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A two-cage reconstruction versus a single mega-cage reconstruction for lumbar interbody fusion: an experimental comparison

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Abstract *Background.* Interbody cages are used as an adjunct to anterior lumbar interbody fusion, but exposure and insertion of two cages can be difficult. A biomechanical study was performed to compare the stability and exposed surface for fusion obtained with interbody reconstruction using two traditional cylindrical cages (18-mm diameter) vs. a single expanded mega-cage (24-mm diameter). A single-cage technique could result in safer exposure, shorter operating time, and less cost. *Methods.* Study design: nondestructive testing of L5–S1 motion segments with cages compared the two configurations, and direct measure of the size of the fusion bed was made. Patient sample: 16 human cadaveric lumbar motion segments. Outcome measures: significant differences in motion segment stiffness and cancellous surface areas were compared using a Wilcoxon rank sum test. Motion segments were biomechanically tested intact, and then tested again after insertion of two interbody cages ($n=8$) or a single mega-cage ($n=8$). Nondestructive biomechanical loading was performed consisting of: (1) compression (maximum load 900 N); (2) Flexion, extension, left and right lateral bending (maximum moment 18 Nm); and (3) left and right torsion (maximum moment 10 Nm). From the load-deformation curves obtained, stiffness values were calculated to compare the two-cage and

the single mega-cage reconstructions. After testing, the specimens were disarticulated and the surface area of the endplate bed created in the cancellous bone (of both vertebrae) was measured to compare the potential vascular surface for osteogenesis with both constructs. *Results.* The averages of the normalized values of stiffness were significantly greater for the two-cage group as compared to the mega-cage group in flexion only (1.08 vs. 0.74, $p<0.05$). For extension, torsion and lateral bending there was no significant difference in stiffness. In compression the two-cage group was stiffer, although not significantly (0.92 vs. 0.68, $p<0.07$). The average cancellous bed surface area was slightly greater for the single-cage reconstruction (1,208 mm² vs. 1,155 mm²), although this difference was not significant. *Conclusions.* The stiffness with a single anterior mega-cage was significantly lower in flexion compared with two standard cages. However, in all other modes of testing the constructs were statistically equivalent, although neither construct was significantly stiffer than the intact specimen. Additionally, the single mega-cage provides an equivalent cancellous bed for fusion as compared to dual cages. While this study is not sufficient to recommend human application, these results and our previous experience with the successful in

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vivo use of a single cage in rhesus monkeys [4] suggest that the single expanded anterior cage may be an acceptable concept although subsidence risk needs further investigation. The potential advantages of a

single mega-cage (safer for the foramen, safer for the vessels, more consistent decortication and possibly cheaper) further suggest that examination should be given to this method as an approach to anterior inter-

body reconstruction in selected patients.

Keywords Stiffness · Interbody cages · Lumbar spine

Introduction

Interbody cages have gained increasing acceptance as an adjunct to anterior or posterior arthrodesis in lumbar interbody fusion [2, 5, 6, 7, 8, 11, 18, 24, 25, 29, 31, 32]. While various designs exist, a threaded cylindrical type is commonly used. Several authors have reported encouraging results with stand-alone threaded cages placed anteriorly [6, 11, 16, 18]. With threaded cages it is usual to insert two cages per disk space whenever possible, based on the presumption that two cages provide adequate stability whereas a single cage may not in a stand-alone application [28]. There is much published work on the use of two cages, and their orientation, in stabilization of the spine [9, 14, 17, 22, 23, 28].

While using two threaded cages for anterior lumbar interbody fusion may seem biomechanically correct, there are at least four practical problems encountered with this.

Fig. 1 Thicker disks require two larger diameter cages. These present as a wide overall reconstruction that may intrude into the foramen posterolaterally

Fig. 2 If there is marked endplate concavity and/or asymmetric placement of the cage, then the endplate may not be sufficiently decorticated to expose the cancellous blood supply for cellular ingrowth

First, placing two cages creates a wider reconstruction and may present a potential risk posterolaterally at the foramen (Fig. 1). This is especially an issue with a tall disk, when larger diameter cages are necessary to achieve adequate distraction and endplate reaming. This risk is further compounded if cage placement is off center. Second, diameter constraints allow for only 3–4 mm of endplate penetration with reaming or tapping. If there is marked endplate concavity, the midportion of the endplate may not be sufficiently decorticated to expose the cancellous blood supply for cellular ingrowth. This potential problem will be compounded if the cage is not placed exactly parallel to the endplates (Fig. 2).

A third potential problem presented by the placement of two cages is the very wide vascular mobilization and extreme lateral vascular retraction that is sometimes necessary to provide a safe working zone for two cages side by side. This may place the iliac vessels at risk during reaming or insertion, especially at L4–L5 or with a bifurcation located near the disk space. Far lateral mobilization of the vessels in revision cases with two cages is particularly risky and revision of a single cage would be potentially less dangerous. The fourth problem arising from the use of two cages is the potential for loosening of the first cage following insertion of the second cage [15].

One solution to these four problems would be to insert a single cage of larger diameter (i.e. a mega-cage). We see several potential advantages of a single cage: (1) a single cage would reduce the lateral exposure required for insertion, hence reducing the risk to the foramen and great vessels during insertion; (2) A single cage of larger diameter would allow for consistent endplate penetration, which might enhance exposure of the cancellous blood supply, theoretically promoting osteogenesis; (3) using a single cage could result in lower direct cost to the patient by reducing implants and shortening operative time. Finally, evolving minimally invasive techniques may be more easily adapted to single cage insertion. These theoretical advantages of a single cage of larger diameter have to be weighed against potential disadvantages, particularly the biomechanical ones of stability and subsidence.

We reported on laparoscopic fusion with rhBMP-2 in an interbody cage using rhesus monkeys in a study to address efficacy and dose of BMP [4]. An interesting observation emerged from that in-vivo primate work, since the study utilized a single threaded cage. The use of a single interbody cage in fully active and unrestrained monkeys resulted in no evidence of instability or biomechanical

failure. We observed no subsidence, implant failure, or migration on serial radiographs or postmortem studies [4]. We reasoned that if a single cage was clinically successful in vivo for nonhuman primates, it might also be considered for humans. These observations with a single cage in monkeys, together with the four practical problems outlined above for two cages, prompted this study. Our purpose was; (1) to compare the biomechanical properties of a standard reconstruction using two threaded cages (18-mm diameter) with a single mega-cage (24-mm diameter); and (2) to compare the surface area of the cancellous bed created by placing two 18-mm cages or a single 24-mm cage. We considered that the surface area of the cancellous bed should correlate positively to blood supply for osteogenesis.

Materials and methods

Cadaveric material

After screening over 40 specimens, 16 L5–S1 lumbar motion segments were selected from fresh human cadavers (age 67–89 years). None of the specimens had a history of spinal disease and each was radiographed to ensure that no structural abnormalities were present. These 16 were selected due to very similar characteristics of L5–S1 disk and vertebral morphology. Each specimen was assessed at grade 2 degeneration with the method of Galante et al., on a scale of 1–4, with 1 showing no degeneration and 4 severe degeneration [12]. Importantly, selected specimens also had to have a disk height of 8–10 mm, using surgical X-ray templates. Templating was done using standard preoperative radiographic templates (Medtronic Sofamor Danek, Memphis, TN) to ensure that each disk space was correctly suited for an 18-mm-diameter cage.

Eight motion segments were then randomized to receive two cages and the other eight a single mega-cage. In the two-cage group, there were five males and three females with a mean age of 78.0 years (range 67–89 years). Four of these disks were templated to 8-mm-high and the other four to 10-mm-high, as measured from X-ray templates. In the single mega-cage group, there were also five males and three females with a mean age of 77.8 years (range 67–88 years). Four of these disks were also templated to 8-mm-high and the other four to 10 mm. All specimens were frozen to -50°C and stored until the day before testing, when they were allowed to thaw slowly to room temperature.

Specimen preparation

Each motion segment was stripped of muscle, with care taken to preserve all ligaments, joint capsules, disks, and bone structures. Each vertebra of the L5–S1 motion segment was then potted up to its midbody in a 10-cm-diameter polyvinylchloride (PVC) end cap using dental cement (Fig. 3). A digital goniometer (accuracy of 0.1° and 1-sec dampening; Pro Smart Level, Wedge Innovations, San Jose, CA) was attached to the cap. This goniometer was used to detect any irregular rotation of the specimen.

Biomechanical loading sequence

The specimen was mounted in a materials testing machine (MTS, Minneapolis, MN), and after a cyclic compression conditioning period ($500\text{ N} \pm 75\text{ N}$, at 1 Hz, for 1,000 cycles) the motion segment was tested with an eight-step loading sequence. At each step, the

Fig. 3 The motion segment (with a single cage inserted) is shown potted in dental cement and in position in a clamp in the testing machine

load was applied three times and a load-deformation curve was obtained each time. The three load-deformation curves were always identical, and the first was used to calculate stiffness (see below).

Step 1 (Establishing the center of rotation)

The center of rotation for flexion/extension and lateral bending was established in the intact motion segment using a pure compressive load of 50 N applied through a ball bearing to the top surface of the end cap of L5. The load was applied, repositioned and reapplied until no angular rotation in the coronal or sagittal planes could be detected using the digital goniometer. (This was done to ensure that no bending of the specimen took place during pure compression at step 2). This spot on the end cap was designated the center of rotation and was clearly marked as the reference point for all the remaining steps.

Step 2 (Compression)

The specimen was then loaded at the center of rotation in pure compression with a displacement rate of 0.25 cm/min. Load was applied up to a maximum of 900 N and held for 2 sec before reading the goniometer. A load-deformation curve was obtained.

Step 3 (Flexion)

A 900 N load was then applied 2 cm anterior to the center of rotation, producing a maximum bending moment of 18 Nm (i.e. $0.02 \text{ m} \times 900 \text{ N} = 18 \text{ Nm}$) in flexion. A load-deformation curve was obtained. The specimen was never flexed more than 7° .

Step 4 (Extension)

The 900 N load was applied 2 cm posterior to the center of rotation, and a load-deformation curve was obtained. The specimen was never extended more than 7° .

Step 5 (Right lateral bending)

The 900 N load was applied 2 cm to the right of the center of rotation, and a load-deformation curve was obtained. The specimen was never laterally flexed more than 7° .

Step 6 (Left lateral bending)

The test was repeated as in step 5 with the load applied 2 cm to the left of the center of rotation. The specimen was never laterally flexed more than 7° .

Step 7 (Right axial torsion)

To apply axial torsion, the specimen was first compressed to 900 N and then an axial torque was applied in a clockwise motion (about the center of rotation), to a maximum of 10 Nm. A torque-angular deformation curve was obtained. The specimen was never twisted more than 2° .

Step 8 (Left axial torsion)

The test was repeated as in step 7 in a counterclockwise direction.

Experimental protocol carried out on each motion segment

Condition 1 (Intact specimen)

The center of rotation for the intact specimen was determined (step 1) and the intact specimen was tested with the entire loading sequence described above (steps 2–8).

Condition 2 (Specimen with the cage, or cages)

Interbody threaded cages (Medtronic Sofamor Danek, Memphis, TN) were inserted from the anterior approach in accordance with the manufacturer's instructions. We chose two standard 18-mm-major-diameter (16.25 mm minor diameter) cages for the two-cage group and a custom 24-mm-major-diameter (22.25-mm minor diameter) cage for the single-cage group. The pitch, thread design and length for the cages were identical; they only differed in diameter.

An anterior annulotomy for insertion of the dilator(s) was made with a 15 blade. For this experiment, a full manual discectomy was not done in order to avoid any variation that could be introduced by inconsistent manual techniques. This experiment utilized a consistent reamed discectomy technique (Medtronic Sofamor Danek, Memphis, TN) to minimize preparation variables, with all dilation, reaming and tapping done using standard instrumentation. Maxi-

mum dilation of the disk space was taken to 8 mm or 10 mm based on preoperative templating. Once dilation was complete, the working channel was inserted maintaining distraction at the fixed height during reaming. After reaming (18-mm or 24-mm diameter), cages were inserted and centered within the disk space. The center of rotation as measured on the intact specimen was then checked to ensure that it had not changed, and the motion segment with the inserted cage(s) was tested again according to steps 2–8 of the sequence.

Load-displacement curves

The stiffness of the motion segment was determined from each load-deformation curve. The deformation was noted when the curve reached 900 N (or 10 Nm in the case of torsion). This deformation was then divided by two and the slope of the latter half of the curve was measured (Fig. 4). We reasoned that the first half of the curve could have concealed displacement artifacts of the experimental setup, and it was not until these were removed that the effective stiffness was revealed. This method of measuring stiffness is similar to one published earlier [30].

Each value of stiffness for each loading sequence after cage insertion was then normalized against the corresponding value of stiffness for that motion segment intact specimen. For example, the stiffness in compression for the intact specimen A was 388 N/mm, and 318 N/mm after two cages had been inserted; this yielded a normalized value of 0.82 (i.e. $318/388=0.82$). This normalization allowed us to adjust for any individual variation in motion segment stiffness.

Vascular bed surface area

Fig. 5 shows the method used to calculate the surface area of the cancellous bone bed. R is the known radius of the cage, while

Fig. 4 A typical load-displacement curve. The stiffness of the specimen was obtained by measuring the slope (θ) of the latter half of the curve

Fig. 5 The calculation used to obtain the surface area of the cancellous bone bed

a and b were measured from the surface of the endplate after disarticulation and cage removal. From a, b, and R we calculated A and B, and then the surface area. Any concavity in the endplate was ignored in the calculations.

Statistics

Statistically significant differences in each of the measured values were tested for using a Wilcoxon rank sum test. Significance was established at the $p < 0.05$ level.

Results

For the intact specimens in all load directions, there was no significant difference in average stiffness between the eight motion segments allocated to the two-cage group and the eight motion segments allocated to the single-cage group.

The normalized values for stiffness of the single- and two-cage groups are shown in Fig. 6 and Table 1. Table 1 shows that after cage insertion the change in stiffness was less for the two-cage group than the mega-cage group, since normalized values for the two-cage group were closer to one. The respective averages of the normalized values for the two-cage group versus the single-cage group were 0.92 vs. 0.68 for compression, 1.08 vs. 0.74 for flexion, 0.91 vs. 0.83 for extension, 0.91 vs. 0.83 for right lateral bending, 0.91 vs. 0.82 for left lateral bending, 1.25 vs. 1.36 for right axial torsion and 1.17 vs. 1.18 for left axial torsion.

Overall, the two-cage construct was slightly stiffer than the single-cage construct. However none of the differences between the two-cage and single-cage group were statistically significant with the exception of flexion ($p = 0.02$). The difference in compression was not significant at the 0.05% level, but was significant at the 7% level. The stiff-

Fig. 6 The average values of normalized stiffness for the two-cage group and the mega-cage group as shown in Table 1. (COMP compression, FLEX flexion, EXT extension, RLB right lateral bending, LLB left lateral bending, RAT right axial torsion, and LAT left axial torsion). The only significant difference between the two groups is in flexion (error bar standard deviation; * significant difference $p < 0.05$)

ness of the constructs in lateral bending, extension and rotation were not different ($p > 0.3$). However, the power for each of our comparisons was noted to be low ($< 50\%$). The cancellous bed average surface area (Table 2) was slightly greater for the single-cage group (1,208 mm²) as compared to the two-cage group (1,155 mm²), though this difference was not significant ($p = 0.38$).

Discussion

The main findings from these experiments are: (1) overall, the two-cage construct was slightly more stiff than the single-cage construct, although none of the differences were statistically significant, except in flexion; (2) there was no reduction in the exposed cancellous bed using the mega-cage. Therefore a single mega-cage might be viable, with consideration for subsidence and the practical considerations of the four problems mentioned in the Introduction (i.e. a single cage should require less exposure and vascular retraction, pose less risk to the foramen, allow more consistent reaming and ingrowth, and be quicker and cheaper than two cages). However, we are unable to say with confidence that there is no difference between the two reconstructions, since the power for our comparisons was very low ($< 50\%$). Given the large standard deviations for the average normalized values, the sample size in some of the comparisons would need to be over 50 to obtain adequate power. Clearly, the difficulty of obtaining 50 suitable matched human motion segments is effectively prohibitive.

Table 1 The normalized values of stiffness for the two-cage group and the mega-cage group. Each number was obtained by dividing the value of stiffness of the specimen after the cage (or

cages) was inserted by the value of stiffness of the intact specimen. Values >1.0 indicate that the specimen was stiffer than the intact specimen

Group		COMP	FLEX	EXT	RLB	LLB	RAT	LAT
Two-cage group	A	0.82	1.00	0.93	0.98	1.16	1.06	1.05
	B	0.51	0.74	0.67	0.72	0.58	0.89	0.87
	C	0.72	1.03	1.13	0.87	1.00	0.78	0.80
	D	0.82	0.68	1.00	0.84	0.79	0.87	1.03
	E	0.99	1.55	0.71	0.80	0.71	1.55	1.49
	F	0.96	0.94	1.23	1.16	0.95	0.83	0.91
	G	0.89	1.05	0.72	0.85	0.94	2.69	1.86
	H	1.68	1.66	0.88	1.14	1.13	1.37	1.35
	Average	0.92	1.08	0.91	0.92	0.91	1.25	1.17
	SD	0.34	0.35	0.20	0.16	0.20	0.64	0.37
Mega-cage group	I	0.66	0.73	0.83	0.75	0.93	1.03	0.78
	J	1.06	0.94	1.02	1.24	1.05	2.34	1.31
	K	0.50	0.66	0.69	0.65	0.63	1.23	0.96
	L	0.56	0.59	0.69	0.66	0.66	1.29	1.51
	M	0.68	0.81	0.85	0.96	0.85	1.39	1.28
	N	0.78	0.80	1.04	0.96	1.01	1.00	1.29
	O	0.81	0.75	0.99	0.93	0.87	1.55	1.18
	P	0.40	0.62	0.52	0.50	0.54	1.01	1.17
	Average	0.68	0.74	0.83	0.83	0.82	1.36	1.18
	SD	0.21	0.12	0.19	0.24	0.19	0.45	0.22

Table 2 The values of exposed surface area of cancellous bone bed for the two-cage group and the mega-cage group. The theoretical values of exposed surface area of cancellous bone bed are shown at the bottom of the table; these theoretical values are based on the assumptions that: (1) the endplates are parallel and flat; (2) the cages are placed symmetrically in each endplate (see Results for more details)

Two-cage group			Mega-cage group		
Specimen	Surface area (mm ²)	Dilation height (mm)	Specimen	Surface area (mm ²)	Dilation height (mm)
B	1,116	8	I	1,295	8
C	877	10	J	1,244	10
D	1,439	8	K	915	10
E	1,110	8	L	1,330	8
F	1,169	10	M	955	10
G	1,275	8	N	1,261	10
H	1,096	10	O	1,363	8
			P	1,305	8
Mean	1,155	—	Mean	1,208	—
SD	160	—	SD	162	—
Theoretical	2,058	8	Theoretical	1,536	8
Theoretical	1,828	10	Theoretical	1,414	10

It would be ideal to have specimens with identical disk characteristics, vertebral morphology, and bone density. Over 40 specimens were screened to find 16 with matched overall morphology and identical templating. Bone density measurement was not available to us, and it is possible that variations in bone density could have affected our data. However, specimens were randomized by age and sex to minimize this variation.

The load limit of 900 N was chosen on the basis of it being a middle value within the range of 500 N for erect standing and 2,000 N for light labor [21]. Volkman et al. showed that this load allowed repeated cycles without

causing damage to the intervertebral joint [30]. An alternative method for testing is applying pure moments [3]. This method is more accurate for obtaining absolute values of stiffness, however, it does not easily allow for the high, physiological-type, compressive loads (such as 900 N) used here.

We have previously published studies using both the pure moment method [3] and the method presented here [20, 30]. We used the current method for this study to allow for loads we felt important to simulate in vivo conditions. Tencer et al. also used a similar method in their biomechanical study of lumbar cages [27]. Additionally, a

bending moment of 18 Nm was chosen because this is within the range applied to an intervertebral joint in vivo. This is the maximum value suggested by Adams et al. [1]. This method of applying bending introduces a small component of shear; however, since we were comparing each specimen with itself, the shear was the same in similar steps.

The rationale for the 24-mm-diameter single mega-cage was based on practical and anatomic considerations. In clinical practice dual cages of approximately 16- to 18-mm diameter are commonly used with reaming 3–4 mm off each endplate (i.e. dilators of 10–12 mm diameter for an 18-mm reamer and cage). In some cases asymmetric reaming or overly biconcave endplates result in incomplete cancellous bone exposure throughout the length of the reamed channel (Fig. 2).

Increasing the diameter in order to consistently expose a cancellous bed for vascular ingrowth to the graft was one consideration in choosing 24-mm diameter. However we did not want a diameter so large that a massive vertebral defect might result, in the event revision was ever necessary. Since the average lumbar vertebra is approximately 40 mm tall, a reaming defect of approximately 20% would exist with a 24-mm-diameter cage (i.e. 8-mm reaming depth into each vertebral body). This additional 6-mm diameter seemed an appropriate size compromise given considerations of achieving a consistent vascular channel without excessive defect in the vertebral body.

Complete disk excision is often felt necessary to provide a satisfactory environment for fusion, but this may not be achieved especially with laparoscopic and “reamed” technique [19]. Generally, we agree that complete manual discectomy is preferred, but we selected the reamed discectomy technique to avoid experimental variables introduced with manual techniques. We assume that exposed cancellous vertebral bone is key for cellular differentiation and ingrowth in the interbody fusion environment.

One important finding of the current study is that the area of vascularized bone bed offered by the single 24-mm-diameter cage was equivalent to the bone bed offered by two 18-mm-diameter cages. Table 2 shows that the measured values of the cancellous bed surface area for the mega-cage group were nearer to their theoretical maximum than the measured values for the two-cage group. It is interesting to note that the two lowest values of cancellous bed surface were obtained with the thicker disks (i.e. 10 mm). This would suggest that deeper reaming is more likely to penetrate the cancellous bed predictably.

One observation from these experiments was the potential for reduction in stiffness after cages were inserted, as illustrated by the number of normalized values less than 1.0 in Table 1. Our finding is similar to results by Tencer et al. [27] who reported that the threaded cage itself contributed little to construct stiffness. In our experiment, the load conditions were even harsher – which we feel mimic the in vivo condition (900 N and 18 Nm in our experiment versus 235 N and 10 Nm for Tencer et al.).

The observation of a potential stiffness decrease following one- or two-cage insertion certainly raises theoretical concern about “stand-alone” cage reconstruction clinically, which this study does not directly address. However, reports from authors such as Burkus et al. indicate very acceptable results in large series of patients (679 patients) with stand-alone ALIF cages [6]. While there are no human clinical series with “stand-alone” single mega-cages, Boden et al. observed that the in vivo use of a single cage in primates was clinically successful with no evidence of subsidence or mechanical failure [4]. It should be emphasized that our study deals only with the biomechanics of ALIF cages and not posterior interbody fusion (PLIF). The use of cages with PLIF is often done, and facet destruction creates further destabilization requiring supplemental pedicle screw fixation [10].

Fig. 7 **A** A motion segment bisected through the intervertebral disk after removal of the two-cages. The impression left by the cages reveals a lack of symmetry; very little exposed vascular bone bed on the left side (1). Note that the posterior foramen is at risk on the left side. Note how short the distance between the arrows at 2 is; compare this distance with that shown in B. **B** A motion segment bisected through the intervertebral disk after removal of the single mega-cage. Note the deep exposed cancellous bone bed (1) and the safe zone for the nerve root in the foramen. Note how much greater the distance between the arrows at 2 is, compared to A

In theory, the consistent exposure of the cancellous bed may be easier to achieve with the larger 24-mm-diameter cage since the reamed channel is deeper, which may be advantageous with asymmetric reaming or endplate bi-concavity (Fig. 7). The consistent cancellous bed offered by the mega-cage may be biologically advantageous but clearly may create new problems with subsidence. Grant et al. have shown that the central part of the endplate is the weakest part [13] and could also be the weakest zone of the underlying cancellous bone.

This concern has led some to design implant load bearing on the stronger rim of the endplate to reduce subsidence (e.g. Syncage cage: Synthes Spine, West Chester, PA). This has biomechanical appeal, but does create other practical issues of proximity to foramen and great vessels. Additionally, cages which are perched on the edge of the vertebrae with minimal peripheral bony coverage could be more risky if any displacement occurred. For these reasons we have continued investigations on cage designs that are more centrally located since they may provide a greater factor of safety for neurological and vascular structures. Some of these important biomechanical considerations could be further addressed with computer modeling.

As mentioned earlier, placement of two cages risks violation of the posterior foramina which can induce nerve root irritation postoperatively. Examination of the vertebral body after the motion segment was disarticulated revealed no risk to the posterior foramina in the single-cage reconstruction compared with the two-cage reconstruction (Fig. 7B). The single mega-cage technique clearly provided a wider "zone of safety" for the exiting nerve root.

Lumbar interbody fusion with, or without cages can produce a loss of disk height. In a study of anterior lumbar interbody fusion (using autogenous, autologous, or mixed iliac crest graft), Dennis et al. [9] noted that 100% of patients lost disk height during the postoperative phase. In an in vivo model using threaded cages, Sandhu et al. [26] showed an average of 20% postoperative loss of disk height attributable to bony subsidence. Our study provides no direct data about subsidence of a single cage versus two cages, although findings in flexion and compression could

suggest a greater potential for subsidence with mega-cage reconstruction. However, we did not observe any decrease in disk height during these experiments – but then again, our loads were not applied long term.

Additionally, Boden et al. did not observe any subsidence using single mega-cages in the primate [4]. The concern about subsidence merits further investigation, since there are also clear potential advantages to a single-cage concept. However, the current data might suggest that a single mega-cage be avoided with osteoporosis or instability where flexion loads may be a higher risk. Additionally, further modifications of the mega-cage could improve performance in flexion and compression and minimize subsidence.

Conclusions

In this study, the stiffness with a single anterior mega-cage was significantly lower in flexion compared with two standard cages. However, in all other modes of testing, the constructs were statistically equivalent, although neither construct was significantly stiffer than the intact specimen. Additionally, the single mega-cage provided an equivalent-sized cancellous bed for fusion as compared to the dual cages.

While this study is not sufficient to recommend human application, these results and our previous experience with successful in vivo use of single cages in monkeys suggest that the single anterior mega-cage may be an acceptable concept. However, the risk of subsidence will need further investigation. The potential advantages of inserting a single mega-cage (safer for the foramen, safer for the vessels, consistent decortication and possibly cheaper) also suggest that further examination be given to this method as an approach to anterior interbody reconstruction in selected patients.

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