The Bagby and Kuslich (BAK) method of lumbar interbody fusion is a safe and effective technique to restore spinal stability through the anterior or posterior approach. In a 2-year follow-up prospective, multi-center study, the BAK cage (Sulzer Spine-Tech, Minneapolis, Minnesota) as posterior lumbar interbody fusion (PLIF) was evaluated to have an overall fusion rate of 86% with no device-related death and complications in 12 months after surgery. Conventionally, 2 BAK cages are inserted from the posterior approach as posterior interbody fusion.

Comparison of Stabilities between Obliquely and Conventionally Inserted Bagby and Kuslich Cages as Posterior Lumbar Interbody Fusion in a Cadaver Model

Background. The Bagby and Kuslich (BAK) cage as posterior lumbar interbody fusion (PLIF) is reported to give satisfactory results in restoring spinal stability. Moreover, correction by obliquely inserting a single BAK cage has the advantages of reducing exposure, precise implantation, and lower cost. However, biomechanical data on this procedure are not abundant. This study was designed to compare the stability imparted by the cages placed using an oblique and posterior approaches and to determine the effects of supplementary posterior instrumentation.

Methods. After affixing nine human cadaveric spines (L2-S1) within a testing frame, load testing in several clinically relevant modes was performed sequentially for the intact and the following procedures across the L4-5 segments: posterior destabilization, stabilization using 2 parallel BAK cages (CBAK group) or 1 oblique BAK cage (OBAK group), and additional stabilization with posterior instrumentation. Spatial locations of vertebral bodies were recorded after each loading step using a 3-D motion measurement system.

Results. Except the OBAK group that had a lower stability in left axial rotation, there were no significant differences in the stability between both groups in all loading modes for the stabilization using cages alone. Compared with the intact cases, CBAK cages provide significant improvement in the stability in 5 displacement modes and OBAK cage may restore the stabilities of the specimens to the intact state in 5 modes and provide significant improvement in flexion. Addition of supplementary posterior instrumentation significantly reduced the angular displacements in both groups.

Conclusions. Both methods of cage insertion have similar stability. Both implantations, alone or with posterior instrumentation, may improve the stability of the spine, although posterior instrumentation may further strengthen the stability. The oblique insertion is more favorable since it requires less exposure, enables precise implantation, and is less expensive.
lumbar interbody fusion. Recently, implanting a single BAK cage obliquely from a posterior approach to provide anterior column support has also been employed. This implantation has the advantages of reducing exposure, precise implantation and lower cost.

The biomechanical properties of BAK (bilateral approach) and SynCage (central approach) have been compared to find no significant difference in the stabilization provided by these 2 designs. Moreover, PLIF with a single posterolateral long threaded cage with unilateral facetectomy shows to be capable of providing sufficient decompression and maintaining most of the posterior elements in bovine lumbar functional spinal units. In combination with a facet joint screw, adequate postoperative stability was achieved. In this study, we employed a cadaver model to compare the stability of the oblique insertion of a single BAK cage and the conventional insertion of two BAK cages in parallel for PLIF across the L4-L5 segments. In addition, the effects of supplementary posterior instrumentation were also investigated.

METHODS

Specimen preparation
Nine intact fresh human cadaver spines (L2-S1) were prepared and randomly divided into 2 groups: 4 for the conventional insertion of 2 BAK cages (CBAK group) and 5 for the oblique insertion of a single BAK cage (OBAK group). The bone mineral density of these specimens was determined by DEXA (dual energy x-ray absorptiometry) scanning to exclude highly degenerated and osteoporotic specimens. The soft tissues on each specimen were stripped off and the ligamentous structures were left intact. Metallic screws were then inserted into the vertebral bodies to ensure a secure fixation between the vertebral bodies before affixing the superior half of the proximal vertebral body and inferior half of the distal body before pouring polyester resin. The methodology of preparing the specimens and testing is well-established.

Testing procedures
Mechanical testing on the spine specimens was performed according to the protocol in our previous study. Each specimen was sequentially tested in the following states: (1) intact; (2) destabilization unilaterally on the right (hemilaminectomy) by total facetectomy and partial discectomy across L4-L5 in the OBAK group or destabilization by total bilateral laminectomy and discectomy at the same level in the CBAK group; (3) stabilization using an obliquely inserted BAK cage in the OBAK group or 2 parallel BAK cages in the CBAK group; and (4) additional stabilization using variable screw plates (VSP) system (DePuy-AcroMed, Raynham, Massachusetts) across the L4-L5 segments in both groups. All implements were inserted according to the instructions of the manufacturer.

RESULTS
The mean angular displacements for all 6 load types

November 2003
Obliquely vs. Conventionally Inserted BAK Cages
evaluated are summarized in Tables 1. After stabilization, a much larger left axial rotation was found in the OBAK group than in the CBAK group (OBAK 1.77° vs. CBAK 0.30° p < 0.05). However, no significant differences were found in the remaining directions (p > 0.05). Analyses using the normalized data also showed the same patterns in the differences of angular changes between the implementation designs (Figs. 1-3).

Table 1. Summary of flexion/extension, lateral bending, and axial rotation motions for the intact and stabilized specimens with BAK cages inserted obliquely (OBAK) or conventionally (CBAK) at the L4-L5 lumbar levels of human cadaveric specimens

<table>
<thead>
<tr>
<th>Step</th>
<th>CBAK</th>
<th>OBAK</th>
<th>p</th>
<th>CBAK</th>
<th>OBAK</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extension (°)</td>
<td></td>
<td></td>
<td>Flexion (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>2.34</td>
<td>0.78</td>
<td>1.75</td>
<td>0.61</td>
<td>0.221</td>
<td>-4.95</td>
</tr>
<tr>
<td>D</td>
<td>2.95</td>
<td>0.96</td>
<td>2.51</td>
<td>0.43</td>
<td>0.221</td>
<td>-8.29</td>
</tr>
<tr>
<td>C</td>
<td>1.26</td>
<td>0.78</td>
<td>1.98</td>
<td>1.92</td>
<td>0.624</td>
<td>-1.82</td>
</tr>
<tr>
<td>C+I</td>
<td>0.87</td>
<td>0.99</td>
<td>0.33</td>
<td>0.15</td>
<td>0.806</td>
<td>-0.90</td>
</tr>
<tr>
<td></td>
<td>Left lateral bending (°)</td>
<td></td>
<td></td>
<td>Right lateral bending (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>2.91</td>
<td>0.88</td>
<td>3.18</td>
<td>2.14</td>
<td>0.806</td>
<td>-3.02</td>
</tr>
<tr>
<td>D</td>
<td>3.46</td>
<td>1.04</td>
<td>4.22</td>
<td>1.87</td>
<td>0.806</td>
<td>-3.77</td>
</tr>
<tr>
<td>C</td>
<td>0.84</td>
<td>0.36</td>
<td>2.75</td>
<td>1.64</td>
<td>0.221</td>
<td>-0.71</td>
</tr>
<tr>
<td>C+I</td>
<td>0.43</td>
<td>0.24</td>
<td>0.74</td>
<td>0.43</td>
<td>0.327</td>
<td>-0.36</td>
</tr>
<tr>
<td></td>
<td>Left axial rotation (°)</td>
<td></td>
<td></td>
<td>Right axial rotation (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1.85</td>
<td>0.71</td>
<td>1.11</td>
<td>0.64</td>
<td>0.221</td>
<td>-1.46</td>
</tr>
<tr>
<td>D</td>
<td>2.01</td>
<td>1.41</td>
<td>1.82</td>
<td>0.17</td>
<td>0.221</td>
<td>-2.91</td>
</tr>
<tr>
<td>C</td>
<td>0.30</td>
<td>0.22</td>
<td>1.77</td>
<td>0.72</td>
<td>0.014</td>
<td>-0.66</td>
</tr>
<tr>
<td>C+I</td>
<td>0.25</td>
<td>0.07</td>
<td>0.51</td>
<td>0.33</td>
<td>0.327</td>
<td>-0.33</td>
</tr>
</tbody>
</table>

Sample size: OBAK n = 5, CBAK n = 4; corresponding to a 6-Nm load step in four different loading modes (I - intact, D - destruction, C - cage only, C+I - cage plus instrumentation).

Fig. 1. Normalized angular changes in extension and flexion for the CBAK (□) and OBAK (■) cases. Nomenclature used is: I - intact, D - destruction, C - cage only, C+I - cage plus instrumentation. Graphs are for the 6-Nm load step and error bars represent standard deviations. There was no significant difference in the angular changes between the 2 groups.
Although the values after destabilization became higher than at the intact stage in general, significant differences in the angular displacements were only observed in the extension, flexion, and right lateral bending modes of the CBAK group and the extension mode of the OBAK group ($p < 0.05$). Except in the right axial rotation.

**Fig. 2.** Normalized angular changes in bending motions for the CBAK (□) and OBAK (■) cases. Nomenclature used is: I - intact, C - cage only, D - destruction, C+I - cage plus instrumentation. Graphs are for the 6-Nm load step and error bars represent standard deviations. There was no significant difference in the angular changes between the 2 groups.

**Fig. 3.** Normalized angular changes in axial rotations for the CBAK (□) and OBAK (■) cases. Nomenclature used is: I - intact, C - cage only, D - destruction, C+I - cage plus instrumentation. Graphs are for the 6-Nm load step and error bars represent standard deviations. Although there was no significant difference in the angular changes between the 2 groups in right axial rotation, OBAK had a significantly larger angular change in left axial rotation than CBAK.
mode ($p > 0.05$), the mean angular displacements became significantly lower than the intact cases after implantation of the CBAK cages ($p < 0.05$). The implementation of CBAK cages provides significant improvement in the stability of the specimens in 5 displacement modes. In the OBAK group, the mean angular displacement became significantly lower in the flexion mode than in the intact cases after cage implantation ($p < 0.05$). However, there were no significant difference in the remaining 5 displacement modes ($p > 0.05$). The OBAK cage may restore the stability of the specimens to the intact state in 5 modes and provide significant improvement in flexion. The same patterns in the angular displacement differences between the intact state and cage implementation after destabilization were observed in the two implementation designs using the normalized data (Table 1 and Figs. 1-3).

Except in the left axial rotation mode ($p > 0.05$), the displacements became significantly lower than the intact after implementing CBAK cages and adding posterior instrumentation ($p < 0.05$). In the OBAK group, significantly lower displacements were observed in all modes ($p < 0.05$) after adding posterior instrumentation. These findings indicate the significant improvement in the stability of the specimens in both implementation design groups after adding the posterior instrumentation (Table 1 and Figs. 1-3).

DISCUSSION

The BAK cage has been evaluated to be a superior interbody fusion device than other graft materials in vivo and in vitro using a calf spine model. This implantation with posterior instrumentation is found to have the greatest stiffness in flexion/extension and axial rotation while bone graft alone gives less initial stiffness than that of the intact spine, although the results in axial compression seem inconclusive. Moreover, this cage is reported to have similar biomechanical characteristics as the Threaded Interbody Fusion Device or SynCage. In an in vivo study with a sheep thoracic spine model, BAK with bone graft or recombinant human bone morphogenetic proteins was demonstrated to have the same effects on biomechanics and histomorphometry as bone graft alone.

In a previous study, the stability of these 2 BAK cage implantations has been evaluated in 18 bovine lumbar functional spinal units. The PLIF with a single posterolateral long threaded cage with unilateral facetectomy not only enables sufficient decompression but also maintains most of the posterior elements. Although the single cage implantation is stiffer than the two-cage implantation in pure compression, flexion, and left and right bending, the differences are not significant. Although the study of functional spinal units may provide valuable information on the mechanical properties, the results may be different in many ways from those obtained from multi-segmental cadaveric spinal models. Moreover, information from functional spinal units may not be applied directly to explain the multi-segmental motion properties. Biomechanical evaluation using multi-segmental models should be more appropriate for simulating the physiologic movements.

This study provided a cadaveric spinal model to compare between the conventional insertion of 2 BAK cages and the oblique insertion of a single BAK cage across the L4-L5 segments via a posterior approach. The results indicate that both methods of cage insertion, with or without supplementary posterior fixation, provided similar stability in all loading modes, except that the latter method was found to have a much higher degrees of left axial rotation than the former in the horizontal plane, because the single BAK was inserted oblique by right total facetectomy at the right side. Although CBAK improved the stability of the spine a lot in 5 displacement modes, OBAK may restore the spine to the intact state in 5 modes and help improve flexion. These findings indicated the usefulness of OBAK in restoring the stability of the spine.

The biomechanical behaviors of implants with or without instrumentation have also been evaluated. In a comparative study using calf and human cadaveric spines on bone graft and RAY cage, increase in flexion, lateral bending stiffness and reduced laxity on flexion, extension, and lateral bending were observed in both implants with supplemental posterior plates fixed by pedicle screws across the fusion segment. In another biomechanical study on human cadaver spines, the Strattec,
Ray, and Brantigan cages were determined to achieve the
greatest stabilization in flexion and lateral bending by the
addition of posterior transpedicular instrumentation. Although the BAK cage may be used as a standalone de-
vice, the results of this study indicate that the BAK
cages, when implanted from a posterior approach, may
provide higher stability with supplementary posterior in-
strumentation.

Based on the results of this study, CBAK and OBAK
have similar stability in the cadaveric spine model. The
unilateral approach of OBAK might greatly reduce the
exposure requirements. It also offers the advantage of the biomechanics of a construct consisting of anterior col-
umn support combined with pedicle screws. The imple-
mentation of a single cage also significantly diminishes
the cost. In addition, supplementary posterior instrumen-
tation may also increase the stability in both types of im-
plantation.

ACKNOWLEDGEMENTS

This study was supported in part by the Sulzer
Spine-Tech, Inc. and DePuy, Inc. for providing the pedicle
screw spinal instrumentation.

REFERENCES

1. Weiner BK, Fraser RD. Spine Update. Lumbar interbody
2. McCafee PC. Interbody fusion cages in reconstructive opera-
3. Kuslich SD, Ulstrom CL, Griffith SL, Ahern JW, Dowdle JD.
The Bagby and Kuslich method of lumbar interbody fusion.
History, technique, and 2-year follow-up results of a United
4. Oxland TR, Hoffer Z, Nydegger T, Rathonyi GC, Nolte L-P. A
comparative biomechanical investigation of anterior lumbar
interbody cages: central and bilateral approaches. J Bone Joint
5. Zhao J, Hai Y, Ordway N, Park CK, Yuan HA. Posterior lum-
bar interbody fusion using posterolateral placement of a single
6. Abumi K, Panjabi M, Duranceau J. Biomechanical evaluation
of spinal fixation devices. Part III. Stability provided by six
spinal fixation devices and interbody bone graft. Spine 1989;
14:1239-55.
GO. Response of the ligamentous lumbar spine to cyclic bend-
8. Goel VK, Lim TH, Gwon J, Chen JY, Winterbottom J, Park J,
et al. Effects of rigidity of an internal fixation device: a com-
prehensive biomechanical investigation. Spine 1991;16:
S155-61.
9. Hitchon PW, Goel VK, Serhan H, Rogge T, Grosland N,
Sairyo K, Torner J. Biomechanical studies on two anterior
thoracolumbar implants in cadaveric spines. Spine 1999;24:
213-8.
Biomechanical evaluation of anterior and posterior fixations
11. Brodke DS, Dick JC, Kunz DN, McCabe R, Zdeblick TA. Pos-
terior lumbar interbody fusion. A biomedical comparison, in-
12. Rapoff AJ, Ghanayem AJ, Zdeblick TA. Biomechanical com-
parison of posterior lumbar interbody fusion cages. Spine
JC, Fedder IL, Mcfee PC. Osteogenic protein versus
autologous interbody arthrodesis in the sheep thoracic spine.
A comparative endoscopic study using the Bagby and Kuslich
14. Lee CK, Langrana NA. Lumbosacral spinal fusion. A bio-
15. Tencer AF, Hampton D, Eddy S. Biomechanical properties of
threaded inserts for lumbar interbody spinal fusion. Spine
16. Lund T, Oxland TR, Jost B, Cripton P, Grassmann, Etter C,
Nolte L-P. Interbody cage stabilisation in the lumbar spine.
Biomechanical evaluation of cage design, posterior instru-
mentation and bone density. J Bone Joint Surg 1998;80-B:
351-9.