Two column lesions in the thoracolumbar junction: anterior, posterior or combined approach? A comparative biomechanical in vitro investigation

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Abstract There are various surgical techniques for the treatment of spinal fractures in the thoracolumbar region. Several implants have been developed for anterior or posterior instrumentation. Optimal treatment of unstable thoracolumbar osseous and ligamentous injuries remains controversial. To compare the stabilizing effects of an antero-lateral, thoracoscopically implantable plate system (macsTL, Aesculap, Germany) with the stability provided by a fixateur interne (SOCON, Aesculap, Germany), this in vitro investigation examined six human bisegmental (T12–L2) spinal units. Specimens were tested intact, and with simulation of osseous lesions in the anterior and ligamentous lesions in the posterior column (combined A/B-fracture). While loaded in the main anatomical planes such as flexion/extension, left and right lateral bending and left and right axial rotation with a bending moment of 7.5 Nm in a special testing jigs, motion analysis was performed. Quantitative interpretation of the stabilizing effect was achieved using a contactless three-dimensional motion analysis system. Each specimen was tested in four different scenarios: the first step measured movements of intact spinal segments.

For the second step, specimens underwent simulation of combined A/B-fracture provided with bisegmental (T12/L2) antero-lateral fixation and bone strut graft from the iliac crest. For the third step, segments were additionally stabilized by the fixateur interne. The last measurement (fourth step) was performed after removing the anterior instrumentation. Range of motion (ROM) values were compared and statistically evaluated. Compared to the intact specimens the anterior instrumentation of the combined lesion, simulated A/B-fracture, leads to a stabilizing effect in flexion/extension and lateral bending. In contrast to these findings the torsional instability increased for the upper segment and bisegmentally. A maximum rigidity, beyond intact values, was registered for each anatomical plane with the combined instrumentation: antero-lateral and fixateur interne. After removing the anterior screw plate system maximum movements, in all segments for flexion/extension and lateral bending, bisegmentally and for the upper segment in axial rotation, were less than ROM values measured with the anterior system only. With respect to these findings a combined ventro-dorsal stabilization procedure should be considered for ligamentous disruptions of the posterior column in combination with A-fractures in the thoracolumbar junction.

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Introduction

Surgery is commonly used for the treatment of traumatic, infectious or malignant disorders of the thoracic

and lumbar spine that may cause instability or affect the spinal cord [16, 18]. The surgical method depends on the fracture type, biomechanical and anatomical properties and the surgeon's experience. Main targets for the treatment of unstable fractures of the spinal column are: effective decompression of the spinal cord, reduction and stable fixation of the restored alignment, osseous fusion of the affected segments and a painfree unrestricted postoperative motion [2, 17, 32]. A variety of different surgical procedures are described in literature [2, 7, 12, 17–20, 32, 36] for anterior, posterior or combined fixation techniques. On one hand, a general agreement for the need and the feasibility for a dorsal instrumentation in unstable situations persists [14, 26, 29, 37]. In spite of that a disagreement exists concerning the necessity for a combined anterior and posterior stabilization [22] even though good clinical results with an angle stable plating system (macsTL) for anterior stabilization were reported [3–5, 32]. As Slosar et al. concluded, it is the biomechanical behavior of the injured and stabilized spine that must rule the treatment [33]. Therefore, in vitro investigations can provide important informations about the immediate postoperative stability [1, 13, 14, 22, 31, 35].

The purpose of our in vitro study was to describe the biomechanical behavior of a bisegmental antero-lateral angle stable plating device (macsTL, Aesculap, Germany) and a fixateur interne system (SOCON, Aesculap, Germany) in the thoracolumbar junction (T12–L2) after single implantation and in combination. In case of a combined bisegmental A-fracture [23] with limited posterior ligamentous disruption (B1-fracture [23]) in the thoracolumbar junction, our hypothesis is that an immobilization beyond the stability levels of intact specimens can only be warranted by combined antero-posterior instrumentation for all anatomical planes.

Materials and methods

Specimens

For this biomechanical examination six human bisegmental (T12–L2) specimens were used. At harvest the spines were dissected and the surrounding soft tissues were carefully removed to preserve the bony parts and spinal ligaments. The specimens were stored in plastic bags at -28°C and thawed to room temperature before testing, according to the recommendations of Wilke et al. [34]. Bone density was measured using the method of DEXA (Dual-Energy X-ray Absorption, Norland XR-26 MARK II, Cooper Surgical Inc.,

USA). The upper half of each cranial (T12) and the lower half of the caudal (L2) vertebra were fixed in epoxy-resin (Ureol 5202-1A/B, Vantico, Quillan, France). To retain the specimens' biomechanical behavior all spines were kept moist with saline during the tests.

Spine testing setup

The testing setup, the procedure of data acquisition and evaluation were described in detail previously [30, 31]. The unconstrained force induced motion in the frontal (left/right lateral bending) and sagittal (flexion/extension) plane. Due to an alternating maximum load of $\pm 20.0\text{ N}$ and the lever arm (375 mm), an alternating maximum bending moment of $\pm 7.5\text{ Nm}$ was implemented (Fig. 1). For axial rotation the specimens were loaded in the transversal plane with a pure alternating maximum torsional moment of $\pm 7.5\text{ Nm}$.

Vertebrae's three-dimensional movements (in sagittal, frontal and transversal plane) were recorded by two digital video cameras. The evaluation of the angular changes was performed using a three-dimensional motion analysis system (SIMI-Motion 5.2, SIMI Reality Motion Systems GmbH, Germany).

Prior to testing two markers were attached to each of the three vertebrae in the spinous and transverse process. Markers were visible in both cameras at any time of the movement and detected three dimensionally. With the projection of the connecting straight line between the two markers of each vertebra onto the major anatomical planes, angular changes were measured two dimensionally. So intervertebral angular changes were detected for each functional unit (T12/L1, L1/L2) as well as bisegmentally (T12–L2). The acquired load/deformation curves were analyzed as range of motion (ROM: motion at maximum loading)

Fig. 1 Spine testing setup with two digital cameras

and the neutral zone (NZ: motion at no loading). Each step—intact, bisegmental anterior, combined ventro-dorsal and posterior fixation only—was evaluated in each anatomical plane, respectively.

Statistical analysis of the evaluated ROM data was performed with the Wilcoxon exact test ($\alpha = 0.05$) using SPSS software (version 10.0). As Wilcoxon exact test was used for statistical analysis several times, the calculated *P* values can only be indicated with reservation and can be used for explorative data analysis only.

Implant systems

The modular anterior fixation system, macsTL (Aesculap, Germany), was developed for thoracoscopic instrumentation. It is applied in the antero-lateral position and can be used for mono or multisegmental stabilization. The exact procedure and operation techniques were described by Beisse et al. [4] previously.

For the transpedicular stabilization, the fixateur interne system SOCON (Solid connection, Aesculap, Germany) was used. This instrumentation system allows the restoration of the fractured anterior column and can also be used mono- or multi-segmentally.

Test protocol

Each of the six specimens (no. I–VI) underwent the following test protocol: first, the specimens were tested intact (first step). After that a vertebral body lesion (A-fracture) was simulated by a partial corpectomy (L1) with a partial resection of the cranial (T12/L1) and caudal (L1/L2) disc. This defect had a width of 12 and 20 mm depth. The defect was filled using a tricortical bone graft taken from the iliac crest of the same corpse. After cutting the supra- and inter-spinal ligaments between T12–L1 and the capsula of the facet joint T12–L1 (B1-fracture) at the instrumented right side, bisegmental antero-lateral instrumentation with macsTL followed on the same side (second step).

For the third, test-step specimens were additionally stabilized by a bisegmental fixateur interne system (SOCON) between T12 and L2. In the last step, only SOCON was tested with the tricortical bone graft after removing the anterior macsTL system (fourth step) (Fig. 2).

Each test-step included loading in all three main anatomical planes (frontal, sagittal and transversal). The specimens underwent two cycles of preconditioning in each plane and test-step. Only motions of the third cycle were evaluated.

Fig. 2 In vitro stabilization of a specimen showing the four test-steps: 1 intact, 2 antero-lateral stabilization with a bone graft, 3 ventro-dorsal stabilization and 4 transpedicular fixation

Results

Bone quality (median density 0.883 g/cm^2 , range $0.661\text{--}1.140 \text{ g/cm}^2$) of the specimens showed values within the double standard deviation (median z-score 0.45 , range -2.00 to 1.13) of the reference values. Specimens showed no sign of degeneration.

As the load/deformation curves (hysteresis) were recorded for each test-step and functional unit, maximum segmental movements (ROM) were extracted. In the following box-plot diagrams ROM-values are shown. The mono (T12/L1, L1/L2) and bisegmental (T12–L2) values are grouped within the test-steps, of which each box-plot shows the median, 25- and 75-percentile as well as the maximum and the minimum values. Whenever a peak value was between 1.5- and 3-fold above, or below 75- or 25-percentile, it was marked with an O and the corresponding specimen number. To compare the stabilizing effect, median values were used. The values are given in Tables 1, 2, and 3, with further information on increase or decrease of maximum movements for each step ($\uparrow$, $\downarrow$), as well as significances (*) and *P* values.

Flexion/extension

Maximum median deflection of the intact bisegmental spine was 15.7° (T12–L2/step 1). After bisegmental ventral stabilization of the A/B-fracture a reduction to 9.5° (39.5%) was observed (step 2). The combined ventro-dorsal bisegmental instrumentation caused significant reduction of the ROM in all segments, i.e., mono- and bi-segmentally (maximum bisegmental movement after third step: 2.2° , Table 1). Looking at the last test-step (fixateur interne only), an increase of

Table 1 Median values of ROM for flexion/extension

Test-step	ROM (°) in flexion/extension					
	Segment					
	T12–L2		T12–L1		L1–L2	
First step (intact)	$P = 0.094$		$P = 0.844$		$P = 0.094$	
	15.7	↓	7.3	↓	7.7	↓
Second step (macsTL-bisegment–B-fracture)	9.5		6.3		4.5	
Second step (macsTL-bisegment–B-fracture)	$P = 0.031$	*	$P = 0.031$	*	$P = 0.031$	*
	9.5	↓	6.3	↓	4.5	↓
Third step (macsTL-bisegment–B-fracture/SOCON)	2.2		0.6		1.7	
Third step (macsTL-bisegment–B-fracture/SOCON)	$P = 0.125$		$P = 0.500$		$P = 0.125$	
	2.2	↑	0.6	↑	1.7	↑
Fourth step (SOCON)	3.6		1.5		1.9	
Second step (macsTL-bisegment–B-fracture)	$P = 0.125$		$P = 0.125$		$P = 0.125$	
	9.5	↓	6.3	↓	4.5	↓
Fourth step (SOCON)	3.6		1.5		1.9	

↑ Increase of ROM, ↓ decrease of ROM, * level of significance α below 0.05

Table 2 Median values of ROM for lateral bending

Test-step	ROM (°) in lateral bending					
	Segment					
	T12–L2		T12–L1		L1–L2	
First step (intact)	$P = 0.063$		$P = 0.063$		$P = 0.063$	
	16.3	↓	7.4	↓	8.2	↓
Second step (macsTL-bisegment–B-fracture)	6.1		3.6		2.2	
Second step (macsTL-bisegment–B-fracture)	$P = 0.063$		$P = 0.031$	*	$P = 0.156$	
	6.1	↓	3.6	↓	2.2	↓
Third step (macsTL-bisegment–B-fracture/SOCON)	0.9		1.2		0.9	
Third step (macsTL-bisegment–B-fracture/SOCON)	$P = 0.063$		$P = 0.313$		$P = 0.688$	
	0.9	↑	1.2	↑	0.9	↓
Fourth step (SOCON)	2.7		1.8		0.7	
Second step (macsTL-bisegment–B-fracture)	$P = 0.219$		$P = 0.344$		$P = 0.063$	
	6.1	↓	3.6	↓	2.2	↓
Fourth step (SOCON)	2.7		1.8		0.7	

↑ Increase of ROM, ↓ decrease of ROM, * level of significance α below 0.05

the maximum deformation was observed for all levels compared to the combined stabilization. The values reveal that primary rigidity is higher with the dorsal transpedicular instrumentation system than with ventral stabilization only (Table 1, Fig. 3).

Left/right lateral bending

With median values of 16.3°, the intact specimen showed the largest deflection at left/right lateral bending. The second step revealed a reduction of the bisegmental ROM by 62.6% from 16.3° to 6.1°. After the third step (combined dorso-ventral stabilization), maximum rigidity could be observed mono- and bisegmentally. In the bisegmental examination a stiffening effect of 85.2% can be registered. Analyzing the specimens' behavior after removing the antero-lateral

stabilization an increase of mobility by 1.8° for the whole specimen was registered. The comparison of specimens' movements with anterior and posterior instrumentation in lateral bending revealed a similar behavior to flexion/extension. For the whole specimen with fixateur interne a reduction by 55.7% (3.4°) compared to the anterior system can be described (Table 2, Fig. 4).

Right/left axial rotation

The lesion provided with bone graft and antero-lateral instrumentation (step 2) caused a significant increase of mobility (bisegment and the cranial segment) to 8.3° (153.7%) and to 6.3° (175%), respectively. Only between L1 and L2 a higher rigidity compared to the intact spine was registered. Maximum stiffness was

Table 3 Median values of ROM for axial rotation

Test-step	ROM (°) in axial rotation					
	Segment					
	T12–L2		T12–L1		L1–L2	
First step (intact)	$P = 0.031$	*	$P = 0.031$	*	$P = 0.844$	
	5.4	↑	3.6	↑	2.5	↓
Second step (macsTL-bisegment–B-fracture)	8.3		6.3		2.0	
Second step (macsTL-bisegment–B-fracture)	$P = 0.031$	*	$P = 0.031$	*	$P = 0.313$	
	8.3	↓	6.3	↓	2.0	↓
Third step (macsTL-bisegment–B-fracture/SOCON)	4.6		2.1		1.7	
Third step (macsTL-bisegment–B-fracture/SOCON)	$P = 0.031$	*	$P = 0.031$	*	$P = 0.031$	*
	4.6	↑	2.1	↑	1.7	↑
Fourth step (SOCON)	8.2		4.2		3.9	
Second step (macsTL-bisegment–B-fracture)	$P = 1.000$		$P = 0.031$	*	$P = 0.031$	*
	8.3	↓	6.3	↓	2.0	↑
Fourth step (SOCON)	8.2		4.2		3.9	

↑ Increase of ROM, ↓ decrease of ROM, * level of significance α below 0.05

observed by combined ventro-dorsal instrumentation, significant when compared to the prior step 2 for T12/L2 and L1/L2. With the ventro-dorsal stabilization maximum rigidity was achieved, exceeding intact spines' stability level by 14.8% for T12/L2, 41.7% for T12/L1 and 32% for the caudal segment. In the last test-step with fixateur interne only a significant loss of stability was registered for all segments. The direct comparison of the ventral and dorsal instrumentation

reveals a higher rigidity provided by the fixateur interne system for the whole specimen and the upper segment (Table 3, Fig. 5).

Discussion

To ensure solid fusion of the affected spinal segments immobilization is indispensable. Although the needed

Fig. 3 Box-plot-diagram for median values of flexion/extension showing the grouped bi- and mono-segmental results: first step (intact), second step (macsTL-bisegment–A/B-fracture), third step (macsTL-bisegment–A/B-fracture/SOCON), fourth step (SOCON); peak values 1.5 to 3-fold above, or below 75- or 25-percentile are marked with an O and the corresponding specimen number

Fig. 4 Box-plot-diagram for median values of lateral bending showing the grouped bi- and mono-segmental results: first step (intact), second step (macsTL-bisegment–A/B-fracture), third step (macsTL-bisegment–A/B-fracture/SOCON), fourth step (SOCON); peak values 1.5 to 3-fold above, or below 75- or 25-percentile are marked with an O and the corresponding specimen number

Fig. 5 Box-plot-diagram for median values of axial rotation showing the grouped bi- and mono-segmental results: first step (intact), second step (macsTL-bisegment-A/B-fracture), third step (macsTL-bisegment-A/B-fracture/SOCON), fourth step (SOCON); peak values 1.5 to 3-fold above, or below 75- or 25-percentile are marked with an O and the corresponding specimen number

grade of stabilization still remains unclear, it is generally accepted that flexibility should be diminished within the physiological range or beyond [6]. There are several different surgical methods for the operative stabilization of spinal fractures in the thoracolumbar region. Single dorsal techniques with transpedicular screw fixation offer a fast, stable and safe possibility for stabilization and correcting malalignments [8, 21, 27, 37]. They rely on tensioning the posterior longitudinal ligaments and annulus fibrosis with indirect decompression of the canal and restoration of vertebral height and lordosis [15]. In absence of a ventral load-bearing reconstruction, the possibility of subsequent postoperative loss of correction including residual kyphotic deformities, a high pseudarthrosis rate and implant fatigue with implant failure is given [11, 22].

Anterior fixation techniques offer a better access for spinal decompression and restoration of the affected load-bearing anterior column. Surgery can be limited to a single approach without touching the posterior muscles, which are important for the dynamic stabilization of the spine. Anterior techniques allow a decompression of the neural elements by direct visualization and a better debridement of fracture fragments, malignant growths or infectious focuses [7, 9, 29]. Disadvantages of the anterior approach are the

more challenging operation techniques with a large lumbotomy including the risk of blood vessel lesions and a higher incidence of postoperative complications [17, 25]. A simple anterior A-fracture can be treated by anterior minimally invasive surgery [3, 4, 31]. The degree of posterior instability is often difficult to assess intraoperatively. Therefore, lesions of posterior structures should be excluded preoperatively [24].

This *in vitro* examination evaluated the primary stability of two fixation systems (anterior: macsTL, posterior: SOCON) after A/B-fractures in the thoracolumbar junction of human spines. Our biomechanical investigations showed that primary stability was achieved with both the hereby used single antero-lateral fixation device and the fixateur interne system. ROM levels were reduced beyond intact levels for flexion/extension and lateral bending (for the whole specimen T12–L2, and the segments T12–L1 and L1–L2). In axial rotation, neither the anterior nor the posterior instrumentation system reduced maximum torsional movements to intact specimen levels. Only for macsTL in the caudal segment a stiffening effect was registered.

The direct comparison of the two stabilization systems shows a higher immobilization of the vertebrae for the fixateur interne in all directions and almost all levels. Maximum rigidity, beyond intact levels, was achieved by combined antero-posterior instrumentation. As the comparative results are not statistically significant (exception, axial rotation upper and lower segment), we only want to describe trends which can be relevant for the clinical use of the aforementioned implant systems.

Our findings are in concordance with the investigations of Mann et al., who described the biomechanical behavior of human thoracolumbar spines with anterior or posterior instrumentation and combined ventro-dorsal ligamentous/osseous lesions. They concluded that after anterior burst fractures combined with serious posterior ligamentous and osseous injuries the anterior system tested (Syracuse I-plate) cannot provide as much stability as the internal fixator under the same loading conditions. However, the axial rotation stiffness was not restored to pre-injury levels with the fixateur interne system [24].

In contrary to our *in vitro* examinations, Mann et al. transected all bony and ligamentous posterior structures, leaving only the fixation device (anterior or posterior system), disc and anterior longitudinal ligament intact [24]. We found that already limited posterior lesions have to be stabilized by a combined antero-posterior approach to restore primary stability to pre-injury levels.

Flamme et al. compared the posterior (SOCON) with the anterior (macsTL) stabilization system monosegmentally in bovine specimens. The anterior system was tested alone and in combination with an intercorporal cage. They concluded that, except for movements in the frontal plane, the augmented anterior instrumentation may provide similar stability as does the posterior stabilization [14]. For monosegmental A-fractures we also consider anterior instrumentation as appropriate treatment [31], but our actual study shows the necessity of additional posterior stabilization when posterior ligamentous disruption is detected.

Schultheiss et al., who compared the macsTL with the dorsal US instrumentation system, found a higher stiffening effect for the anterior system in lateral bending, left/right axial rotation and extension. They simulated a corpectomy, bridged the defect with a wooden graft and supplemented the lesion with macsTL [32]. Except for these differences specimens were larger (T10–L2), maximum loads were different (3.75 vs. 7.5 Nm in our study [30–32]) and the posterior column, partially destroyed in our study, was left intact. With the comparison of the studies' results the importance of the intact posterior column's ligamentous and osseous structures can be confirmed [32].

With their nonlinear finite element study, Rohlmann et al. concluded a higher stiffening effect of the macsTL implant compared with a fixateur interne system. In their simulation again posterior elements were left intact and the anterior bonegraft only replaced small parts of the intervertebral discs [28]. Here the intact anterior vertebral body and the exactly fitting bone grafts can contribute to the better stabilizing effect of the macsTL system.

In vitro studies can only represent an approach to the in vivo situation as shown by Danisa et al. In a retrospective study they considered anterior, posterior and combined instrumentation of thoracolumbar fractures as equally effective [10].

A prospective randomized study by Wood et al. [37] comparing anterior and posterior stabilization of acute isolated burst fractures in the thoracolumbar junction showed similar patient outcomes for both stabilization systems. Oertel et al. [26] recommended after a prospective clinical study a primary anterior instrumentation of lesions with initial kyphotic and wedge angles of 20° or more and in highly unstable fractures of the thoracolumbar region. Detecting a significantly higher rigidity of a ventro-dorsal construction would help to understand the good clinical results [5] of the endoscopic anterior stabilization system and to justify the ventral procedure. Looking at our results with maxi-

mum movements in axial rotation exceeding intact spines' values with both single instrumentations, we consider the antero-posterior treatment for combined ventro-dorsal thoracolumbar lesions of the spine as appropriate from a biomechanical point of view. With respect to the controversial results of the abovementioned in vitro and in vivo investigations concerning correct therapy for thoracolumbar lesions, further investigation is urgently needed [26].

Conclusions

This biomechanical in vitro investigation gives comparative data about the primary stability of different surgical approaches to combined osseous and ligamentous fractures in the thoracolumbar junction. Both implant systems tested, the anterior screw plate system and the fixateur interne, can provide stability to the injured spine exceeding intact levels for flexion/extension and lateral bending. A direct comparison of the two methods reveals a not significantly higher stiffening effect of the dorsal system in all main anatomical planes. Looking at the maximum rigidity of the spines in axial rotation provided by single anterior or posterior instrumentation, stability levels of the intact spines were neither reached for the ventral nor the dorsal technique. To provide sufficient primary stability in all main anatomical planes and to insure osseous fusion a combined ventro-dorsal instrumentation of the injured osseous and ligamentous structures should be considered in fractures with ventro-dorsal instability. Apart from a reliable biomechanical stabilization, relative risks of combined antero-posterior instrumentation, e.g., high blood loss, operating time, post operative pain management, longer hospitalization or costs must be considered preoperatively.

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