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Original Article

Comparison of the adjacent-level fracture rate between instrumented fusion plus vertebroplasty and vertebroplasty alone in osteoporotic spine

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ABSTRACT

Background/Purpose: Previous study revealed a high incidence of adjacent-level fracture after vertebroplasty. On the other hand, instrumented fusion plus bone cement augmentation of anterior column have been reported to achieve significant sagittal alignment reduction and strong spinal fixation. Our hypothesis is that instrumented fusion plus vertebroplasty can prevent adjacent-level fractures in high-risk patients.
Methods: Patients with predisposing risk factor for adjacent-level fracture were included. All enrolled patients were treated with instrumented fusion plus vertebroplasty (IF) or vertebroplasty alone (VP), and a standardized postoperative care and follow-up protocol was followed. Data from charts and radiographs were collected and analyzed.
Results: A total of 59 patients (40 women and 19 men) with a mean age of 75.4 years were included in this study: 21 patients (15 females) in the IF group and 38 patients (25 females) in the VP group; the mean follow-up period was 34 months. Both groups were similar with respect to age, gender, bone density, involved level, preoperative visual analog scale, and image parameters. It was noted that a greater volume of bone cement was injected in the IF group. Both groups achieved significant improvement in pain scale and image parameters. The overall adjacent-level fracture was 57.89% in VP group. But no adjacent-level fracture was noted in the IF group.
Conclusion: Instrumented fusion plus vertebroplasty and vertebroplasty alone can provide significant image parameters recovery, and visual analog scale score improvement. However, instrumented fusion plus vertebroplasty is effective in prophylaxis against adjacent-level fracture.

1. Introduction

Vertebral compression fractures are the most common fractures associated with osteoporosis,[1] and typically cause incapacitating back pain,[2] decreased daily activity, and increased days of bed rest.[3,4] Vertebroplasty (VP), first described by Galibert et al,[5] has become one of the mainstream treatments in patients with osteoporotic compression fractures due to its advantages such as vertebral height preservation,[6] rapid pain relief,[7] and relative simplicity with the procedure being performed under a local anesthesia. However, complications of VP identified in previous studies included pulmonary embolism, cement leakage, nerve root irritation, pneumothorax, rib fractures, and adjacent-level fractures.[7–11] Among them, adjacent-level fractures has recently attracted great attention because of its high incidence, reported between 12% and 52%.[7,11]

The risk factors for adjacent-level fractures included osteoporosis,[11] previous vertebral fracture,[12,13] old age,[14] higher initial wedge angle and wedge angle change,[14,15] greater cement injected,[16] and treatment of vertebrae at the thoracolumbar junction.[14]

On the other hand, there have been reports on posterior instrumented fusion plus bone cement augmentation of anterior column in the treatment of osteoporotic spine fracture.[17–19] Despite the shortcoming of open surgery, pedicle screw fixation achieves strong spinal fixation[19] and bone cement augmentation improves construct stiffness.[20] However, the question might be raised that whether these advantages are enough able to prevent adjacent-level fractures.

The purpose of this study was to compare between the adjacent-level fracture risk after instrumented fusion plus VP and that after VP alone in high-risk patients.

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2. Methods

2.1. Patients

All patients with painful osteoporotic compression fracture, who were treated surgically between August 2006 and August 2010 by a single spine surgeon (J.W. Yu), were enrolled. Inclusion criteria for this study were as follows: (1) single and fresh osteoporotic compression fractures; (2) involved thoracolumbar junction (T11, T12, L1, and L2); (3) severe deformity with loss of more than 60% anterior vertebral height (compared with the mean posterior vertebral height of the upper and lower adjacent vertebrae); and (4) received instrumented fusion plus vertebroplasty (IF) or vertebroplasty alone (VP). The exclusion criteria were as follows: incomplete radiologic data or follow-up for less than 1 year, spinal deformity, previous vertebral fracture or spinal surgery, and past history of stroke, limb weakness, preoperative neurologic deficits, senile dementia, and cancer.

2.2. Surgical procedure

A standard unilateral transpedicular approach was used to perform VP under fluoroscopic guidance.[21] Postural reduction was achieved with patient placed on two soft radiolucent frames (Fig. 1). The procedure was terminated if the bone cement leaked anteriorly or into the disk space, or reached the posterior one-fourth of the vertebral body.

In the IF group, after general anesthesia, patients were laid in a prone position on the Hall-Relton brace that supported the body at the front of both shoulders and anterior superior iliac spines so that the spine was in a hyperextension position, and postural reduction was performed. The surgical procedure is performed using a posterior approach. Decompression was performed at the fracture level with bone graft collected. Principally, pedicle screw instrumentation construct includes two adjacent vertebrae above and two vertebrae below the collapsed vertebra. VP procedure, as mentioned above, was performed after instrumented distraction. Subsequently, a posterolateral fusion was achieved using the auto- and allogeneous bone grafts (Fig. 2). In both the groups, polymethylmethacrylate was used for VP. After surgery, a Taylor brace protection was suggested for at least 3 months.

2.3. Clinical and radiological evaluation

Medical records were reviewed to determine each patient's age, gender, medical history, level of fracture, and bone marrow density (BMD). The follow-up duration and the volume of cement injected were also determined.

All pre- and postoperative radiographs were evaluated. Radiologic parameters included wedge angle, kyphotic angle, and vertebral body height. Loss of the vertebral body height was calculated as a ratio of the height of the collapsed vertebral body to the average height of the intact adjacent vertebrae above and below.

Clinical follow-ups were performed 2 weeks after the operation, after 1 month, and every 3 months thereafter. At each follow-up visit, visual analog pain score was recorded. If the patient complained of recurrent back pain, additional radiography or MRI was performed. Adjacent-level compression fracture was confirmed if plain film radiograph revealed height loss or a broken end plate, or if MRI showed a signal change at T1 weight or postcontrast enhancement.

2.4. Statistical procedures

Categorical variables, such as the patient's gender, and fracture levels were analyzed with the Chi-square test. Scaled variables such as kyphotic angle, vertebral height, bone cement injected, and patient's bone mineral density (BMD) were analyzed with the Student *t* test.

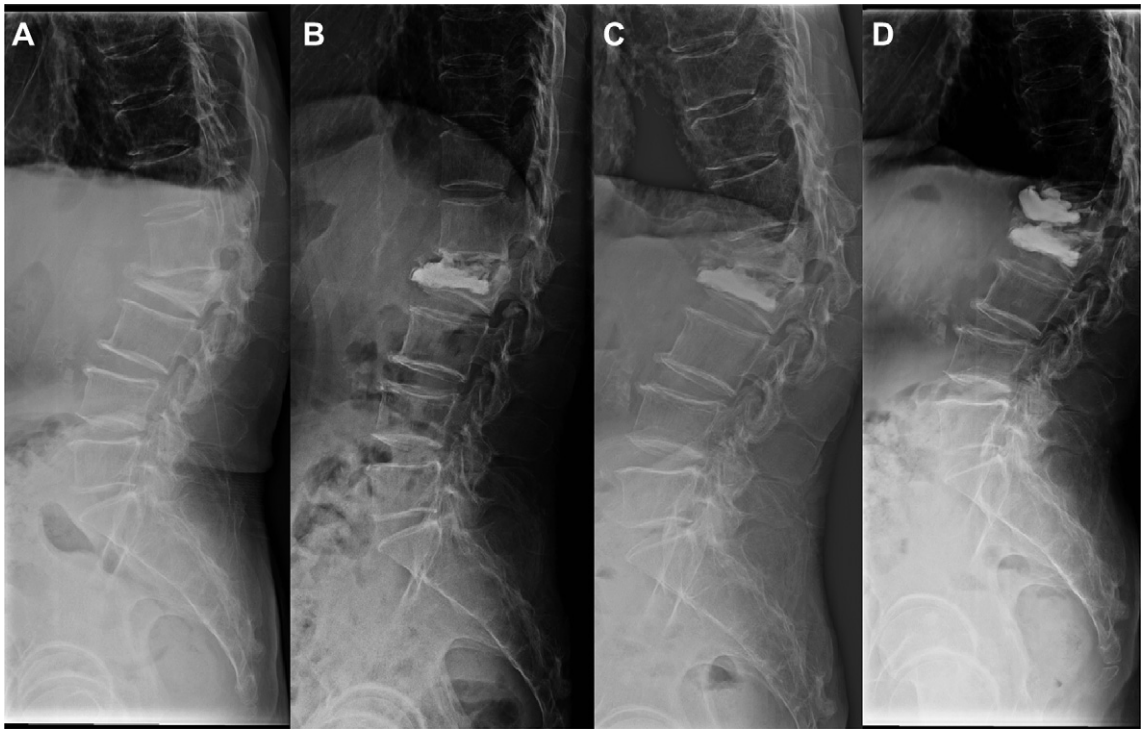

Fig. 1. An 80-year-old man presented with severe low back pain for 2 weeks. (A) Imaging study revealed L2 osteoporotic compression fracture. (B) The patient underwent L2 VP. (C) Six weeks after the procedure, the patient experienced acute back pain. Plain radiography revealed a compression fracture over L1. (D) The patient had a second VP and reported excellent pain relief. VP = vertebroplasty.

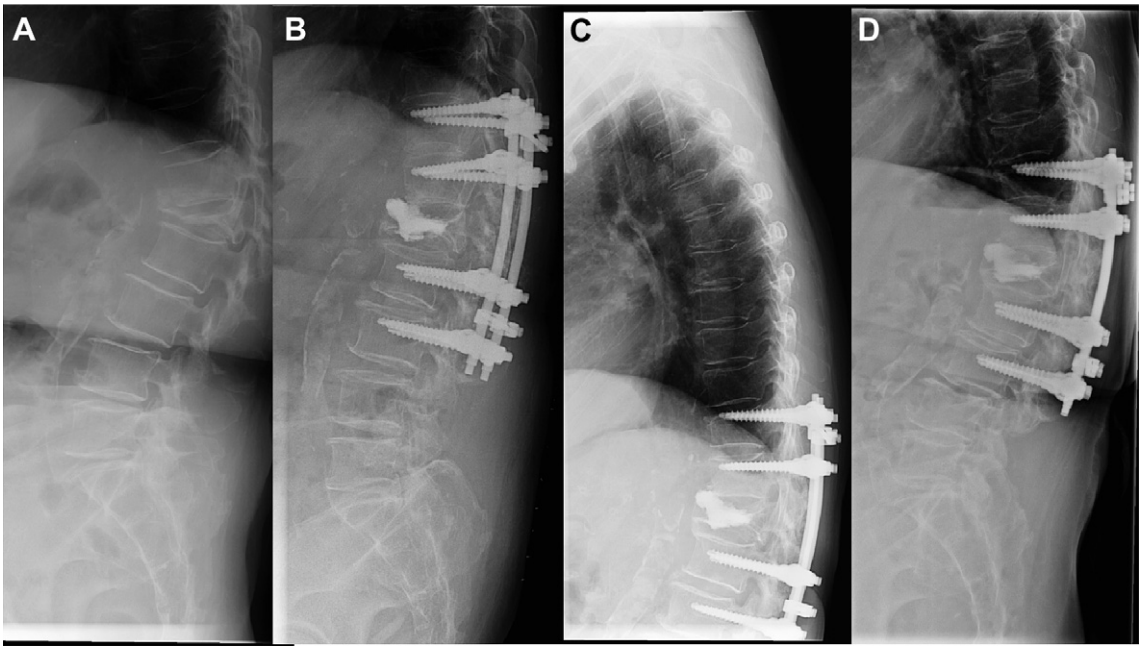

Fig. 2. A 79-year-old woman presented with severe low back pain for 4 weeks. (A) Imaging study revealed L1 osteoporotic compression fracture. (B) The patient underwent T12–L3 instrumented fusion, L2 decompression, and VP. (C, D) Two years' follow-up revealed neither adjacent-level fracture nor subsequent fracture, but L4–5 adjacent segment degeneration. VP = vertebroplasty.

3. Results

There were 84 patients who met the inclusion criteria. However, 18 patients could not be followed up due to relocation, five patients had preoperative neurologic symptoms, and two patients had a history of stroke with limb weakness; these patients were excluded. Therefore, 59 patients, 40 women and 19 men, with an average age of 75.4 years (range 55–94) were included in this study, 21 patients (15 female) in the IF group and 38 patients (25 female) in the VP group. The average follow-up period was 34 months (range 13–60).

Both groups were similar with respect to age, gender, visual analog scale (VAS) score, Dual energy X-ray absorptiometry (DEXA), involved level, and preoperative radiologic parameters ($p > 0.1$) However, more cement is injected during VP in IF group (mean 7.05 vs. 5.55, $p = 0.002$) (Table 1).

Both groups experienced marked improvements in the postoperative VAS value. All the image parameters including kyphotic angle, wedge angle, and height loss recovery improved significantly after the surgery (Table 2). The mean vertebral body height restoration and wedge angle improvement was found higher in the IF group (36.26%; 11.24°) than in the VP group (24.98%; 6.84°). The difference was statistically significant ($p = 0.03$; 0.018) (Table 3). However, the postoperative kyphotic angle and VAS improvement revealed no difference between these two groups ($p = 0.104$; 0.693) (Table 3).

The IF group had six complications: three patients had symptomatic implant, one had adjacent segment degeneration, and two had segment screws back-out without symptoms (four screws in two patients). The patients with symptomatic implant finally received removal of implant after consolidation of the fusion mass. The patient who suffered from adjacent segment degeneration received conservative treatment and tolerated well. The VP group had 24 adjacent-level fractures in 22 patients (57.89%). Eight of them received another VP, and others chose conservative treatment with brace protection and pain-relief medication.

4. Discussion

There have been several reports on posterior decompression and stabilization in the treatment of osteoporotic vertebral collapse.[17,22–24] However, there remains the issue of osteoporotic bone that makes it difficult for the spinal instrumentation to maintain the alignment of the fixed spine.[19] There is also a risk of loosening of the instrumentation when insufficiency of anterior column support[25,26] and local kyphotic deformity remain.[2,19,27] Therefore, the anterior approach has been proposed.[28–32] However, anterior surgery for the treatment of osteoporotic vertebral collapse was not easy to perform in elderly patients with more severe comorbid medical problems.[17,23,33] Recently, there

Table 1
Basic characteristics and comparisons between IF and VP groups prior to operation.

	Preoperative, mean ± SD		*p*
	IF group ($n = 21$)	VP group ($n = 38$)	
Age (y)	72.86 ± 9.51	76.74 ± 8.54	0.114
Gender			
Female	15 (71.4%)	25 (65.8%)	0.111
Male	6 (28.6%)	13 (34.2%)	
DEXA	2.59 ± 0.63	2.62 ± 0.67	0.887
Cement amount	7.05 ± 1.86	5.55 ± 1.61	0.002**
Level			
L1	11 (47.62%)	18 (47.45%)	0.023*
L2	5 (23.81%)	9 (23.68%)	
T11 + T12	6 (28.52%)	12 (28.95%)	
VAS	8.10 ± 0.94	7.95 ± 1.01	0.577
Kyphotic angle	19.81 ± 14.25	21.37 ± 10.17	0.628
Wedge angle	15.10 ± 6.11	17.76 ± 7.76	0.152
Height loss (%)	28.45 ± 8.98	30.45 ± 8.27	0.391

*$p < 0.05$; **$p < 0.005$.
IF = instrumented fusion plus vertebroplasty; SD = standard deviation; VP = vertebroplasty.

Table 2
Differences between before and after operation.

Variable	IF group, mean ± SD		p^a	VP group, mean ± SD		p^a
	Preoperative	Postoperative		Preoperative	Postoperative	
VAS	8.10 ± 0.94	4.57 ± 0.98	0.000**	7.95 ± 1.01	4.58±1.06	0.000**
Kyphotic angle	19.81 ± 14.25	10.76 ± 12.15	0.003*	21.37 ± 10.17	16.82 ± 9.06	0.003*
Wedge angle	15.10 ± 6.11	3.86 ± 8.86	0.000**	17.76 ± 7.76	10.92 ± 6.32	0.000**
Height loss (%)	28.45 ± 8.98	64.71 ± 9.95	0.000**	30.45 ± 8.27	55.43 ± 12.57	0.000**

*$p < 0.005$; **$p < 0.001$.
IF = instrumented fusion plus vertebroplasty; SD = standard deviation; VP = vertebroplasty.
[a] Two-tailed t test.

have been several reports on managing fresh burst fracture in posterior instrumentation with cement augmentation.[18–20,33] Pflugmacher et al[34] reported 25 cases with osteoporotic vertebral compression that received short-segment posterior fixation in combination with balloon kyphoplasty with significant reduction in pain and disability. Maintenance of the height restoration and kyphotic deformity correction were also found at 1-year follow-up. Only four patients had asymptomatic screw movement. In our study, we used longer-segment instrumentation (two adjacent vertebrae above and two vertebrae below the collapsed vertebra) and expected to reach more rigid fixation. In the IF group, only two segments (four screws) had been observed movement in two of 25 patients (9%) without any symptoms. Mean follow-up period was 36 months (13–60 months). These data further confirmed that the combination of both surgical techniques was able to restore and maintain the sagittal alignment and prevent the screw back-out in osteoporotic spine.

Xu et al[35] compared the effectiveness of postural reduction and instrumental reduction in the treatment of vertebrae fractures in 40 patients and concluded that the prevertebral height recovery happened mainly during posture reduction, while instrumental reduction exerts only a relatively weak reduction effect but it is particularly useful in maintaining the reduction. In our study, both groups achieved significant improvement in wedge angle, kyphotic angle, and height loss recovery after the treatment. Although the improvements in wedge angle and vertebral height are more significant in IF group, these might have been due to the relaxation of muscles and ligaments after general anesthesia.

In the present study, our study design focused on patients with greater risk of adjacent-level fracture. The incidence of adjacent fracture in our VP group was 57.89% (22 in 38 patients), higher than previously reported (12–52%[7,11]). However, When considering similar factors such as age, DEXA score, fracture level, and image parameters for both the groups, no adjacent-level fracture was noted in IF group. These may be (1) because of the rigid fixation and good maintenance, and (2) because the fusion construct prevented the contact between osteoporotic vertebrae and cement-augmented vertebrae, which has been proved as one of the main risk factors of adjacent-level fractures,[36] in the IF group.

Table 3
Postoperative differences between IF and VP groups.

	Postoperative difference, mean ± SD		p
	IF group	VP group	
VAS	3.52 ± 1.36	3.39 ± 1.46	0.693
Kyphotic angle	9.05 ± 12.12	4.55 ± 8.65	0.104
Wedge angle	11.24 ± 6.99	6.84 ± 6.47	0.018*
Height loss (%)	36.26 ± 12.66	24.98 ± 13.79	0.003**

*$p < 0.05$; **$p < 0.005$.
IF = instrumented fusion plus vertebroplasty; SD = standard deviation; VP = vertebroplasty.

In a study by Li et al,[16] greater volume of bone cement injected when performing VP contributed to the risk of subsequent adjacent-level fracture but resulted in greater improvement of kyphosis. In our study, although more cement was injected during VP in IF group, correction of wedge angle was a risk factor for adjacent-level fractures after VP,[14,15] but a protective factor against screw back-out after instrumentation in osteoporotic spine.[2,19,27]

In conclusion, both instrumented fusion plus VP and VP alone can provide significant image parameters recovery and VAS score improvement. However, instrumented fusion plus VP is effective in prophylaxis against adjacent-level fracture.

There are some drawbacks in our study. First, this is a small retrospective study, and the difference in the number of patients between the two groups may lead to statistical bias. Second, some authors believe that activity is a factor in adjacent-level fracture. Unfortunately, there is no accurate way to measure the activity level and muscle power of the patient. Similar improvement in VAS scores was noted for both the groups, which may provide some balance on the measurement. Third, patient grouping was done based on patient's will and surgeon's clinical judgments. A prospective, randomized trial is needed to identify the advantages of instrumented fusion plus VP clearly.

References

1. O. Johnell, J.A. Kanis. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. Osteoporos Int 17 (2006) 1726–1733.
2. K. Kaneda, S. Asano, T. Hashimoto, S. Satoh, M. Fujiya. The treatment of osteoporotic-posttraumatic vertebral collapse using the Kaneda device and a bioactive ceramic vertebral prosthesis. Spine (Phila Pa 1976) 17 (1992) S295–S303.
3. R. Hasserius, M.K. Karlsson, B. Jonsson, I. Redlund-Johnell, O. Johnell. Long-term morbidity and mortality after a clinically diagnosed vertebral fracture in the elderly—a 12- and 22-year follow-up of 257 patients. Calcif Tissue Int 76 (2005) 235–242.
4. D.M. Kado, W.S. Browner, L. Palermo, M.C. Nevitt, H.K. Genant, S.R. Cummings. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. Arch Intern Med 159 (1999) 1215–1220.
5. P. Galibert, H. Deramond, P. Rosat, D. Le Gars. Preliminary note on the treatment of vertebral angioma by percutaneous acrylic vertebroplasty. Neurochirurgie 33 (1987) 166–168.
6. H. Deramond, C. Depriester, P. Toussaint, P. Galibert. Percutaneous vertebroplasty. Semin Musculoskelet Radiol 1 (1997) 285–296.
7. F. Grados, C. Depriester, G. Cayrolle, N. Hardy, H. Deramond, P. Fardellone. Long-term observations of vertebral osteoporotic fractures treated by percutaneous vertebroplasty, vol. 39, Rheumatology, Oxford, 2000, pp. 1410–1414.
8. H. Deramond, C. Depriester, P. Galibert, D. Le Gars. Percutaneous vertebroplasty with polymethylmethacrylate. Technique, indications, and results. Radiol Clin North Am 36 (1998) 533–546.
9. E.P. Lin, S. Ekholm, A. Hiwatashi, P.L. Westesson. Vertebroplasty: cement leakage into the disc increases the risk of new fracture of adjacent vertebral body. AJNR Am J Neuroradiol 25 (2004) 175–180.
10. T.A. Predey, L.E. Sewall, S.J. Smith. Percutaneous vertebroplasty: new treatment for vertebral compression fractures. Am Fam Physician 66 (2002) 611–615.
11. A.A. Uppin, J.A. Hirsch, L.V. Centenera, B.A. Pfiefer, A.G. Pazianos, I.S. Choi. Occurrence of new vertebral body fracture after percutaneous vertebroplasty in patients with osteoporosis. Radiology 226 (2003) 119–124.
12. W.S. Lee, K.H. Sung, H.T. Jeong, Y.S. Sung, Y.I. Hyun, J.Y. Choi, K.S. Lee, et al. Risk factors of developing new symptomatic vertebral compression fractures after

percutaneous vertebroplasty in osteoporotic patients. Eur Spine J 15 (2006) 1777–1783.
13. M.I. Syed, N.A. Patel, S. Jan, A. Shaikh, B. Grunden, K. Morar. Symptomatic refractures after vertebroplasty in patients with steroid-induced osteoporosis. AJNR Am J Neuroradiol 27 (2006) 1938–1943.
14. S.H. Kim, H.S. Kang, J.A. Choi, J.M. Ahn. Risk factors of new compression fractures in adjacent vertebrae after percutaneous vertebroplasty. Acta Radiol 45 (2004) 440–445.
15. C.C. Lin, I.H. Chen, T.C. Yu, A. Chen, P.S. Yen. New symptomatic compression fracture after percutaneous vertebroplasty at the thoracolumbar junction. AJNR Am J Neuroradiol 28 (2007) 1042–1045.
16. Y.A. Li, C.L. Lin, M.C. Chang, C.L. Liu, T.H. Chen, S.C. Lai. Subsequent vertebral fracture after vertebroplasty: incidence and analysis of risk factors. Spine (Phila Pa 1976) 37 (2011) 179–183.
17. Y. Matsuyama, M. Goto, H. Yoshihara, T. Tsuji, Y. Sakai, H. Nakamura, K. Sato, et al. Vertebral reconstruction with biodegradable calcium phosphate cement in the treatment of osteoporotic vertebral compression fracture using instrumentation. J Spinal Disord Tech 17 (2004) 291–296.
18. J.J. Verlaan, W.J. Dhert, A.J. Verbout, F.C. Oner. Balloon vertebroplasty in combination with pedicle screw instrumentation: a novel technique to treat thoracic and lumbar burst fractures. Spine (Phila Pa 1976) 30 (2005) E73–E79.
19. X.Y. Wang, L.Y. Dai, H.Z. Xu, Y.L. Chi. Kyphosis recurrence after posterior short-segment fixation in thoracolumbar burst fractures. J Neurosurg Spine 8 (2008) 246–254.
20. L.E. Mermelstein, R.F. McLain, S.A. Yerby. Reinforcement of thoracolumbar burst fractures with calcium phosphate cement. A biomechanical study. Spine (Phila Pa 1976) 23 (1998) 664–670 discussion 670–661.
21. Y.P. Lo, W.J. Chen, L.H. Chen, P.L. Lai. New vertebral fracture after vertebroplasty. J Trauma 65 (2008) 1439–1445.
22. K.T. Kim, K.S. Suk, J.M. Kim, S.H. Lee. Delayed vertebral collapse with neurological deficits secondary to osteoporosis. Int Orthop 27 (2003) 65–69.
23. K. Saita, Y. Hoshino, T. Higashi, K. Yamamuro. Posterior spinal shortening for paraparesis following vertebral collapse due to osteoporosis. Spinal Cord 46 (2008) 16–20.
24. J. Shikata, T. Yamamuro, H. Iida, K. Shimizu, J. Yoshikawa. Surgical treatment for paraplegia resulting from vertebral fractures in senile osteoporosis. Spine (Phila Pa 1976) 15 (1990) 485–489.
25. F.C. Oner, R.R. van der Rijt, L.M. Ramos, W.J. Dhert, A.J. Verbout. Changes in the disc space after fractures of the thoracolumbar spine. J Bone Joint Surg Br 80 (1998) 833–839.
26. J.J. Verlaan, W.H. van Helden, F.C. Oner, A.J. Verbout, W.J. Dhert. Balloon vertebroplasty with calcium phosphate cement augmentation for direct restoration of traumatic thoracolumbar vertebral fractures. Spine (Phila Pa 1976) 27 (2002) 543–548.
27. K. Uchida, S. Kobayashi, H. Nakajima, Y. Kokubo, T. Yayama, R. Sato, G. Timbihurira, et al. Anterior expandable strut cage replacement for osteoporotic thoracolumbar vertebral collapse. J Neurosurg. Spine 4 (2006) 454–462.
28. M. Aebi, C. Etter, T. Kehl, J. Thalgott. The internal skeletal fixation system. A new treatment of thoracolumbar fractures and other spinal disorders, Clin Orthop. Relat Res 227 (1988) 30–43.
29. H.D. Been. Anterior decompression and stabilization of thoracolumbar burst fractures by the use of the Slot–Zielke device. Spine (Phila Pa 1976) 16 (1991) 70–77.
30. H. Daniaux, P. Seykora, A. Genelin, T. Lang, A. Kathrein. Application of posterior plating and modifications in thoracolumbar spine injuries. Indication, techniques, and results. Spine (Phila Pa 1976) 16 (1991) S125–S133.
31. K. Okuyama, E. Abe, M. Chiba, N. Ishikawa, K. Sato. Outcome of anterior decompression and stabilization for thoracolumbar unstable burst fractures in the absence of neurologic deficits. Spine (Phila Pa 1976) 21 (1996) 620–625.
32. L. Vanden Berghe, H. Mehdian, A.J. Lee, C.R. Weatherley. Stability of the lumbar spine and method of instrumentation. Acta Orthop Belg 59 (1993) 175–180.
33. P. Korovessis, A. Hadjipavlou, T. Repantis. Minimal invasive short posterior instrumentation plus balloon kyphoplasty with calcium phosphate for burst and severe compression lumbar fractures. Spine (Phila Pa 1976) 33 (2008) 658–667.
34. R. Pflugmacher, A. Agarwal, F. Kandziora, C. K-Klostermann. Balloon kyphoplasty combined with posterior instrumentation for the treatment of burst fractures of the spine—1-year results. J Orthop Trauma 23 (2009) 126–131.
35. Y. Xu, X. Zhou, C. Yu, M. Cheng, Q. Dong, Z. Qian. Effectiveness of postural and instrumental reduction in the treatment of thoracolumbar vertebra fracture. Int Orthop 32 (2008) 361–365.
36. A. Boger, P. Heini, M. Windolf, E. Schneider. Adjacent vertebral failure after vertebroplasty: a biomechanical study of low-modulus PMMA cement. Eur Spine J 16 (2007) 2118–2125.