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Biomechanical evaluation of immediate stability with rectangular versus cylindrical interbody cages in stabilization of the lumbar spine

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Abstract

Background: Recent cadaver studies show stability against axial rotation with a cylindrical cage is marginally superior to a rectangular cage. The purpose of this biomechanical study in cadaver spine was to evaluate the stability of a new rectangular titanium cage design, which has teeth similar to the threads of cylindrical cages to engage the endplates.

Methods: Ten motion segments (five L2-3, five L4-5) were tested. From each cadaver spine, one motion segment was fixed with a pair of cylindrical cages (BAK, Sulzer Medica) and the other with paired rectangular cages (Rotafix, Corin Spinal). Each specimen was tested in an unconstrained state, after cage introduction and after additional posterior translaminar screw fixation. The range of motion (ROM) in flexion-extension, lateral bending, and rotation was tested in a materials testing machine, with +/- 5 Nm cyclical load over 10 sec per cycle; data from the third cycle was captured for analysis.

Results: ROM in all directions was significantly reduced ($p < 0.05$) with both types of cages. There was no significant difference in reduction of ROM in flexion-extension ($p = 0.6$) and rotation ($p = 0.92$) between the two cage groups, but stability in lateral bending was marginally superior with the rectangular cages ($p = 0.11$). Additional posterior fixation further reduced the ROM significantly ($p < 0.05$) in most directions in both cage groups, but did not show any difference between the cage groups.

Conclusions: There was no significant difference in immediate stability in any direction between the threaded cylindrical cage and the new design of the rectangular cage with endplate teeth.

Background

Various designs of interbody fusion cages have been developed over the last few years for fusion of the lumbar spine. Interbody fusion cage provide structural support as well as restore original disc height to open the intervertebral foramen. Use of tricortical iliac crest allograft in anterior or posterior lumbar interbody fusion (ALIF or PLIF) tends to collapse over time, regardless of additional posterior fixation [1,2].

The type of surgical technique and approach are dependent on the design of the cage. The single large interbody implants e.g., SynCage® (STRATEC Medical Ltd. Welwin Garden City, UK) or Femoral Ring Allografts are used only for anterior interbody fusion by open approach. The smaller implants may be cylindrical or rectangular and are normally used in pairs. The cylindrical threaded interbody cages (BAK; Sulzer Spine-Tech Inc, Minneapolis, Minnesota and Ray TFC; Surgical Dynamics Inc, Concord, California) can be used for anterior or posterior interbody fusion and may be introduced by open or laparoscopic technique. The paired rectangular implants e.g., Brantigan carbon-fibre cage (DePuy-Acromed Corporation, Cleveland, Ohio) or Contact® titanium porous cages with smooth surface (Stratec Ltd. Welwin Garden City, UK) can be used for either ALIF or PLIF procedures by an open approach only. Rectangular cages are not normally recommended for laparascopic insertion.

The immediate three-dimensional stability depends on the cage design. In a study on calf and pig spine, two cylindrical implants were found to be more stable than one [3]. Lund et al [4] evaluated immediate stability with a rectangular porous titanium cage (Contact® cage), a rectangular carbon-fibre cage(Brantigan cage), and a cylindrical threaded titanium cage (Ray TFC) on cadaver spine. They found no significant difference in stabilizing potential of the three cage designs, but the cylindrical cage provided a marginally greater stability against axial rotation compared to the rectangular cages, which offered no stability at all against rotation. The Ray TFC cylindrical cages are designed to engage into the end-plate, where as the rectangular Contact® cages have smooth surface, designed to fit the endplate contours.

The purpose of this study is to evaluate the immediate stability in lumbar spine after fixation with a new design of rectangular titanium porous cage, which has teeth to engage into the endplate, and to compare it with a commonly used cylindrical cage (BAK).

Methods

The rectangular cage design

The newly designed rectangular cage (Fig 1) (made by Corin Spinal, Gloucestershire, UK) had a tapered rectangular design to restore the lumbar lordosis. The large central cavity allowed adequate space for packing large amount of cancellous bone graft inside the cage. The teeth on the superior and inferior surfaces were designed to engage into the endplate to provide additional stability. The cages were designed to be used in pair at each level, and could be used for either ALIF or PLIF procedures. The rectangular cage was inserted by its smaller diameter into the disc space, and then rotated by right angle to engage its teeth into the endplate, and to align the longer diameter of the cages cranio-caudally.

Figure 1
A. The rectangular cages (Corin). It has wedge shape with larger cranio-caudal diameter in front. The teeth are on the cranio-caudal surfaces. There is a large central cavity which can be filled with bone graft. The cages are designed to be inserted with smaller diameter into the disc space, and then rotated by 90° to orient its long diameter cranio-caudally and to engage the teeth into the endplate. B. The Cylindrical cages (BAK).

Specimen preparation

Ten functional spinal units (FSU; five L2-L3, five L4-L5) of human cadaver lumbar spine from 5 subjects (3 male, 2 female) were tested. The donors had a mean age of 76.4 years (range, 68 – 82 years). X-ray and bone densitometry were done to rule out any metastatic or metabolic bone disease. Varying degrees of degenerative changes were found in all of them. From the same cadaver spine one FSU was tested with the rectangular cages and the other with the cylindrical cages. The specimens were stored at -20°C until the 48 hours before testing.

On the day before testing the thawed specimens were stripped carefully all the soft tissues leaving the ligaments and joint capsules intact. Specimens were then potted with plaster of Paris in aluminium pots of the loading jig. To improve anchorage, screws were introduced obliquely into the vertebral bodies close to the endplates away from the disc space.

Test protocol

Each of the ten specimens was tested for flexibility of the intact spine, after stabilization with a pair of the either rectangular (Corin) or cylindrical (BAK) cages and after additional posterior stabilisation with a pair of translaminar facet screws, as described by Montesano and Magerl et al [5]. Five specimens were tested for each type of implant.

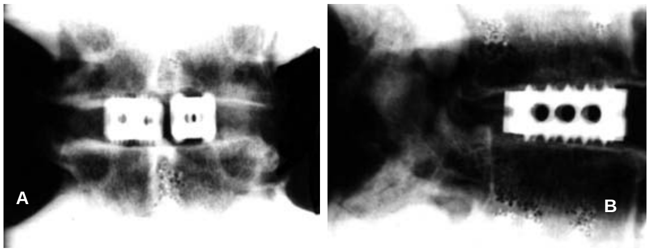

Figure 2
Rectangular (Corin) cages inserted from the anterior aspect (as in anterior lumbar interbody fusion). Radiographs confirmed proper cage position and adequate disc height restoration. A. Antero-Posterior view, B. Lateral view

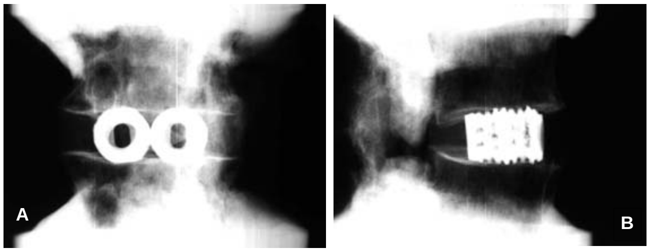

Figure 3
Cylindrical (BAK) cages inserted from the anterior aspect (as in anterior lumbar interbody fusion). Radiograph confirmed proper cage position and adequate disc height restoration. A. Antero-Posterior view, B. Lateral view

The cages were introduced through the anterior aspect, following the manufacturer's guidelines for surgical technique and estimation of desired disc height. Following stabilization with the cage A-P and lateral radiographs were obtained to ensure correct placement of the implants with adequate restoration of the disc height (Fig 2 and 3).

Measurement of flexibility

Flexibility was tested in a servo-hydraulic material-testing machine (Dartec Ltd., Stourbridge, UK) (Fig 4). Special loading jig of similar design as described by Chiba et al [6] was used for mounting the potted specimens eccentrically in the loading frame, to test the flexion-extension movement (Fig 5). The length of the lever arm from the axis of motion was 10 cm. A 50 N of preload was applied with a lever arm of 40 cm in the opposed direction, at the bottom end of the specimen (Fig 4). The specimens were rotated by 90° in the loading jig for testing the lateral bending movement (Fig 6A and 6B). A bending moment was used to produce flexion-extension and lateral bending by applying a vertical load to the eccentrically mounted specimen through the 10 cm lever arm. A preload of 50 N was applied to a lever arm of 40 cm from the fulcrum, in the opposite direction, at the bottom end of the specimen, as described by Chiba et al [6]. Two digital goniometers, placed at the junction of the loading frame and the lever arm, measured the angular displacement at the FSU with application of the bending moment.

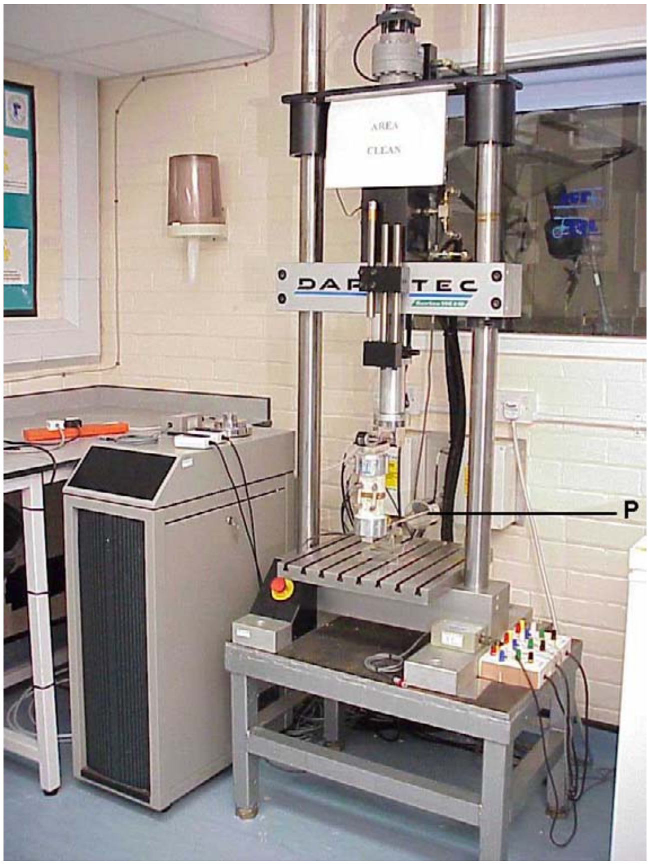

Figure 4
The Dartec® (Stourbridge, UK) material testing machine, with a spine model in the testing jig. A spine model is mounted in the jig, for eccentric loading using a 10 cm lever arm. 'P' indicates the position of the 50 N preload, applied through a 40 cm lever arm, in the opposite direction from the fulcrum, at the bottom end of the specimen.

Axial rotation was tested by mounting the specimens in the centre of the material-testing machine, so that the axis of torsion lies midway between the centre and the posterior edge of the vertebral body in the sagittal plane. Torsion load was applied directly by a rotary actuator on the machine and the axis of torsion of the specimen was aligned to the centre of the actuator. A 200 N compressive load was applied throughout the tests with the linear actuator.

The specimens were loaded with a continuous cyclical bending moment of 5 Nm in either direction, at a constant rate of 0.5 Nm per second, for four cycles at a time. The load and angular deformation data were captured from the third cycle. The software (Datamanager 96, Dartec Ltd, Stourbridge, UK) produced the load-deformation curves directly from the captured data (Fig 7).

Statistical methods

Because of the small number of specimens tested in each group, non-parametric methods were used for statistical analysis using SPSS for Windows version 10.0 (SPSS Inc. Chicago, Illinois) statistical software. The range of movement (ROM) of each specimen after cage fixation and after additional posterior stabilisation was normalised (ratio of ROM of stabilized to intact specimen) with respect to that of the intact FSU. The ROM for the intact specimens between the two cage-groups was compared for any difference using the Mann-Whitney Test. The difference in ROM in the individual cage group between intact specimen, after cage insertion and after additional posterior stabilisation were analysed with the related sample Wilcoxon test. The difference in ROM between the cage groups was compared using the Mann-Whitney test. The critical level of significance was 0.05.

Results

The ROM for the intact specimen, after cage insertion and after additional posterior stabilisation were recorded from the load-deformation curves (Fig 7). Table 1 and 2 shows the ROM obtained from the specimens tested with the rectangular (Corin) and cylindrical (BAK) cages respectively.

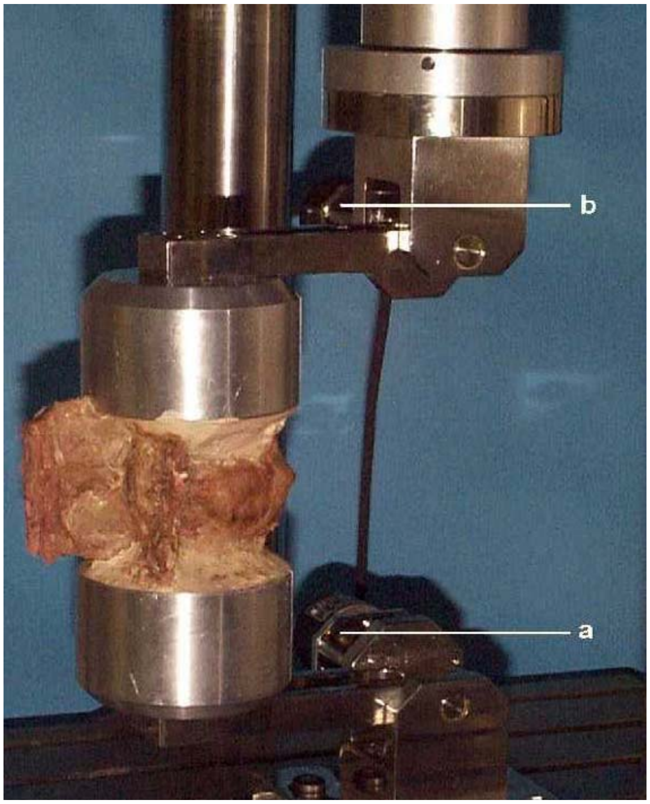

Figure 5
An intact cadaver spine specimen in the eccentric loading jig, mounted for testing flexion-extension movement. a, b are the two digital goniometers, which measure the angular deformation directly. (The preload is not shown in this picture).

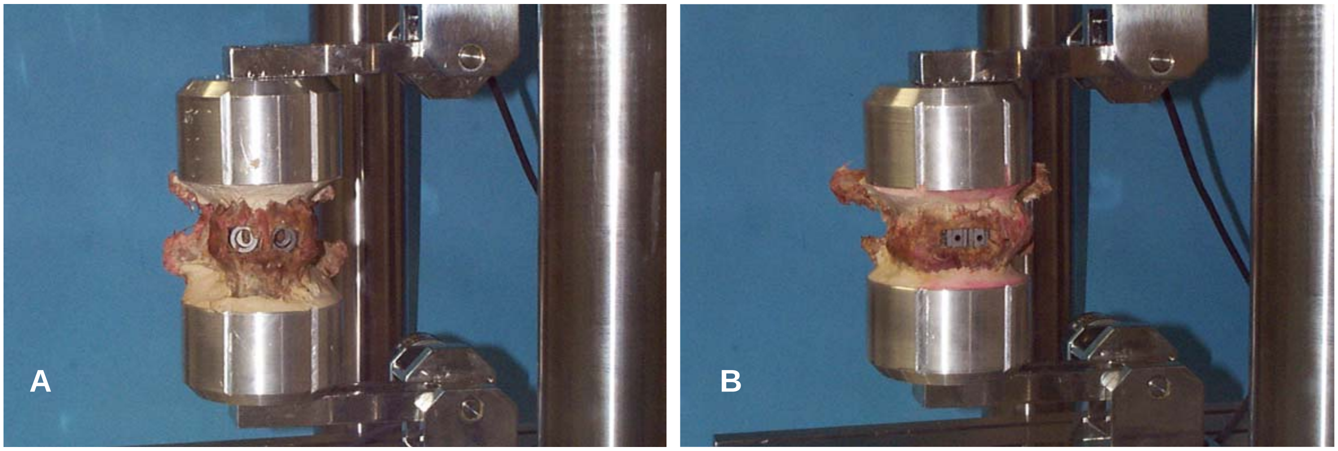

Figure 6
The cadaver spine specimens fixed with the cylindrical cages (A) and rectangular cages (B), and mounted in the eccentric loading jig rotated 90° to test the lateral bending movements. (The preload is not shown in this picture).

Table 1: ROM in individual specimen in the rectangular cage group. The ROM in degrees in intact specimen, following fixation with the rectangular cage, and following additional posterior translaminar screw fixation.

	Intact			Following cage insertion			Following additional translaminar screw fixation		
	FE	LAT	ROT	FE	LAT	ROT	FE	LAT	ROT
Specimen 1	3.882	1.801	4.978	1.502	0.357	2.801	0.85	0.366	0.986
Specimen 2	7.236	3.263	5.213	3.632	2.691	4.176	1.975	0.829	1.361
Specimen 3	5.086	2.75	2.173	0.951	0.706	0.636	0.193	0.08	0.2
Specimen 4	7.193	4.073	4.283	4.999	1.783	1.593	1.237	0.525	0.574
Specimen 5	6.342	3.001	2.982	2.778	1.095	1.428	1.218	0.558	0.534

FE-flexion-extension, LAT-lateral bending, ROT-rotation.

Table 2: ROM in individual specimen in the cylindrical cage group. The ROM in degrees in intact specimen, following fixation with the cylindrical cage, and following additional posterior translaminar screw fixation.

	Intact			Following cage insertion			Following additional translaminar screw fixation		
	FE	LAT	ROT	FE	LAT	ROT	FE	LAT	ROT
Specimen 1	7.183	4.502	6.827	3.089	2.767	2.635	1.925	1.202	1.318
Specimen 2	4.803	2.691	3.016	0.999	2.223	2.286	1.446	0.689	0.651
Specimen 3	6.581	3.803	5.293	4.153	1.145	2.228	1.283	0.73	0.519
Specimen 4	3.982	2.015	4.168	1.262	1.201	2.384	0.725	0.197	1.096
Specimen 5	5.871	3.692	3.923	2.483	3.81	0.82	1.016	0.609	0.769

FE-flexion-extension, LAT-lateral bending, ROT-rotation.

The distribution of ROM (median, quartiles and range) of the intact specimens in the two cage groups are shown in Fig 8. There was no significant difference in the ROM of intact specimens between the two groups (Mann-Whitney U test $p = 0.602$, 0.602, 0.465 for flexion-extension, lateral bending and rotation movements respectively).

Figure 9 and 10 present the distribution of normalised motions (median, quartiles and range) after cage insertion and additional posterior stabilisation respectively, for both the cage groups.

Flexion-extension

The range of flexion-extension after insertion of both rectangular and cylindrical cages were significantly reduced as compared to that of the intact specimens ($p < 0.05$ related sample Wilcoxon test). The normalised median flexion-extension after stabilization with the rectangular and the cylindrical cages were 0.438 (range 0.187 – 0.695), and 0.423 (range 0.208 – 0.631) respectively. There was no significant difference ($p = 0.602$ Mann-Whitney test) between the two cage groups (Fig 9).

Lateral bending

The range of lateral bending was significantly reduced after both types of cage insertion ($p < 0.05$). The normalised median lateral bending after stabilisation with the rectangular and the cylindrical cages were 0.365 (range 0.198 – 0.825) and 0.615 (range 0.301 – 1.032) respectively. There was a trend of better stability with the rectangular cages compared to the cylindrical cage group, but the difference was not significant ($p = 0.117$, Mann-Whitney test), (Fig 9).

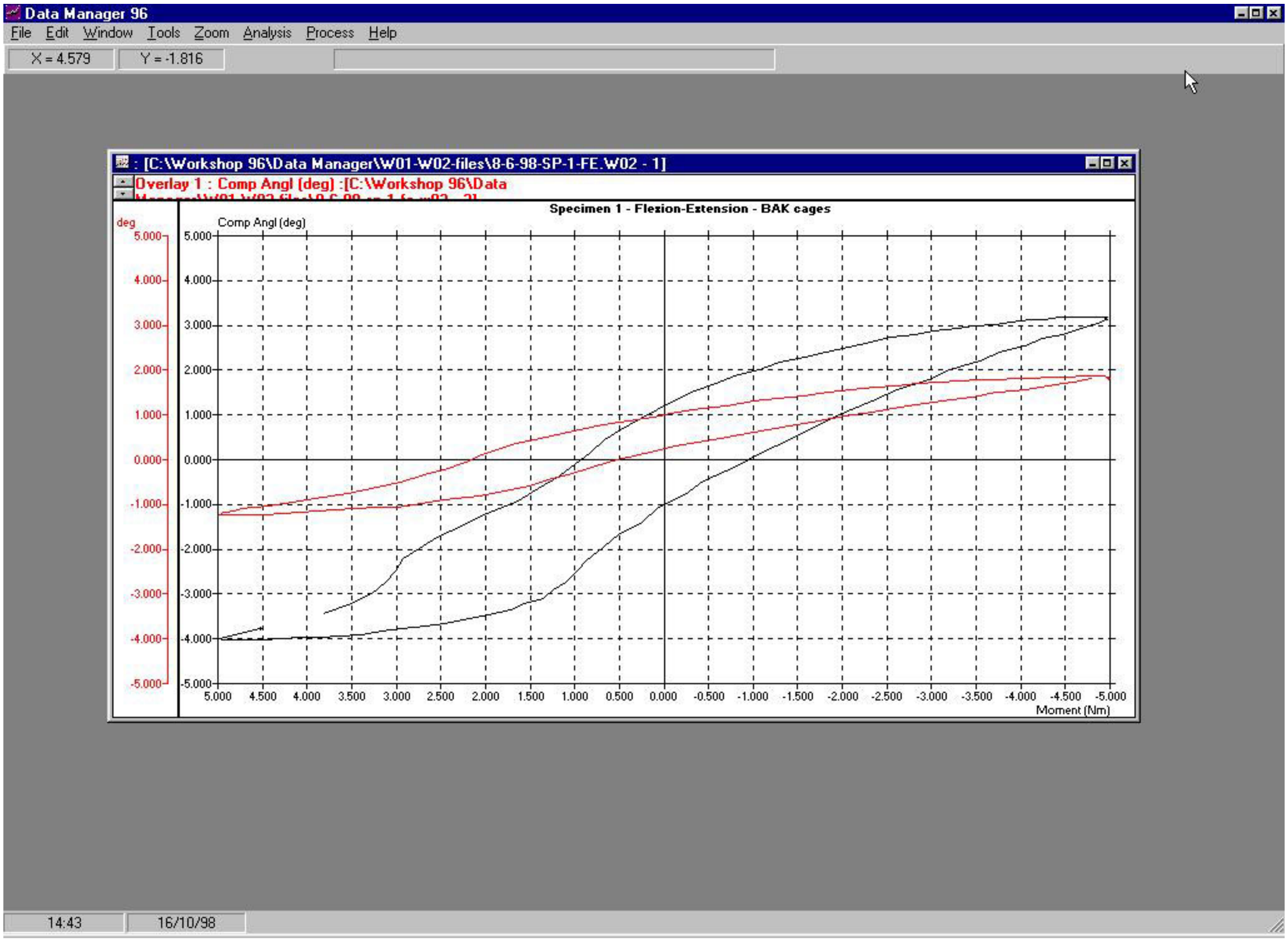

Figure 7
Example of range of motion and hysteresis produced from an intact specimen (black), and after BAK cage insertion (red), with ± 5 Nm cyclical loading to produce flexion-extension movement.

Axial rotation

The range of axial rotation was significantly reduced after both types of cage insertion ($p < 0.05$). The normalised median axial rotation after stabilisation with the rectangular and the cylindrical cages were 0.479 (range 0.293 – 0.801) and 0.421 (range 0.209 – 0.758) respectively. The difference was not significant ($p = 0.917$, Mann-Whitney test), (Fig 9).

Additional posterior fixation

The ROM after additional posterior fixation with translaminar screws was significantly reduced as compared to cage insertion alone for most of the movements for both cage groups ($p < 0.05$ related sample Wilcoxon test), except in two situations. The range of lateral bending in the rectangular group, and the range of flexion-extension in the cylindrical cage group were only marginally different following additional posterior stabilization ($p = 0.08$ for both).

There was no significant difference between the two cage groups, in ROM in any direction, following additional posterior stabilisation ($p = 0.465$ for all the movements, Mann-Whitney test), (Fig 10).

Discussion

With increasing popularity in the use of cages for spinal fusion, a large number of cages have been introduced during the last decade, with a corresponding number of cage biomechanics studies reported in the recent literature. These include assessment of individual cages [3,7–10], comparison of stability with different cage designs [4,10–13], the effect of direction of cage insertion [13–16], the effect of additional posterior fixation [10,13,17], and literature reviews on biomechanical studies [18,19]. The

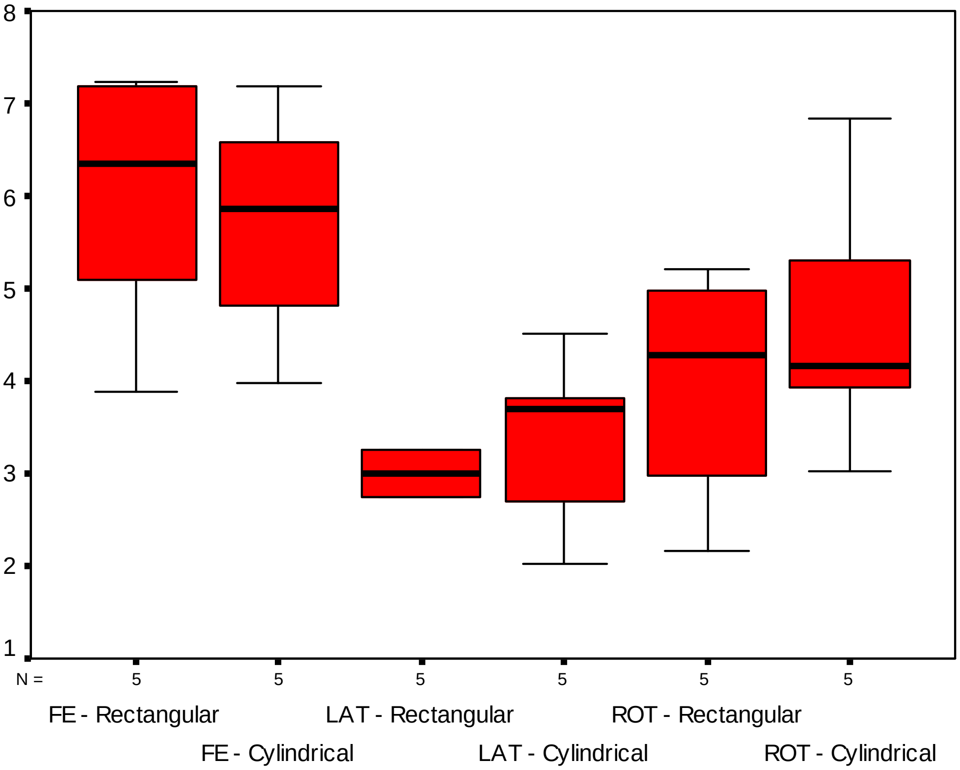

Figure 8
The distribution of range of motion in degrees (median, quartiles and range) of the intact specimens in the two groups fixed with rectangular and cylindrical cages. There was no significant difference between the two cage groups in flexion-extension (FE), lateral bending (LAT), and rotation (ROT).

cage in this study was designed to combine the advantages of a rectangular shape, freedom of anterior or posterior insertion, and to improve the rotational stability with teeth that engage the vertebral endplate.

Effect of cage insertion

In the present study, both cage designs significantly reduced movement in all directions when compared to that of intact specimens. In flexion-extension the stability was almost identical for both types of cages investigated. This is consistent with reports of earlier investigators [4,11,13,16].

Lund et al [4] noted inability of two types of rectangular cages (Brantigan carbon fiber, and Contact®) to resist axial rotation. In fact ROM in axial rotation significantly increased. In contrast, the cylindrical cages (Ray TFC) provided a marginally superior stability against axial rotation compared to the control. Tsantrizos et al [11] observed superior stability with a ScrewCage compared to the other cage designs. The superior stability to rotation with screw-in cages may be related to the screw threads engaging the endplate. In a biomechanical study on cadaver spine, using BAK cages and translaminar screw, Rathonyi et al [17] observed very poor rotational stability in specimens with poor endplate contact. They concluded that the quality of endplate contact may be the most important factor for axial rotational stability. This may explain the poor rotational stability with rectangular cages as observed by Lund et al [4] The Contact® cages have smooth surfaces to fit the endplate contour. The Brantigan carbon fiber cages have serrations on their cranial and caudal surface, which prevent cage migration but they are not designed to cut into the endplate.

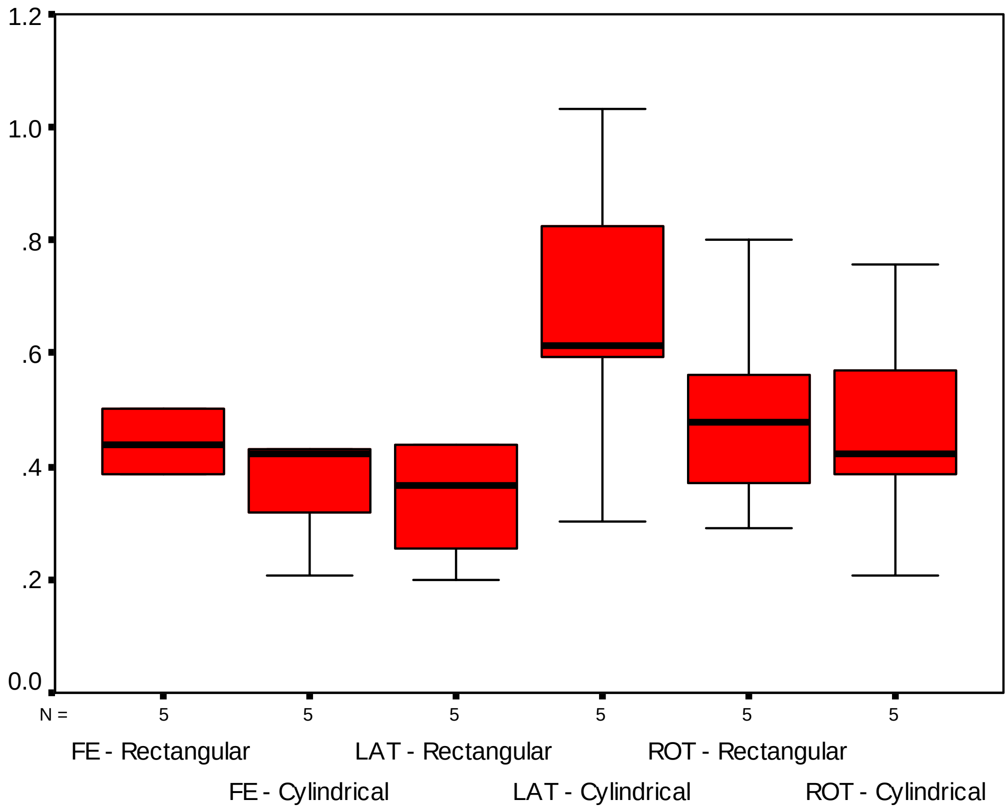

Figure 9
The distribution of normalized range of motion (median, quartiles and range) following cage insertion. (The ROM of intact motion segment is = 1). There was no significant difference between the two cage groups in flexion-extension (FE) and rotation (ROT). Although there was a trend of better stability in lateral bending (LAT) with rectangular cages, the difference was not significant.

In our study, insertion of the rectangular cages (Corin) increased the rotational stability compared to the control, and the stability was comparable to that with the cylindrical (BAK) cages. This may be the effect of the teeth in these rectangular cages engaging into the endplates.

Both Lund et al [4] and Tsantrizos et al [16] observed no difference in lateral bending stability between the cylindrical and rectangular cage constructs. In our study rectangular cages produced a marginally superior stability in lateral bending motion ($p = 0.117$) compared to the cylindrical cage constructs. Although the difference was not statistically significant, this may indicate a small advantage of a rectangular over a cylindrical shape. Theoretically, there is a possibility of side to side rocking movement of the vertebra over the cylindrical cages inserted in sagittal plane.

Effect of additional posterior stabilization

Posterior stabilization with translaminar screws was described by Montesano and Magerl et al [5]. Although the stability achieved by stand-alone translaminar or transfacetal screw fixation is less rigid compared to pedicle screw-rod instrumentations [20], most investigators suggested that translaminar screws provide sufficient stability in all directions, when combined with anterior column support [17,21].

Most studies suggest that supplemental posterior fixation using pedicle screw-rod construct improves stability in all

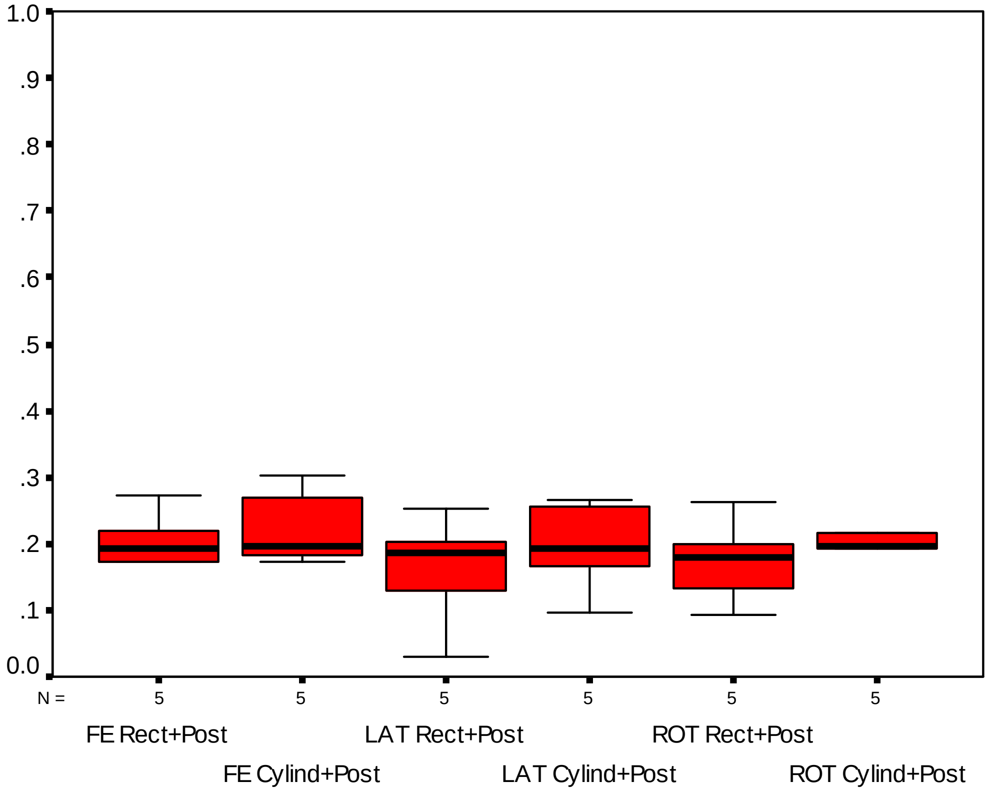

Figure 10
The distribution of normalized range of motion (median, quartiles and range) following cage insertion and additional posterior stabilization with translaminar screws. (The ROM of intact motion segment is = 1). There was no significant difference between the two cage groups in flexion-extension (FE), lateral bending (LAT), and rotation (ROT).

direction, and also levels off any difference in stability between stand alone interbody implant constructs [4,16]. In a cadaver spine study Rathonyi et al [17] reported that stand alone BAK cages failed to provide stability in extension and axial rotation. However, supplemental translaminar screw fixation significantly increased stability in both axial rotation and extension. In a similar study Oxland et al [13] reported significant increase in stability with standalone cages (BAK and Syncage) in all directions except in extension; addition of translaminar screw fixation significantly increased the stability in extension.

In the present study additional posterior stabilization with translaminar screw fixation significantly increased the stability in all directions except in two situations. With rectangular cages there was no significant further increase in stability to lateral bending after posterior fixation (p = 0.08). A similar effect was observed with cylindrical cages where the difference in stability in flexion-extension between the stand-alone cages and additional posterior stabilization was not significant (p = 0.08).

Anterior or posterior cage instrumentation

Most investigators agree that interbody cages provide good stability in flexion and lateral bending but little or no stability in extension and axial rotation [4,11,13,16,17,19]. The loss of stability in extension and axial rotation may be related to the obligatory damage to the specific anatomical structures needed for cage insertion. Stability in extension depends most on the distraction of the anterior annulus and stability in rotation depends primarily on the integrity of the facet joints. It may be anticipated that with anterior cage insertion (ALIF) damage to the anterior longitudinal ligament and annulus will lead to loss of stability in extension. In contrast, with posterior cage insertion (PLIF) damage to the facet joints will lead to greater loss of stability in rotation. The cage diameter for cylindrical cages and cage height in rectangular cages (where cage is inserted and rotated 90°) dictates the extent of medial facetectomy needed for cage insertion.

With posterior cage insertion (PLIF) Tsantrizos et al [16] reported marginal changes in extension, but stability in axial rotation decreased significantly, more with Ray TFC than with Contact® cages. Lund et al [4] found increased range of axial rotation with posterior insertion of both Contact® and Brantigan cages, and no significant change in extension with any cage design compared to the control.

With anterior cage insertion (ALIF) Oxland et al [13] found no stabilization in extension but significant stabilization in axial rotation using BAK cages in cadaver spine. Rathonyi et al [17] found a similar decrease in stability in extension but no change in axial rotation.

Tencer et al [14] evaluated a cylindrical cage (Ray TFC) in different orientations within the interbody space in calf and human cadaver spine. There was no significant difference with the direction of cage insertion except when posterior placement damaged facets or lamina. In this case torsional stiffness was reduced. Stiffness achieved with anterior implantation decreased when the anterior annulus was damaged.

The rectangular cage used in the present study is designed for insertion from both an anterior and posterior direction, but was tested for anterior insertion only. We observed increased stability in axial rotation, and in flexion-extension in both the cage groups.

Limitations

The principle limitation in this study was the use of a constrained system for applying load. Rotations were allowed in one axis only, and coupled motions were prevented. It has been described in the literature that a closer estimate of a physiological load-deformation in any specimen may only be obtained by applying pure moment, with six degrees of freedom, allowing coupled motion [22] However, it is expected that a constrained system would affect the load-deformation and the ROM patterns almost equally, for both the stabilization system. Therefore, a constrained system may not give a true estimate of a physiological ROM but will be good enough to compare two different stabilization systems. The constrained system used here is certainly much simpler, faster, and allows cyclical loading of the specimen, as opposed to the stepwise quasi-static loading often applied during pure moment testing. Additionally, it produced a precise measurement of load-deformation curve and ROM on repeat testing on the same specimen, which helps to identify relatively small difference between the two systems.

The second limitation was that, like many other biomechanical studies [3,8,11] the flexion-extension ROM was recorded in this study as one composite movement. In practice however, the cage insertion should have a different effect on flexion as compared to extension. Consequently, our study may have missed the lack of stability in extension with the cages. This fact was stressed by Lund et al [4]. The reason behind our method is that we used an eccentric loading jig to apply a continuous cyclical load, to produce flexion-extension movement. The hysteresis curve was directly produced by the software (Datamanager 96, Dartec Ltd, Stourbridge, UK) in our experimental setup from a continuous flexion-extension movement. This offered a more sensitive and precise record of the flexibility of the spine, which improved the comparison between the two different cage systems.

The other limitation is that our study does not provide the effect on stability with posterior insertion of the rectangular cage. The cage is designed to be rotated 90° after insertion requiring medial facetectomy equal to the cranio-caudal height of the cages. Therefore the axial rotation stability observed with the stand-alone cages after anterior insertion may not hold true for their posterior insertion.

Conclusions

1) There was no significant difference in immediate stability achieved with a standard threaded cylindrical cage and the new rectangular cage with inferior and superior teeth.

2) The rectangular cages alone achieved significant stability in axial rotation after anterior insertion. It may be possible that the teeth in the new rectangular cages designed to engage the endplates contributed to the improved mechanical stability in rotation.

3) Additional posterior stabilization increased the stability for all movements.

Competing interests

No remuneration, financial or otherwise was received for this study from any party. The rectangular interbody cage used in this study was developed by the senior author Mr. SMH Mehdian, in collaboration with The Corin Group, Cirencester, Glcestershire, UK. It has subsequently been made available for clinical use by the same company as Rotafix® intervertebral cage.

Authors' contributions

DKSG participated in design of the study, biomechanical testing, data analysis, and drafting the manuscript. SHM designed the cage, conceived of the study, evaluated the guidelines and commented on the paper. RCM participated in design of the study and evaluation of the guidelines of biomechanical testing. JKW participated in the design of the study and evaluation of the guidelines. DDO participated in the design of the study, statistical analysis, and provided feedback on manuscript.

All authors read and approved the final manuscript.

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