Introduction

Thoracolumbar fractures are very common, accounting for 67% of all spinal injuries [1]. In general, thoracolumbar fractures are classified into types A, B and C, according to the Magerl/AO classification [2]. Numerous studies have reported on the clinical outcome of surgically treated thoracolumbar fractures, comprising A 3.1 (cranial burst), A3.2 (burst-split) and A3.3 (burst) fractures [3,4]. In our evaluation, we focused especially on A1.3 compression and A3.1 burst fractures, which are common and have been the focus in several other studies before [5,6]. Geographical and institutional variations in treating thoracolumbar fractures are well-known. Stable bursting or simple compression fractures are generally treated by conservative management.

A standard treatment for instability and deformity of the thoracolumbar spine is a dorsally based stabilization technique with the use of an internal fixation device [7]. Dorsal stabilization can be performed with the open technique or the minimally invasive technique.

One limitation to the MIS procedure is the difficulty to control the reduction and maintain lordosis [8]. The clear advantage with MIS is that there is relatively less soft tissue damage and blood loss compared to the open technique [8]. However, the general perception of spine surgeons seems to be that accurate control, as with open techniques, is not possible and reduction might be worse [9].

Thus, while minimally invasive posterior stabilization is well established and appears to offer distinct advantages, to our knowledge, no clinical studies have compared the reduction and lordosis achieved with minimally invasive methods to traditional open posterior instrumentation. In this study we compare both techniques in terms of reduction, loss of reduction over time, operating time and hospital stay after stabilisation of thoracolumbar fractures.
Materials and methods

Patient population

104 patients between the age of 15 and 86 were evaluated in a retrospective clinical study. Of this number, 46 patients underwent open surgery (OS) (17 = female, 29 = male), and 58 patients were treated by minimally invasive surgery (MIS) (30 = female, 28 = male). The median age was 46.52 ± 16.91 years in the OS group and 50.5 ± 13.95 years in the MIS group (Fig. 1).

Cause of disease

Falling was the cause of 90% of patients who underwent MIS and 82% of patients who received OS. Motor accidents were the cause of the remaining fractures in both groups. Pathologic fractures were excluded. Patients with underlying disease processes such as osteoporosis, or suspected osteoporosis, were excluded from this study.

Fracture location

The vertebral bodies TH12 and L1 were affected most frequently in both groups (MIS = 59%, OS = 63%). The vertebral body L2 was also often fractured (MIS = 18%, open technique = 22%), (Fig. 1).

Fracture classification

All fractures were classified according to Magerl [2]. In the majority of cases, A3.1 fractures were found (OS = 37%, MIS = 59%) (Fig. 1). The study included patients treated surgically with posterior instrumented fixation for A1, A2, and A3 thoracolumbar fractures without neurological deficits at the trauma unit of the University Medical Centre of Schleswig-Holstein, Kiel Campus, Germany. All patients were operated on between 20 December 2006 to 31 January 2013, and received open or minimally invasive stabilization.

<table>
<thead>
<tr>
<th></th>
<th>MIS</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>58</td>
<td>46</td>
</tr>
<tr>
<td>Female</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td>Male</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td>Age (median)</td>
<td>50.5 ± 13.95 years</td>
<td>46.52 ± 16.91 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level of distribution (%)</th>
<th>MIS</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th9</td>
<td>2 %</td>
<td>1 %</td>
</tr>
<tr>
<td>Th11</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Th12</td>
<td>28%</td>
<td>30%</td>
</tr>
<tr>
<td>L1</td>
<td>34%</td>
<td>33%</td>
</tr>
<tr>
<td>L2</td>
<td>17%</td>
<td>22%</td>
</tr>
<tr>
<td>L3</td>
<td>9%</td>
<td>4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fracture classification</th>
<th>MIS</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A2</td>
<td>29%</td>
<td>55%</td>
</tr>
<tr>
<td>A3.1</td>
<td>69%</td>
<td>37%</td>
</tr>
<tr>
<td>B</td>
<td>2%</td>
<td>6%</td>
</tr>
<tr>
<td>C</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Stabilisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mono-segmental</td>
<td>18%</td>
<td>13%</td>
</tr>
<tr>
<td>bi-segmental</td>
<td>80%</td>
<td>83%</td>
</tr>
<tr>
<td>tri-segmental</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>Time period from trauma to operative treatment (median)</td>
<td>MIS</td>
<td>OS</td>
</tr>
<tr>
<td>3.62 ± 2.67 days</td>
<td>3.87 ± 2.85 days</td>
<td></td>
</tr>
<tr>
<td>Hospital stay (median)</td>
<td>MIS</td>
<td>OS</td>
</tr>
<tr>
<td>11.28 ± 7.36 days</td>
<td>14.22 ± 4.38 days</td>
<td></td>
</tr>
<tr>
<td>screws</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mono-axial</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td>poly-axial</td>
<td>76%</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Demographics of the study.
Results

Operative therapy

46 Patients were stabilized by open posterior fixation, and 58 patients were stabilized by MIS. The required average time from point of trauma to operation was 3.87 ± 2.85 days for open stabilization and 3.62 ± 2.67 days for the minimally invasive technique.

Retention time for implants

The retention time for implants was 305.5 ± 107.5 days after minimally invasive stabilization and 313.9 ± 169.9 days after

---

Fig. 2 a-g. Radiological follow-up of minimally invasive posterior fixation.
the open technique. At the time of data collection, there were still 21 patients (48%) after minimally invasive stabilization and 9 patients (20%) after open stabilization with implants still in place. An early removal of implants due to increased pain was not required in either group. There were no differences in patient satisfaction, especially in terms of pain or daily activities between both groups.

Reduction achieved by posterior instrumentation

There was no significant difference in Cobb angle’s correction between minimally invasive and open stabilization (MIS versus OS: 7.51° ± 4.97 versus 9.52° ± 4.53; p = 0.70 (MIS); p = 0.74 (OS); n = 51 (MIS); n = 37 (OS)) (Fig. 4 a, Fig. 5 a). The selective comparison of minimally invasive poly-axial and

Fig. 3 a-g. Follow-up of open posterior fixation over one year after trauma.

Mono-axial stabilization showed no statistically significant difference (7.85° ± 4.53 versus 6.51° ± 5.04; p = 0.81 (poly-axial); p = 1.40 (mono-axial); n = 38 (poly-axial); n = 13 (mono-axial)) (Fig. 4 a, Fig. 5 a).

Reduction in A3.1 fractures
Isolated examination of post-operative Cobb angle in bi-segmental A 3.1 fractures (Magerl classification) did not show any significant difference between minimally invasive poly-axial and open stabilization (MIS poly-axial versus OS: 7.2° ± 4.93 vs. 10.5° ± 2.9; p = 0.75 (MIS); p = 0.92 (poly-axial); p = 1.07 (OS); n = 10 (MIS poly-axial); n = 4 (poly-axial); n = 8 (OS); n = 5 (OS)) (Fig. 4 c, Fig. 5 b), (months: -5.38° ± 3.56 versus -5.21° ± 6.16; p = 0.12 (MIS poly-axial); p = 1.3 (poly-axial); n = 3 (MIS mono-axial); n = 14 (OS)) (Fig. 4 c, Fig. 5 b).

Control of Cobb angle after 6 weeks, 3 months, 6 months and 12 months
Isolated examination of bi-segmental A 3.1 fractures (Magerl classification) did not show any significant difference between minimally invasive poly-axial and open stabilization after 6 weeks, 3 months, 6 months and 12 months (MIS poly-axial versus OS after 6 weeks: -3.21° ± 1.77 versus -2.84° ± 1.98; p = 0.56 (MIS); p = 0.75 (OS); n = 10 (MIS poly-axial); n = 14 (poly-axial); n = 8 (OS); n = 5 (OS)) (Fig. 4 d, Fig. 5 b), (months: -5.45° ± 4.32 versus -6.16° ± 4.30; p = 0.12 (MIS poly-axial); p = 1.3 (poly-axial); n = 3 (MIS mono-axial); n = 14 (OS)) (Fig. 4 d, Fig. 5 b).

Reduction in A3.1 fractures
Isolated examination of post-operative Cobb angle in bi-segmental A 3.1 fractures (Magerl classification) did not show any significant difference between minimally invasive poly-axial and open stabilization (MIS poly-axial versus OS: 7.2° ± 4.93 vs. 10.5° ± 2.9; p = 0.75 (MIS); p = 0.92 (poly-axial); p = 1.07 (OS); n = 10 (MIS poly-axial); n = 4 (poly-axial); n = 8 (OS); n = 5 (OS)) (Fig. 4 c, Fig. 5 b), (months: -5.38° ± 3.56 versus -5.21° ± 6.16; p = 0.12 (MIS poly-axial); p = 1.3 (poly-axial); n = 3 (MIS mono-axial); n = 14 (OS)) (Fig. 4 c, Fig. 5 b).

Control of Cobb angle after 6 weeks, 3 months, 6 months and 12 months
Isolated examination of bi-segmental A 3.1 fractures (Magerl classification) did not show any significant difference between minimally invasive poly-axial and open stabilization after 6 weeks, 3 months, 6 months and 12 months (MIS poly-axial versus OS after 6 weeks: -3.21° ± 1.77 versus -2.84° ± 1.98; p = 0.56 (MIS); p = 0.75 (OS); n = 10 (MIS poly-axial); n = 14 (poly-axial); n = 8 (OS); n = 5 (OS)) (Fig. 4 d, Fig. 5 b), (months: -5.45° ± 4.32 versus -6.16° ± 4.30; p = 0.12 (MIS poly-axial); p = 1.3 (poly-axial); n = 3 (MIS mono-axial); n = 14 (OS)) (Fig. 4 d, Fig. 5 b).

Reduction of all fractures measured as the decrease in Cobb angle pre- and postoperatively. b) This effect is even more pronounced if only A3.1 fractures treated with MIS and OS are analyzed. c) Loss of reduction is measured as increase of Cobb angle over time. Analysis of all fractures showed no differences between the different retention methods. Of note polyaxial screw design did not influence loss of reduction significantly. d) The selective analysis of A3.1 fractures did not reveal statistically significant differences either.

<table>
<thead>
<tr>
<th>Reduction (cobb angle)</th>
<th>MIS Poly-axial</th>
<th>MIS Mono-axial</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>After operation</td>
<td>7.51° ± 4.97</td>
<td>6.51° ± 5.04</td>
<td>9.52° ± 4.53</td>
</tr>
<tr>
<td>After 6 weeks</td>
<td>-3.86° ± 3.00</td>
<td>-3.51° ± 2.30</td>
<td>-4.92° ± 4.61</td>
</tr>
<tr>
<td>After 3 months</td>
<td>-4.94° ± 3.84</td>
<td>-5.01° ± 3.39</td>
<td>-4.6° ± 6.24</td>
</tr>
<tr>
<td>After 6 months</td>
<td>-5.33° ± 3.88</td>
<td>-5.38° ± 3.56</td>
<td>-5.21° ± 4.68</td>
</tr>
<tr>
<td>After 12 months</td>
<td>-5.64° ± 4.32</td>
<td>-6.16° ± 4.30</td>
<td>-6.7° ± 4.51</td>
</tr>
</tbody>
</table>

Reduction in A3.1 fractures
<table>
<thead>
<tr>
<th>Reduction in A3.1 fractures</th>
<th>MIS Poly-axial</th>
<th>MIS Mono-axial</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>After operation</td>
<td>7.2° ± 4.93</td>
<td>-5.9° ± 4.93</td>
<td>10.5° ± 4.54</td>
</tr>
<tr>
<td>After 6 weeks</td>
<td>-3.21° ± 1.77</td>
<td>-4.92° ± 4.61</td>
<td>-2.84° ± 1.98</td>
</tr>
<tr>
<td>After 3 months</td>
<td>-4.56° ± 2.92</td>
<td>-5.73° ± 7.12</td>
<td>-3.3° ± 2.40</td>
</tr>
<tr>
<td>After 6 months</td>
<td>5.01° ± 2.28</td>
<td>-5.25° ± 5.00</td>
<td>-4.9° ± 0.99</td>
</tr>
<tr>
<td>After 12 months</td>
<td>-5.45° ± 3.04</td>
<td>-4.57° ± 4.93</td>
<td>-6.9° ± 1.42</td>
</tr>
</tbody>
</table>

There was no significant difference between minimally invasive poly-axial and mono-axial stabilization (6 weeks: -3.51° ± 2.30 versus -4.92° ± 4.61; p = 0.50 (poly-axial); p = 1.74 (mono-axial); n = 21 (poly-axial); n = 7 (mono-axial)) (Fig. 4 c, Fig. 5 a), (3 months: -5.38° ± 3.56 versus -5.21° ± 6.16; p = 0.12 (MIS poly-axial); p = 1.3 (poly-axial); n = 17 (poly-axial); n = 3 (mono-axial)) (Fig. 4 c, Fig. 5 a).

Control of Cobb angle in A3.1 fractures after 6 weeks, 3 months, 6 months and 12 months
Isolated examination of bi-segmental A 3.1 fractures (Magerl classification) did not show any significant difference between minimally invasive poly-axial and open stabilization after 6 weeks, 3 months, 6 months and 12 months (MIS poly-axial versus OS after 6 weeks: -3.21° ± 1.77 versus -2.84° ± 1.98; p = 0.56 (MIS); p = 0.75 (OS); n = 10 (MIS poly-axial); n = 7 (OS)); (3 months: -4.56° ± 2.92 versus -3.3° ± 2.40; p = 0.92 (poly-axial); p = 1.07 (OS); n = 10 (MIS poly-axial); n = 5 (OS)) (Fig. 4 d, Fig. 5 b), (months: -5.01° ± 2.28 versus -4.9° ± 0.99; p = 0.76 (poly-axial); p = 0.31 (OS); n = 9 (poly-axial); n = 10 (OS)) (Fig. 4 d, Fig. 5 b), (12 months: -5.45° ± 3.04 versus -6.9° ± 1.42; p = 1.52 (MIS poly-axial); p = 0.50 (OS); n = 4 (MIS poly-axial); n = 8 (OS)) (Fig. 4 d, Fig. 5 b).

There was no significant difference between the minimally invasive mono-axial and open technique: MIS mono-axial versus open technique (6 weeks: -4.92° ± 4.61 versus -2.84° ± 1.98; p = 1.74 (MIS mono-axial); p = 0.75 (OS); n = 7 (MIS mono-axial); n = 7 (OS)) (Fig. 4 d, Fig. 5 b), (months: -5.73° ± 7.12 versus -3.28° ± 1.98;
2.4; p = 4.12 (MIS mono-axial), p = 1.07 (OS); n = 3 (MIS mono-axial); n = 5 (OS), (6 months: -5.25° ± 5.00 versus -4.99° ± 0.99; p = 0.06 (MIS mono-axial), p = (OS); n = 8 (MIS mono-axial); n = 10 (OS)); (12 months: -4.57° ± 4.93 versus -6.94° ± 1.42; p = 2.01 (MIS mono-axial), p = 0.50 (OS); n = 6 (MIS mono-axial); n = 8 (OS)).

Length of surgery
Analysis of length of surgery showed significant differences between minimally invasive and open stabilization techniques (76.35 min ± 28.96 versus 103.2 min ± 37.27; p = 0.02 (MIS); p = 5.75 (OS); n = 52 (MIS); n = 42 (OV)) (Fig. 6 a).

Post-operative hospitalisation
Analysis of the duration of the post-operative stay revealed significant differences between minimally invasive and open stabilization (7.40 d ± 4.91 versus 9.52 d ± 4.86; p = 0.78 (MIS), p = 1.01 (OS); n = 40 (MIS); n = 23 (OV)) (Fig. 6 b). The shortest hospital stay post-operatively was 2 days, and the longest stay 48 days.

Discussion
The most common site of injury to the spine is the thoracolumbar junction [10]. Thoracolumbar spine injuries frequently occur after high-energy motor vehicle accidents [10]. There is a higher frequency of trauma related spinal fractures in males than in females [11]. In some studies the highest frequency of thoracolumbar injury occurs in patients between 15 and 29 years of age [12]. On the contrary, some authors showed a maximum of cases at the age of 50 to 59 years in the group of males and females [13,14]. With the growth of the elderly population, an increase of vertebral fractures has frequently been reported [15,16]. Osteoporotic fractures were not included in our study.

In view of geographical and institutional variations there are differences in therapy and treatment of thoracolumbar burst fractures. The treatment of thoracolumbar fractures remains controversial in terms of mono-segmental or bi-segmental stabilization. Short segment stabilization is one of the most common operative approaches to stabilize thoracolumbar fractures.

Although the clinical results of this surgery are usually satisfactory, progressive kyphosis and a high rate of implant failure remain a concern compared to long-segment stabilization [17].

Extension by long-segment stabilization can reduce instrument failure rates, but tends to minimize additional motion segments and reduce the range of motion [18].

In our study, fusion level of dorsal stabilization was chosen depending on instability and type of fracture. Mono-segmental stabilization was only performed in case of stable cranial fractures. Analogous to AO criteria, long-segment stabilization was also provided in A3 and B fractures to generate better reduction forces.

Implants were removed after 9 to 12 months to open the range of movements again.

Previous studies confirm that use of posterior instrumentation alone results in a respectively high risk of failure, instability or correction loss [19,20].

Further anterior decompression and fusion for thoracolumbar fractures can restore vertebral body height and correct the kyphotic deformity [21-23]. A loss of body height is usually observed after posterior stabilization but several studies have shown none or minimal loss of correction after ventral fusion in combination with dorsal stabilization [21,24]. Interestingly, recent studies have, in contrast, shown that there are no clinical or radiological differences in outcome between dorsal stabilization and fusion and only dorsal stabilization [25,26].

Several fractures may require a second treatment with fusion materials, such as autogenous iliac crest bone graft or allograft. Bone grafting is often performed as an adjunct to spinal fixation, but there are several advantages in not performing fusion. Apart from longer surgery time and blood loss, long-term studies have shown that up to 37% of patients had permanent donor side pain after operation [27]. Secondly, in several studies it was shown that there is an increase in failure of short segment stabilization supplemented with intracorporal bone graft [28]. In our examination, no fusion materials were used.

To evaluate both techniques in term of reduction, we analysed the Cobb angle after operation. The average correction angle was 7.51° ± 4.97 following the minimally invasive technique, and 9.52° ± 4.53 following the open technique. Comparison of both groups directly post-operatively showed no significant differences in the reduction achieved.

When one bears in mind that most of the fracture reduction is achieved through positioning and that the open technique offers
the possibility of direct manipulation of the vertebral body, it might be unexpected that MIS seems to generate similar results compared to open technique. Previous studies have shown an extensive loss of reduction in a follow-up after minimally invasive stabilisation [29].

Loss of reduction was evaluated over 12 months, while all the cases were considered to be healed after 1 year. Some of the implants were removed after 9 months, which meant that not all cases could be evaluated for the full 12 months.

The Cobb angle was measured after 6 weeks, 3 months, 6 months and after 12 months. There were no significant differences in loss of reduction between OS and MIS, which correlates with results of other studies [13]. Cobb angle loss increased over time after treatment with both methods, which might be caused by stability loss [13,30].

We devoted special attention to the most common vertebral body fracture, the A3.1 fracture [8]. These fractures are simple to compare and there seems to be no difference in loss of reduction after long segment stabilisation and bi-segmental stabilisation [13,31]. Separate inspection of these fractures showed also no significant difference between minimally invasive and open stabilisation.

For minimally invasive stabilisation, we used mono-axial or poly-axial screws. Segmental fixation with mono-axial pedicle screws increases construct stiffness and shields the fractured vertebral body from anterior loads [32,33]. Poly-axial screws offer a better coupling between the screw heads and the connecting rod, which causes less torsion and consequently less stress on the entire construct [26]. Loss of correction observed during follow up in patients treated with poly-axial screws has been described in previous studies [32]. For this reason insertion of mono-axial screws in percutaneous technique is recommended [33,34].

Palmisani et al. assert that the Cobb angle after stabilisation with poly-axial screws is conducive to screw loosening and a loss of vertebral body height [35]. Opposite Shepard et al. suggested that poly-axial screws do not significantly decrease the stiffness of the construct [32].

Consideration our findings, it was interestingly that there was not a significant difference in loss of Cobb angle between mono-axial and poly-axial screws. This might be explained by the combined effect of bending loads and shear force on the rods, which cause higher resistance to rotational slippage between the rods and the screw head [26].

Minimally invasive stabilisation seemed to be associated with a higher incidence of malpositioned pedicle screws compared to the open technique previous [36] but we did not observe any malpositioned pedicle screws after minimally invasive stabilisation.

In keeping with other studies, dorsal stabilisation is generally accompanied by hospitalisation for 14 days [31], which correlates with our results.

A reduction in post-operative stay was achieved by MIS, with patients being hospitalized for 7.40 d ± 4.91. Minimal invasive instrumentation of the spine reduces operative time and hospital stay [8]. Our analysis showed a hospital stay of 9.52 d ± 4.86 after open treatment, which corroborates other studies [31].

Extended hospital stay after open treatment is attributable to soft tissue trauma, muscle dissection and wound healing [13]. Despite blood loss and muscle trauma, the open technique offers the clear surgical field, while the minimally invasive technique requires continuous observation by X-ray or intra-operative CT scanning [35]. As the hospital stay is essentially influenced by the length of the operation [8], the shorter length of operation associated with the minimally invasive technique would appear to be a distinct advantage. The average duration of the operation was 76.35 min. ± 28.96 for MIS and 103.2 min. ± 37.27 for OS. Similar results are shown by Wang et al., who highlighted the reduced operating time achieved with improvements in the minimally invasive techniques [13].

In this study we examined both dominant posterior fixation methods comparing them in terms of various parameters. Radiological results of MIS are comparable to the open technique. MIS offers distinct advantages in terms of shorter hospital stay and shorter operative times. In summary, beside several advantages the clinical outcome has to be evaluated in further long-term studies.

Conclusion

All together, even though minimally invasive stabilization proceeds without direct mobilization of the vertebra body, both groups show similar early results in reduction and loss of reduction. There were no significant differences in loss of reduction over time. A significant difference could not be shown between mono-axial and poly-axial screws either. A reduction in post-operative stay and shorter length of operation was achieved by MIS compared to OS. The method of MIS allows an approach that does not damage the important posterior elements and also avoids fusion while advancing rehabilitation. Overall, we recommend MIS as surgery of choice because, from our point of view, the minimally invasive stabilization generates similar results but several essential advantages, such as shorter operation time or shorter hospital stay.

Even so, further investigations – especially an evaluation over a longer period between 1.5 and 2 years – will be necessary. In addition, a future ideal study will be to compare the A3 fractures treated with MIS versus non operative measures.

Acknowledgment

The authors thank Dr. Sophie Fargher from Starship Childrens Hospital, Auckland, New Zealand for technical assistance and helpful advice.

Conflict of interest

The authors declare that no conflict of interest exists.

References


