

Five-year clinical and radiological results of combined anteroposterior stabilization of thoracolumbar fractures

Clinical article

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Object. Despite promising early clinical results, the long-term outcome of the use of expandable titanium cages to reconstruct the anterior column after traumatic burst fractures is still unknown. The purpose of this prospective study was to assess the clinical and radiological outcomes of the use of expandable titanium cages 5 years postoperatively.

Methods. Eighty patients with traumatic thoracolumbar burst fractures (T4–L5) underwent posterior stabilization followed by anterior corpectomy and reconstruction using expandable titanium cages with or without additional anterior plating. After 5 years, fusion was evaluated by means of plain radiographs and CT scans, and the patients' scores on the Oswestry Disability Index (ODI), their neurological status, and clinical results were assessed.

Results. Forty-five (56%) of the 80 patients could be examined after 5 years. There was a relatively high rate of complications related to thoracotomy (26%), but there were no complications directly related to the cages. Revision surgery was required in 1 case. The average postoperative loss of correction was only 2.4° due to minimal subsidence of the cages. No cage showed a radiolucent line or instability in flexion-extension views. Bony fusion, as assessed by CT scan, was achieved in 41 patients (91%). On clinical examination, 96% of all patients were ambulatory and showed minimal restriction of spinal range of motion; 71% did not need analgesic medication at all; and 67% were able to work. The average ODI score was 12. Thirty-one percent of patients complained of some kind of anterior approach–related complications.

Conclusions. Combined anteroposterior stabilization of thoracolumbar burst fractures with expandable titanium cages is a relative safe procedure with satisfactory radiological and clinical long-term outcome. High fusion rates can be achieved, with only minor loss of correction, typically occurring in the 1st year. However, open thoracotomy carries the risks of additional complications and development of post-thoracotomy syndrome.

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KEY WORDS • anterior approach • CT scan • thoracic • lumbar •
expandable titanium cage • burst fracture • thoracolumbar • thoracotomy

ENSURING adequate stability to prevent loss of fracture reduction and facilitate healing constitutes the primary aim of modern operative treatment of thoracolumbar spinal fractures. Although there appears to be a consensus concerning the importance of primary stability, there is still controversy regarding the optimal treatment concept, whether unstable thoracolumbar fractures should be treated with a posterior, anterior, or combined anteroposterior approach. Despite the fact that good results were reported for anterior-only approaches^{8,39} and the superiority of anteroposterior approaches still remains to be proven, anteroposterior stabilization of unstable thoracolumbar fractures is advocated by several authors.^{4,14,17,26,28,33} The advantages claimed for combined procedures are increased primary stability, optimal reduction capability, and decreased postoperative correction loss. As a result, the use of corpectomy cages has significantly increased in anterior column reconstruction

in an effort to address the issues concerning donor-site morbidity by autologous iliac crest graft harvesting. Additionally, corpectomy cages were found to be biomechanically superior.^{7,17} Until now, reported results on the use of corpectomy cages have had either a short follow-up^{1,9} or have been based on heterogeneous case series.^{12,29,34}

The aim of this prospective study was to investigate the long-term radiological and clinical results of the anteroposterior instrumentation of thoracolumbar fractures with use of expandable titanium corpectomy cages, with special attention to surgical access–related complications.

Methods

Eighty consecutive patients who had suffered an unstable thoracolumbar injury (from T-4 to L-5) of Type A.3, B, or C according to the Magerl AO-classification²⁰ were included in this prospective study. Patients with osteoporosis were excluded from the study.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.

Abbreviations used in this paper: AIS = ASIA Impairment Scale; ASIA = American Spinal Injury Association; BKA = bisegmental kyphosis angle; ODI = Oswestry Disability Index; VAS = visual analog scale.

Indications for a combined posterior-anterior procedure were defined as followed: Type A, B, or C injuries with severe comminution of the vertebral body and/or local kyphosis of more than 15°–20° (compared with physiological values).³⁷

All patients were initially treated by posterior stabilization with an internal fixator (USS Fracture or USS II, Synthes).

Following placement of posterior instrumentation, the patients underwent an anterior corpectomy of the fractured vertebra and implantation of an expandable cage (VBR, Ulrich). Local autologous bone harvested from the corpectomy site was placed inside and around the cage to promote fusion. The cage implantation was performed through an open thoracotomy for corpectomies down to L-1 and through an open retroperitoneal approach for more caudal fractures.

In addition, in 43 cases (54%), a plate (“St. Georg” plate, Link, or LCP, Synthes) was placed anterolaterally during the same surgical session (“St. Georg” plate, Link, or LCP, Synthes). The application of a plate was based on intraoperative assessment of the local stability by the surgeons but was not related to the type of fracture.

All patients were evaluated clinically and radiologically at 1 year after surgery and annually thereafter until the last follow-up examination, 5 years postoperatively.

Radiological Evaluation

Conventional standing anteroposterior and lateral radiographs as well as flexion-extension lateral views of the surgically treated spinal region were obtained at the follow-up visits. Additionally, a CT scan with 2D reconstruction was performed at the 1- and 5-year follow-up visits (LightSpeed 8/16, General Electric; slice thickness 2.5 mm, reconstruction 1.5 mm).

Conventional radiographs were evaluated by use of the Osiris Software program for calculating the following parameters: 1) Bisegmental kyphosis angle (BKA). This was defined as the angle between the superior endplate of the cephalad intact vertebra and the inferior endplate of the caudad intact vertebra, as measured by the Cobb method in the lateral and in the flexion-extension views (Fig. 1); 2) Cage subsidence. The distance from the superior endplate of the cephalad intact vertebra to the inferior endplate of the caudad intact vertebra was measured along the longitudinal axis of the cage on lateral radiographs at each time point. The difference in this measurement was used for calculating cage subsidence (Fig. 2); 3) Cage tilting. The angle between the cage axis and the inferior endplate of the caudad intact vertebra was measured in both lateral and anteroposterior views, and these angles were used for calculating the sagittal and coronal tilting of the cage, respectively (Fig. 3).

CT scans including transverse images and 2D reconstructions were used for evaluating the bony fusion.

Criteria used for fusion evaluation are listed in Table 1.

Clinical Evaluation

Perioperative and postoperative complications (related to either the dorsal or the ventral approach) were recorded.

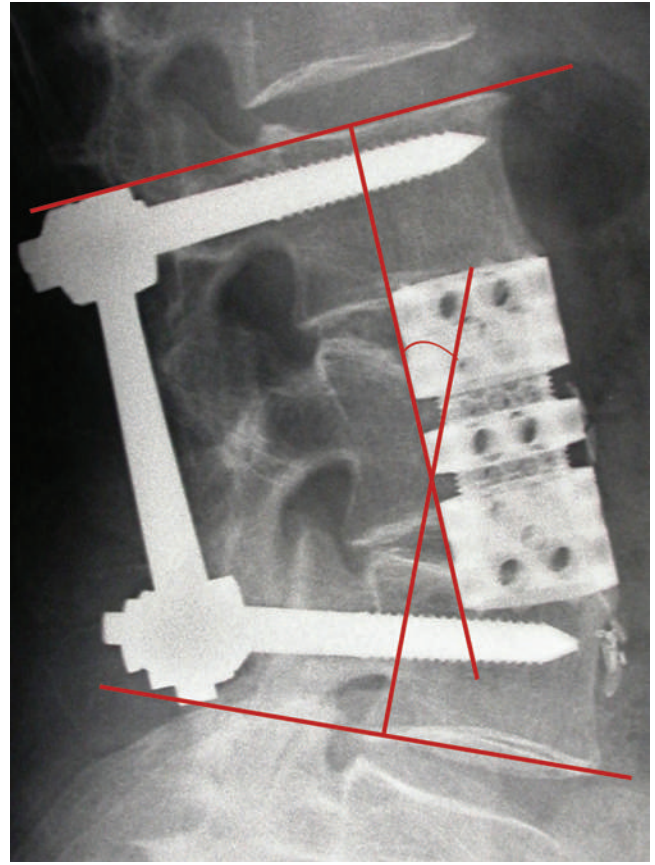


FIG. 1. Lateral radiograph showing the bisegmental kyphosis angle (BKA) as measured by the Cobb method. The BKA was measured on plain lateral radiographs and in flexion-extension views.

The patients' neurological status was evaluated according to the American Spinal Injury Association (ASIA) Impairment Scale (AIS), though some patients were evaluated by emergency doctors at the accident site and did not receive a proper ASIA examination.

Patients' performed self-assessment using the Oswestry Disability Index (ODI).²¹

For assessment of spinal mobility, the range of motion of the thoracolumbar spine was evaluated by measuring of the following parameters: side bending (left, right), spinal rotation (left, right), and finger-to-ground distance.

A 100-point visual analog scale (VAS) was used for patients' self-evaluation of perceived back and leg pain. In addition, the patients were asked to categorize their rest and/or stress pain as permanent, frequent, occasional, or absent.

Finally, the evolution of pain intensity, the use of analgesics, patients' complaints regarding the ventral approach and their ability to walk, sit, and work were recorded at each time point.

Statistical Analysis

Normal distribution of the variables was assessed with the nonparametric Kolmogorov-Smirnov test. Paired sample values were compared with the Wilcoxon test; the Mann-Whitney test was used for independent sample

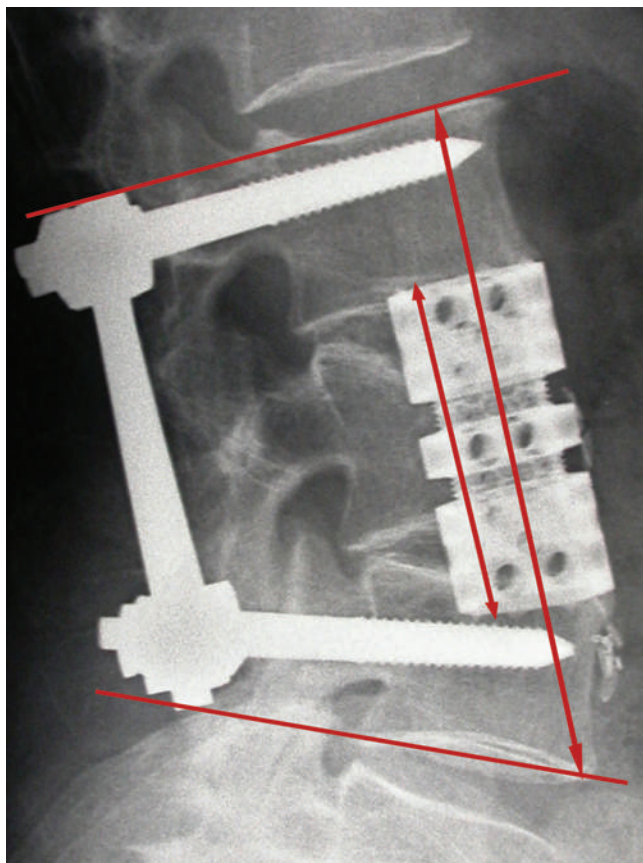


Fig. 2. Lateral radiograph illustrating the method for calculating cage subsidence. The long double-headed arrow indicates the distance measured along the longitudinal axis of the cage.

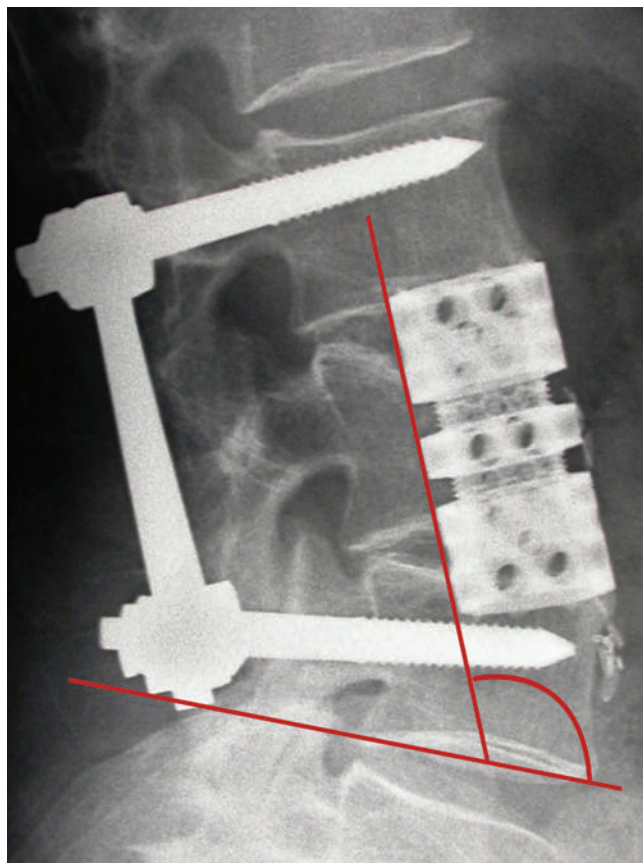


Fig. 3. Lateral radiograph showing the method for calculating cage tilting. The angle was calculated based on measurements in both the lateral and the anteroposterior view. The resulting angles were used for calculating sagittal and coronal tilting, respectively.

values. Statistical correlations were calculated by use of the Spearman rank correlation coefficient, while the chi-square test was used for binomial distribution. For statistical correlations of interval-scaled, normally distributed sample values the Pearson correlation coefficient was used. Statistical analysis was conducted using SPSS 14 (SPSS, Inc.).

Results

Of the 80 patients who met the initial inclusion criteria, 45 (56%) were still available for follow-up and could be examined after 5 years. Twenty-four patients (30%) lived too far away to come to our center for a follow-up examination, 8 (10%) refused examination for personal reasons, and 3 (4%) had died of causes unrelated to surgery. Statistical analysis revealed that there was no statistically significant difference among the demographic characteristics between patients initially included in the study and those available for the final 5-year follow-up evaluation.

Radiological Results

Preoperatively, the mean BKA was 8.9° (kyphosis). Through surgical treatment a significant correction of the BKA was obtained (mean correction -9.1°) ($p < 0.001$),

since a lordotic BKA of a mean of -0.2° could be achieved. At the 5-year follow-up evaluation, a significant loss of correction was present (mean 2.6°) ($p < 0.001$), resulting in a mean remaining BKA correction of -6.5° compared with the preoperative BKA values. Most of the correction loss (mean 2.4°) as well as most of the cage subsidence and cage tilting occurred within the first 12 months postoperatively. There was no significant difference in these parameters between the 1- and 5-year follow-up examinations (Table 2). There was a significant correlation between cage subsidence, cage tilting, and loss of correction ($p < 0.05$).

According to the aforementioned criteria, bony fusion

TABLE 1: Criteria for fusion evaluation based on CT

Criteria for Fusion
bony bridge between endplates, assessed in radiographs, axial CT slices, & sagittal/coronal 2D reconstructions
bone formation in & around the cage in all axial CT slices & sagittal/coronal 2D reconstructions
no bisegmental kyphosis angle difference $>3^\circ$ in flexion-extension radiographs
no radiolucency around the cage, assessed in radiographs, axial CT slices, & sagittal/coronal 2D reconstructions

was judged as complete in 41 (91%) patients (Fig. 4), with 35 patients (78%) demonstrating a visible bony bridge between the endplates. Four patients (9%) displayed only incomplete fusion signs but no signs of instability, since no cage showed a radiolucent line or instability in flexion/extension views.

Clinical Results

The mean age of the patients who completed the 5-year follow-up was 44 years at the time of surgery (range 28–67 years; 67% male, 33% female).

Complications. In the entire patient group (80 patients), 42 complications occurred, resulting in a rate of 52.5% (Table 3). The complication rate due to the posterior approach was 13%. The overall peri- and postoperative complication rate (in all 80 cases) due to the anterior approach was 37.5%, but most of the complications were not clinically significant. The rate of complications due to the thoracotomy itself was 26.25%. Transient pulmonary complications were most frequent (with an overall rate of 18.75%). Revision surgery (repeat thoracotomy) was needed in 1 case (1.25%) of an extensive thoracic seroma. No cage-related complications requiring revision surgery were recorded.

Neurological Status. Data on neurological status were available for 42 (93.3%) of the 45 patients who completed the 5-year follow-up evaluation. Upon admission 7 (16.7%) of these 42 patients were classified as having a complete paralysis (AIS Grade A). Three of these patients could not be examined properly due to the fact that they were already anesthetized. Their neurological status had been assessed by the emergency physician at the accident site. Five patients (12%) presented with an incomplete paralysis (AIS Grade B, C, or D), while 30 patients (71.4%) were neurologically intact (Table 4).

The status of the neurologically impaired patients improved by a mean of 1.9 grades in the AIS between preoperative status and last follow-up examination.

ODI Score. At the 1-year follow-up examination the mean ODI score was 12.5 (range 0–35).

At the 5-year follow-up examination it remained practically unchanged (mean ODI score 12, range 0–33).

Spinal Mobility. According to recorded results, spinal mobility tended to improve at the 5-year examination compared with the 1-year follow-up, but this improvement failed to reach statistical significance ($p > 0.05$) (Table 5). Overall, at 5 years postoperatively, patients showed only a minimal restriction of spinal range of motion.

Pain Intensity and Progress. Pain evaluation with use of the VAS demonstrated an overall significant improvement between the 1- and the 5-year follow-up visit for back pain, buttock pain, and leg pain ($p < 0.001$).

At the final follow-up visit, 40 patients (89%) reported no or only occasional rest pain, while 31 (69%) reported no or only occasional stress pain.

In terms of overall pain at the 5-year follow-up compared with previous follow-up visit (usually the 1-year evaluation), 5 patients (11%) reported a deterioration, 15 (33.3%) described their pain as unchanged, 21 (46.7%) reported an improvement, while 4 (9%) claimed to be pain free.

Thirty-one patients (69%) did not use any analgesics at all and 10 (22%) used them only occasionally, while 4 (9%) needed oral analgesics on a regular basis.

Walking, Sitting, and Working Capability. At the 5-year examination, 43 patients (96%) were able to walk unassisted, while 1 patient needed support to ambulate and 1 patient was not ambulatory. All patients were able to sit.

Concerning the patients' ability to work, 27 (60%) were working, 3 (6.6%) were unemployed, 12 (26.6%) were retired, and 3 patients (6.6%) reported that they were unable to work.

Anterior Approach–Related Complaints. Thirty-one patients (69%) felt that their anterior scar was unattractive, while 6 patients (13.3%) reported paresthesias in the region and 8 (17.7%) complained of a mild ache after pressure was applied. Overall, almost one-third of the patients complained of some kind of anterior approach–related complications.

Discussion

Combined anteroposterior treatment of thoracolumbar fractures is advocated by several authors to improve

TABLE 2: Radiological data from 45 patients

Variable	Preop	Operative Correction	Postop	12 Mos Postop	60 Mos Postop	Correction Loss 60 Mos Postop	Remaining Correction
BKA(°)	8.9	−9.1*	−0.2*	2.2†	2.4‡	2.6	−6.5
cage subsidence (mm)							
into cranial endplate			0	2.1†	2.2‡		
into caudal endplate			0	1.9†	2.1‡		
cage tilting (°)							
in coronal plane			0	1.5†	1.5‡		
in sagittal plane			0	2.4†	2.5‡		

* $p < 0.001$ (compared to preoperative values).

† $p < 0.001$ (compared to postoperative values).

‡ No statistically significant difference (compared to 12-month postoperative values).

Anteroposterior stabilization of thoracolumbar burst fractures

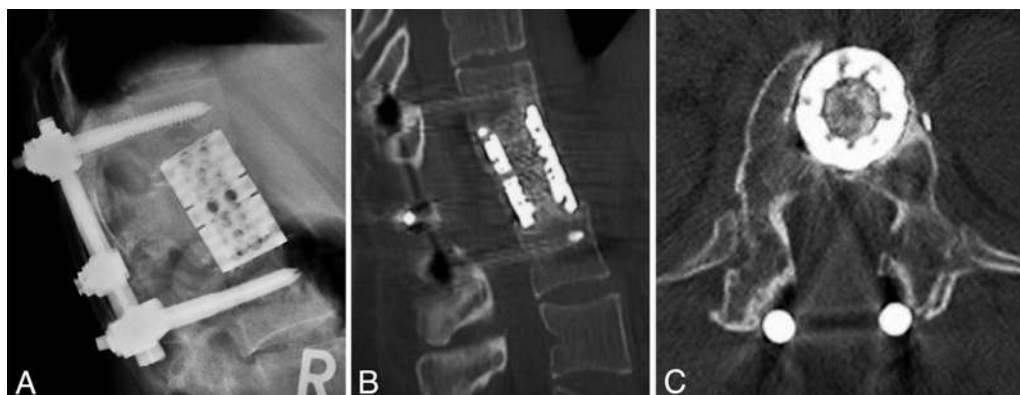


Fig. 4. A plain radiograph (A) and CT images (B and C) showing solid fusion 5 years after posterior stabilization and anterior corpectomy and cage insertion for treatment of a complete burst fracture of L-1.

fracture reduction and to minimize postoperative reduction loss.

According to our local treatment recommendations,³⁷ we perform combined anteroposterior stabilization in burst fractures with severe comminution of the vertebral body and/or if local kyphosis exceeds 15°. The goals are to achieve anatomical reduction, long-lasting stability, and minor loss of reduction in the follow-up period. In

cases of residual spinal stenosis after posterior stabilization, the anterior approach is further used to perform adequate decompression of the neural structures. The use of corpectomy cages for anterior reconstruction has significantly increased in the last years,^{1,8,9,14,26,28,39} tending to largely replace the use of autologous tricortical iliac graft, because of the cage's favorable biomechanical properties and the lack of donor-site morbidity, an issue traditionally associated with autologous iliac crest grafts.^{17,28} In a re-

TABLE 3: Perioperative complications in 80 patients

Category or Complication	No. of Cases	%
operative complications of the ventral approach		
peritoneal injury (due to adhesions)	2	2.5
postop complications		
paresis of phrenic nerve following thoracotomy w/ diaphragm-splitting	1	1.25
hematoma of thoracic wall w/ ventilation problems following thoracotomy	2	2.5
subsplenic hematoma	1	1.25
deep venous thrombosis	2	2.5
high need for transfusion	1	1.25
gastritis/gastrointestinal bleeding	3	3.75
renal insufficiency	1	1.25
cardiac rhythm disorders	2	2.5
pulmonary complications	15	18.75
pneumonia	4	5
pleural effusion	6	7.5
seroma of the thorax (requiring re-thoracotomy)	1	1.25
recurrent sero-/pneumothorax	1	1.25
repeat pneumothorax after drainage removal	2	2.5
dystelectasis, incomplete lung expansion, requiring prolonged ventilation	1	1.25
operative complications of the dorsal approach		
wound dehiscence	4	5
wound infection	3	3.75
wound seroma/hematoma	3	3.75
drain attachment*	1	1.25
iliac crest wound seroma	1	1.25

* In one case a drain was accidentally sewed to a deep tissue layer and the wound had to be reopened in order to remove the drain.

TABLE 4: Neurological status of 42 patients

Preop AIS Grade	AIS Grade at Last Follow-Up				
	A	B	C	D	E
A	1	0	1	2+1*	2*
B	0	0	0	0	0
C	0	0	1	0	1
D	0	0	0	1	2
E	0	0	0	1	29

* Patients with questionable preoperative neurological evaluation.

cent biomechanical study, the stiffness of titanium cages was similar to that of a fibular graft in a cadaveric model.⁵

The use of an anterior cage can significantly decrease the load on the posterior fixation system and avoid loosening or fatigue fracture of the screws,^{11,18} reduce the loss of anterior column height, and prevent secondary kyphotic deformity. There is evidence that anteroposterior treatment provides the most stable biomechanical solution for thoracolumbar vertebral traumas.^{3,11,19,25,26,36}

In our study, an expandable titanium corpectomy cage was used for anterior column reconstruction following posterior reduction and stabilization. The cage was used to stabilize the anterior column but not for reduction, since anatomical reduction is difficult to achieve from an anterior approach and immediate cage subsidence may occur. In contrast to nonexpandable cages, expandable cages ease intraoperative handling and may reduce the operation time. However, correct positioning of nonexpandable cages can be challenging. Some distraction forces and shaping of the endplates may be necessary to insert a rigid implant. Even then, the position of the implant can be inadequate; endplates can weaken with consequent subsidence, and restoring sagittal alignment can be insufficient. One of the main advantages of expandable cages for vertebral body replacement is easy, nondistracted insertion of the cage. The height can be adjusted to the corpectomy defect in situ, and correction of deformity and restoration of height can be achieved.⁹

According to our results, bony fusion could be achieved in 91% of treated fractures, and there were no signs of a gross instability in any patient. These results are in concordance with existing literature, where high fusion rates are consistently reported, after anterior column reconstruction with corpectomy cages with or without posterior instrumentation.^{1,12}

Although no significant instability was present in any of our patients and solid fusion could be achieved in most cases, we found a correction loss as well as subsidence and tilting of the cages (Fig. 4). These phenomena mainly occurred within the 1st postoperative year, when the whole construct “settles down,” reaching its final stable position. These objective expressions of cage subsidence are interdependent and their progression diminishes after the 1st year, with their values remaining practically unchanged between the 1- and 5-year follow-up assessments. This cage subsidence, which is often reported in the literature,^{1,4,14,39} appears to be an unavoidable effect, especially within the 1st postoperative year. In a recent

TABLE 5: Range of spinal mobility in 45 patients

Assessment	12 Mos Postop	60 Mos Postop
side bending (right-0-left)	17°-0°-17°	28°-0°-26°*
spinal rotation (right-0-left)	26°-0°-26°	42°-0°-36°*
finger-to-ground-distance (cm)	17	14*

* No statistically significant difference (compared to 12-month postoperative values).

study, a mean cage subsidence of 1.4 mm was documented in half of the studied population already after a mean follow-up period of 9 months.¹ It seems that early cage subsidence causes a loss of tension within the stabilized construct, resulting in a decrease of the primary stability and an overload of the remaining load-bearing structures, especially the posterior fixator. Hence there appears to be a correlation between cage subsidence and postoperative loss of correction.^{32,35} Expandable cages carry the risk of overdistraction, because there is no clear sign to warn the surgeon to stop the expansion. In cases of posterior anatomical reduction with pedicle screws, further distraction is useless but it may lead to overdistraction of the segment and consequently to subsidence and tilting of the cage. Nevertheless, some authors reported a correlation between additional posterior instrumentation and reduced cage subsidence, although it failed to reach statistical significance.^{1,2} In a recent study, a loss of correction at a mean of 8° secondary to cage subsidence was reported when titanium corpectomy cages were solely used.¹⁶

Some kind of perioperative complication was reported for more than one-third of the patients, but none of these complications was life threatening, and reoperation was needed only in one patient. Existing literature provides varying data in this field, with studies reporting from rather high to very low rates of complications and reoperations.^{13,34}

Concerning the clinical evaluation, the ODI, although not validated for spinal trauma, is widely accepted as being adequate for the clinical assessment of back problems and reproducible and sensitive enough to detect even minor changes that are clinically significant. In our study, as in the study of Salas et al.³⁰ a satisfactory mean ODI score was already achieved at the 1-year follow-up and, unlike in other studies,¹⁶ it remained practically unchanged afterward. The spinal mobility of the examined patients tended to improve over time, but this improvement failed to reach statistical significance and was not reflected in the ODI score.

The reported rate of ability to return to work in our study is similar to rates in the existing literature.^{22,23} Since spinal fractures mainly involve younger patients usually lacking significant comorbidities, the reported rates are justified.

An interesting finding of our study was that almost one-third of our patients reported some kind of complaints related to the anterior approach, even 5 years postoperatively. It could be argued that this high incidence of anterior approach-related complaints represents a significant drawback of performing an anteroposterior sta-

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bilization of thoracolumbar fractures, taken into consideration that the superiority of such a treatment compared with a posterior-only approach still remains unclear. This is correct, but it should be pointed out that cage placement in this study population was performed via an open thoracotomy, which was our standard approach at that time. We believe that new anterior approaches, such as the video-assisted thoracoscopic approach, which has replaced open thoracotomy in our practice, will significantly contribute to reducing these approach-related complications. Comparative data from the area of thoracic surgery^{6,38} as well as early data from spinal surgery^{15,27} support this notion, by showing a significant reduction in complication rates for thoracoscopically assisted approaches in comparison with open thoracotomies, but these results must be validated in larger comparative studies from the area of spinal surgery. Posterior-only approaches for corpectomy and cage insertion have been recently described, but their potential advantages still remain unclear.^{16,24,31}

Our study also has some disadvantages. First of all, the relatively low percentage (56%) of the patients able to complete the 5-year follow-up might raise some questions concerning the results of the study. Secondly, the overall number of patients participated in our study is not that large, but it is comparable to the numbers of patients in similar studies reported in the literature.

Another limitation involves the preoperative assessment of neurological deficits in some patients. The excellent neurological recovery of some patients may be due to an inadequate preoperative neurological examination. However, we believe that early decompression and stabilization should be performed in any patient with a thoracolumbar burst fracture presenting with neurological deficits.¹⁰ Indications to perform surgery in trauma differ widely. The need for additional anterior support, in particular, is a matter of ongoing discussion. It is likely that in other geographical regions, some of our patients would have been treated with posterior stabilization only. Since no comparative studies are available, the decision whether to perform an additional anterior stabilization mainly depends on the surgeon's experience, local treatment recommendations, and biomechanical considerations.

Since the anterior approach carries an increased risk of additional complications, our study does not provide further evidence for a clinical benefit of additional anterior treatment.

Among the strengths of this study is the increased homogeneity of the studied population. All patients initially underwent dorsal surgery, followed by an anterior corpectomy, in which a single cage type was inserted in all cases. Reported results on the use of corpectomy cages, usually refer to inhomogeneous case series with various indications (trauma, tumor, degenerative) for surgery, various corpectomy localization (cervical, thoracic, lumbar), and use of various surgical procedures (anterior, anteroposterior)³⁴ and implants,³⁰ or have quite small patient's numbers.³¹ To our knowledge, this is the first report of long-term results of a single-center homogeneous case series of anteroposteriorly stabilized thoracolumbar fractures, where corpectomy cages were used. Furthermore, it is a prospective study with a relatively long duration of

follow-up and used CT scans and strict criteria for the evaluation of fusion.

Conclusions

Our results demonstrate that anteroposterior instrumentation of unstable thoracolumbar fractures with the use of a titanium expandable cage for anterior reconstruction following anterior corpectomy is a safe and effective procedure. A significant correction of kyphotic deformity and high fusion rates could be achieved. Furthermore, a successful clinical result was obtained early and was sustained and slightly improved over the 5-year follow-up period.

The relatively high complication rate resulting from thoracotomy may improve through application of less-invasive thoracoscopic procedures. With the classic open thoracotomy approach however, a postoperative thoracotomy syndrome should be expected in about one-third of the patients.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Schnake, Kandziora. Acquisition of data: Schnake, Stavridis. Analysis and interpretation of data: all authors. Drafting the article: Schnake, Stavridis. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Schnake. Statistical analysis: Schnake, Stavridis. Study supervision: Kandziora.

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