Prophylactic Vertebroplasty Decreases the Fracture Risk of Adjacent Vertebrae

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INTRODUCTION
Osteoporosis, the most common metabolic disorder, can eventually lead to fragility fractures. Of all osteoporotic fractures, vertebral wedge fractures are the most common\(^5\). They are associated with pain, a decrease in quality of life, and a change in spinal alignment. The changed spinal alignment increases the chance of subsequent fractures: a wedge fracture changes the loading direction on adjacent vertebrae from what is normally an axial load\(^9\) into a more shearing load\(^2\). In a previous study we have shown that intact, osteoporotic vertebrae are indeed more prone to failure under such off-axis loads\(^1\). As the currently available treatments for wedge fractures are unable to fully remove the wedge shape of the fractured vertebra, the shearing aspect of the load remains after treatment\(^9\).

We hypothesize that the previously found increased fracture risk of adjacent (intact but osteoporotic) vertebrae, can be reduced when these adjacent vertebrae are prophylactically injected with bone cement.

METHODS
Four fresh frozen cadaveric spines were obtained and evaluated for bone density by dual energy X-ray absorptiometry (DEXA, Table 1). An orthopedic surgeon reviewed X-rays of these spines in order to exclude already fractured vertebrae from the experiment. From these spines thirty one individual vertebrae were dissected and the intervertebral discs were excised. The posterior elements were resected at the pedicles in order to facilitate placement in our testing setup. Twenty one vertebrae were used in our previous study into the effect of the shearing loads\(^1\), while ten were used in this study into the effects of prophylactic vertebroplasty.

Table 1: Distribution of the vertebrae over the various groups.

<table>
<thead>
<tr>
<th>Cadaver</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>♀</td>
<td>♂</td>
<td>♀</td>
<td>♂</td>
</tr>
<tr>
<td>Age</td>
<td>87</td>
<td>89</td>
<td>92</td>
<td>85</td>
</tr>
<tr>
<td>Dexas (T-score)</td>
<td>-2.3</td>
<td>-4.4</td>
<td>-4.8</td>
<td>-4.1</td>
</tr>
<tr>
<td>0° group(^1)</td>
<td>L4, L1, T10</td>
<td>L4, L1, T10</td>
<td>L4, L1, T10</td>
<td>L4, L1, T10</td>
</tr>
<tr>
<td>20° group(^1)</td>
<td>L5, T12, T11</td>
<td>L5, T12, T11</td>
<td>L5, T12, T11</td>
<td>L5, T12, T11</td>
</tr>
<tr>
<td>prophylactic group</td>
<td>L3, L2, T9</td>
<td>L3, L2, T9</td>
<td>L3, L2, T9</td>
<td>L3, L2, T9</td>
</tr>
</tbody>
</table>

These ten vertebrae underwent a bipediculated, prophylactic vertebroplasty with an average injected bone cement volume of 7.35 ml (SD = 1.1 ml). Both endplates of each vertebra were cast in bone cement and the vertebrae were subsequently placed in our testing setup under 20° (Figure 2). The 20° loading angle was chosen in order to mimic the loading condition of the vertebra adjacent to a fractured one. The load-axis of the testing machine (MTS machine) was aligned through the center of the vertebral body, and each vertebra was loaded with a displacement of 2 mm/min. During each test, force and displacement were registered at 10 Hz, allowing us to calculate the failure load (the highest peak) and the stiffness (the linear elastic part of the curve).

These data were compared to data from our previous experiment\(^1\). In which unfilled vertebrae were loaded either perpendicular to the endplate (n=11, 0° group) or under an angle of 20° (n=10, 20° group). The measured failure load and stiffness of all 3 groups were compared using a one-way ANOVA (with an LSD post hoc test). Significance was set to p<0.05.

RESULTS
We previously found that the mean failure load of the 0° group (2845N, SD=591N) was significantly higher (p=0.02) than the failure load of the 20° group (2163N, SD=670N). For the prophylactically treated group, that was loaded under 20°, the mean failure load was 2850N (SD=703N). This was comparable to the mean failure load of the 0° group (p=0.99) but significantly higher than the failure load of the 20° group (p=0.03, Figure 2).

We previously found that the mean stiffness of the 0° group (3979N/mm, SD=928N/mm) was significantly higher (p<0.01) than the stiffness of the 20° group (2478N/mm, SD=453N/mm). For the prophylactically treated group that was loaded under 20° the mean stiffness was 3156N/mm (SD=582N/mm). This was significantly lower than that of the 0° group (p=0.01), and significantly higher than that of the 20° group (p=0.04, Figure 2).

DISCUSSION
Currently available treatments for wedge fractures are unable to lastingly remove the wedge shape of fractured vertebrae\(^5\). As a result the loading on the adjacent vertebrae remains to have a shearing component, which greatly increases the fracture risk of adjacent vertebrae. In this study we found that when these adjacent vertebrae are prophylactically filled with bone cement, they are better capable to withstand such off-axis loads. The failure load of these vertebrae is increased to a level comparable to axially loaded vertebrae. These results are in line with other studies that reported positive mechanical effects of prophylactic vertebroplasty\(^5\).

There are also possible risks involved with prophylactic filling: there is still no consensus on whether the high stiffness of PMMA increases the fracture risk of adjacent vertebrae and cement extravasation remains a problem in vertebroplasty, thus also in prophylactic filling. However, given the clear mechanical benefit of prophylactic filling, research into more advanced filling materials and into more advanced delivery techniques appears opportune.

In conclusion; a prophylactically augmented, osteoporotic vertebra is better able to withstand the off-axis loads that occur after the first fracture than an unfilled vertebra. However, more research is needed in order to assess and eliminate the risks that are associated with the currently available techniques for vertebroplasty.

REFERENCES