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The Influence of Endplate-to-Endplate Cement Augmentation on Vertebral Strength and Stiffness in Vertebroplasty

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Study Design. Controlled *in vitro* trial.

Objective. To study vertebral strength in relation to cement augmentation technique after vertebroplasty and to assess the influence of the biomechanical compression model on postoperative results.

Summary of Background Data. In the treatment of osteoporotic vertebral fractures, the role of vertebroplasty has been well established. Biomechanical compression models thus far used, compressing vertebrae by only 25% of their initial height, did not show a correlation between cement augmentation volumes and postoperative compression strength. In these studies, even very small volumes of cement seem effective. However, these models may not realistically simulate clinically relevant osteoporotic wedge fractures. We hypothesize that, in clinically relevant osteoporotic wedge fractures, postoperative vertebral body strength is strongly dependent on endplate-to-endplate cement augmentation.

Methods. Twenty-five intact osteoporotic cadaver vertebrae were obtained (10 lumbar, 15 thoracic). In 21 vertebrae, anterior wedge fractures (AO type A1.2) were created by controlled external force, with preset height reduction by 35%. After height reconstruction, 9 vertebrae were augmented endplate-to-endplate and 12 vertebrae were partially augmented with polymethylmethacrylate (PMMA). Another 4 vertebrae were compressed by only 25%. Posttreatment strength and stiffness of the vertebrae were determined by a compression test identical to the pretreatment compression protocol.

Results. In the 35% compression group, posttreatment strength was significantly decreased in vertebrae that were partially augmented with cement compared with the endplate-to-endplate augmented group (767 ± 257 N *vs.* 1141 ± 325 N, $P < 0.01$). Postoperative strength amounted 106% ± 27% of preoperative strength values in the endplate-to-endplate augmented vertebrae, compared with 65% ± 18% in the partially augmented vertebrae ($P < 0.001$). In the 25% compression group, results in height restored and augmented vertebrae were similar to the nontreated vertebrae.

Conclusions. Endplate-to-endplate PMMA augmentation restores the biomechanical properties of vertebrae in clinically relevant anterior wedge fractures. Our preliminary data suggest that biomechanical models with only 25% compressive deformation unlikely form a good model to assess the mechanical effects of cement augmentation in osteoporotic fractures.

Key words: vertebroplasty, osteoporosis, vertebral fractures, PMMA. **Spine 2007;32:E419–E422**

In the treatment of osteoporotic vertebral fractures, the role of vertebroplasty has been well established.[1,2] To avoid iatrogenic complications related to cement leakage,[3] such as neurologic deficits and cardiovascular or pulmonary problems, recommendations are made regarding "safe volumes" of cement augmentation. Previous studies did not show a correlation between cement augmentation volumes and postoperative compression strength. Oddly, even very small volumes of cement seemed effective in restoring the strength of the ventral body (VB). When injecting limited cement volumes, endplate-to-endplate augmentation may not be achieved, which, as we hypothesize, may strongly determine postoperative vertebral body strength in vertebroplasty of clinically relevant osteoporotic fractures.

We further question whether biomechanical fracture models thus far used,[4–11] in which vertebrae are compressed by 25% of their initial height, actually influence vertebral strength. They may not provide an adequate model for clinically relevant (*i.e.*, AO 1.2) osteoporotic wedge impaction fractures.

In this study, we assessed the *in vitro* vertebral strength in relation to cement augmentation height after vertebroplasty and tested the influence of the biomechanical compression model on postoperative results.

Materials and Methods

Twenty-five intact human osteoporotic vertebrae were obtained (10 lumbar vertebrae, 15 thoracic vertebrae). A dual energy x-ray absorptiometry (DEXA) scan confirmed the osteoporotic condition of each VB. Baseline geometric and DEXA data are presented in Table 1.

Preoperative Compression Sequence. In 21 vertebra, AO type A1.2 anterior wedge fractures were created by a displacement controlled eccentric external force, with a preset height reduction of 35%. The MTS actuator was set at a low speed rate (5 mm/min) to avoid dynamic effects.[7,10] Recorded data were visualized in force/displacement diagrams. Assessed from

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Table 1. Preoperative Vertebral Characteristics

Characteristics	Mean ± SD
Geometrical characteristics	
Anterior height (mm)	29 ± 5 mm
Posterior height (mm)	30 ± 4 mm
Estimated VB volume (mL)	37 ± 14 mL
DEXA characteristics	
Bone mineral density (g/cm^2)	0.46 ± 0.07 g/cm^2
t score	−5.3 ± 0.9

these diagrams, maximum force just before failure of the vertebra determined vertebral strength. VB stiffness was also assessed at this point.

In addition, to verify our results with results of known literature,[4–11] 4 vertebrae were compressed by only 25%.

Height Restoration and Cementing Technique. An experimental vertebral jack tool (VJT, Surgicraft) was used bilaterally and transpedicularly, to restore the VB height to within 0.5 mm of its original height. The VJT cuts vertical slits in the VB cancellous bone to direct the cement flow from endplate to endplate. VB height reconstruction and polymethylmethacrylate (PMMA) insertion were performed under an axial load of 50 to 100 N.

Two sizes of the VJT accommodated variation in vertebral geometry. After using the large VJT, 3.3 mL of PMMA was inserted in each cavity; after using the small VJT, 1.3 mL was used. No extrusion of PMMA outside the VB was observed.

Cement filling height, expressed as percentage of vertebral body height, was assessed using lateral radiograph images. In the 35% compression series, 9 vertebrae were augmented endplate to endplate. Twelve vertebrae were partially filled with cement.

Of the 4 vertebrae that were compressed by 25%, 2 specimens were reconstructed and endplate-to-endplate augmented as described above. The other 2 vertebra were not reconstructed or augmented after height reduction.

The Parallax cementing system (Arthrocare Europe AB, Stockholm, Sweden) was used in accordance to manufacturers' instructions.

Postoperative Compression Sequence. Posttreatment strength and stiffness of the vertebrae were determined by a compression test identical to the pretreatment compression protocol and compared with their preoperative values.

The 25% compressed vertebra in which height restoration was not attempted were also retested in order to determine remaining postfracture strength of an untreated vertebra.

Statistical Analysis. Results are presented as mean ± SD. For comparison within groups, paired *t* tests were used. For comparison between groups, unpaired *t* tests were used. Correlation is presented as Pearson's correlation coefficient (r).

■ Results

Preoperative and Postoperative Strength and Stiffness (35% Deformation Tests)

Figure 1 shows the force/displacement graph as typically obtained. The fracturing of the vertebral cortical wall is clearly visible as a sudden drop in force after reaching

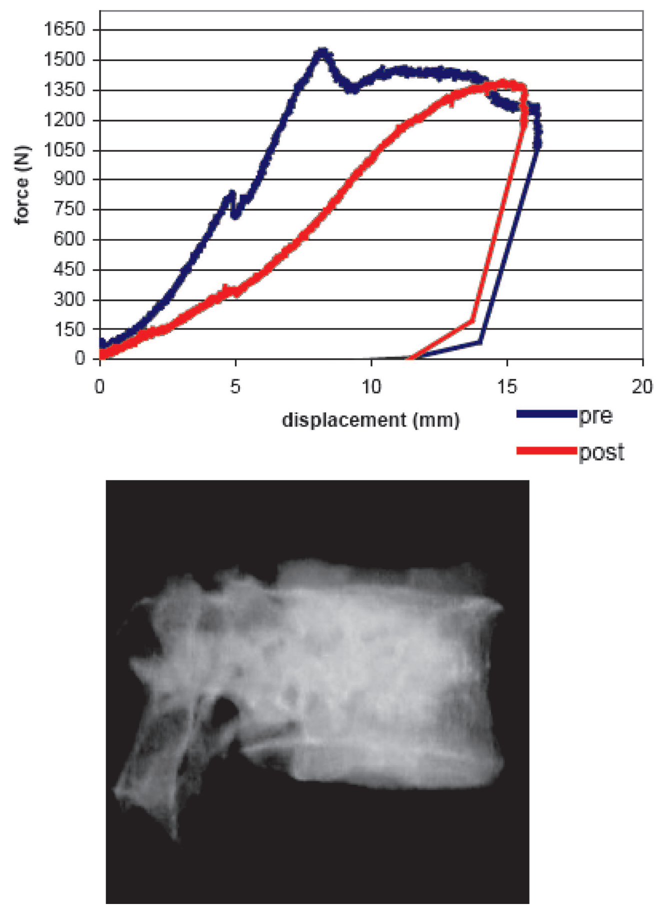

Figure 1. Force/displacement graph in endplate-to-endplate PMMA filling.

peak force. As illustrated in Figure 2, incomplete PMMA filling impaired restoration of pretreatment strength.

In the 35% compression group, posttreatment strength was significantly decreased in the partial PMMA filling group compared with the endplate-to-endplate augmented group (767 ± 257 N *vs.* 1141 ± 325 N, $P < 0.01$). Postoperative strength amounted 106% ± 27% of preoperative strength values in the endplate-to-endplate augmented vertebrae, compared with 65% ± 18% in the partially augmented vertebrae ($P < 0.001$). These data are summarized in Table 2.

Preoperative and Postoperative Strength and Stiffness (25% Deformation Tests)

Results in vertebrae compressed by 25% but restored to their original height and augmented endplate-to-endplate, were similar to the nontreated 25% compression vertebrae (Table 3). In the reconstructed vertebrae, postoperative maximal force was 690 ± 14 N, compared with 865 ± 190 N before surgery. In the untreated vertebrae, the maximal force observed at the second compression sequence was very similar (680 ± 141 N) as compared with the maximal force during the first sequence (715 ± 233 N).

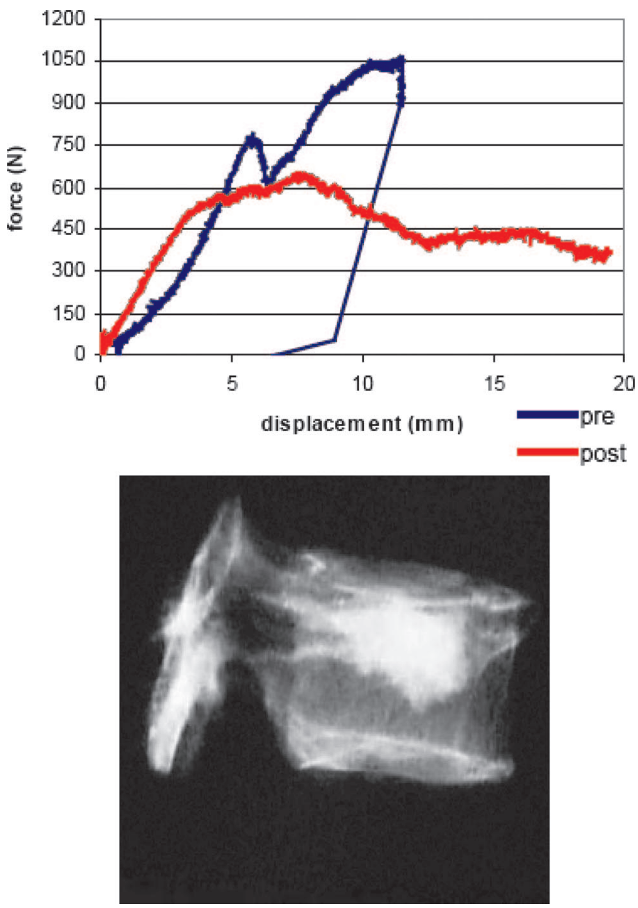

Figure 2. Force/displacement graph in partial VB height PMMA filling.

■ Discussion

This *in vitro* study shows that, in vertebroplasty of clinically significant AO 1.2 osteoporotic wedge fractures, surgeons should pursue endplate-to-endplate PMMA augmentation to obtain significantly better postoperative VB compression strength. Previous studies, which reported a weak correlation between cement augmentation volume and postoperative strength, did not define

Table 2. Influence of Endplate-to-Endplate PMMA Filling

	100% PMMA Filling (n = 9) (mean ± SD)	Non-100% PMMA Filling (n = 12) (mean ± SD)	*P*
Reconstruction height (%)	102 ± 2	102 ± 2	0.78
% PMMA filling height (%)	100 ± 0	61 ± 18	<0.001
Maximum force			
Preoperative (N)	1196 ± 594	1202 ± 436	0.97
Postoperative (N)	1141 ± 325	767 ± 257	0.01
P	0.62	0.001	
Maximum stiffness			
Preoperative (N/mm)	214 ± 151	247 ± 108	0.56
Postoperative (N/mm)	113 ± 42	77 ± 43	0.07
P	0.03	<0.001	
Postoperative *vs.* preoperative maximum force ratio (%)	106 ± 27	65 ± 18	<0.001

Table 3. Compression Sequences: Strength and Stiffness Data

	Preoperative Compression Sequence (mean ± SD)	Postoperative Compression Sequence (mean ± SD)
35% fracture height, 100% PMMA filling (n = 9)		
Maximum force (N)	1196 ± 594	1141 ± 325
Maximum stiffness (N/mm)	214 ± 155	113 ± 42
25% fracture height, no height restoration, no PMMA augmentation (n = 2)		
Maximum force (N)	715 ± 233	680 ± 141
Maximum stiffness (N/mm)	112 ± 37	106 ± 8
25% fracture height, with height restoration and PMMA augmentation (n = 2)		
Maximum force (N)	865 ± 191	690 ± 14
Maximum stiffness (N/mm)	131 ± 35	87 ± 18

cement augmentation volume as a situation of end-plate-to-endplate augmentation.[9] "Safe volumes," as recommended in previous studies to prevent iatrogenic complications,[6] may not result in endplate-to-endplate augmentation. To direct the cement flow endplate to endplate, we used an advanced augmentation technique, in which no "spherical void" but vertical slits were created during reduction of the fracture. Therefore, lower volumes of cement were needed, and no extravasations of cement were observed in our study. This endplate-to-endplate laminar augmentation technique may be of clinical advantage, but obviously further studies must validate this technique.

In previous biomechanical vertebral body fracture models, which have become standard, a decrease in vertebral height of 25% was targeted.[4–6,8–11] This compression model originates from a study, not designed to reproduce surgically clinical relevant osteoporotic fractures but to test the value of radiologic methods in predicting vertebral body strength.[7] In our series of vertebrae that were compressed by 25%, some reversible plastic deformation of the vertebral body was induced, but the cortical walls remained visually and radiologically intact. AO 1.2-type fractures were observed only after compressing vertebral bodies by 35%. No differences in strength were observed within the 25% compression group between treated and nontreated vertebrae. This implies that vertebral body fracture models with 25% compressive deformation may not be suitable for the assessment of the mechanical effects of vertebroplasty. They may have caused misinterpretation of successful results of low-cement-volume vertebroplasty[4,5] and explain the observed weak relation between cement augmentation volume and postoperative VB strength.[9] For better simulation of clinically relevant osteoporotic vertebral fractures, we suggest that the 35% reduction model should be adopted, although obviously our results need to be confirmed in larger series.

Key Points

- After vertebroplasty in clinically relevant osteoporotic wedge fractures, postoperative vertebral strength is significantly decreased in vertebrae that were partially augmented with cement compared with endplate-to-endplate augmented vertebrae.
- In endplate-to-endplate augmented vertebrae, postoperative strength reaches preoperative strength values, in contrast to partially augmented vertebrae.
- After incomplete fracturing (compression to 25% vertebral height reduction), results in height restored and augmented vertebrae were similar to nontreated vertebrae.

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