Original Article

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

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Bagby and Kuslich (BAK) cage;
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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.

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.[1,2] In a 2-year follow-up prospective, multicenter 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.[3] Conventionally, 2 BAK cages are inserted from the posterior approach as posterior

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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.[4] 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.[5] 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.[6-10]

Testing procedures

Mechanical testing on the spine specimens was performed according to the protocol in our previous study.[6-10] 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.

Testing steps

The three-dimensional load-displacement behavior of each of the vertebra was quantified using the Selspot II® Motion Measurement System (Innovision Systems, Inc., Warren, MI). Loads, in form of pure moments to L2, were applied to the spine in 6 degrees of freedom: flexion-extension (6 Nm), right and left lateral bending (6 Nm), and right and left torsional loading (6 Nm). The maximum load was achieved in 5 equal steps. Spatial location of the specimen was recorded after each loading step. To prevent dehydration during preparation and testing, specimens was sprayed with 0.9% NaCl solution.

Statistical analysis

Since there were only 4 specimens in the CBAK group and 5 in the OBAK group, non-parametric tests were employed to analyze changes in the angular motion for each loading mode. The raw data and the data normalized with respect to the intact state were analyzed. The Kruskal-Wallis test was used to compare the effect of cage design and the Friedman test was used to evaluate the changes in each state of the 2 groups. The critical level of significance was 0.05.

RESULTS

The mean angular displacements for all 6 load types 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

Step	CBAK		OBAK		*p*	CBAK		OBAK		*p*
	Extension (°)					Flexion (°)				
I	2.34	0.78	1.75	0.61	0.221	-4.95	2.64	-4.42	1.60	1.000
D	2.95	0.96	2.51	0.43	0.221	-8.29	2.61	-5.44	3.63	0.142
C	1.26	0.78	1.98	1.92	0.624	-1.82	1.11	-1.39	1.72	0.806
C + I	0.87	0.99	0.33	0.15	0.806	-0.90	0.87	-0.65	0.48	0.086
	Left lateral bending (°)					Right lateral bending (°)				
I	2.91	0.88	3.18	2.14	0.806	-3.02	0.91	-2.63	1.53	0.806
D	3.46	1.04	4.22	1.87	0.806	-3.77	1.43	-2.99	1.68	0.462
C	0.84	0.36	2.75	1.64	0.221	-0.71	0.56	-2.23	1.80	0.050
C + I	0.43	0.24	0.74	0.43	0.327	-0.36	0.14	-0.68	0.36	0.327
	Left axial rotation (°)					Right axial rotation (°)				
I	1.85	0.71	1.11	0.64	0.221	-1.46	1.65	-1.49	0.91	0.624
D	2.01	1.41	1.82	0.17	0.221	-2.91	1.32	-1.98	1.19	0.221
C	0.30	0.22	1.77	0.72	0.014	-0.66	0.27	-0.78	0.42	0.086
C + I	0.25	0.07	0.51	0.33	0.327	-0.33	0.15	-0.44	0.20	0.539

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).

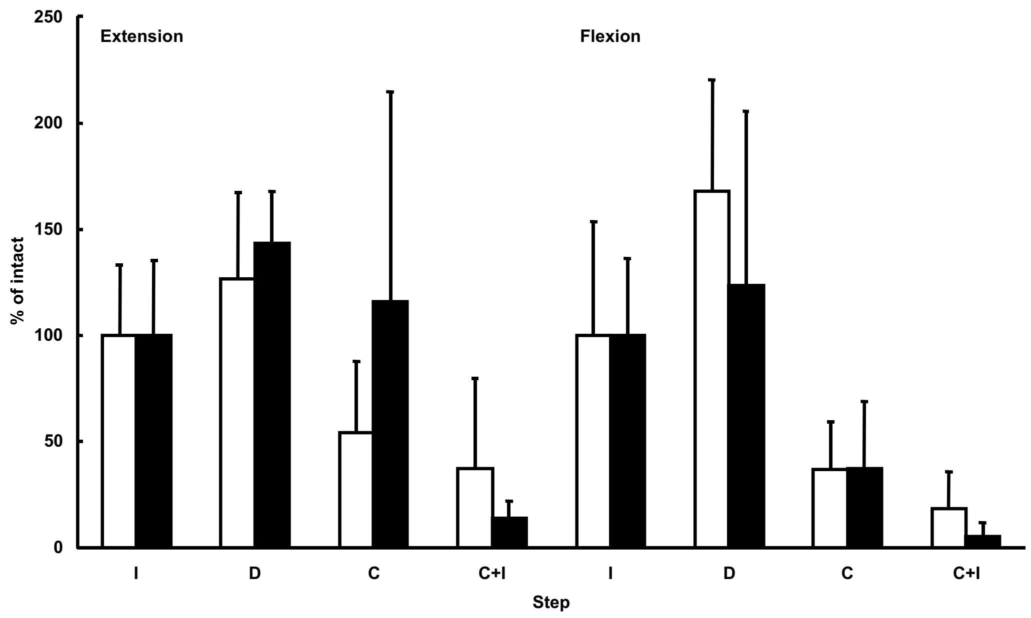

Fig. 1. Normalized angular changes in extension and flexion for the CBAK (□) and OBAK (■) cases. Nomenclature used is: I - intact, D - destruction, C - cage only, C+I - cage plus instrumentation. Graphs are for the 6-Nm load step and error bars represent standard deviations. There was no significant 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

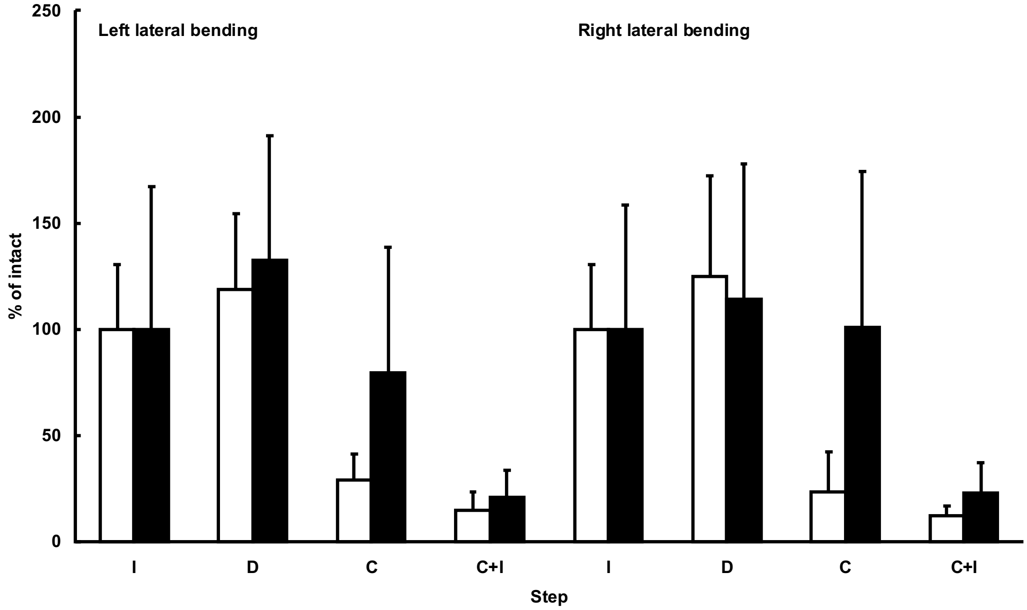

Fig. 2. Normalized angular changes in bending motions for the CBAK (□) and OBAK (■) cases. Nomenclature used is: I - intact, C - cage only, D - destruction, C+I - cage plus instrumentation. Graphs are for the 6-Nm load step and error bars represent standard deviations. There was no significant difference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

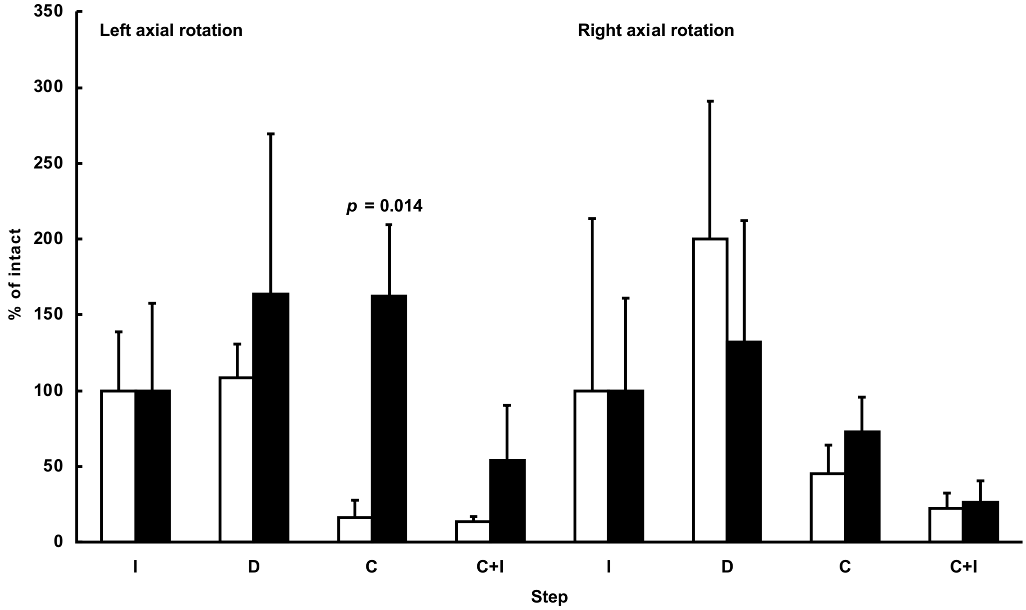

Fig. 3. Normalized angular changes in axial rotations for the CBAK (□) and OBAK (■) cases. Nomenclature used is: I - intact, C - cage only, D - destruction, C+I - cage plus instrumentation. Graphs are for the 6-Nm load step and error bars represent standard detions. Although there was no significant 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.[11] Moreover, this cage is reported to have similar biomechanical characteristics as the Threaded Interbody Fusion Device or SynCage.[12] 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.[13]

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.[5] 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.[14]

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 cardaveric 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.[15] In another biomechanical study on human cadaver spines, the Stratec,

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