

Original Article

Posterior instrumentation improves the stabilities of Brantigan and Bagby and Kuslich (BAK) methods of posterior lumbar interbody fusion across the L4–L5 segments in a cadaveric model



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ABSTRACT

Background: The Brantigan and Bagby and Kuslich (BAK) cages for posterior lumbar interbody fusion have different geometric characteristics. However, both cage designs have been demonstrated to be helpful in restoring disc space across spinal motion segments in clinical observations. This study was designed to compare the biomechanical performance of these devices at one-motion segments and to determine the effects of posterior instrumentation on their stabilities.

Methods: Eight intact fresh human cadaver spines (L2–S1) were affixed within a testing frame for *in vitro* biomechanical testing: four randomly assigned spines for the BAK cage group and four for the Brantigan cage group. For each spine, the three-dimensional load-displacement behavior of each vertebra was quantified using the Selspot II Motion measurement system during the following steps: (1) intact state; (2) destabilization after laminectomy and discectomy across L4–L5; (3) stabilization using a pair of BAK cages or Brantigan cages; and (4) additional stabilization using variable screw plates (VSP) across L4–L5.

Results: The Brantigan cage alone did not show satisfactory results in improving the stability of one-motion segment destabilized spines in left and right axial rotation. However, the BAK cages appeared to provide significant stability in extension, flexion, left and right lateral bending, and left axial rotation. After implanting the additional posterior instrumentation, both cages provided similar and significantly improved stabilities.

Conclusion: Although the results indicate that the Brantigan cage did not provide satisfactory improvement in the stabilities as the BAK cage in the one-motion segment model, implantation with additional posterior instrumentation may significantly improve the stabilities and reduce the differences between the two cage designs.

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1. Introduction

In the treatment of spinal instability, successful fusion is one of the most important goals for spinal surgery.¹ Although bone graft alone may lead to a high failure rate and complications, stand-alone anterior fusion cages with autogenous bone graft has been reported

to have high rates of success.² Recently, a number of interbody fusion cages have been developed with different rationales.^{3,4} These cages may be implemented through the anterior or posterior approach and have been evaluated to be helpful in achieving successful interbody fusions.^{3,5,6}

The implantation of Bagby and Kuslich (BAK) cages (Sulzer Spine-Tech, Minneapolis, MN, USA) has been evaluated to be safe and effective for interbody fusion through the anterior or posterior approach.^{3,6} As a posterior lumbar interbody fusion (PLIF) technique, this cage design has a high overall fusion rate of 86% at month 12 after surgery. This fusion rate was then increased to 91%

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at month 24 and 98% at month 36. The rates were 87%, 94%, and 100% in one-level cases and 75%, 71%, and 90% in the two-level cases. Moreover, no device-related deaths or complications have been observed.⁵ The Brantigan cage (DePuy-AcroMed, Raynham, MA, USA) is a carbon fiber rectangular cage.⁷ In addition to possessing better mechanical strength than allografts,⁸ the implantation of the Brantigan cage showed a 100% fusion rate among 26 patients in a 2-year follow-up investigation, whereas a fusion rate of 54.5% was observed after the application of an allograft fusion.⁹ Moreover, no statistically significant differences were found among the stabilities among the Stratec, Ray, and Brantigan cages using a cadaveric spine model.¹⁰

Although the clinical observations and biomechanical studies have demonstrated the effectiveness of these two cage designs, there is no information concerning with the comparison of the stabilities between the Brantigan and BAK cages. Moreover, the necessity of implantation of posterior instrumentation to these cages remained undetermined. In this study, we employed a human cadaveric spinal model to compare the stabilities between the two types of cages implanted across the L4–L5 segments through a posterior approach. The effects of using supplementary posterior instrumentation on the stability were also investigated.

2. Materials and methods

2.1. Specimen preparation

Eight intact fresh human cadaveric spines (L2–S1) were used for the *in vitro* biomechanical testing. These spines were divided randomly into two groups: one implanted with Brantigan cages and the other with BAK cages. The bone mineral density of these specimens was determined using DEXA (dual energy x-ray absorptiometry) scanning. The bone density information and the interpretations of the radiographs enabled us to exclude highly degenerative, severe osteoporotic, malformation, metastatic, or fractured ones from the study. After stripping off the soft tissues and leaving the ligamentous structures intact, the superior half of the proximal vertebral body (L2) and inferior half of the distal body (S1) of each specimen were affixed in a polyester resin. To ensure a secure fixation between the vertebral bodies and resin, metallic screws were inserted into the vertebral bodies before pouring the polyester resin. The disc spaces between L2 and L3, L3 and L4, L4 and L5, and L5 and S1 were left unhindered.

2.2. Testing procedures

Mechanical testing on the spine specimens was performed according to the protocol in our previous study.^{11–15} Each specimen was tested in the following states: (1) intact state; (2) destabilization by partial laminectomy, facetectomy, and discectomy across L4–L5; (3) stabilization using a pair of BAK cages or Brantigan cages; (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.

2.3. Testing steps

After affixing the spine to an immobile base plate within a testing frame, infrared light emitting diodes (LEDs) were attached to the anterior part of vertebral bodies of L3, L4, and L5. A special set of LEDs was also attached to the immobile base for reference. Loads of 1.5, 3.0, 4.5, and 6.0 Nm in the form of pure moments to L2 were applied to the spine through a system of arms, pulleys, and weights. The loads were applied in six degrees of freedom: extension (EXT),

flexion (FLEX), right and left lateral bending (RLB, LLB), and right and left axial rotation (RAR, LAR). The three-dimensional (3-D) load-displacement in each vertebra was quantified using the Sel-spot II Motion measurement system (Innovision Systems, Inc., Warren, MI, USA). The maximum load was achieved in five equal steps and spatial location of the specimen was recorded after each load step. In response to the loads, cameras tracked the LEDs in an XYZ Cartesian axis system and transformed the 3-D motions into degrees of angular rotation. Mean changes in motion were calculated for different loading modes. To prevent dehydration during preparation and testing, specimens were sprayed with 0.9% NaCl solution.

2.4. Statistical analysis

The angular data collected from the *in vitro* tests at different stages within each group were converted into percentage changes with reference to the intact stage. The percentage changes were calculated as $100 \times (\text{Angular rotation} - \text{Angular rotation at intact stage}) / \text{Angular rotation at intact stage}$. Difference between the intact stage and the remaining ones in each group were compared using the Wilcoxon sign test (matched pair). The Wilcoxon rank sum test (two independent samples) was used to compare the differences between Brantigan and BAK cages at different stages. A p -value < 0.05 was considered statistically significant.

3. Results

In this study, the specimens were obtained from three females and five males aged between 46 and 78 years (62.8 ± 13.1 years). Averages and S.D. of the bone mineral densities were, respectively, $0.9 \pm 0.3 \text{ g/cm}^2$, $0.9 \pm 0.3 \text{ g/cm}^2$, $0.9 \pm 0.3 \text{ g/cm}^2$, $0.8 \pm 0.3 \text{ g/cm}^2$ at L2, L3, L4, and L5. There were no significant differences in these parameters for the specimens implanted with the Brantigan cages ($0.8 \pm 0.4 \text{ g/cm}^2$ at L2, $0.8 \pm 0.4 \text{ g/cm}^2$ at L3, $0.8 \pm 0.4 \text{ g/cm}^2$ at L4, and $0.7 \pm 0.4 \text{ g/cm}^2$ at L5) and those with the BAK cages ($1.0 \pm 0.1 \text{ g/cm}^2$ at L2, $1.1 \pm 0.1 \text{ g/cm}^2$ at L3, $1.0 \pm 0.1 \text{ g/cm}^2$ at L4, and $0.9 \pm 0.1 \text{ g/cm}^2$ at L5) groups ($p > 0.05$).

Figs. 1–3 show percentage changes with reference to the intact stage at the destabilization, cage only, and cage with posterior instrumentation stages. The intra-group variations became extremely higher at the destabilization stage. In the Brantigan group, there were no significant percentage changes in extension,

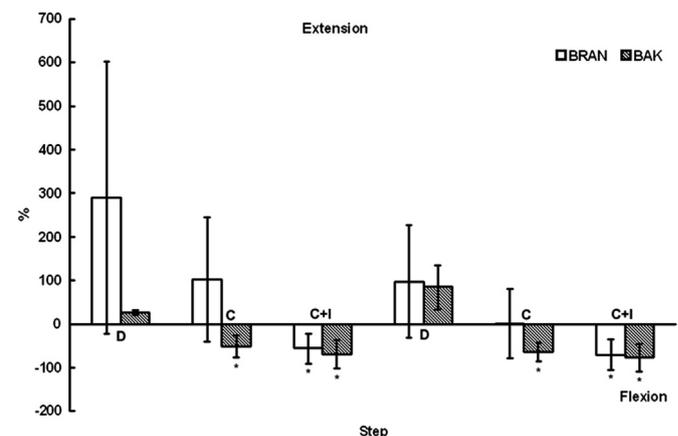


Fig. 1. Percentage changes (mean \pm SE) in extension and flexion rotations for the Brantigan (BRAN) and Bagby and Kuslich (BAK) cages across the L4–L5 segments. Graphs are for a 6 Nm load step. (*Intact vs. remaining stages: $p < 0.05$.) C = cage only; C+I = cage plus instrumentation; D = destruction.

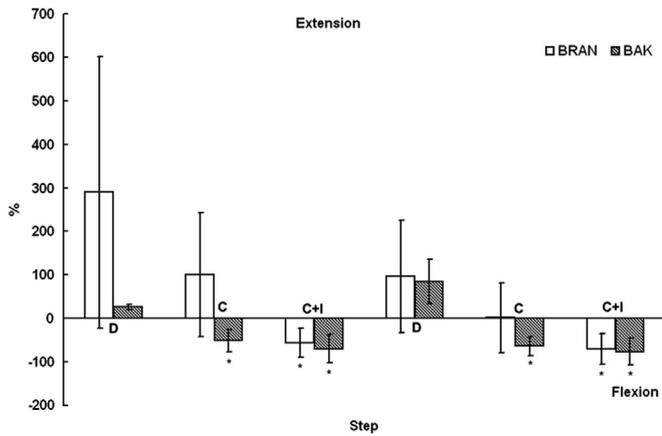


Fig. 2. Percentage changes (mean \pm SE) in left and right lateral bending motions for the Brantigan (BRAN) and Bagby and Kuslich (BAK) cages across the L4–L5 segments. Graphs are for a 6 Nm load step. (*Intact vs. remaining stages: $p < 0.05$.) C = cage only; C+I = cage plus instrumentation; D = destruction.

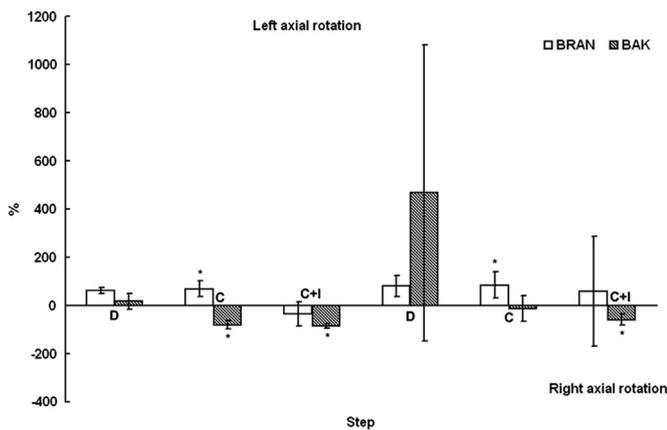


Fig. 3. Percentage changes (mean \pm SE) in left and right axial rotations for the Brantigan (BRAN) and Bagby and Kuslich (BAK) cages across the L4–L5 segments. Graphs are for a 6 Nm load step. (*Intact vs. remaining stages: $p < 0.05$.) C = cage only; C+I = cage plus instrumentation; D = destruction.

flexion, and left and right lateral bending at the cage only stage ($p > 0.05$). However, the percentage changes were found to be significantly higher than the intact stage than in left and right axial rotation ($p < 0.05$). After implanting the posterior instrumentation, the percentage changes became significantly lower than the intact stage in extension, flexion, and left and right lateral bending ($p < 0.05$). Moreover, there were no significant differences in the percentage changes to the intact stage in left and right axial rotation ($p > 0.05$).

In the BAK group, the percentage changes were found to be significantly lower than the intact stage in extension, flexion, left and right lateral bending, and left axial rotation at the cage only stage ($p < 0.05$). Moreover, there was no significant difference in the percentage change between the cage only and intact stages in right axial rotation ($p > 0.05$). After implantation of posterior instrumentation, the percentages changes were found to be significantly lower than the intact stage in the six directions ($p < 0.05$) (Figs. 1–3).

Comparisons of the two cage implantations were also made (Table 1). There were no significant differences in the percentage changes in rotations compared to the intact case between the two implantations at the destabilization stage ($p > 0.05$), although the

Table 1

Average percent change in rotations for the two cages (Brantigan cages – BRAN, Bagby and Kuslich cages – BAK) in various loading modes, as compared to the intact cases. Data correspond to 6.0 Nm load step. The data were obtained at the stages of destruction, cage only, and cage plus instrumentation. Percentages were calculated as $100 \times (\text{Angular rotation} - \text{Angular rotation at intact stage}) / \text{Angular rotation at intact stage}$.

Load type	Cage		<i>p</i>
	BRAN	BAK	
Destabilization			
Extension	289.74 \pm 312.03	26.31 \pm 6.00	0.34
Flexion	96.77 \pm 129.49	84.71 \pm 50.60	0.89
Left lateral bending	18.81 \pm 22.56	20.72 \pm 25.55	1.00
Right lateral bending	31.13 \pm 20.78	22.32 \pm 13.69	0.56
Left axial rotation	63.32 \pm 12.72	17.80 \pm 33.03	0.06
Right axial rotation	80.93 \pm 43.98	467.56 \pm 614.03	1.00
Cage only			
Extension	101.30 \pm 142.36	-51.06 \pm 25.37	0.04
Flexion	1.63 \pm 79.52	-63.13 \pm 21.80	0.15
Left lateral bending	-17.83 \pm 17.31	-71.46 \pm 9.04	0.02
Right lateral bending	-8.74 \pm 22.52	-78.82 \pm 12.31	0.02
Left axial rotation	69.62 \pm 32.91	-80.10 \pm 16.95	0.02
Right axial rotation	85.85 \pm 53.59	-12.05 \pm 53.70	0.04
Cage plus instrumentation			
Extension	-55.61 \pm 33.80	-69.31 \pm 32.81	0.77
Flexion	-69.68 \pm 34.64	-76.65 \pm 30.90	0.56
Left lateral bending	-75.21 \pm 18.59	-84.11 \pm 10.88	0.39
Right lateral bending	-63.82 \pm 38.78	-88.24 \pm 1.43	0.08
Left axial rotation	-33.28 \pm 50.32	-83.73 \pm 9.86	0.25
Right axial rotation	59.18 \pm 229.47	-58.69 \pm 24.00	0.77

intra-group variations were very high. However, the BAK group was found to have lower percentage changes than the Brantigan group in extension (101.30% vs. -51.06%), left (-17.83% vs. -71.46%) and right (-8.74% vs. -78.82%) lateral bending, and left (69.62% vs. -80.10%) and right (85.85% vs. -12.05%) axial rotation ($p < 0.05$) whereas there was no significant difference in the percentage changes between the two groups in flexion ($p > 0.05$). After implementation of the addition posterior instrumentation, no significant differences were found in the percentage changes between the two groups in the six directions ($p > 0.05$).

4. Discussion

The BAK device is a titanium screw cage that is inserted between the end plates into the disk spaces and has the capacity to hold a bone graft.¹⁶ Although this cage may have complications associated with PLIF,¹⁷ a recent study indicates that the early positive benefits of interbody fusion cage procedures are maintained through 4 years with acceptably low morbidity.¹⁸ Moreover, *in vivo* and *in vitro* studies demonstrated that the BAK cage is a superior interbody fusion device than other graft material. In a calf spine model, the BAK cage with posterior instrumentation was found to have the greatest stiffness in flexion/extension and axial rotation while a bone graft alone had less initial stiffness than that of the intact spine.³ Using an *in vitro* human cadaveric model, implantation of the BAK cage on L5–S1 via an anterior approach was demonstrated to have the advantage of increasing the stiffness in all directions except in extension. The biomechanical change in extension is mainly due to the destruction of anterior longitudinal ligament and anterior annulus.¹⁹ Moreover, this cage has similar biomechanical characteristics as the Threaded Interbody Fusion Device or SynCage.²⁰ In a sheep thoracic spine model, the BAK cages with bone graft or recombinant human bone morphogenetic proteins have been shown to have the same effects in biomechanics and histomorphometry as a bone graft alone.²¹

The Brantigan cage is made of carbon fiber. The cage-like implant has ridges or teeth to resist pullout or retropulsion, struts to support weight bearing, and a hollow center for packing of autologous bone graft.⁷ The biocompatibility of this material has been evaluated in Spanish goat. Moreover, it required a shorter interval for fusion than allograft.⁸ This cage design not only provides a compression similar to bone graft but also has a higher pull-out. Moreover, it has the advantages of providing rigid support and precision of dimensions and it requires no donor bone.⁷ The implantation of this device may also avoid the blood-borne viral infections such as AIDS and hepatitis.⁸ Recently, this cage has been evaluated to achieve clinical success in 32 of 37 patients (86.5%) at 24 months and in 29 of 33 patients (87.8%) at 10 years. Although adjacent segment degeneration was common, this complication was considered not clinically significant.²²

Although *in vitro* tests on these two cage designs employing a functional spinal unit or animal spine model provided valuable information on these two cage designs, the knowledge on the performance of these cages on cadaver spine for interbody fusion is not available. Moreover, biomechanical evaluation using multi-segmental models should be more appropriate for the simulation of the physiologic movements.¹ In this study, we employed human cadaveric lumbar spines (L2–S1) to evaluate the biomechanical characteristics of the Brantigan and BAK cages. In this cadaveric model, the Brantigan cage alone was not able to restore the spine to the intact stage in the axial rotations. However, it was able to provide stabilities at least equivalent to the intact spine in the remaining four directions. The BAK cage was able to provide improvement to the stabilities of the spine in all directions except right axial rotation. However, these differences did not exist after implanting the additional posterior instrumentation. These findings indicate that implantation of posterior instrumentation may reduce the differences between cage designs with different geometric characteristics.

Based on the results of this study, the Brantigan group had larger percentage changes in movement in axial rotations. These findings may be attributed to its rectangular geometry and intervertebrate implantation. According to the Food and Drug Administration of the USA, the Brantigan cage is approved to be only used with supplementary posterior instrumentation whereas BAK may be used as a stand-alone device. In our recent study, we determined that the supplementary posterior instrumentation may reduce the subtle differences in the implementations of conventional two parallel BAK cages and one oblique BAK cage.²³ This study provided further biomechanical evidence for the effectiveness of the supplementary posterior instrumentation. Implanting both cages with supplementary posterior instrumentation may also lead to more satisfactory clinical outcomes.

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