protocol of a systematic review = page 1
1Update	1b	If the protocol is for an update of a previous systematic review, identify as such = N/A
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number = N/A
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author = page 1
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review = N/A
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments = N/A
Support:		
Sources	5a	Indicate sources of financial or other support for the review = N/A
Sponsor	5b	Provide name for the review funder and/or sponsor = N/A
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol = N/A
INTRODUCTION		
Rationale	6	Describe the rationale for the review in the context of what is already known = pages 3-6
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO) = page 6
METHODS		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review = pages 7-9
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage= pages 7-9
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated = pages 7-9
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review = pages 7-9
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis) = page 7
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators = page 7-9
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications = N/A
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale = page 7-9
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis = page 18
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised = page 18-19; table 1 and 2
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2 , Kendall's τ) = table 1 and 2
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression) = N/A
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned = table 1 and 2
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies) N/A
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE) = page 8-9, 18-19

*It is strongly recommended that this checklist be read in conjunction with the PRISMA-P Explanation and Elaboration (cite when available) for important clarification on the items. Amendments to a review protocol should be tracked and dated. The copyright for PRISMA-P (including checklist) is held by the PRISMA-P Group and is distributed under a Creative Commons Attribution Licence 4.0.



antero-lateral fixation [43]. The vertebral height restoration is also better using AA technique [42] (Table 1 and 2, Figure 3). The AA protects the integrity of the posterior column and is associated with a sustained correction of angular deformity and vertebral height maintenance as well [42,43]. The supplementation of an anterior construct with posterior instrumentation is generally unnecessary, but it may be indicated in unique cases in which there are two adjacent vertebral bodies fractures or three-column injuries [43].

The PA, however, is usually performed with shorter surgical timing, consequently, less blood loss, and better postoperative pulmonary function (Table 1 and 2, Figure 4 and 5) [42,44,49]. Nevertheless, this method may fail upon anterior spinal compression that hinders effective removal of compressed bone and disc fragments. Upon severe violent injuries, the patients with TL fractures are mainly manifested as considerable height losses of anterior and middle vertebral bodies with spinal instability, thus reducing the bearing and support forces of the anterior column. Since the spinal cord is injured by being compressed with the intervertebral disc tissues in front of the spinal dura mater and fractured bones, anterior decompression seems to be more suitable for alleviating or eliminating spinal cord compression under antero-lateral direct vision [42,50].

Postoperative complications after TL spinal surgeries include: pain, surgical site infection, implant loosening and screw breakage, pseudoarthrosis and bone grafting failure, misplaced screws, spinal deformity, pulmonary complications, urinary tract infection, among others [31,33,35]. Complications of respiratory system infection and intercostal nerve pain were not significantly different between the AA and PA, but complications of hemopneumothorax, abdominal distension, and constipation were fewer in PA group [51]. The Systematic Review of Zhu et al. [52] showed no significant difference in postoperative complications between the anterior and posterior approaches. The randomized controlled study (RCT) of Wood et al. [33] compared anterior versus posterior treatment of stable thoracolumbar burst fractures in 38 patients neurologically intact, being allocated 18 patients to PA and 20 to AA group. The authors reported 94.4% (17/18) complications in individuals treated with PA, including late removal of painful posterior instrumentation, instrumentation breaks, and failure of posterior fixation; whereas only 15% (3/20) in patients treated with the AA, without infections nor instrumentation-related problems. However, it seems that there were fewer complications of hemopneumothorax, abdominal distension, and constipation in the PA group, because the posterior approach avoids violating the pulmonary, visceral, and vascular structures, and is less technically demanding for most of the spinal surgeons [33,51,52].

This Evidence-based Systematic Review identified an average postoperative complication rate of 11.3% (10/88) of the patients, according to the study of Stancic et al. [44] and Hitchon et al. [43] AA presented with overall less complication rate than PA group, 7.8% (4/51) versus 16.2% (6/37), respectively (Table 1 and 2, Figure 6) [43,44].

There were some limitations to this work. This is a Systematic Review of a few available studies addressing the topic, limited comparable results, and there was lack of a standardized way to describe the main results. The number and quality of the studies included was not very satisfactory.

Classification of the Best Available Evidence

Level I of Medical Evidence (well done randomized controlled studies or systematic reviews of such studies) for Therapeutic Study [39] was provided with this Systematic Review supporting that anterior approach (AA) for decompression and fixation of the unstable thoracolumbar (TL) fractures in patients with neurological deficit was superior to posterior approach (PA) for neurological recovery (motor and sensory function) and for vertebral height restoration [42].

Level I of Medical Evidence (well done randomized controlled studies or systematic reviews of such studies) for Therapeutic Study [39] was provided with this Systematic Review supporting that posterior approach (PA) for decompression and fixation of the unstable thoracolumbar fractures in patients with neurological deficit had shorter operation time and less intraoperative blood loss than anterior approach (AA) [42,44].

Recommendations

Recommendation Grade B (fair evidence, either a single Level I study or consistent findings from multiple Level II or III studies) [39] can be formulated supporting the role of anterior approach (AA) as the preferred technique in comparison with posterior approach (PA) for the treatment of unstable thoracolumbar fracture in patients with neurological deficit, in order to improve the neurological (motor and sensory) function and to increase the vertebral height of the fractured vertebra [42].

Recommendation Grade B (fair evidence, either a single Level I study or consistent findings from multiple Level II or III studies) [39] can be formulated supporting the role of posterior approach (PA) as the preferred technique in comparison with anterior approach (AA) for the treatment of unstable thoracolumbar fracture in patients with neurological deficit, in order to reduce operation time and minimize intraoperative blood loss [42,44].

Conclusions

This Evidence-based Systematic Review of the literature demonstrated that anterior surgical approach for decompression and fixation of the thoracolumbar fractures in patients with neurological deficit increases the chance of achieving a better neurological function [42] and sustained anatomical correction of the fracture than posterior approach [42,43]. Nonetheless, posterior surgical approach group had shorter operation time and less blood loss than those patients submitted to anterior approach. The rate of general surgical complications was less in the anterior approach group in comparison to posterior approach [42,44].

There is a limited number of papers with high Level of Evidence to support any specific surgical technique for the treatment of TL fractures in patients with neurological deficit. Therefore, selection of the appropriate approach must be made cautiously and on case-by-case basis. However, according to the available medical evidence, the anterior surgical approach seems to offer better therapeutic results than posterior approach for decompression and fixation of unstable thoracolumbar fractures in patients with neurological deficit [42,43].

Directions for Future Research

A prospective multicenter registry of a higher number of cases of

thoracolumbar burst fractures, in patients with neurological deficit, would allow for a more consistent outcome reporting and better comparison between different treatment modalities.

Acknowledgment

We thank Aster MIMS Library from Aster-Medcare Group (Kerala, India) and Al Maktoum Medical Library team of Dubai Health care City (Dubai, UAE) for the librarian's support for this study.

We also thank Professor Hafez Ahmed, Dubai Medical College, and Mr. Gheever Paulose, IT-Department, Medcare Group, for the statistical analyses.

Disclosure

The authors Nicandro Figueiredo, Nikola Vagic, Rajamagesh Duraisamy, Wesley Arruda; Krzysztof Wasilewski, Hafez Ahmed, and Zbigniew Brodzinski, have no conflict of interest.

References

- Bensch, FV., Koivikko, MP., Kiuru, MJ., Koskinen, SK. (2006) The incidence and distribution of burst fractures. *Emerg Radiol*, 12(3): 124-129.
- Magerl, F., Aebi, M., Gertzbein, SD., Harms, J., Nazarian, S. (1994) A comprehensive classification of thoracic and lumbar injuries. *Eur Spine J*, 3(4): 184-201.
- Maior, T., Ungureanu, G., Kakucs, C., Berce, C., Petrushev, B., Florian, IS. (2018) Influence of Gender on Health-Related Quality of Life and Disability at 1 Year After Surgery for Thoracolumbar Burst Fractures. *Global Spine J*, 8(3): 237-243.
- Oner, FC., Ramos, LM., Simmermacher, RK., Kingma, PT., Diekerhof, CH., Dhert, WJ., et al. (2002) Classification of thoracic and lumbar spine fractures: problems of reproducibility. A study of 53 patients using CT and MRI. *Eur Spine J*, 11(3): 235-245.
- Oner, FC., Wood, KB., Smith, JS., Shaffrey, CI. (2010) Therapeutic decision making in thoracolumbar spine trauma. *Spine (Phila Pa 1976)*, 35(21 Suppl): S235-244.
- Bakkum, BW. (2014) Surface anatomy of the back and vertebral levels of clinically important structures. In: Cramer G, Darby S (eds.) *Clinical anatomy of the spine, spinal cord and ANS*, 3rd edn. Elsevier, Saint Louis, pp 1-14.
- Figueiredo, N. (2017) Motor exam of patients with spinal cord injury: a terminological imbroglio. *Neurol Sci*, 38(7): 1159-1165.
- Susan, A., Darby. (2014) Neuroanatomy of the autonomic nervous system. In: *Clinical anatomy of the spine, spinal cord and ANS*; In: Cramer G, Darby S (eds.), 3rd edn. Elsevier, Saint Louis, pp 413-507.
- Gertzbein, SD. (1992) Scoliosis Research Society. Multicenter spine fracture study. *Spine (Phila Pa 1976)*, 17(5): 528-540.
- National Highway Traffic Safety Administration. Traffic Safety Facts. <http://www.nrd.nhtsa.dot.gov/Pubs/811172.pdf>. Accessed 30 July 2014.
- Doud, AN., Weaver, AA., Talton, JW., Barnard, RT., Meredith, JW., Stitzel JD., et al. (2015) Has the incidence of thoracolumbar spine injuries increased in the United States from 1998 to 2011? *Clin Orthop Relat Res*, 473(1): 297-304.
- Starnes M. Trends in non-fatal traffic injuries: 1996-2005. National Highway Traffic Safety Administration. <http://www-nrd.nhtsa.dot.gov/pubs/810944.pdf>. Accessed 18 December 2013.
- Aleem, IS., Nassr, A. (2016) Cochrane in CORR®. Surgical versus non-surgical treatment for thoracolumbar burst fractures without neurological deficit. *Clin Orthop Relat Res*, 474(3): 619-624.
- Karimi, M. (2015) The effects of orthosis on thoracolumbar fracture healing: A review of the literature. *J Orthop*, 12(Suppl 2): S230-237.
- Kim, BG., Dan, JM., Shin, DE. (2015) Treatment of thoracolumbar fracture. *Asian Spine J*, 9(1): 133-146.
- Thomas, KC., Bailey, CS., Dvorak, MF., Kwon, B., Fisher, C. (2006) Comparison of operative and nonoperative treatment for thoracolumbar burst fractures in patients without neurological deficit: a systematic review. *J Neurosurg Spine*, 4(5): 351-358.
- Vaccaro, AR., Lim, MR., Hurlbert, RJ., Lehman, RA, Jr., Harrop, J., Fisher, DC., et al. (2006) Surgical decision making for unstable thoracolumbar spine injuries: results of a consensus panel review by the Spine Trauma Study Group. *J Spinal Disord Tech*, 19(1): 1-10.
- Vaccaro, AR., Oner, C., Kepler, CK., Dvorak, M., Schnake, K., Bellabarba, C., et al. (2013) AOSpine Spinal Cord Injury & Trauma Knowledge Forum. AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers. *Spine (Phila Pa 1976)*, 38(23): 2028-2037.
- Dai, LY., Jiang, LS., Jiang, SD. (2008) Conservative treatment of thoracolumbar burst fractures: a long-term follow-up results with special reference to the load sharing classification. *Spine (Phila Pa 1976)*, 33(23): 2536-2544.
- Heary, RF., Salas, S., Bono, CM., Kumar, S. (2006) Complication avoidance: thoracolumbar and lumbar burst fractures. *Neurosurg Clin N Am*, 17(3): 377-388.
- Kim, HS., Lee, SY., Nanda, A., Kim, JY., Park, JO., Moon, SH., et al. (2009) Comparison of surgical outcomes in thoracolumbar fractures operated with posterior constructs having varying fixation length with selective anterior fusion. *Yonsei Med J*, 50(4): 546-554.
- Cresswell, TR., Marshall, PD., Smith, RB. (1998) Mechanical stability of the AO internal spinal fixation system compared with that of the Hartshill rectangle and sublaminar wiring in the management of unstable burst fractures of the thoracic and lumbar spine. *Spine (Phila Pa 1976)*, 23(1): 111-115.
- Parker, JW., Lane, JR., Karaikovic, EE., Gaines, RW. (2000) Successful short-segment instrumentation and fusion for thoracolumbar spine fractures: a consecutive 41/2-year series. *Spine (Phila Pa 1976)*, 25(9): 1157-1170.
- Sjostrom, L., Karlstrom, G., Pech, P., Rauschnig, W. (1996) Indirect spinal canal decompression in burst fractures treated with pedicle screw instrumentation. *Spine (Phila Pa 1976)*, 21(1): 113-123.
- Zhang, Z., Chen, G., Sun, J., Wang, G., Yang, H., Luo, Z., et al. (2015) Posterior indirect reduction and pedicle screw fixation without laminectomy for Denis type B thoracolumbar burst fractures with incomplete neurologic deficit. *J Orthop Surg Res*, 10: 85.
- Dai, LY., Jiang, LS., Jiang, SD. (2009) Anterior-only stabilization using plating with bone structural autograft versus titanium mesh cages for two- or three-column thoracolumbar burst fractures: a prospective randomized study. *Spine (Phila Pa 1976)*, 34(14): 1429-1435.
- McDonough, PW., Davis, R., Tribus, C., Zdeblick, TA. (2004) The management of acute thoracolumbar burst fractures with anterior corpectomy and Z-plate fixation. *Spine (Phila Pa 1976)*, 29(17): 1901-1909.
- Zdeblick, TA., Sasso, RC., Vaccaro, AR., Chapman, JR., Harris, MB. (2009) Surgical treatment of thoracolumbar fractures. *Instr Course Lect*, 58: 639-644.

29. Dai, LY., Jiang, SD., Wang, XY., Jiang, LS. (2007) A review of the management of thoracolumbar burst fractures. *Surg Neurol*, 67(3): 221-231.
30. Danisa, OA., Shaffrey, CI., Jane, JA., Whitehill, R., Wang, GJ., Szabo, TA., et al. (1995) Surgical approaches for the correction of unstable thoracolumbar burst fractures: a retrospective analysis of treatment outcomes. *J Neurosurg*, 83(6): 977-983.
31. Sasso, RC., Renkens, K., Hanson, D., Reilly, T., McGuire, RA Jr., Best, NM. (2006) Unstable thoracolumbar burst fractures: anterior-only versus short-segment posterior fixation. *J Spinal Disord Tech*, 19(4): 242-248.
32. Scheer, JK., Bakhsheshian, J., Fakurnejad, S., Oh, T., Dahdaleh, NS., Smith, ZA. (2015) Evidence-based medicine of traumatic thoracolumbar burst fractures: a systematic review of operative management across 20 Years. *Global Spine J*, 5(1): 73-82.
33. Wood, KB., Bohn, D., Mehbod, A. (2005) Anterior versus posterior treatment of stable thoracolumbar burst fractures without neurologic deficit: a prospective, randomized study. *J Spinal Disord Tech*, 18: S15-23.
34. Xu, GJ., Li, ZJ., Ma, JX., Zhang, T., Fu, X., Ma, XL. (2013) Anterior versus posterior approach for treatment of thoracolumbar burst fractures: a meta-analysis. *Eur Spine J*, 22(10): 2176-2183.
35. Zhu, Q., Shi, F., Cai, W., Bai, J., Fan, J., Yang, H. (2015) Comparison of anterior versus posterior approach in the treatment of thoracolumbar fractures: a systematic review. *Int Surg*, 100(6): 1124-1133.
36. PMC. US National Library of Medicine PubMed. <http://www.ncbi.nlm.nih.gov/pmc>. Accessed June 2018.
37. Cochrane Library website. <http://cochranelibrary-wiley.com/cochranelibrary/search>. Accessed June 2018.
38. Wright, JG., Swiontkowski, MF., Heckman, JD. (2003) Introducing levels of evidence to the journal. *J Bone Joint Surg Am*, 85(1): 1-3.
39. Kaiser, MG., Eck, JC., Groff, MW., Watters, WC 3rd., Dailey, AT., et al. (2014) Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 1: introduction and methodology. *J Neurosurg Spine*, 21(1): 2-6.
40. Downs, SH., Black, N. (1998) The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*, 52(6): 377-384.
41. Maynard, FM Jr, Bracken, MB., Creasey, G., Ditunno, JF Jr., Donovan, WH., et al. (2011) International standards for neurological and functional classification of spinal cord injury. *J Spinal Cord Med*, 34(6): 535-546.
42. Cui, H., Guo, J., Yang, L., Guo, Y., Guo, M. (2015) Comparison of therapeutic effects of anterior decompression and posterior decompression on thoracolumbar spine fracture complicated with spinal nerve injury. *Pak J Med Sci*, 31(2): 346-350.
43. Hitchon, PW., Torner, J., Eichholz, M., Beeler, SN. (2006) Comparison of anterolateral and posterior approaches in the management of thoracolumbar burst fractures. *J Neurosurg Spine*, 5(2): 117-125.
44. Stancic, MF., Gregorović, E., Nozica, E., Penezić, L. (2001) Anterior decompression and fixation versus posterior reposition and semirigid fixation in the treatment of unstable burst thoracolumbar fracture: prospective clinical trial. *Croat Med J*, 42(1): 49-53.
45. Frankel, HL., Hancock, DO., Hyslop, G., Melzack, J., et al. (1969) The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. *Paraplegia*, 7(3): 179-192.
46. Denis, F. (1983) The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. *Spine (Phila Pa 1976)*, 8(8): 817-831.
47. Kaneda, K., Taneichi, H., Abumi, K., Hashimoto, T., Satoh, S., Fujiya, M. (1997) Anterior decompression and stabilization with the Kaneda device for thoracolumbar burst fractures associated with neurological deficits. *J Bone Joint Surg Am*, 79(1): 69-83.
48. Verheyden, AP., Spiegl, UJ., Ekkerlein, H., Gercek, E., Hauck, S., Josten, C., et al. (2018) Treatment of Fractures of the Thoracolumbar Spine: Recommendations of the Spine Section of the German Society for Orthopaedics and Trauma (DGOU). *Global Spine J*, 8(2): 34-45.
49. Gertzbein, SD., Court-Brown, CM., Marks, P., Martin, C., Fazl, M., Schwartz, M., et al. (1988) The neurological outcome following surgery for spinal fractures. *Spine*, 13(6): 641-644.
50. Suzuki, T., Abe, E., Miyakoshi, N., Murai, H., Kobayashi, T., Abe, T., et al. (2012) Anterior decompression and shortening reconstruction with a titanium mesh cage through a posterior approach alone for the treatment of lumbar burst fractures. *Asian Spine J*, 6(2): 123-130.
51. Chen, ZW., Ding, ZQ., Zhai, WL., Lian, KJ., Kang, Guo, LX., et al. (2012) Anterior versus posterior approach in the treatment of chronic thoracolumbar fractures. *Orthopedics*, 35(2): 219-224.
52. Muller, U., Berlemann, U., Sledge, J., Schwarzenbach, O. (1999) Treatment of thoracolumbar burst fractures without neurologic deficit by indirect reduction and posterior instrumentation: bisegmental stabilization with monosegmental fusion. *Eur Spine J*, 8(4): 284-289.