INTERBODY cage devices used to assist interbody fusion are popular in the surgical management of degenerative diseases of lumbar discs. In the last few years many different cage designs have been developed. Some of them are cylindrical and have to be drilled into the intervertebral space, others are near cuboid in shape and therefore must be placed into the disc space. They may be implanted via an anterior approach (anterior lumbar interbody fusion) or a posterior approach (posterior lumbar interbody fusion). However, all of these cages serve to stabilize the spinal segments primarily by distracting them and secondarily by allowing bone ingrowth and bone fusion.

For efficient formation of bone tissue adequate stability is required, but the initial stability is likely reduced due to repeated movements of the spine during everyday activity. Therefore, in addition to immediate stability, stability after cyclic loading is of remarkable relevance; however, this has not yet been investigated. The object of this study was to investigate the immediate stabilizing effect of three different posterior lumbar interbody fusion cages and to clarify the effect of cyclic loading on the stabilization.

Methods. Before and directly after implantation of a Zientek, Stryker, or Ray posterior lumbar interbody fusion cage, 24 lumbar spine segment specimens were each evaluated in a spine tester. Pure lateral bending, flexion-extension, and axial rotation moments were applied continuously. The motion in each specimen was measured simultaneously. The specimens were then loaded cyclically (40,000 cycles, 5 Hz) with an axial compression force ranging from 200 to 1000 N. Finally, they were tested once again in the spine tester.

Conclusions. In general, a decrease of movement in all loading directions was noted after insertion of the Zientek and Ray cages and an increase of movement after implantation of a Stryker cage. In all three cage groups greater stability was demonstrated in lateral bending and flexion than in extension and axial rotation. Reduced stability during cyclic loading was observed in all three cage groups; however, loss of stability was most pronounced when the Ray cage was used.

KEY WORDS • lumbar spine • interbody fusion device • flexibility • cyclic testing

Abbreviations used in this paper: NZ = neutral zone; ROM = range of motion.

Stabilizing effect of posterior lumbar interbody fusion cages before and after cyclic loading

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Object. The function of interbody fusion cages is to stabilize spinal segments primarily by distracting them as well as by allowing bone ingrowth and fusion. An important condition for efficient formation of bone tissue is achieving adequate spinal stability. However, the initial stability may be reduced due to repeated movements of the spine during everyday activity. Therefore, in addition to immediate stability, stability after cyclic loading is of remarkable relevance; however, this has not yet been investigated. The object of this study was to investigate the immediate stabilizing effect of three different posterior lumbar interbody fusion cages and to clarify the effect of cyclic loading on the stabilization.

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nium implant with two hooks, one attached to the upper and one to the lower surface (Fig. 1). The second implant, the Stryker cage, is a ridged bullet-shaped polymethylmethacrylate implant (Fig. 2). The third cage, the Ray TFC, is a cylindrical threaded titanium cage (Fig. 3). All of them must be inserted in pairs from a posterior direction into the intervertebral space. For this purpose, after partial facetectomy, a central discectomy is performed. Thereafter, the almost cuboid Zientek and Stryker cages can be placed and the cylindrical Ray cage screwed into the intervertebral space.

Specimen Preparation

Twelve human cadaveric lumbar spine sections (L2–L5) were used in this study. They were freshly dissected and frozen at −80°C until testing. Their bone mineral density was measured using quantitative computerized tomography, and they were then divided into three matching groups with respect to age, sex, and bone mineral density (Table 1). Because each specimen was cut into two monosegmental specimens (L2–3 and L4–5), each group finally consisted of eight specimens (four L2–3 and four L4–5).

Before testing, the specimens were thawed and all muscles were carefully removed while maintaining the ligamentous and bony structures. The upper half of the upper vertebra and the lower half of the lower vertebra of these specimens were embedded in polymethylmethacrylate with horizontally aligned midplanes of the L2–3 and L4–5 discs. Before embedding them, several screws were fixed in both vertebrae to improve the fixation between vertebrae and polymethylacrylate. Care was taken to keep the specimens moist throughout the testing period.

Flexibility Testing With Intact Specimens

In the first step, each specimen was fixed and tested in an intact state, without preload, in a spine tester20 in a spine tester17 (Fig. 4). This spine tester allows movements in all six degrees of freedom. Alternating sequences of right/left lateral bending, flexion/extension, and axial left/right rotation movements were applied continuously at a constant rate of 1° per second by stepper motors that are integrated into the gimbal of the spine tester. Two precycles were applied continuously to minimize the effect of the viscous component in the viscoelastic response. Data were collected on the third cycle. As recommended,20 the specimens were tested between 7.5 and −7.5 Nm, starting and ending in the neutral position with zero load. During each test, the five uncontrolled degrees of freedom were unconstrained. The motion in each single segment was measured simultaneously by rotary potentiometers (accuracy 0.01°) integrated in the three axes of a Cardan joint, which allows rotations around all three main axes.

Range of motion and NZ values were determined from the resulting load-deformation curves (Fig. 5). The ROM is defined as the angulation at the maximum moment for the two directions separately. The NZ measurement of the laxity of the spinal specimen indicates the range over which the specimen moves essentially free of applied loading, as, for instance, under its own weight. The NZ is defined as the difference in angulation at zero load for both directions separately.

Primary Stability After Implantation

In a second step, the cages were implanted by an experienced neurosurgeon who used tools designed by the respective cage manufacturer and followed their recommended protocols. Plain anteroposterior and lateral radiographs were obtained to document the position of the cages. Immediately after implantation of the cages, the specimens were tested in the spine tester as described in Flexibility Testing.

Cyclic Loading

After the primary stability test the specimens were mounted in a servohydraulic material testing machine. Overall, 40,000 axial compression cycles, each ranging sinusoidal from 200 to 1000 N, were applied with a frequency of 5 Hz (five cycles/second). The axial translation was recorded simultaneously by a translation variable displacement transducer that was integrated into the testing machine (accuracy 0.005 mm).

The minimum axial force of 200 N simulates the axial load in vivo that occurs during upright standing or sitting.6 Even at 1000 N, failure of the endplates should not occur.6

With 40,000 cycles at a frequency of 5 Hz, we tried to apply as many loading cycles as possible within a testing period of no more than 15 hours because the properties of each specimen will begin to change beyond this point.6

Stability After Cyclic Loading

In a third step, after cyclic loading the specimens were once again tested in the spine tester as previously described.

Statistical Analysis

Before and after cyclic loading, ROM and NZ were divided by the ROM values of the intact specimens to normalize the data. Intergroup comparisons were made using the Kruskal–Wallis test. If the results indicated differences among the groups, comparisons between pairs of cage groups were made using the Mann–Whitney U-test. Within each group separately the status before cyclic loading was compared statistically with that after cyclic loading by using the Friedman test, and this, if indicated, was followed by a Wilcoxon signed-rank sum test.

Because multiple comparisons have been conducted, all p values are considered to indicate trends and not statistical evidence.

Regression coefficients were determined between normalized flexibility increase values and subsidence depth for all three cage designs in all loading directions.

Sources of Equipment

We acquired the Zientek cages from Dieter Marquardt Medizintechnik GmbH (Spaichingen, Germany), the Stryker cages from Stryker Implants (ZI Marticot, Cestas, France), and the Ray cages from Surgical...
Stabilizing effect of posterior lumbar interbody fusion cages

Results

Primary Stability

In general, the implantation of Zientek and Ray cages had a stabilizing (normalized ROM < 1) and the insertion of Stryker cages a destabilizing effect in relation to the intact specimens (normalized ROM > 1). The only exception was axial rotation in which the Zientek cage demonstrated a slightly destabilizing effect and values close to 1 in the Ray cage group (Fig. 6, Table 2). In all three cage groups greater stability was demonstrated in lateral bending and flexion than in extension and axial rotation.

The median value obtained for primary stability in lateral bending position was 0.45 (lateral bending to the right) and 0.46 (lateral bending to the left) after insertion of Zientek cages and 0.51 and 0.49, respectively, after implantation of Ray cages (Fig. 6 upper and Table 2). Both the Zientek and Ray cages were shown to have a greater primary stabilizing effect than the Stryker cage (1.06 and 1.12, respectively) with p values of 0.0038 between Zientek and Stryker and 0.0066 between Ray and Stryker cages.

The same tendency was found in flexion: the Zientek (0.48) and Ray cages (0.50) demonstrated a greater stabilizing potential than the Stryker cages (1.07) (Fig. 6 center and Table 2) (p = 0.0038 between Zientek and Stryker and p = 0.0101 between Ray and Stryker, but p = 0.6514 between Zientek and Ray).

In extension, spinal stability in each of the three groups was less than that in lateral bending and flexion positions. Values of 0.78 and 0.94 were demonstrated after implantation of Zientek and Ray cages, respectively, (p = 0.6056) (Fig. 6 center and Table 2). A distinctly greater stability value (1.46) was observed after insertion of Stryker cages. Analysis demonstrated p values of 0.0109 between Zientek and Stryker and 0.0053 between Ray and Stryker.

Compared with the other positions, in axial rotation all three cages showed the least stabilizing effect, with the greatest stabilizing effect achieved after implantation of Ray cages (0.98 in axial rotation to the left and 0.99 in axial rotation to the right; Fig. 6 lower and Table 2). Less spinal stability was noted after implantation of Zientek cages (1.22 [left axial rotation] and 1.14 [right axial rotation]) and least stability was observed after implantation of Stryker cages (1.37 [left axial rotation] and 1.42 [right axial rotation]). Differences were most distinct between the Ray and the Stryker cage group (p = 0.0043 in axial rotation to the left and p = 0.0066 in axial rotation to the right). The NZ was generally around 10 to 30% of the overall flexibility (Fig. 6 and Table 2).

Cyclic Loading

After 40,000 axial compression cycles, a median subsidence of 0.9 mm was found in the Zientek cage group. The loss of height was greater when Stryker (1.22 mm) and Ray cages (1.39 mm) were used.

Stability After Cyclic Loading

The initial spinal stability that was measured in the three cage groups decreased during cyclic loading in all three loading directions (p values of 0.0180–0.0759; Fig. 6 and Table 2). In general, the greatest loss of stability was observed in the Ray cage specimens and the smallest in the Stryker cage specimens.

In lateral bending to the right and to the left a stability decrease of 180% and 190%, respectively, was caused by cyclic loading in the Ray cage group followed by 136% and 157%, respectively, in the Zientek cage group and 113% and 111%, respectively, in the Stryker cage group (Fig. 6 and Table 2). When compared with the primary stability, p values were greater especially between Stryker and Ray cages (p = 0.0639 [lateral bending to the right]) and p = 0.0350 [lateral bending to the left]).

In flexion and in extension, respectively, the loss of stability was greater in the Ray (168% and 147%, respectively) than in the Zientek cage groups (138% and 122%, respectively) and in the Stryker cage group (111% and 117%, respectively) (Fig. 6 center and Table 2). After cyclic loading, statistical analysis demonstrated that all p values were greater than before cyclic loading, most distinctly between Stryker and Ray cages (p = 0.1102 in flexion and in extension).

In axial rotation the reduction in stability was less pronounced than that observed in lateral bending, flexion, and extension testing. It ranged between 108% in axial rotation to the left in the Stryker cage group to 130% in axial rotation to the right in the Ray cage group (Fig. 6 lower and Table 2). Just as before cyclic loading, the lowest p values were demonstrated between Ray and Stryker cages (p = 0.0253 in axial rotation to the left and p = 0.0181 in axial rotation to

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Zientek</th>
<th>Stryker</th>
<th>Ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMD (mg/cm³) ± SD</td>
<td>136.1 ± 35.9</td>
<td>139.2 ± 23.4</td>
<td>132.7 ± 24.4</td>
</tr>
<tr>
<td>age (yrs) ± SD</td>
<td>34.5 ± 8.2</td>
<td>34.8 ± 11.2</td>
<td>35.0 ± 7.4</td>
</tr>
<tr>
<td>sex distribution (f/m)</td>
<td>1/3</td>
<td>0/4</td>
<td>1/3</td>
</tr>
</tbody>
</table>

* BMD = bone marrow density; SD = standard deviation.
The NZ also decreased in all three loading directions and in all three cage groups (Fig. 6 and Table 2).

Correlation Between Flexibility Increase and Subsidence
No correlation between flexibility increase and subsidence could be found except for Ray cages tested in flexion. In this loading direction the amount of flexibility increase was large in specimens with large subsidence and small in specimens with small subsidence ($r^2 = 0.507$).

Discussion

Immediate Stability
The reduction of movement that was generally found in the testing of all loading directions after insertion of Zientek and Ray cages and the increase of movement after implantation of Stryker cages might be a consequence of the different insertion techniques and the different shapes of the cages. The threaded Ray cage penetrates the endplates and provides an interference fit, which reduces movement. This reduction of movement is expected to be most evident in axial rotation because, in this loading direction, friction between the cage and endplate is the most important stabilizing factor. The two hooks of the Zientek cage might be responsible for a stable connection between endplates and cage that provides more stability than that created by connection between the ridges of the Stryker cage and the endplates. However, it is not as stable as the fit of threaded cages.

In general the primary stability was greater in lateral bending and flexion than in extension and axial rotation. This finding accords well with data reported in the literature. The lack of stability demonstrated in extension might be caused by a deficiency of bone resistance against extension movements. Physiologically, because the articular facet surfaces of two adjacent lumbar vertebrae are close to each other, they prevent excessive extension. However, during surgery a distraction of the segment is realized, and this is followed by an increasing distance between the facet surfaces. Furthermore, during cage insertion following the posterior approach, a medial facetectomy must be performed. Therefore, less bone remains to resist extension movements.

Cyclic Loading
In general, the recorded subsidence results from a creeping effect of the whole specimens (nondestructive compression) in combination with a penetration of the surface structures of the cages, such as the threads of Ray cages, the hooks of the Zientek cages, and the ridges of the Stryker cages, into the endplates (destructive compression). It can be assumed that such a penetration strongly depends on the preparation of the endplates and the insertion technique involved in implanting the cages, as well as on the cage design itself.

Stability After Cyclic Loading
The decrease in distraction height that we recorded during cyclic loading might be the main reason for the loss of stability noted in all three cage groups. Furthermore, when the Ray cages were used, cyclic loading might have destroyed the bone threads and therefore impaired the interference fit between the cage and endplates, causing the cage to loosen.

### Table 2

<table>
<thead>
<tr>
<th>Loading Test</th>
<th>Zientek ROM</th>
<th>Zientek NZ</th>
<th>Stryker ROM</th>
<th>Stryker NZ</th>
<th>Ray ROM</th>
<th>Ray NZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>lateral bending to the right</td>
<td>6.9</td>
<td>0.8</td>
<td>6.2</td>
<td>0.7</td>
<td>4.9</td>
<td>0.9</td>
</tr>
<tr>
<td>intact specimen</td>
<td>6.2</td>
<td>0.7</td>
<td>6.1</td>
<td>1.5</td>
<td>2.9</td>
<td>0.7</td>
</tr>
<tr>
<td>before cyclic loading</td>
<td>3.0</td>
<td>0.7</td>
<td>7.9</td>
<td>1.8</td>
<td>4.9</td>
<td>1.1</td>
</tr>
<tr>
<td>after cyclic loading</td>
<td>4.0</td>
<td>1.0</td>
<td>7.0</td>
<td>1.6</td>
<td>3.8</td>
<td>0.6</td>
</tr>
<tr>
<td>flexion</td>
<td>7.1</td>
<td>0.7</td>
<td>6.8</td>
<td>0.6</td>
<td>8.8</td>
<td>0.7</td>
</tr>
<tr>
<td>intact specimen</td>
<td>7.0</td>
<td>0.7</td>
<td>7.0</td>
<td>1.6</td>
<td>3.8</td>
<td>0.6</td>
</tr>
<tr>
<td>before cyclic loading</td>
<td>4.3</td>
<td>1.0</td>
<td>7.5</td>
<td>2.3</td>
<td>5.4</td>
<td>1.1</td>
</tr>
<tr>
<td>after cyclic loading</td>
<td>4.3</td>
<td>0.7</td>
<td>3.7</td>
<td>0.6</td>
<td>3.3</td>
<td>0.7</td>
</tr>
<tr>
<td>extension</td>
<td>4.3</td>
<td>0.8</td>
<td>5.5</td>
<td>1.6</td>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>intact specimen</td>
<td>4.3</td>
<td>0.8</td>
<td>5.5</td>
<td>1.6</td>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>before cyclic loading</td>
<td>4.4</td>
<td>1.0</td>
<td>6.1</td>
<td>2.3</td>
<td>4.1</td>
<td>1.1</td>
</tr>
<tr>
<td>after cyclic loading</td>
<td>4.4</td>
<td>0.8</td>
<td>3.9</td>
<td>0.8</td>
<td>3.0</td>
<td>0.7</td>
</tr>
<tr>
<td>axial rotation to the left</td>
<td>2.6</td>
<td>0.6</td>
<td>3.0</td>
<td>0.6</td>
<td>2.7</td>
<td>0.4</td>
</tr>
<tr>
<td>intact specimen</td>
<td>2.6</td>
<td>0.6</td>
<td>3.0</td>
<td>0.6</td>
<td>2.7</td>
<td>0.4</td>
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<tr>
<td>before cyclic loading</td>
<td>3.5</td>
<td>0.8</td>
<td>6.2</td>
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<tr>
<td>after cyclic loading</td>
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<td>2.3</td>
<td>4.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*All values are nonnormalized and expressed in degrees.
Correlation Between Flexibility Increase and Subsidence

In cases in which the Ray cages were used a large subsidence depth was associated with a large increase in flexibility in flexion. Such a correlation is expected because a decreasing distraction height associated with loosening of the annulus fibers enables larger movements. However, in all other loading directions as well as with all other cages this correlation could not be proven. This finding might be explained by the small number and the small variance of the single values.

Simulation Methods

We tried to simulate daily life activity in the postoperative phase by applying a cyclic axial compression force which, obviously, does not represent the physiological loading of the spine. However, this method can easily be standardized. Furthermore, the number of times a patient’s spine moves within a period of several weeks can be simulated within some hours.

Study Limitations

The results of experimental investigations have shown that bone ingrowth can occur in the presence of some movement ($\leq 28 \, \mu m$), whereas excess movement ($\geq 150 \, \mu m$) can result in attachment by mature connective tissue ingrowth. However, concrete data are not yet available regarding the degree of spinal stability required by the implantation of lumbar interbody fusion cages.

In addition to stability, many other parameters such as the dislocation tendency or the material properties of the cages are of remarkable clinical relevance. Therefore, the clinical outcome cannot be predicted by performing single flexibility tests.

Although biological effects cannot be predicted in in vitro tests, they do play an important role in the healing process.

Conclusions

Before and after cyclic loading, the stabilizing effect after insertion of Ray and Zientek cages was greater than...
that obtained after implantation of Stryker lumbar interbody fusion cages. A loss of stability after cyclic axial loading was observed after implantation of all three types of cage, however, that loss was most pronounced when using the Ray cage.

For clinicians, we recommend choosing cages with a good fit by threads or large hooks to optimize the primary stability, as well as cages that are implanted with as little endplate destruction as possible to minimize postoperative loosening of the cage during spinal movements.

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