Comparative biomechanical study of cervical spine stabilisation by cage alone, cage with plate, or plate-cage: a porcine model

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ABSTRACT

Purpose. To compare stability and subsidence associated with 3 types of cervical spine stabilisation.

Methods. The C3 to C4 vertebrae of 28 Polish pigs were used. Pigs with intact vertebrae (group 1) underwent standard anterior cervical discectomy (group 2), followed by stabilisation using a cage alone (group 3), a cage with plate (group 4), or a plate-cage (group 5). Cervical spine stability and subsidence were compared in all 5 groups.

Results. Stability was significantly increased after stabilisation by a cage with plate or a plate-cage, but not by a cage alone. The difference between stabilisation by a cage with plate and a plate-cage was not significant. Subsidence was maximal after the cage-alone stabilisation (3.1 mm), being 1.6 mm after the cage-with-plate and plate-cage stabilisations.

Conclusion. Additional plating as a supplement to anterior interbody cervical cage stabilisation significantly improves segmental stability and subsidence.

Key words: biomechanics; bone plates; cervical vertebrae; discectomy; intervertebral disk; spinal fusion

INTRODUCTION

Cervical plates have been used in stabilisation procedures since the early 1970s, and many biomechanical studies have confirmed their efficacy in this respect, especially for traumatic fractures. The first plates used were unconstrained\(^1\); the
connections between the plate and screws were not blocked, enabling independent movement of the screws, causing screws to pull-out. Various screw-blocking systems were introduced, but were less stable than the unconstrained system. Stress shielding complications (pseudoarthrosis, graft osteolysis, breakage of screws or plates) cause subsidence and affect stabilisation and bone fusion. Dynamic plates were therefore developed to enable more efficient axial compressive load transfer to bone grafts so as to facilitate earlier fusion.

Good interbody stabilisation is important for anterior cervical stabilisation and load distribution of the plating systems. Cervical interbody cages improve spinal stability, because of their mechanical durability. Plate-cages are easy to implant, clinically useful, and have fewer implant-related complications. They ensure restoration and maintenance of an interbody space height and cervical lordosis, with good stabilisation.

We aimed to compare stability and subsidence of 3 different types of cervical spine stabilisation (by cage alone, cage with plate, and plate-cage) after one-level anterior cervical discectomy and fusion, carried out according to the recommendations of the German Society for Spinal Surgery.

**MATERIALS AND METHODS**

28 6-month-old Polish pigs weighing 100 to 120 kg were used. The porcine model ensures a good bone quality, consistency, and repeatability of anatomic and biomechanical conditions. Pigs with intact C3 to C4 vertebrae (group 1) were dissected and underwent standard anterior cervical discectomy with full decompression of neural elements (group 2), followed by stabilisation using a cage alone (group 3), a cage with plate (components of the plate-cage, group 4), or a plate-cage (group 5). The plate-cage (LFC Zielona Gora, Poland) consisted of a threaded conical interbody cage (16 mm in diameter), a cervical ‘butterfly’ plate (28-mm long), bone screws (4 mm in diameter, 16-mm long), and a special screw blocker for connecting the plate with the cage (Fig. 1).

A stability test was performed in the sagittal (flexion and extension) and frontal (right and left bending) planes of 7 specimens. The C4 vertebra was attached to the base of the MTS 858 Mini Bionix testing machine (MTS Systems, Minneapolis [MN], US) and the C3 vertebra to the gimbal (Fig. 2). The mean baseline stability of the intact vertebrae was compared with that after discectomy and that after each of the 3 types of stabilisation. The stability of the C3 vertebra was measured (in mm), with a displacement force of 2.5 Nm and speed of 40 cm/min. Six attempts were made and the results of the last 3 recorded. The Le Huec stability ratio $r$ was equal to the range of movement (ROM), e.g. for flexion, extension, right bending, and left bending of the intact vertebra over the ROM of the stabilised vertebra:

$$r = \frac{\text{ROM}_{\text{intact}}}{\text{ROM}_{\text{stabilised}}}$$

A value of $r<1$ indicates an increase of segmental ROM after stabilisation (destabilised); $r=1$ indicates a lack of stabilising effect; and $r>1$ indicates increased stability.
A subsidence test was performed in 21 specimens after stabilisation (cage alone, cage with plate, or cage-plate). The vertebrae were subjected to 21,000 cycles of axial loads with a force ranging from 20 to 200 N and a frequency of 2.5 Hz. The subsidence was measured by subtracting displacements before and after the test with a 200 N preload. The extent of subsidence (in mm) between groups was compared. Analysis of variance (ANOVA) was used to evaluate the differences in mean stability ratios for each type of stabilisation. The Levene test was used to verify the assumption of homogeneity of variances; if significant, the variances were not equal across the groups. The non-parametric ANOVA (Kruskal Wallis test) was applied to verify the results. A Tukey post-hoc test was used to compare groups. A p value of ≤0.05 was considered significant.

RESULTS

The mean stability ratio of the total ROM of intact vertebrae was equal to one, it decreased to 0.8 after discectomy, and increased after stabilisation by a cage alone to 1.2, by a cage with plate to 1.5, or by a plate-cage to 1.6. Stability was significantly increased after stabilisation by a cage with plate or a plate-cage, but not by a cage alone. The difference between stabilisation by a cage with plate and a plate-cage was not significant. A Tukey post-hoc test showed that there were significant differences between groups 2 and 5 (p<0.001), 2 and 4 (p=0.001), 1 and 5 (p=0.006), and 1 and 4 (p=0.024). The mean stability ratios for flexion, extension, right bending, and left bending are shown in the Table.

Subsidence was greatest after the cage-alone stabilisation (3.1 mm); it was 1.6 mm after the cage-with-plate and plate-cage stabilisations. The Tukey post-hoc test indicated that there were significant differences between cage-alone and cage-with-plate stabilisations (p<0.001), and cage-alone and plate-cage stabilisations (p=0.001).

DISCUSSION

Biomechanical studies using cadavers are limited and inhomogeneous with regard to age, bone mineral density, and degree of degenerative changes. Porcine specimens are widely available and ensure specimen-to-specimen consistency for comparison.4 Biomechanical results after stabilisation on porcine and human cervical spines are similar in the sagittal plane (flexion-extension) but not in the frontal plane (lateral bending and axial rotation).17 Thus, the results of left and right bending in our porcine model should be interpreted with caution.

In human cervical spines, excision of the posterior longitudinal ligament and posterior part of uncovertebral joints causes marked segmental

<table>
<thead>
<tr>
<th>Range of movement</th>
<th>Intact vertebrae (group 1)</th>
<th>After discectomy (group 2)</th>
<th>Cage alone (group 3)</th>
<th>Cage with plate (group 4)</th>
<th>Plate-cage (group 5)</th>
<th>p value (Tukey post-hoc test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total range of movement</td>
<td>1 (0)</td>
<td>0.8 (0.78–0.81)</td>
<td>1.2 (1.15–1.29)</td>
<td>1.5 (1.35–1.66)</td>
<td>1.6 (1.41–1.78)</td>
<td>&lt;0.001 (groups 2 vs 5) 0.001 (groups 2 vs 4) 0.006 (groups 1 vs 5) 0.024 (groups 1 vs 4) 0.01 (groups 1 vs 4) 0.002 (groups 2 vs 4) Not significant between groups</td>
</tr>
<tr>
<td>Flexion</td>
<td>1 (0)</td>
<td>0.8 (0.7–0.81)</td>
<td>1.3 (1.13–1.37)</td>
<td>2.3 (1.76–2.79)</td>
<td>1.7 (1.45–1.84)</td>
<td>0.04 (groups 1 vs 3) 0.001 (groups 1 vs 4) 0.001 (groups 1 vs 5) 0.02 (groups 2 vs 3) 0.001 (groups 2 vs 4) 0.001 (groups 2 vs 5) Not significant between groups</td>
</tr>
<tr>
<td>Extension</td>
<td>1 (0)</td>
<td>0.6 (0.55–0.67)</td>
<td>0.9 (0.69–1.04)</td>
<td>0.8 (0.7–0.91)</td>
<td>1 (0.86–1.07)</td>
<td>Not significant between groups</td>
</tr>
<tr>
<td>Right bending</td>
<td>1 (0)</td>
<td>1 (0.9–1.02)</td>
<td>1.4 (1.34–1.53)</td>
<td>1.7 (1.56–1.85)</td>
<td>1.7 (1.57–1.84)</td>
<td>0.04 (groups 1 vs 3) 0.001 (groups 1 vs 4) 0.001 (groups 1 vs 5) 0.02 (groups 2 vs 3) 0.001 (groups 2 vs 4) 0.001 (groups 2 vs 5) Not significant between groups</td>
</tr>
<tr>
<td>Left bending</td>
<td>1 (0)</td>
<td>0.9 (0.8–0.92)</td>
<td>1.3 (1.13–1.52)</td>
<td>1.3 (1.17–1.35)</td>
<td>2.1 (1.39–2.71)</td>
<td>Not significant between groups</td>
</tr>
</tbody>
</table>
destabilisation.\textsuperscript{16,19} Our stability tests indicated that anterior cervical discectomy with removal of anterior and posterior longitudinal ligaments resulted in segmental instability, especially for extension, but the effect was not significant (p=0.09). Discectomy had the least impact on lateral bending. Instability after anterior cervical discectomy without fusion has unfavourable clinical and radiographic effects.\textsuperscript{20-25} Therefore, discectomised spinal segments should be stabilised.

In our study, the use of the threaded conical interbody cage for stabilisation improved overall segmental stability but not significantly (p=0.08); the result was significant only for right bending (p=0.02). The significance was associated with an absence of preliminary interbody space distraction before placement of the cage. Such distraction causes tension in the spinal ligaments and annulus fibrosus,\textsuperscript{26} such that after release of the expanding forces adjacent bodies clump down on the cage and increase stability.\textsuperscript{27}

Most studies confirm an increase in stability with interbody cage stabilisations. Stability (ability to carry loads) is related to the distribution of loads at the cage-bone interface that depends on the shape of the cage.\textsuperscript{28,29} In humans, it is additionally related to bone density and the extent of surgical endplate damage. Our threaded conical interbody cage supported damaged endplates and was installed without preliminary interbody space distraction.

In our study, segmental stability increased significantly after additional plating, as seen in flexion and right bending, but segmental mobility was limited, which was consistent with other biomechanical\textsuperscript{30-33} and clinical\textsuperscript{34-37} studies. There was no stabilising effect in extension, probably because the plate was a dynamic one (enabling screws to move within the oval plate holes). A similar study using human lumbar spines revealed a significant (3-fold) increase of segmental stability after additional plating and a further (0.5-fold) increase after connecting the cage with the plate (plate-cage), indicating a favourable additional effect of plating after interbody cage stabilisation.\textsuperscript{16} However, it is difficult to compare the results of that study with ours, due to differences in anatomy between human lumbar and porcine cervical spines.

Subsidence is a common phenomenon in spinal surgery, because of adjustment of the cage/graft-bony bed interface.\textsuperscript{38-42} Excessive subsidence can cause adverse effects, such as segmental kyphotisation, foraminal stenosis with recurrent radiculopathy,\textsuperscript{43} and neck pain. In our study, the greatest subsidence was noted with cage-alone stabilisation; additional plating significantly decreased the extent of subsidence. With a view to minimising the risk of subsidence and spinal kyphotisation, additional plating has also been suggested for cylindrical cages.\textsuperscript{44}

\section*{REFERENCES}