Changed Loading Direction after Spinal Wedge Fracture Increases Fracture Risk in Adjacent Vertebrae

INTRODUCTION:
Vertebral fractures are the most common fractures in patients affected by osteoporosis1,2 and are associated with pain, increased mortality and morbidity, and a decreased quality of life3,4.

In order to alleviate pain and improve the quality of life, the fractured vertebra can be augmented by injection of bone cement into the vertebral body, i.e. vertebroplasty5. Studies report that up to 60-70% of all the new fractures, after the vertebroplasty, are in adjacent levels6,7. And some believe it to be directly linked to the high stiffness of the bone cement1,2,6. However, an increased risk for new (adjacent) fractures has also been reported for patients that did not receive a vertebroplasty8,9. It thus appears that factors other than the injected bone cement also play a role in the increased risk of adjacent fractures.

We hypothesized that the increased fracture risk of adjacent vertebrae is in part caused by the change in loading of these adjacent vertebrae. The normal axial compression load, perpendicular to the endplate, will likely shift to an off-axis load due to the wedge-like deformities of neighboring vertebrae (Figure 1). Since osteoporotic vertebrae are likely less adapted to such loads5, this would make them prone to fracture. The goal of our study was to test this hypothesis by comparing vertebral strength in axial versus off-axial loading.

Figure 1: Normal situation with axial loading (left) and off-axis loading of a vertebra (right).

METHODS:
Twenty individual vertebrae were obtained from 4 fresh frozen cadavers and loaded until failure. Ten of the vertebrae were crushed axially (0° group) and ten adjacent vertebrae were crushed under an off-axis load (20° group, Table 1). In order to minimize spinal-level bias, the vertebrae of the 20° group were chosen alternately superior and inferior with respect to the 0° group vertebra.

Before testing, the bone density of the spines was evaluated using dual energy X-ray absorptiometry (DEXA, Table 1). Furthermore an experienced orthopedic surgeon reviewed X-rays of these spines in order to exclude already fractured vertebrae from the experiment. The vertebrae were disarticulated and the intervertebral discs were excised. The posterior elements were resected at the pedicles in order to facilitate placement in our testing setup. The endplates of each vertebral body were photographed together with a calibration ruler, allowing us to measure the endplate dimensions (AnalySIS AUTO 3.2, Soft Imaging System GmbH, Münster, Germany).

Table 1

<table>
<thead>
<tr>
<th>Cadaver</th>
<th>Sex</th>
<th>Age</th>
<th>DEXA</th>
<th>Vertebrae Harvested</th>
<th>0° Group</th>
<th>20° Group</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>♀</td>
<td>87</td>
<td>-2.3</td>
<td>L4, L1, T10</td>
<td>L5, T12, T11</td>
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<tr>
<td>2</td>
<td>♀</td>
<td>89</td>
<td>-4.4</td>
<td>L4, L1</td>
<td>L3, L2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>♀</td>
<td>92</td>
<td>-4.8</td>
<td>L1, T10</td>
<td>L5, T12</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>♀</td>
<td>85</td>
<td>-4.1</td>
<td>L4, L1, T10</td>
<td>L3, L2, T9</td>
<td></td>
</tr>
</tbody>
</table>

Both endplates of each vertebra were cast in bone cement and placed in our testing setup (Figure 2). The load-axis of the testing machine (MTS machine) was aligned through the center of the vertebral body for both the 0° and 20° tests (Figure 2). Each vertebra was loaded with a displacement of 2 mm/min. During each test, force and displacement were registered.

The stiffness and vertebral strength of the 0° and 20° groups were compared using a Student’s t-test. Endplate areas were also compared between the groups to assess possible bias in size. Significance was set at p < 0.05.

RESULTS:
The mean compressive strength of the 0° group was significantly higher (2854 N, SD 622 N) than that of the 20° group (2162 N, SD 670 N) (p = 0.028, Figure 3).

Vertebral strengths were significantly stiffer (p < 0.001) when tested at 0° (4017 N/mm, SD 970 N/mm), compared to the 20° group (2478 N/mm, SD 453 N/mm).

The mean endplate size was not significantly different between the 0° group (1524 mm², SD = 433 mm²) and the 20° group (1569 mm², SD = 456 mm²) (p = 0.823).

DISCUSSION:
Various hypotheses have been postulated for the increased occurrence of adjacent fractures after vertebroplasty. Most of them focus on higher stresses in adjacent vertebrae due to either stiff bone cement1,2,6, or an anterior shift of the upper body11. We hypothesized that a change in loading orientation (off-axis) of the adjacent vertebra, together with the already present osteoporosis would lead to an increased susceptibility to fractures. The results of this study confirms our hypothesis as the changed orientation caused an average decrease in vertebral strength of 24%.

This decrease is probably linked to anisotropy, caused by a decreased connectivity of the trabeculae in the osteoporotic vertebral body5. The missing connecting trabeculae are very important for resisting off-axis loads, but also for preventing the axial trabeculae from buckling4.

In conclusion, we found that the strength of osteoporotic vertebrae is 24% lower during off-axis compared to axial loading. Although adjacent fractures after vertebroplasty are probably influenced by many factors, our data show that the increased susceptibility to off-axis loading and the occurrence of such loads after wedge fractures may be important factors. This study may thus lead to a better understanding of the etiology of adjacent vertebral fractures after vertebroplasty.

REFERENCES: