Shih-Tien Wang · Vijay K. Goel · Chong-Yau Fu ·
Shinichiro Kubo · Woosung Choi · Chien-Lin Liu ·
Tain-Hsiung Chen

Comparison of two interbody fusion cages for posterior lumbar interbody fusion in a cadaveric model

Received: 3 December 2005 / Accepted: 15 December 2005 / Published online: 28 February 2006
© Springer-Verlag 2006

Abstract Although the Brantigan cage and Bagby and Kuslich (BAK) cage have different geometrical characteristics, clinical observations suggest that they are equally effective in restoring disc height and stability across the involved spinal segments. This study was designed to compare their performance as posterior lumbar interbody fusion devices at two levels in fresh ligamentous cadaver lumbar spines (L2–S1). After mounting in a testing frame, the three-dimensional load-displacement behaviour of each vertebra was quantified using the Selspot II Motion Measurement System for; the intact state, posterior decompression, and stabilisation, using a pair of Brantigan or BAK cages across L4–S1, additional stabilisation using Isola spinal instrumentation across L4–S1, and cyclic loading in flexion/extension. In the “cage-only” state, the Brantigan cage did not restore the stability in right axial rotation, whereas the BAK cage not only restored stability in all six directions but also improved lateral bending. After implanting the posterior instrumentation, both groups ex-

hibited similar stability, and cyclic loading did not alter this. Although the Brantigan cage appears less effective than the BAK cage, implantation of posterior instrumentation significantly improves stability and reduces the differences between them. This underscores the need to use posterior instrumentation to achieve a higher initial stability.

Résumé Les cages de type Brantigan, Bagby et Kulich (BAK) ont des caractéristiques géométriques différentes pouvant avoir des conséquences cliniques également différentes, notamment en ce qui concerne la restauration de la hauteur des disques et la stabilité des différents segments vertébraux. Cette étude est destinée à comparer la stabilité et la fusion lombaire postérieure intercorporelle aux niveaux rachidiens ; il s’agit d’une expérimentation menée sur des colonnes lombaires prélevées sur cadavres frais. Différentes cages ont été testées en utilisant le système Selspot II et un montage postérieur type Isola, les cages étant positionnées de L4 à S1. Les cages de type Brantigan ne donnent pas de stabilité satisfaisante, notamment en rotation alors que la cage BAK non seulement restaure cette stabilité mais encore l’améliore dans six directions différentes en bending latéral. Avec la mise en place d’une autre instrumentation postérieure on retrouve une stabilité sur les deux types de cages, cependant la cage Brantigan n’apparaît pas aussi efficiente que la cage BAK, elle nécessite l’implantation de matériel postérieur de stabilisation.

S.-T. Wang (✉) · C.-L. Liu · T.-H. Chen
Department of Orthopedics and Traumatology, Veterans
General Hospital-Taipei and National Yang Ming University,
Taipei, Taiwan, Republic of China
e-mail: stwang@vghtpe.gov.tw
Tel.: +886-2-28757558
Fax: +886-2-28745839

V. K. Goel
Spine Research Center, University of Toledo and
Medical College of Ohio,
Toledo, OH, USA

C.-Y. Fu
Institute of Public Health, National Yang Ming University,
Taipei, Taiwan, Republic of China

S. Kubo
Department of Orthopedic Surgery, Miyazaki Medical College,
Miyazaki, Japan

W. Choi
Department of Orthopaedics, Tae Jeon St. Mary’s Hospital,
The Catholic University of Korea,
Seoul, South Korea

Introduction

Providing a solid fusion with complete neural decompression, restoration of normal intersegmental alignment and spinal balance, with preservation of normal spinal function are the goals of posterior lumbar interbody fusion (PLIF) in the treatment of spinal instability [14]. Since the inception of lumbar interbody fusion surgery using bone graft as the spacer in the mid-1940s [7, 13], clinical results show a wide variation in the fusion rate, ranging from 19% to 95%

[23]. In another study, 100% of patients lost disc height during the postoperative phase [9]. The recent interest in performing lumbar interbody arthrodesis using cages is partially due to the high failure rate and complications associated with the use of bone graft alone [20]. A number of interbody fusion cages have been developed to restore disc height and facilitate successful interbody fusion across one- or several spinal segments [2, 4, 15, 20, 25, 26].

The implantation of Bagby and Kuslich cages (BAK) are considered to be safe and effective for interbody fusion through the anterior or posterior approach [20, 26]. In a 2-year prospective, multi-center study, the BAK cage as PLIF showed an overall fusion rate of 86% at one year after surgery, which increased to 91% two years and 98% at three years. In the one-level cases, the rates were 87%, 94%, and 100% whereas the corresponding percentages in the two-level cases were 75%, 71%, and 90% respectively. In addition, no device-related death or complications were observed [16].

In 1991, Brantigan et al. described a carbon-fiber rectangular cage (the Brantigan cage, BRAN) [4]. This cage not only has a better mechanical strength than allograft [3] but also showed a 100% fusion rate among 26 patients in a two year follow-up investigation, as compared to 54.5% for allograft fusion [5].

From a biomechanical perspective, lumbar interbody fusion through an anterior, posterior, or posterolateral approach yields rigid constructions [17]. Biomechanically, no statistically significant differences were found between the stabilities across one-segment fusions of the Stratec, Ray, and Brantigan cages [19]. However, there are no biomechanical data concerning the stabilities of the BAK and Brantigan cages when used to stabilise more than one segment. In this study, we used a cadaveric spine model to compare the BAK cage (Sulzer Spine-Tech Inc., Minneapolis MN, USA) and the Brantigan cage (DePuy-AcroMed, Raynham, MA, USA) implanted across the L4–S1 segments through a posterior approach. The effects of using supplementary posterior instrumentation on the stability were also investigated.

Materials and methods

Specimen preparation

To exclude highly degenerated, severe osteoporotic, malformation, metastatic, or fractured spinal segments from the study, the specimens were radiographed and the bone mineral densities were determined using DEXA (dual energy X-ray absorptiometry). Thus, eight intact fresh human cadaveric spines (L2–S1) were used for the testing. These spines were randomly assigned to two groups: four for the Brantigan cage and the remainder for the BAK cage. 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 mounted in polyester resin. To ensure a secure fixation, metallic screws were

inserted into the vertebral bodies before pouring the polyester resin. The methodology used in preparing the specimens and testing, as described below, is well-established and has been used by several groups, including our own [1, 10–12, 18].

Testing procedures

Each specimen was tested in the following states: (1) intact state, (2) destabilisation by bilateral laminectomy and discectomy across L4–S1, and stabilisation with two pairs of BAK cages or Brantigan cages, and (3) additional stabilisation using Isola instrumentation system (DePuy-AcroMed, Raynham, MA, USA) across L4–S1 (Figs. 1 and 2). Finally, all specimens were retested after fatiguing for 5,000 cycles of flexion and extension at frequency of 0.5 Hz. The cyclic motion was produced by exerting ± 3 Nm of bending moment in the MTS system (Material Testing Systems, Minneapolis, MN, USA). The surgical procedures were performed in accordance with the instructions of the manufacturer.

Testing steps

After fixing the spine to an immobile base plate within the 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 were applied to the loading frame attached to L2 through a system of arms, pulleys, and weights. The loads were applied to produce the following six motion types: extension (EXT), flexion (FLEX), right and left lateral bending (RLB, LLB), and right and left axial rotation (RAR, LAR). The three-

Fig. 1 Radiographs of a cadaveric spine specimen showing the insertion of Brantigan cages with posterior instrumentation across L4–L5–S1 segments via a posterior approach. **a** Anteroposterior view. **b** Lateral view

Fig. 2 Radiographs of a cadaveric spine specimen showing the insertion of Bagby and Kuslich cages with posterior instrumentation across L4–L5–S1 segments via a posterior approach. **a** Anteroposterior view. **b** Lateral view

dimensional (3-D) locations of the LEDs attached to the vertebral bodies and the base plate were quantified after each loading step, using the Selspot II Motion Measurement System (Innovision Systems, Inc., Warren, MI, USA). To prevent dehydration during preparation and testing, specimens were sprayed with 0.9% NaCl solution.

Statistical analysis

The rigid body transformation was used to compute rotations of the vertebral bodies from the LED coordinates in various planes. The data for each case from all of the specimens in each group were polled to calculate mean and

standard deviation (SD) for different loading modes. Thus, the more rigid the spine, the smaller the rotation as compared to the intact case, and conversely the more unstable the spine, the greater the motion. Normalised data were calculated as: $100 \times (\text{angular rotation following a procedure} - \text{angular rotation at intact stage}) / \text{angular rotation at intact stage}$. The data with and without normalisation 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. STATA 7.0 was used for plots and statistical analysis [24].

Results

In this study, the specimens were obtained from three females and five males aged from 46 to 78 years (62.8 ± 13.1 years). Averages and SD of the bone mineral densities were respectively 0.9 ± 0.3 g/cm² (range 0.20–1.12 g/cm²), 0.9 ± 0.3 g/cm² (0.16–1.12 g/cm²), 0.9 ± 0.3 g/cm² (0.16–1.17 g/cm²), 0.8 ± 0.3 g/cm² (0.14–1.08 g/cm²) at L2, L3, L4, and L5 respectively. There were no significant differences in these parameters for the specimens implanted with the Brantigan cages (0.8 ± 0.4 g/cm² at L2, 0.8 ± 0.4 g/cm² at L3, 0.8 ± 0.4 g/cm² at L4, and 0.7 ± 0.4 g/cm² at L5) and those with the BAK cages (1.0 ± 0.1 g/cm² at L2, 1.1 ± 0.1 g/cm² at L3, 1.0 ± 0.1 g/cm² at L4, and 0.9 ± 0.1 g/cm² at L5) groups ($P > 0.05$).

The angular data across L4–L5–S1 for various procedures including the intact case for various load types for the two cage implantations are shown in Table 1. In the Brantigan group, the mean angular change for the “cage-

Table 1 Average (SD) angular changes in rotations in various loading modes for Brantigan (BRAN) and Bagby and Kuslich (BAK) cages across the L4–L5–S1 segments ($n = 4$). Data correspond to the 6.0-Nm load step

Step	BRAN	BAK	BRAN	BAK
	Extension (°)		Flexion (°)	
I	5.05 ± 1.89	6.17 ± 1.39	-15.83 ± 15.58	-11.99 ± 3.83
C	7.05 ± 2.47	4.23 ± 2.31	-12.04 ± 4.65	-7.34 ± 3.03
C + I	0.85 ± 0.76^b	0.68 ± 0.17^b	-0.95 ± 0.49^b	-0.9 ± 0.47^b
C + I + F	1.23 ± 0.92	0.67 ± 0.39	-1.11 ± 0.96	-1.08 ± 0.53
	Left lateral bending (°)		Right lateral bending (°)	
I	7.99 ± 4.9	5.67 ± 1.62	-7.56 ± 5.66	-5.65 ± 1.65
C	7.77 ± 3.42	2.25 ± 1.02^a	-6.41 ± 3.10	-1.98 ± 0.84^a
C + I	0.92 ± 0.48^b	0.70 ± 0.28^b	-0.81 ± 0.21^b	-0.64 ± 0.21^b
C + I + F	0.91 ± 0.42	0.91 ± 0.38	-0.72 ± 0.47	-0.72 ± 0.18
	Left axial rotation (°)		Right axial rotation (°)	
I	2.05 ± 0.98	3.07 ± 1.54	-2.23 ± 0.78	-2.92 ± 1.13
C	3.71 ± 1.91	1.82 ± 0.8	-4.43 ± 1.69^a	-1.86 ± 0.89
C + I	0.96 ± 0.41^b	0.55 ± 0.16^b	-0.75 ± 0.17^b	-0.78 ± 0.31^b
C + I + F	0.90 ± 0.33	0.59 ± 0.21	-0.83 ± 0.19	-0.68 ± 0.24

The nomenclature used is: intact stage (I), cage-only (C), cage plus instrumentation (C + I), and cage plus instrumentation after cyclic loading (C + I + F)

I vs C: ^a $P < 0.05$. C vs C+I: ^b $P < 0.05$

only" stage (-4.43°) was significantly higher than that at the intact stage (-2.23°) in right axial rotation ($P < 0.05$). However, there was no significant difference in the average motions between the two stages in the remaining five directions ($P > 0.05$). In the BAK group, there was no significant difference in the average angular motions between the intact and cage-only stage in extension, flexion, left axial rotation, and right axial rotation ($P > 0.05$). Moreover, the average motion after implementation of the cages became significantly smaller than those in the intact stage in left (intact 5.67° vs cage-only 2.25°) or right (intact -5.65° vs cage-only -1.98°) lateral bending ($P < 0.05$).

After implementation of the posterior instrumentation in both groups, the average angular motion became significantly smaller than the values obtained in the cage-only stage for all of the six directions ($P < 0.05$). In addition, there was no significant difference between the average motion for the cage plus posterior instrumentation before and after cyclic loading ($P > 0.05$). Moreover, there was also no significant difference in the average angular motion between the two designs of cage in the six directions at cage plus posterior instrumentation and after cyclic loading ($P > 0.05$) (Table 1).

The percentage changes in rotation, as compared to the intact case, revealed several other comparative trends in the effectiveness of the cage orientation in imparting stability to the decompressed segment. The Brantigan cages appeared significantly less effective in providing stability as compared to the BAK group in left and right bending and left and right axial rotation ($P < 0.05$). However, application of additional posterior instrumentation significantly reduced these differences, and there were no significant differences in the percentage angular changes, even after cyclic loading ($P > 0.05$) (Figs. 3, 4 and 5).

Discussion

BAK cages have been demonstrated to be superior to other graft materials in interbody fusion both in vivo and in vitro [6, 8, 21, 22]. The biomechanics of BAK has been compared with bone graft alone using a calf-spine model. Although the results were inconclusive in axial compression, the BAK cage with posterior instrumentation was found to have the greatest stiffness in flexion/extension and axial rotation, while bone graft alone had less initial stiffness than that of the intact spine [6]. Using an in vitro human cadaveric model, implantation of the BAK cage from L5–S1 via an anterior approach was demonstrated to have the advantage of increasing the stiffness in all directions except in extension. The ineffectiveness in extension is mainly due to the destruction of anterior longitudinal ligament and anterior annulus [21]. In an in vivo study using a sheep thoracic spine model, the BAK cages with bone graft or recombinant human bone morphogenetic proteins were demonstrated to be similar to the bone graft alone, in terms of biomechanics and histomorphometry [8].

Based on clinical studies, both BAK and Brantigan cages are effective posterior lumbar interbody fusion devices in restoring disc height and stability across the involved spinal segments [5, 16]. The BAK cage is a hollow, porous, squared-threaded, slightly tapered, cylindrical, titanium device. The tapered leading edge, the large cephalocaudal holes, and the square threads cut bone on insertion such that the implant is driven into the bone and provides intimate contact between the bone graft and the vertebral bodies [16]. The Brantigan cage is rectangular in structure and made of carbon fibre. Although this cage provides a compression similar to bone graft, it has higher pull-out strength than allograft bone. It has the advantages of providing rigid support and precision of dimensions

Fig. 3 Average percentage change in extension and flexion rotations for the Brantigan (BRAN) and Bagby and Kuslich (BAK) cases across the L4–L5–S1 segments. Nomenclature used is: C—cage-only, C+I—cage plus instrumentation, C+I+F—cage plus instrumentation after cyclic loading. Graphs are for 6 Nm load step. Percentages were calculated as $100 \times (\text{angular rotation} - \text{angular rotation at intact stage}) / \text{angular rotation at intact stage}$. BRAN vs BAK: * $P < 0.05$

Fig. 4 Average percentage change in left and right lateral bending motions for the Brantigan (BRAN) and Bagby and Kuslich (BAK) cases across the L4–L5–S1 segments. Nomenclature used is: C—cage only, C+I—cage plus instrumentation, C+I+F—cage plus instrumentation after cyclic loading. Graphs are for 6 Nm load step. Percentages were calculated as $100 \times (\text{angular rotation} - \text{angular rotation at intact stage}) / \text{angular rotation at intact stage}$. BRAN vs BAK: * $P < 0.05$

without the need for donor bone, thus avoiding blood-borne viral infections [3]. However, BAK cages also have these advantages [22].

Although in vitro tests employing functional spinal units or animal spine models provided valuable information on these two cage designs, little is known about their performance at multiple levels in the cadaveric spine. The stability results of one motion segment may not be applicable to multi-segmental cases. Biomechanical evaluation using multi-segmental models is more appropriate for the simulation of the physiological movements [17].

In this study, we used human cadaveric lumbar spines (L2 to S1) to evaluate the biomechanical characteristics of the Brantigan and BAK cages. The Brantigan cage may

restore the stability of the spine to the intact stage, whereas the BAK cage may not only restore the stability in four directions but also provide more stability in left and right lateral bending. However, this difference in angular rotation did not exist after adding 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 significantly larger angular movement in lateral bending than the intact stage. Moreover, this cage design also appeared significantly less effective in providing stability than the BAK cages in left and right bending and left and right axial rotation. These findings may be

Fig. 5 Average percentage change in left and right axial rotations for the Brantigan (BRAN) and Bagby and Kuslich (BAK) cases across the L4–L5–S1 segments. Nomenclature used is: C—cage only, C+I—cage plus instrumentation, C+I+F—cage plus instrumentation after cyclic loading. Graphs are for 6 Nm load step. Data for all of the specimens is included and the solid lines represent averages of the group. Percentages were calculated as $100 \times (\text{angular rotation} - \text{angular rotation at intact stage}) / \text{Angular rotation at intact stage}$. BRAN vs BAK: * $P < 0.05$

attributed to its rectangular geometry and the design in that it does not cut into the endplates. According to the Food and Drug Administration, the Brantigan cage is approved to be only used with supplementary posterior instrumentation, whereas BAK may be used as a stand-alone device. This study provided biomechanical evidence to support these recommendations. Implanting both cages with supplementary posterior instrumentation may also lead to better clinical outcomes.

Acknowledgements This study was supported in part by DePuy-AcroMed. Sulzer Spine-Tech Inc. provided the Bagby and Kuslich (BAK) cages. The authors thank Mr. Justin Coppes for his valuable technical support.

References

1. Abumi K, Panjabi M, Duranceu J (1989) Biomechanical evaluation of spinal fixation devices. Part III. Stability provided by six spinal fixation devices and interbody bone graft. *Spine* 14:1239–1255
2. Bagby GW (1988) Arthrodesis by the distractive-compression method using a stainless steel implant. *Orthopaedics* 11:931–934
3. Brantigan JW, McAfee PC, Cunningham BW, Wang H, Orbegoso CM (1994) Interbody lumbar fusion using a carbon fiber cage implant versus allograft bone. An investigational study in the Spanish goat. *Spine* 19:1436–1444
4. Brantigan JW, Steffee AD, Geiger JM (1991) A carbon fiber implant to aid interbody fusion: Mechanical testing. *Spine* 16: S277–S282
5. Brantigan JW, Steffee AD (1993) A carbon fiber implant to aid interbody lumbar fusion. Two-year clinical results in the first 26 patients. *Spine* 18:2106–2117
6. Brodke DS, Dick JC, Kunz DN, McCabe R, Zdeblick TA (1997) Posterior lumbar interbody fusion. A biomedical comparison, including a new threaded cage. *Spine* 22:26–31
7. Cloward RB (1953) The treatment of ruptured lumbar intervertebral discs by vertebral body fusion. *J Neurosurg* 10:154–168
8. Cunningham BW, Kanayama M, Parker LM, Weis JC, Seftor JC, Fedder IL, Mcfee PC (1999) Osteogenic protein versus autologous interbody arthrodesis in the sheep thoracic spine. A comparative endoscopic study using the Bagby and Kuslich interbody fusion device. *Spine* 24:509–518
9. Dennis S, Watkins R, Landaker S, Dillin W (1989) Comparison of disc space heights after anterior lumbar interbody fusion. *Spine* 14:876–878
10. Goel VK, Lim TH, Gwon J, Chen JY, Winterbottom J, Park J, Weinstein J, Ahn JY (1991) Effects of rigidity of an internal fixation device: a comprehensive biomechanical investigation. *Spine* 16:S155–S161
11. Goel VK, Voo LM, Weinstein JN, Liu YK, Okuma T, Njus GO (1988) Response of the ligamentous lumbar spine to cyclic bending loads. *Spine* 13:294–300
12. Hitchon PW, Goel VK, Serhan H, Rogge T, Grosland N, Sairyo K, Torner J (1999) Biomechanical studies on two anterior thoracolumbar implants in cadaveric spines. *Spine* 24:213–218
13. Jaslow IA (1946) Intercorporeal bone graft in spinal fusion after disc removal. *Surg Gynecol Obstet* 82:215–218
14. Keppler L, Steffee AD, Biscup RS (1997) Posterior lumbar interbody fusion with variable screw placement and Isola instrumentation. In: Bridwell KH, DeWald RL (eds) *The Textbook of Spinal Surgery*, 2nd edn. Lippincott-Raven, Philadelphia: pp 1601–1621
15. Kozak JA, O'Brein JP (1990) Simultaneous combined anterior and posterior fusion: An independent analysis of a treatment for the disabled low back pain patient. *Spine* 15:322–328
16. Kuslich SD, Ulstrom CL, Griffith SL, Ahern JW, Dowdle JD (1998) The Bagby and Kuslich method of lumbar interbody fusion. History, technique, and 2-year follow-up results of a United States prospective, multicenter trial. *Spine* 23:1267–1279
17. Lee CK, Langrana NA (1984) Lumbosacral spinal fusion. A biomechanical study. *Spine* 9:574–581
18. Lim T, An H, Hong J, Ahn J, You J, Eck J, McGrady L (1997) Biomechanical evaluation of anterior and posterior fixations in an unstable calf spine model. *Spine* 22:261–266
19. Lund T, Oxland TR, Jost B, Cripton P, Grassmann S, Etter C, Nolte LP (1998) Interbody cage stabilisation in the lumbar spine. Biomechanical evaluation of cage design, posterior instrumentation and bone density. *J Bone Joint Surg Br* 80:351–359
20. McCafee PC (1999) Interbody fusion cages in reconstructive operations on the spine. *J Bone Joint Surg Am* 81:859–880
21. Nibu K, Panjabi MM, Oxland T, Cholewicki J (1997) Multi-directional stabilizing potential of BAK interbody spinal fusion system for anterior surgery. *J Spinal Disorders* 10:357–362
22. Rapoff AJ, Ghanayem AJ, Zdeblick TA (1997) Biomechanical comparison of posterior lumbar interbody fusion cages. *Spine* 22:2375–2379
23. Schlegel J, Yuan H, Fredricksen B (1991) Anterior interbody fixation devices. In: Frymoyer JW (ed) *The Adult Spine*. Raven Press, New York, pp 1947–1960
24. StataCorp (2001) *Stata Statistical Software: Release 7.0*. College Station. Reference Q-St. Stata Corporation, TX. pp. 213–220
25. Tencer AF, Hampton D, Eddy S (1995) Biomechanical properties of threaded inserts for lumbar interbody spinal fusion. *Spine* 20:2408–2414
26. Weiner BK, Fraser RD (1998) Spine Update. Lumbar interbody cages. *Spine* 23:634–640