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ORIGINAL ARTICLE

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Fate of the transpedicular intervertebral bone graft after posterior stabilisation of thoracolumbar fractures

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Abstract The authors present a retrospective clinical and radiological study addressing the outcome after posterior stabilisation of thoracolumbar fractures with intervertebral fusion via transpedicular bone grafting. The study included computed tomographic (CT) scan after implant removal for analysis of the intervertebral fusion and incorporation of the intervertebral bone graft and its influence on postoperative re-kyphosing. Twenty-nine patients with acute fractures of the thoracolumbar spine, treated between 1988 and 1995 at the Department of Trauma Surgery, Hannover Medical School, underwent posterior stabilisation and interbody fusion with transpedicular cancellous bone grafting. This study group was followed clinically and radiologically for a mean of 3.5 years. All patients underwent spiral CT scan with sagittal reconstruction after implant removal. Twenty-four type A, four type B, and one type C lesion were posteriorly stabilised and transpedicular intervertebral bone grafting was performed. The operative time averaged 2 h 50 min, the intraoperative fluoroscopy time 4 min 7 s, and the mean intraoperative blood loss was 376 ml. Four patients out of six with an incomplete neurologic lesion (Frankel/ASIA D) improved to Frankel/ASIA grade E. Two complications were observed: one delayed wound healing and one venous thrombosis with secondary pulmonary embolism. Compared to the preoperative status, our follow-up examinations demonstrated permanent social sequelae: the percentage of individuals able to do physical labor was reduced, whereas the proportion of unemployed or retired patients increased. The assessment of complaints and functional outcome with the Hannover Spine Score reflected a significant difference ($P<0.001$) between the status before injury (96.6/100 points) and at follow-up (64.4/100 points). The radiographic follow-up revealed a mean loss of correction of 7.8° ($P<0.005$). CT scans after implant removal showed an interbody fusion and incorporation of the transpedicular bone graft in ten patients (34%). In another ten patients (34%), the CT scans demonstrated the interbody fusion at the anterior and posterior walls of the vertebral body via direct contact due to collapse of the disc space. In these patients, the bone graft was not incorporated and no central interbody fusion could be found. In nine patients (31%) neither interbody fusion nor incorporation of the transpedicular graft was achieved. A frequent and reliable intervertebral fusion could not be achieved with the described technique of transpedicular bone grafting. The ineffectiveness of the intervertebral graft was found to be a reason for postoperative re-kyphosing.

Keywords Spinal injuries · Spinal fusion · Internal fixator · Transpedicular bone grafting · Treatment outcome

Introduction

Many authors agree that acute, unstable or significantly kyphotic thoracolumbar spine fractures should be operatively addressed [1, 5, 6, 8, 9, 10, 12, 13, 18, 24, 27, 30, 31, 32]. In the case of injuries that have a significant anterior column deficiency, the issue of whether to approach these fractures from posterior, anterior, or with a combined anterior-posterior approach is controversial [1, 5, 6, 8, 9, 10, 12, 13, 18, 20, 24, 27, 30, 31, 32].

In a survey of the "Spine" Work Study Group of the German Trauma Society (DGU, Deutsche Gesellschaft für Unfallchirurgie), including 18 trauma centers, the most common treatment of unstable thoracolumbar fractures was reported to be a posterior approach with pedicle screw fixation [22, 23]. Between 1994 and 1996, 448 out of 682 patients (66%) were posteriorly stabilised. In 248 (55%) of them, an additional transpedicular intervertebral bone grafting, as described by Daniaux [11, 12], was performed. The objective of this additional technique was to remove the disrupted intervertebral disc and to fill the space between the freshened caudal end-plate of the upper vertebrae and the fractured body below. The idea of this procedure is firstly to restore the load-bearing capacity of the anterior column and secondly to achieve an interbody fusion. Consequently, the method should prevent collapse of the intervertebral disc space in the injured segment, which would result in loss of correction (re-kyphosing).

We found a statistically significant loss of correction (re-kyphosing) in patients with thoracolumbar fractures managed with transpedicular bone grafting of the anterior column [24]. Furthermore, the transpedicular fusion technique did not decrease the loss of correction in comparison with patients who were exclusively treated with posterior stabilisation. These findings were in agreement with the observations of other authors [33, 34, 38, 39] and results of the survey of the "Spine" Work Study Group of the DGU [25, 22, 23].

With this second study on thoracolumbar fractures treated with transpedicular bone grafting, we sought to further evaluate the long-term results of our patient population and to establish a morphologic reason for the surprising, yet frequent, long-term radiologic findings. Bone healing in the fractured vertebral body segment as well as incorporation and remodeling of the transplanted cancellous bone graft were evaluated after implant removal with the aid of spiral computed tomography (CT) including biplanar reconstructions. Clinical evaluation and conventional radiographic imaging were also utilised for complete description of the long-term outcome and possible correlations between results.

Materials and methods

Patient group

A total of 71 patients underwent posterior stabilisation with concomitant transpedicular intervertebral bone grafting at the Trauma Department, Hannover Medical School, from 1988 through 1995. We retrospectively reviewed only acute, traumatic thoracolumbar fractures. Additionally, to be included in the study, the patients had to have undergone hardware removal with subsequent CT evaluation and a clinical examination. Our stringent inclusion criteria resulted in a significant loss of the patient population. We had abandoned the idea of pursuing a prospective study of patients after 1993, because we had discontinued the described transpedicular bone grafting technique on the basis of what we considered to be suboptimal results [24]. The study period was extended to include patients operated prior to 1993. Nevertheless, a significant percentage of the patient population (20/24 patients) was from the period 1993–1995 (Fig. 1).

Twenty-nine patients with a mean age of 46 (range 23–65) years – 12 women, 17 men – met the inclusion criteria, and all were personally interviewed by the lead author. The mean follow-up period was 42 months (range 13–99 months) from the operative procedure and a minimum of 3 months from hardware removal.

In our series, the L1 vertebra was the most commonly involved level (Fig. 2). Burst fractures were the predominant fracture type (Fig. 3). Twenty-six patients had either single- or two-level involvement, with one patient having multi-level (more than two segments) trauma. Two patients had noncontiguous spinal lesion, i.e. two-level involvement with an intact interposed vertebra.

A fall from a height was the most common cause of injury (Fig. 4). Of six initially incomplete paraplegic presentations (Frankel/ASIA D), four patients had complete resolution of neurologic symptoms (Frankel/ASIA E), with two patients unimproved. The

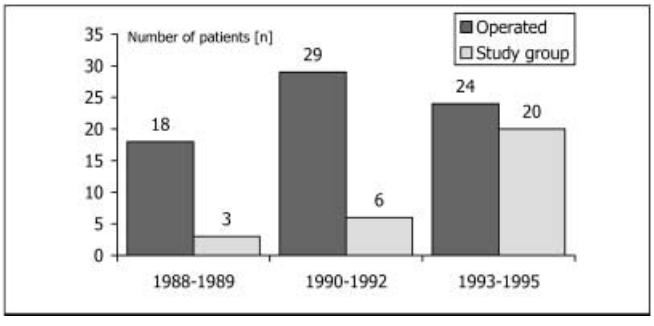


Fig. 1 Total number of operative patients (*n*=71) and participation in follow-up study (*n*=29)

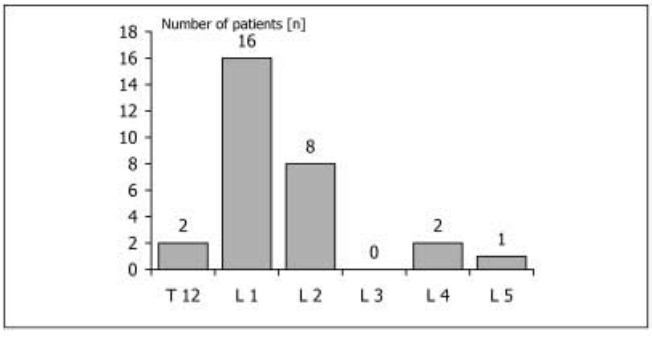


Fig. 2 Distribution of fractures by vertebral level (*n*=29)

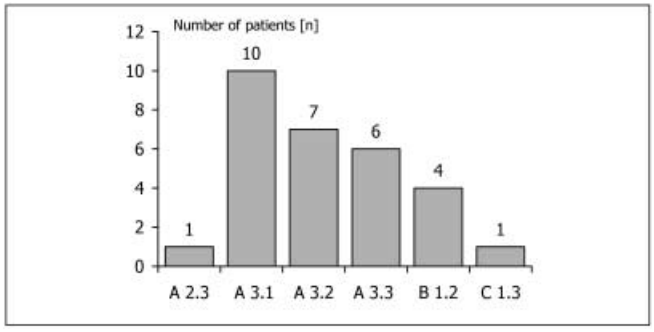


Fig. 3 Distribution of various fracture types (*n*=29) according to the Magerl classification [28]

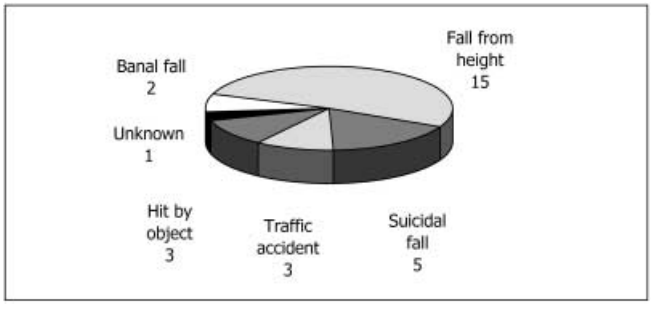


Fig. 4 Distribution of cause of injury

remaining 23 patients were neurologically intact upon presentation (Frankel/ASIA E).

Fifteen of 29 patients (52%) had at least one other injury, with one patient being classified polytraumatised. Extremity injuries (11/29 patients, 38%) were the most common. Two patients had thoracic injuries and two patients pelvic injuries.

Two patients were operated on the day of injury, 7 patients within 3 days and 20 patients within 4–17 days post trauma. The mean interval between date of injury and operative intervention was 7 days. Posterior stabilisation was achieved almost uniformly using a fixateur-interne system. In 17 cases, the fixateur-interne as described by Olerud was used [32]. The USS Synthes system was implanted in six cases. Two patients were stabilised with the fixateur-interne, as described by Kluger and Gerner [21]. Additionally, two patients were stabilised using a plate fixation system, and in two patients a plate fixator was used, as described by Wolter and Kortmann [40].

In 16 of 29 patients (55%) a concomitant posterior interlaminar onlay graft was placed in addition to the transpedicular bone grafting.

The mean operative time was 2 h 50 min (range 78–255 min), with a mean fluoroscopic time of 4 min 7 s (range 126–348 s), and a there was mean blood loss of 376 ml (range 20–600 ml). There were two postoperative complications. One patient had a wound seroma that was percutaneously drained by needle aspiration without further problems and another patient had a pulmonary embolism without hemodynamic instability, which was managed with anticoagulation.

Methods

The following data and parameters were evaluated:

- Patient records were examined for analysing the cause of injury, the treatment modalities, complications during the period of treatment, and neurologic status pre- and postoperatively using the modified Frankel/ASIA classification [3, 17].
- Conventional radiographs from the initial trauma evaluation, postoperatively, 3–6 months postoperatively, after hardware removal, and at follow-up were assessed. We classified the fractures according to the Magerl system [28]. Spinal alignment in the sagittal plane was described by the superior-inferior endplate angle (SIEA), with a negative value indicating kyphosis. The frontal, or coronal, plane was described using Cobb angles. All angle measurements were obtained by standard digitising of the radiographs using a digitising board and Autosketch for Windows. The objective of analysing the radiological course was to determine the operatively achieved correction and the postoperative loss of correction.
- Spiral CT from the initial trauma evaluation and after hardware removal with two-dimensional (2D) sagittal reconstruction utilising 12 sagittal plane cuts through the traumatised and bone grafted region of the vertebral body and adjacent disc space were examined for assessment of the contact of the intervertebral bone graft and whether fusion had occurred. Consent was obtained from all patients for this additional imaging.
- Patient complaints and effect of trauma on activity level were quantified using the Hannover Spine Score [22, 24] to obtain additional information about the patients' outcomes. This subjective score, with a maximum of 100 points (ten items, scored in four categories), was used to rate the relative spine function of patients postoperatively. Assorted data were collected in a retrospective fashion to generate a pre-injury score. The employment status was also recorded.

Statistical analysis for interval-scaled normally distributed data was carried out with the *t*-test, and for ordinal-scaled data with the Wilcoxon or Mann-Whitney test, with an assumed 95% confidence interval.

Results

Radiographic evaluation

Posttraumatic kyphosis, measured as the SIEA, was operatively corrected to –3.4° from a preoperative value of –15.2° ($P<0.001$). At the time of last follow-up, a mean loss of correction of 7.8° (66%) was recorded, with a mean SIEA of –11.2°. This loss of correction was statistically significant ($P<0.005$). Therefore, our net correction was only 4.0° (34%), although this still achieved a level of statistical significance ($P<0.05$; Fig. 5).

No significant posttraumatic angulation in the frontal, or coronal, plane was documented, either initially or on follow-up.

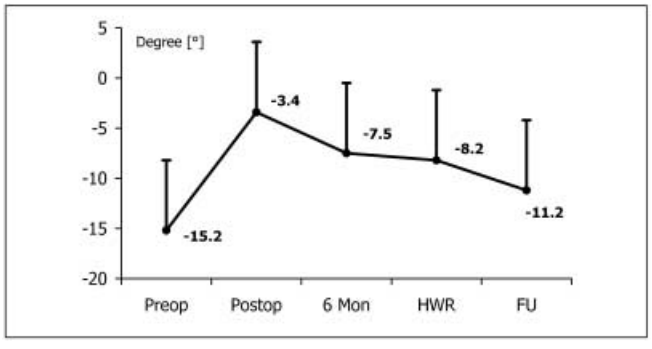


Fig. 5 Superior-inferior endplate angle (SIEA), excluding fractures at L4 and L5, at various stages (*n*=26) (*HWR* hardware removal, *FU* follow-up)

Fig. 6 Two-dimensional (2D) computed tomography (CT) scan of an L1 burst fracture (A 3.3.1) treated with transpedicular bone grafting, taken after hardware removal 14 months postoperatively, demonstrates proven interbody bony fusion

CT findings after implant removal

In 10 of 29 patients (34%) incorporation and consolidation of the cancellous bone graft was confirmed on at least one, and maximally five, of the 2D sagittal reconstruction images. In these patients, true cross-sectional bony bridging in the intervertebral space was visualised (Fig. 6).

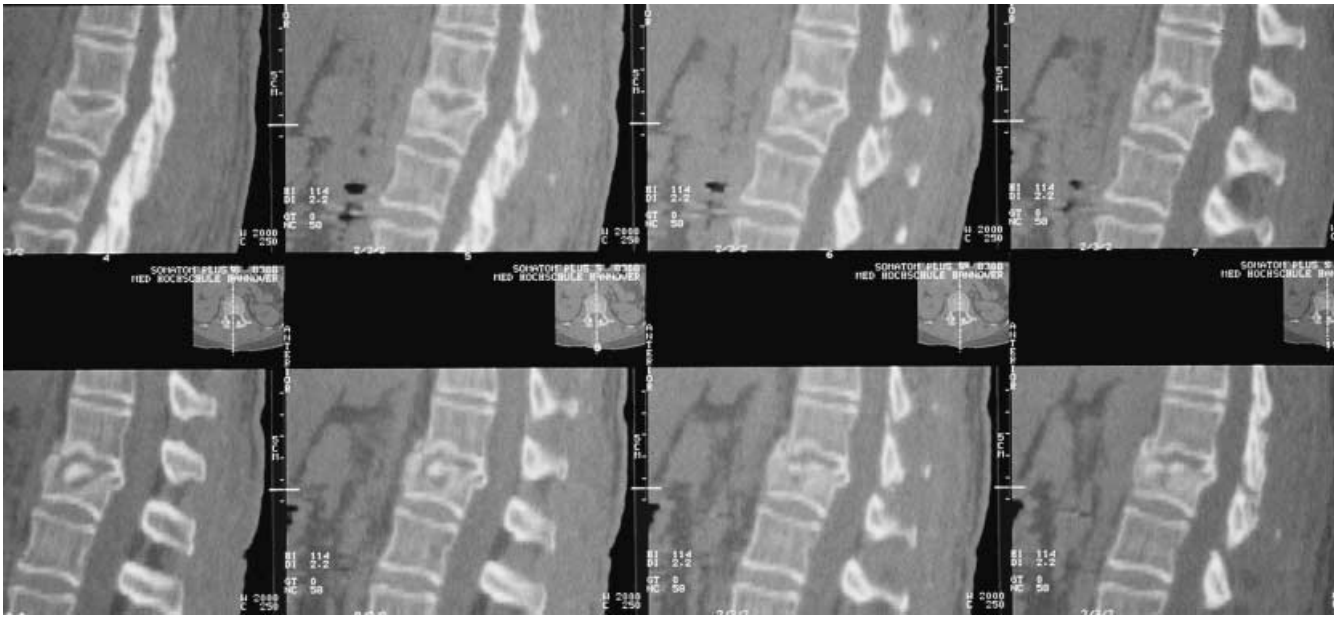
In an additional ten patients, intervertebral fusion was confirmed. In these patients, however, a bridging along the anterior and/or posterior wall was noted. The central portion of the grafted disc space was not consolidated and was partially filled with sclerosed cancellous bone, with circumferential lucency. In this group, loss of interbody height had resulted in direct vertebral body wall contact between adjacent vertebrae, with direct bony fusion in these contact zones. An additional bony bridging in the vicinity of the transpedicular bone grafting could not be seen in these patients. The cancellous bone graft poorly filled the fracture defect and interspace and appeared condensed or sclerosed on CT. In these cases, the cancellous graft was circumferentially surrounded by a lucent osteolytic zone (Fig. 7).

Nine of 29 patients (31%) showed no evidence whatsoever of an interbody fusion, and no incorporation of the cancellous graft (Fig. 8).

Posterior interlaminar bone graft

In our series there appeared to be no additional radiological benefit to coincident interlaminar bone grafting. Relating to the postoperative loss of correction, no differences were noted between the 16 patients with interlaminar bone grafting and the 13 without. In patients with additional posterior fusion, an initial mean traumatic kyphosis of –12.5° was corrected to –1.8°. At follow-up, a segmental kyphotic deformity of –9.9° was noted. The corresponding values of patients treated without additional posterior fusion were –14.5° preoperative, –2.5° postoperative, and –11.0° at follow-up.

Fig. 7 L1 burst split fracture (A 3.2.1) in a 61-year-old female patient, 10 months after surgery: 2D sagittal reconstruction CT scans after hardware removal show a central zone of lysis with sclerosed bone graft without incorporation, and peripheral rim interbody fusion, secondary to interspace height loss



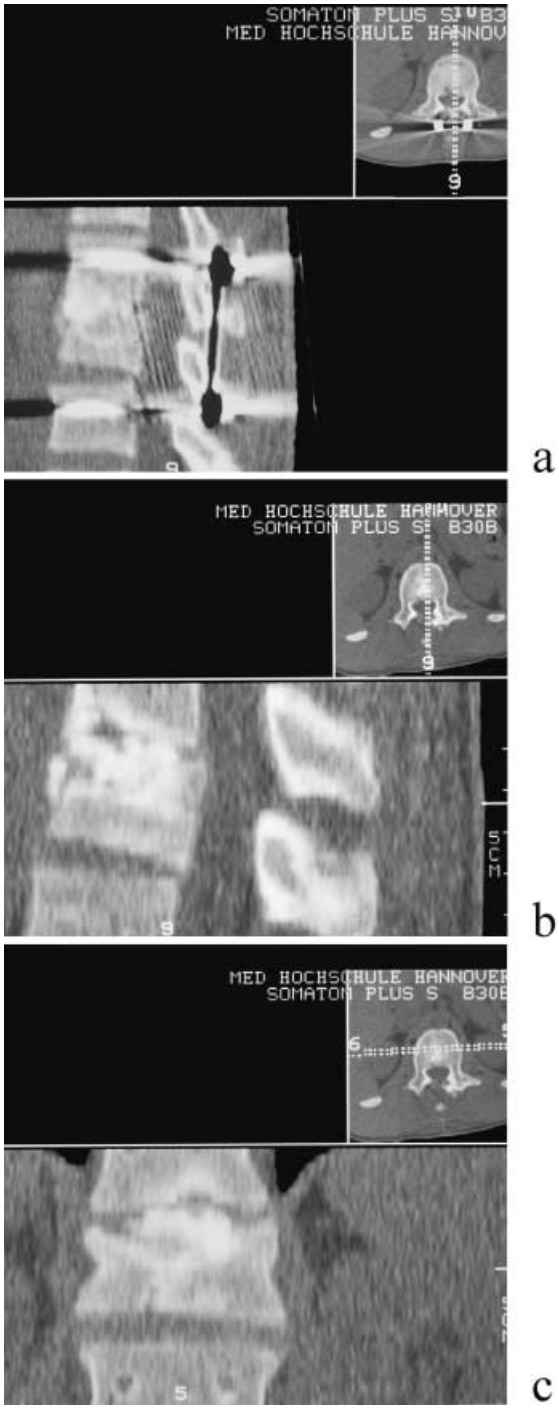


Fig. 8 L1 split burst fracture (A3.2.1) in a 24-year-old male patient: 2D sagittal reconstruction CT scans obtained **a** immediately after posterior instrumentation and transpedicular bone grafting, and **b,c** 13 months postoperatively, following hardware removal. Absence of interbody fusion is demonstrated in the sagittal (**b**) and coronal (**c**) reconstructions. The sclerosed, unincorporated cancellous bone graft is surrounded by a zone of resorption adjacent to the vertebral body

Employment and Hannover Spine Score

The number of patients not employed (retired, jobless, or disabled) increased from 2/29 (7%) pre-injury to 12/29 (41%) at the time of last follow-up ($P<0.001$). Prior to the injury, 15 patients performed manual labor, whereas only 5 patients did so at follow-up ($P<0.01$).

The mean Hannover Spine Score pre-injury was 96.6/100 (range 73–100) points. At follow-up, this score had decreased to a mean of 64.4 (range 13–97) points – a statistically significant difference ($P<0.001$). It should be noted that the pre-injury data were collected retrospectively by requesting patients to rate their pre-injury status.

A correlation between the Hannover Spine Score and conventional radiographic as well as CT findings was not found.

Discussion

As in many retrospective clinical studies, our patient population during the period 1988–1995 was in various aspects non-homogeneous. In a large percentage of our cases, a segmentally stable pedicle screw instrumentation system was implanted. A majority of the patients (20/29, 69%) were treated after 1993, by which time technical expertise with transpedicular bone grafting had been gained, minimising the effect of any learning curve. Our follow-up rate after 1993 was 83% (20/24 patients). In contrast to previous series [2, 7, 11, 12, 15, 32], our study included follow-up and radiographic evaluation *after hardware removal*.

The location and incidence of various fracture types were similar to those reported by other authors [22, 29]. The small percentage of patients with a neurologic deficit in this series can be explained by the fact that during this time period patients with neurologic deficits were almost uniformly operated using either anterior or combined posterior-anterior approaches.

The patient functional outcomes in this study are similar to those of a former study [24]. Even in neurologically intact patients, significant measurable functional and social limitations as a result of the thoracolumbar fractures resulted. The goal of fully functional integration of the patient back into society, a *restitutio ad integrum*, was not uniformly achieved.

The Hannover Spine Score was an attempt to quantify the consequences of the injury and its management. In two similar patient populations, comparable mean individual pre-injury scores were recorded [22, 24]: 93.4 points (n=682) and 96.9 points (n=56), respectively. However, validation of the score has not yet been performed. One has also to keep in mind that the pre-injury score arose from a postoperative survey; therefore, results of the Hannover Spine Score can only be understood as a tendency, without statistical significance.

The use of the SIEA to evaluate sagittal profile at the fracture site has been utilised previously. From these measurements it has been shown that, in addition to changes

in the contour of the traumatised vertebral bodies, changes occur in the grafted adjacent disc spaces. In support of previous authors [1, 4, 12, 26, 27, 33, 34, 36, 38], we evaluated our patients with the SIEA and noted a progressive loss of correction in the sagittal plane. A 66% loss in the operatively achieved correction was documented. In other patient populations, the reported loss of sagittal correction after posterior instrumentation was comparable [11, 12, 16, 24, 26, 27, 35, 36, 37]. In the survey of the "Spine" Work Study Group of the German Trauma Society, results have shown significant loss of correction after posterior instrumentation without significant differences between the preoperative SIEA and the status at follow-up [23, 25]. As to the significance of changes in the adjacent bone grafted disc space and its effect on loss of correction, it was determined that, because of these changes, the vertebral body angle and the sagittal index were not suitable indices for measuring radiologic outcome [24].

The addition of a posterior interlaminar onlay graft was shown in our study to have no statistically significant effect on outcome, although these patients routinely achieved a bony interlaminar fusion as confirmed by CT scanning after hardware removal.

The technique of transpedicular interbody bone grafting is intended to achieve an anterior intervertebral fusion and minimise loss of correction in the anterior column [11, 12, 14, 26, 27, 32, 38]. The theory that transpedicular interbody bone grafting results in improved radiologic and clinical outcomes in the treatment of thoracolumbar fractures is still lacking validation. Previous studies [11, 12, 26, 27, 33, 38] and our previous research have not shown any statistically significant differences in loss of correction or clinical outcomes between posterior instrumentation with and without coincident transpedicular bone grafting. There is also no confirmation in the literature that transpedicular bone graft actually incorporates or achieves fusion with any regularity. Confirmation of graft incorporation via CT scanning has only been reported anecdotally or has been postulated on the basis of conventional radiographic studies [11, 12, 19].

We consider our results significant because of the use of a suitable method to verify the fate of the transpedicular bone graft; namely, spiral CT after hardware removal. Spiral CT analysis confirmed a satisfactory full incorporation of bone graft in only 10 of 29 patients (34%). In an additional ten cases an interbody fusion was achieved, but CT scan sagittal reconstructions showed only peripheral bony bridging in the zones of vertebral body contact, resulting from interspace height loss. The central portion of the interspace consistently lacked graft incorporation, with a resultant void. The remaining nine patients had radiographically confirmed non-fusion without bony bridging either centrally or peripherally, as evidenced by conventional radiography and 2D sagittal reconstruction CT.

Pickel et al. [33], in a prospective study, attempted to address the issue of graft incorporation. The degree of graft consolidation and incorporation was evaluated by magnetic resonance imaging (MRI) with contrast after hardware removal. They found definite, complete bony fusion in only 23% of their 67 patients. In 35% of patients a non-fusion was found without any remnant of interbody bone graft present. This patient population was from a consecutive series of patients operated after 1993, as in our study. A sufficient level of competence in the operative technique of transpedicular interbody bone grafting had by this time been achieved, and the effect of the learning curve minimised. In the Pickel series, postoperative CT scanning confirmed, via random verification, that a thorough discectomy and good filling of the interbody space with bone graft had been achieved.

In summary, we attribute the unsatisfactory rate of bone graft incorporation to the poor bone growth potential of the vertebral interbody space. It is also possible that stress shielding, resulting from the rigidity of the posteriorly implanted pedicle screw instrumentation, played a role.

Conclusions

We consider transpedicular bone grafting to be unreliable for achieving a regular intervertebral fusion. The ineffectiveness of this fusion technique was proven to be a reason for the postoperative loss of correction (re-kyphosing). The authors therefore cannot recommend this operative method for additional support of the anterior column nor for achieving an interbody fusion after posterior stabilisation of thoracolumbar injuries.

References

1. Aebi M, Etter C, Kehl T, Thalgott J (1987) Stabilization of the lower thoracic and lumbar spine with the internal spinal skeletal fixation system. Indications, techniques, and first results of treatment. Spine 12:544–551
2. Aebi M, Etter C, Kehl T, Thalgott J (1988) The internal skeletal fixation system. A new treatment of thoracolumbar fractures and other spinal disorders. Clin Orthop 227:30–43
3. American Spinal Injuries Association (1992) ASIA classification. standards for neurological and functional classification of spinal cord injury. ASIA, Chicago
4. Beck E (1971) Röntgenologische Meßmethoden bei Wirbelbrüchen. Hefte Unfallheilkd 108:36,37
5. Been HD (1991) Anterior decompression and stabilization of thoracolumbar burst fractures by the use of the Slot-Zielke device. Spine 16:70–77

6. Been HD, Bouma GJ (1999) Comparison of two types of surgery for thoraco-lumbar burst fractures: combined anterior and posterior stabilisation vs. posterior instrumentation only. Acta Neurochir Wien 141:349–357
7. Blauth M, Tscherne H, Gotzen L, Haas N (1987) Ergebnisse verschiedener Operationsverfahren zur Behandlung frischer Brust- und Lendenwirbelsäulenverletzungen. Unfallchirurg 90:260–273
8. Blauth M, Knop C, Bastian L, Lobenhoffer P (1997) Neue Entwicklungen in der Chirurgie der verletzten Wirbelsäule. Orthopade 26:437–449
9. Blauth M, Knop C, Bastian L (1998) Brust- und Lendenwirbelsäule. In: Tscherne H, Blauth M (eds) Tscherne Unfallchirurgie – Wirbelsäule, 1st edn. Springer, Berlin Heidelberg New York, pp 241–372
10. Crawford RJ, Askin GN (1994) Fixation of thoracolumbar fractures with the Dick fixator: the influence of transpedicular bone grafting. Eur Spine J 3:45–51
11. Daniaux H (1986) Transpedikuläre Reposition und Spongiosaplastik bei Wirbelkörperbrüchen der unteren Brust- und Lendenwirbelsäule. Unfallchirurg 89:197–213
12. Daniaux H, Seykora P, Genelin A, Lang T, Kathrein A (1991) Application of posterior plating and modifications in thoracolumbar spine injuries. Indication, techniques and results. Spine 16 [3 Suppl]:125-133
13. Defino HLA, Rodriguez-Fuentes AE (1998) Treatment of fractures of the thoracolumbar spine by combined anteroposterior fixation using the Harms method. Eur Spine J 7:187–194
14. Dick W (1987) The “fixateur interne” as a versatile implant for spine surgery. Spine 12:882–900
15. Esses SI, Botsford DJ, Wright T, Bednar D, Bailey S (1991) Operative treatment of spinal fractures with the AO internal fixator. Spine 16 [Suppl]:146-150
16. Eysel P, Meinig G, Sanner F (1991) Vergleichende Untersuchung unterschiedlicher dorsaler Stabilisierungsverfahren bei frischen Frakturen der Rumpfwirbelsäule. Unfallchirurgie 17:264–273
17. Frankel HL, Hancock DO, Hyslop G, Melzak J, et al (1969) The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. Paraplegia 7:179–192
18. Gertzbein SD, Court Brown CM, Jacobs RR, Marks P, et al (1988) Decompression and circumferential stabilization of unstable spinal fractures. Spine 13:892–895
19. Junge A, Gotzen L, Garrel TV, Ziring E, Giannadakis K (1997) Die monosegmentale Fixateur interne-Instrumentation und Fusion in der Behandlung von Frakturen der throrakolumbalen Wirbelsäule. Unfallchirurg 100:880–887
20. 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 79:69–83
21. Kluger P, Gerner HJ (1986) Das mechanische Prinzip des Fixateur externe zur dorsalen Stabilisierung der Brust- und Lendenwirbelsäule. Unfallchirurgie 12:68–79
22. Knop C, Blauth M, Bühren V, Hax P-M, et al (1999) Operative Behandlung von Verletzungen des thorakolumbalen Übergangs. 1. Epidemiologie. Unfallchirurg 102:924–935
23. Knop C, Blauth M, Bühren V, Hax P-M, et al (2000) Operative Behandlung von Verletzungen des thorakolumbalen Übergangs. 2. Operation und röntgenologische Befunde. Unfallchirurg 103:1032–1047
24. Knop C, Fabian HF, Bastian L, Blauth M (2001) Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. Spine 26: 88–99
25. Knop C, Blauth M, Bühren V, Arand M, et al (2001) Operative Behandlung von Verletzungen des thorakolumbalen Übergangs. 3. Nachuntersuchung. Unfallchirurg 104:583–600
26. Liljenqvist U, Mommsen U (1995) Die operative Behandlung thorakolumbaler Wirbelsäulenverletzungen mit dem Fixateur interne und transpedikulärer Spongiosaplastik. Unfallchirurgie 21: 30–39
27. Lindsey RW, Dick W (1991) The fixateur interne in the reduction and stabilization of thoracolumbar spine fractures in patients with neurologic deficit. Spine 16 [3 Suppl]:140-145
28. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. Eur Spine J 3:184–201
29. Magerl F, Engelhardt P (1994) Brust- und Lendenwirbelsäule – Verlaufsformen. In: Witt AN, Rettig H, Schlegel KF (eds) Orthopädie in Praxis und Klinik, Spezielle Orthopädie (Wirbelsäule – Thorax – Becken), vol 5 (2), 2nd edn. Thieme, Stuttgart New York, pp 3.82–3.132
30. Miyakoshi N, Abe E, Shimada Y, Hongo M, Chiba M, Sato K (1999) Anterior decompression with single segmental spinal interbody fusion for lumbar burst fracture. Spine 24:67–73
31. Okuyama K, Abe E, Chiba M, Ishikawa N, Sato K (1996) Outcome of anterior decompression and stabilization for thoracolumbar unstable burst fractures in the absence of neurologic deficits. Spine 21:620–625
32. Olerud S, Karlstrom G, Sjostrom L (1988) Transpedicular fixation of thoracolumbar vertebral fractures. Clin Orthop 227:44–51
33. Pickel H, Hofmeister M, Mückley T, Bühren V (1997) Schicksal der transpedikulären Spongiosaplastik nach Frakturversorgung. Hefte Z Unfallchirurg 268:251
34. Resch H, Rabl M, Klampfer H, Ritter E, Povacz P (2000) Operative vs. konservative Behandlung von Frakturen des thorakolumbalen Übergangs. Unfallchirurgie 103:281–288
35. Sasso RC, Cotler HB (1993) Posterior instrumentation and fusion for unstable fractures and fracture-dislocations of the thoracic and lumbar spine. A comparative study of three fixation devices in 70 patients. Spine 18:450–460
36. Speth MJGM, Cumhur Oner F, Kadic MAC, Klerk dLWL, Verbout AJ (1995) Recurrent kyphosis after posterior stabilization of thoracolumbar fractures. Acta Orthop Scand 66:406–410
37. von Gumppenberg S, Vieweg J, Claudi B, Harms J (1991) Die primäre Versorgung der frischen Verletzungen von Brust- und Lendenwirbelsäule. Aktuelle Traumatol 21:265–273
38. Weckbach A, Vogel S (1997) Einfluß der transpedikulären intercorporellen Spongiosaplastik auf den Korrekturverlust nach alleiniger dorsaler Instrumentierung thoracolumbaler Wirbelsäulenverletzungen. Hefte Z Unfallchirurg 268:205–208
39. Winkler H, Fischer M, Kessler T, Fernandez F, Köpke J (1999) Korrekturverlust und Einheilungsverhalten transpedikulärer Spongiosaplastiken bei der Behandlung thorakolumbaler Wirbelfrakturen. Trauma Berufskrankh 1:294–301
40. Wolter D, Kortmann HR (1992) Transpediculare Spondylodese der Brust- und Lendenwirbelsäulenverletzung. Chirurg 63:866–874