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ORIGINAL ARTICLE

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The role of supplemental translaminar screws in anterior lumbar interbody fixation: a biomechanical study

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Abstract The immediate stabilization provided by anterior interbody cage fixation is often questioned. Therefore, the role of supplementary posterior fixation, particularly minimally invasive techniques such as translaminar screws, is relevant. The purpose of this biomechanical study was to determine the immediate three-dimensional flexibility of the lumbar spine, using six human cadaveric functional spinal units, in four different conditions: (1) intact, (2) fixed with translaminar screws (TLS), (3) instrumented with anterior interbody cage insertion with the BAK system and (4) instrumented with BAK cage with additional TLS fixation. Flexibility was determined in each testing condition by measuring the vertebral motions under applied pure moments (i.e. flexion-extension, bilateral axial rotation, bilateral lateral bending) in an unconstrained manner. Anterior fixation with the BAK alone provided significant stability in flexion and lateral bending. Additional posterior TLS significantly reduced the motion in extension and axial rotation. TLS fixation alone resulted in smaller rotations than BAK fixation in all loading directions. Based on these results, it seems that interbody cage fixation with the BAK system stabilizes the spine in some, but not all, loading directions. The problematic loading directions of extension and axial rotation can be substantially stabilized by using translaminar screw fixation. However, one should emphasize that the degree of stability needed to achieve solid fusion is not known.

Key words Biomechanics · Stability · Implant · Interbody fusion · Translaminar screws

Introduction

For the last 50 years, bone plugs of different shapes have been used for interbody fusion. Various graft-related complications such as graft collapse, retropulsion and donor site pain are well documented [1, 22]. Replacing the graft with a synthetic graft, or cage, can solve some of these complications. Such a cage should be designed so that the best grafting material, autogenous bone, can be used without the risk of graft collapse and the cage can be fixed more securely than graft alone to prevent dislodgment [15].

These cages have often been used with pedicle screws, and high fusion rates have been reported [1]. Holte et al. found the fusion rate of anterior lumbar interbody fusion (ALIF) with femoral ring allograft surrounding autologous bone with posterior translaminar screw (TLS) fixation was 98%, compared with 75% for those without TLS fixation [8]. The desire for minimally invasive fusion procedures (i.e. laparoscopic anterior interbody fusion) raises the question of whether anterior interbody cage fixation alone is stable enough to achieve solid fusion. Some promising clinical data exist for cages without posterior fixation, with fusion rates ranging from 90 to 100% [10, 19, 27]. However, these reports have relatively short follow-up and fusion assessment remains difficult.

Some biomechanical data are available on the stabilizing effect of anterior interbody devices, utilizing the distraction-compression concept of Bagby [15]. A study by Butts et al. showed increased stability of animal motion segments instrumented with threaded cylinders when tested in flexion-extension and lateral bending [3]. Brodke et al. reported doubled stiffness of the calf spine instrumented with BAK implants in flexion-extension and torsion loading [2]. Wilder et al. found similar increases in flexion-extension stiffness in the baboon spine after instrumentation [26]. Note that all the above-mentioned studies used animal motion segments.

Tencer et al. found that threaded inserts increased human lumbar motion segment stiffness in flexion and extension [23]. Lund et al. showed that cage fixation alone increased the human motion segment stability in all loading directions except extension and axial rotation [11]. In contrast, Volkman et al. found that cage fixation did not increase stiffness of human functional spinal units (FSUs) in any loading condition [24]. In each of the three studies with human specimens, additional posterior instrumentation provided significant supplementary stabilization in extension (Volkman used transfacet screws, Lund and Tencer used transpedicular screws).

There exist some biomechanical data on the effect of translaminar and transfacet screw fixation alone. Guyer et al. concluded that transfacet screw fixation limits flexion and, to a lesser extent, extension [6]. Heggeness and Esses found that translaminar screw fixation increased FSU stiffness 2.4 fold in flexion-compression loading [7]. Panjabi et al. compared the stabilizing effect of five posterior fixation devices and found that facet screw fixation was effective in reducing motion to below intact levels in some, but not all, loading directions [18].

No biomechanical papers have been presented previously on the stabilizing effect of anterior BAK instrumentation and supplementary translaminar screw fixation on human cadaveric motion segments. The objectives of the current study were three fold:

1. To determine the three-dimensional stabilizing capacity of an anterior cage system (i.e. BAK) in the lumbar spine
2. To determine whether additional posterior TLS fixation improves the stability of the spine instrumented with an anterior cage
3. To contrast the stabilization achieved with TLS fixation alone with that achieved by anterior cage fixation

Material and methods

Six human cadaveric lumbar functional spinal units (FSUs) (2 × L2–3, 1 × L3–4, 2 × L4–5, 1 × L5–S1) were obtained. All specimens were carefully dissected of all non-ligamentous soft tissue and frozen at –20 °C before and between testing. There was no bone-related disease found in the history of the cadavers or bony abnormality observed on pretest radiographs. The discs showed low to moderate signs of degeneration on pretest radiographs. The upper and lower vertebrae were mounted in PMMA blocks such that the mid-disc plane was horizontal. Each specimen was tested in four different conditions: (1) intact, and (2) instrumented with translaminar screw (TLS), (3) anterior insertion of BAK and (4) TLS fixation added to the BAK cages. During instrumentation of both the TLS (Stratec Medical, Oberdorf, Switzerland) and the BAK cages (SpineTech, Minneapolis, Minn.), the manufacturers` surgical technique manuals were strictly followed. Note that the TLS fixation was removed prior to BAK insertion. Care was taken to ensure that the facet capsules were not damaged during TLS insertion or removal. For the BAK cages, two implants were always placed bilaterally and a large amount of distraction was attempted in all cases. Lateral and anteroposterior radiographs of typical specimens instrumented with BAK and TLS are shown in Figs. 1 and 2 respectively.

For multidirectional flexibility testing, each specimen was mounted in a specially designed apparatus, which allowed the precise application of known pure moments to the spine and the measurement of intervertebral motion in an unconstrained manner. A specimen in the apparatus under extension moment is shown in Fig. 3. The philosophy behind this testing procedure was described previously by Panjabi [16, 17] and the specific apparatus has been used previously in several experiments [11, 14]. In each test condition, pure moments of flexion-extension, bilateral axial rotation and bilateral lateral bending were applied to the upper vertebra individually in a stepwise fashion to a maximum of 10 Nm (four steps of 2.5 Nm). At each load step, the specimen was allowed to creep for 30–45 s. This loading regimen was repeated for two cycles. Due to the apparatus design, the moments remained pure along the specimen length. The rigid body motion of the upper vertebra with respect to the lower vertebra was measured using an optoelectronic camera system (Optotrak 3020, Northern Digital, Waterloo, Ontario). The system monitors the spatial position of marker carriers on each rigid body (see Fig. 3), each carrier having four non-colinearly arranged infrared light-emitting diodes (LEDs). For each applied moment, the complete motion of the upper vertebra with respect to the lower vertebra requires six degrees of freedom (three rotations, three translations). Custom software was used to calculate the relative vertebral rotations in terms of Euler angles (roll, pitch, yaw). For simplicity, the rotation in the direction of the applied moment (e.g. flexion rotation for applied flexion moment) was investigated. For this rotation the range of motion (ROM) was calculated. The neutral zone, which is a measure of joint laxity, was measured but not presented since it is very small after stabilizing procedures. Therefore, for each test, the ROMs were calculated in flexion-extension, axial rotation and lateral bending.

Since six specimens were tested in each group, it is difficult to justify using parametric data analysis, which assumes that the data are normally distributed and the variances between test conditions are equal. Therefore, non-parametric methods were used. To contrast the four test conditions, a Friedman analysis of variance (ANOVA) was conducted for each loading direction. Pairwise comparisons were then made using the Wilcoxon signed rank test with a modified Bonferroni correction [21]. Three pairwise comparisons were made corresponding to the three objectives of the investigation. Firstly, the intact ROM was compared with the ROM with a BAK cage, to assess the effect of cage insertion. Secondly, the ROM with BAK insertion alone was compared with that of BAK with TLS, to determine the effect of supplementary TLS fixation. Finally, the ROM with BAK insertion was compared with that of TLS fixation alone, to determine their relative stabilizing abilities. Statistical significance was selected at the 5% level.

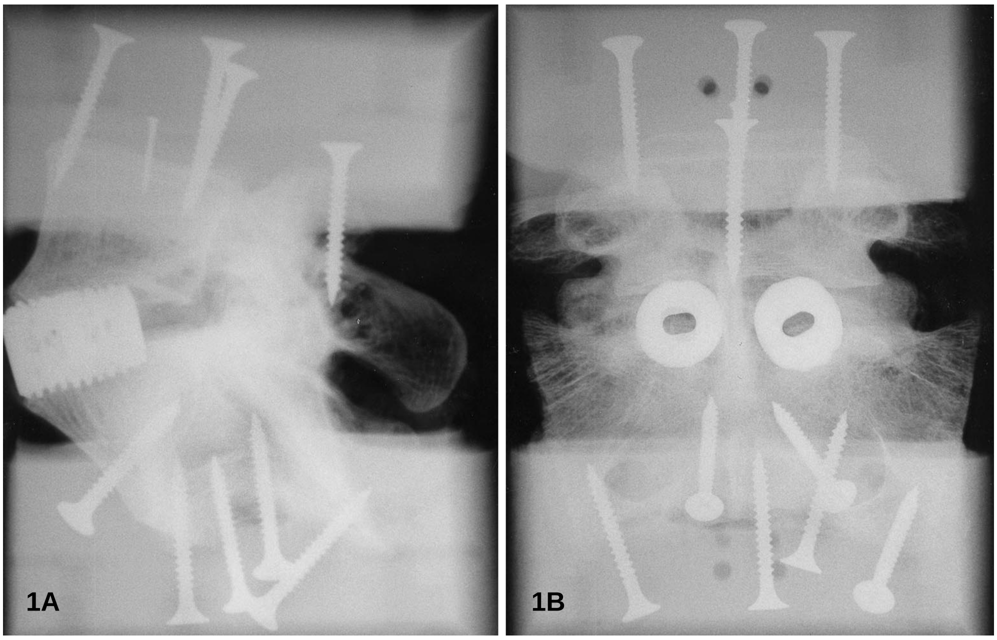

Fig. 1 Lateral and anteroposterior (AP) and lateral radiographs of a functional spinal unit (FSU) instrumented with BAK cages. Note that two cages were inserted parallel to each other into the intervertebral space from an anterior direction

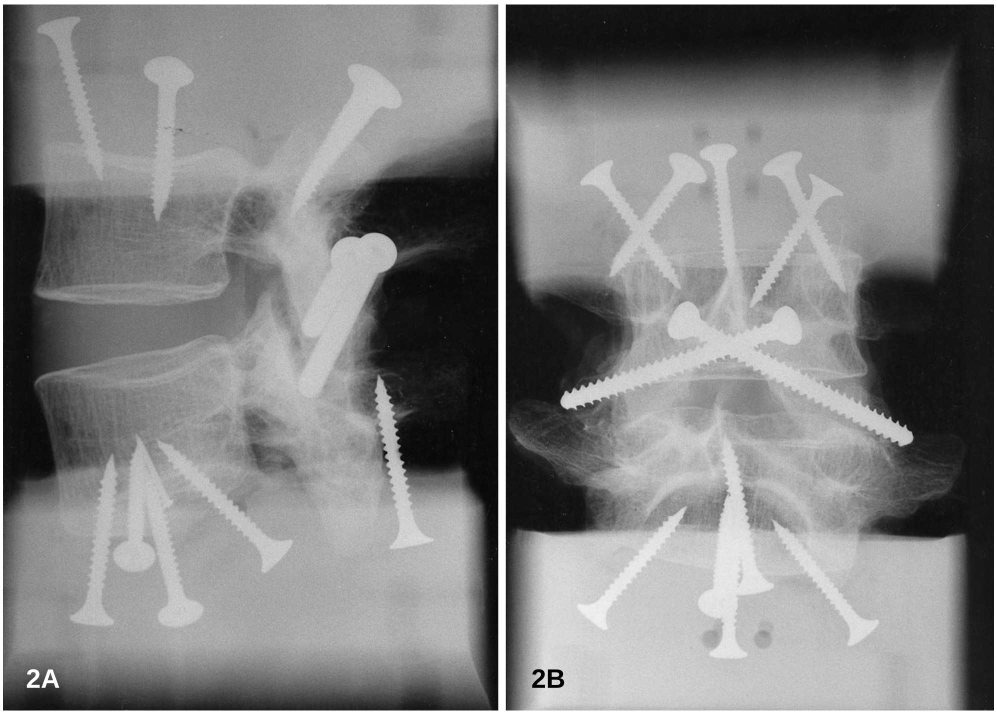

Fig. 2 Lateral and AP radiographs of an FSU instrumented with translaminar screw fixation (TLS). Note that the screw was inserted at the base of the spinous process on one side, and crossed the lamina and the facet joint on the opposite side

Results

The insertion of the translaminar screws was uneventful for each specimen, with good bony purchase and all facet capsules left intact. However, proper TLS positioning sometimes required extremely lateral projection (almost in the frontal plane), which would be difficult in obese patients with deep lumbar lordosis. Screws were inserted using a special guide provided by the manufacturer. This guidance sometimes resulted in different screw alignment than the original Magerl method, but helped us avoid intrusion to the foramen and gave good screw fixation.

During anterior cage insertion we tried to achieve maximal distraction. Excellent purchase of the implants in both endplates was achieved in four of six specimens. Questionable contact of one endplate was observed in one specimen and obvious lack of one endplate contact in one

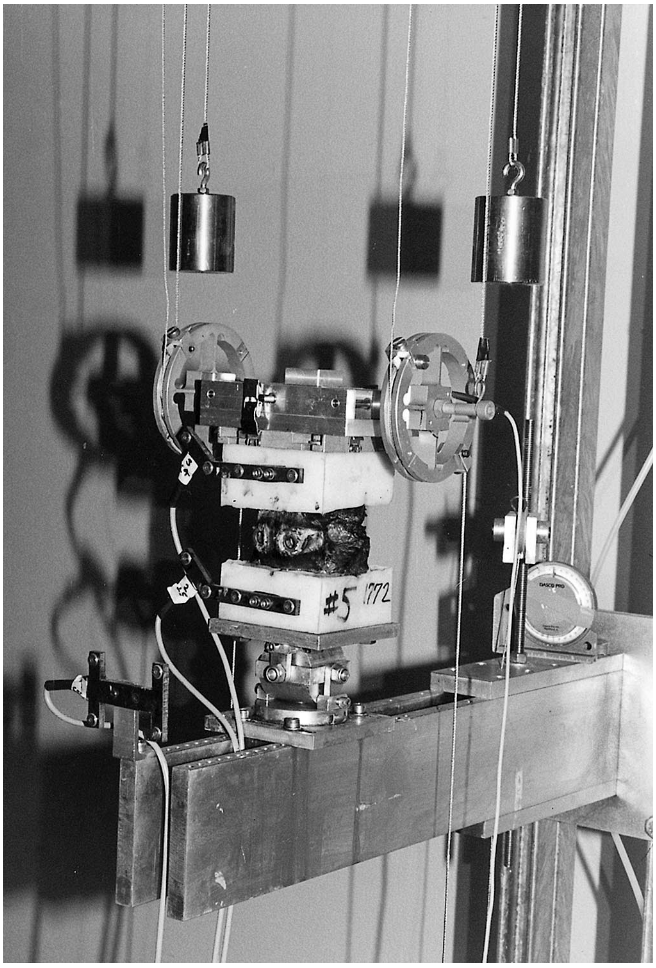

Fig. 3 The testing apparatus for three-dimensional multidirectional flexibility testing. Marker carriers with light-emitting diodes were attached to the specimen. Pure moments, here extension, were applied to the upper vertebra through cables attached to the pulleys. The relative vertebral motion was measured using an optoelectronic camera system

specimen. Stability of this last specimen was the lowest, but the statistical results did not change when it was excluded from the analyses.

The ROMs in flexion, extension, bilateral axial rotation and lateral bending for each testing condition are shown in Figs. 4, 5, 6, and 7 respectively. The ROM data are combined for right and left axial rotation and lateral bending because of the symmetry of the values. Note that the box and whisker plots are a standard format for presenting non-parametric data. They show the median value for each test condition, quartile values and data range.

Flexion

All fixation conditions decreased the flexion ROM to below the intact ROM (see Fig. 4) ($P < 0.004$). ROM with the cage fixation ("cage motion") was significantly different than intact ROM, with its median motion being 43% of intact motion ($P = 0.028$). Supplementary TLS fixation reduced motion, but this change was not significant ($P = 0.046$). The motion with TLS fixation alone was less than the cage motion, but this was not significant ($P = 0.046$).

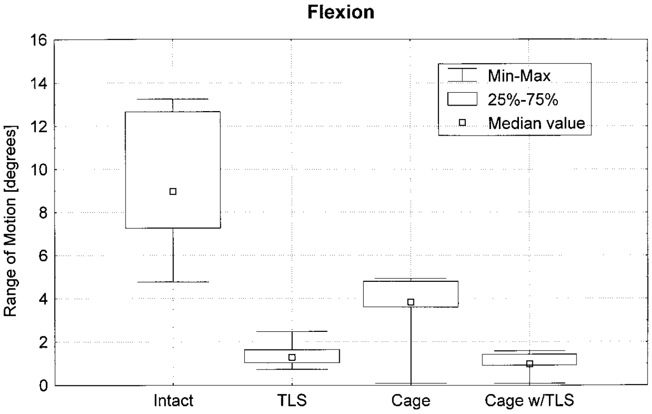

Fig. 4 Median range of motion (ROM) data (with quartiles and ranges) for flexion loading. The ROM with cage fixation was significantly different from that of the intact FSU ($P = 0.028$). Supplementary TLS fixation reduced motion, but this change was not significant ($P = 0.046$). The motion with TLS fixation alone was less than with cage insertion ("cage motion"), but this was not significant ($P = 0.046$)

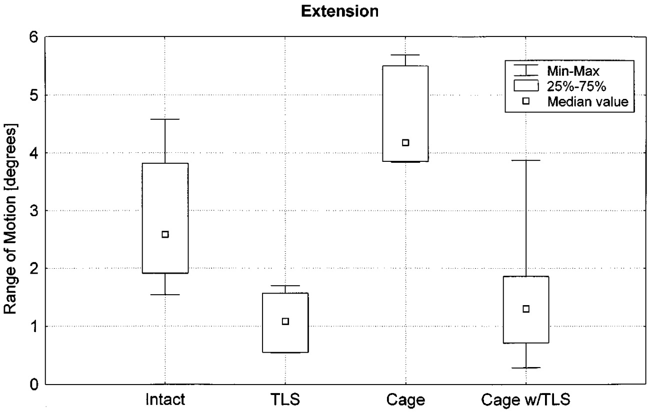

Fig. 5 Median ROM data (with quartiles and ranges) for extension loading. BAK cage fixation alone slightly increased extension ROM above intact values, but this was not significant ($P = 0.0747$). Additional TLS fixation reduced motion significantly, with its median motion being 31% of cage motion ($P = 0.0277$). Motion with TLS fixation alone was significantly less than cage motion, with its median motion being 26% that of cage motion ($P = 0.0277$)

Extension

BAK cage fixation alone increased extension ROM slightly above the intact level, but this was not significant ($P = 0.0747$) (see Fig. 5). Additional TLS fixation re-

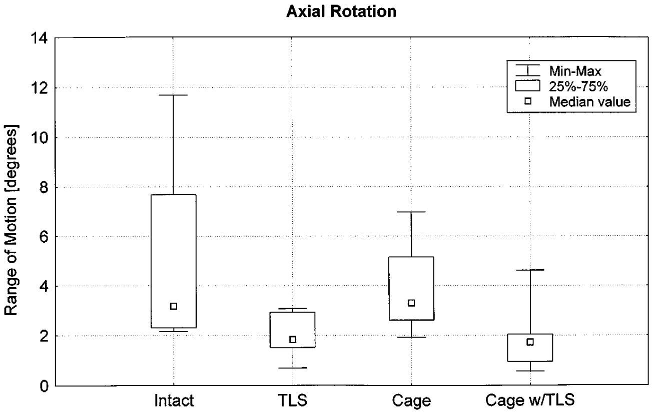

Fig. 6 Median ROM data (with quartiles and ranges) for axial rotation loading. Cage fixation alone did not decrease axial rotation ROM below the intact value ($P = 0.60$). Supplementary TLS fixation reduced motion significantly, with its median motion being 52% of cage motion ($P = 0.0277$). Motion with TLS fixation alone was significantly less than cage motion, with its median motion being 56% that of cage motion ($P = 0.0277$)

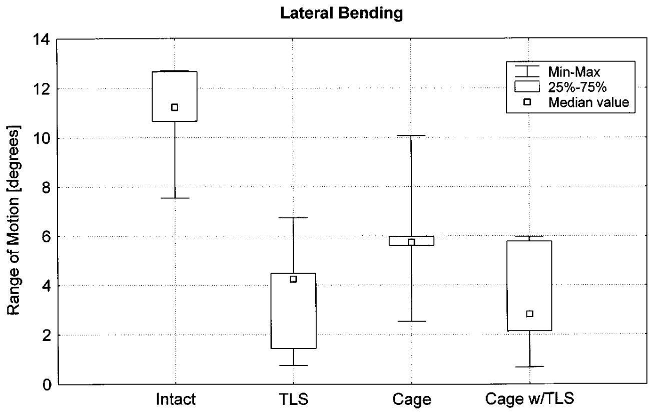

Fig. 7 Median ROM data (with quartiles and ranges) for lateral bending loading. All fixation conditions decreased the lateral bending ROM below intact value. BAK cage fixation alone significantly reduced motion, with its median motion being 51% that of intact motion ($P = 0.043$). Additional TLS fixation further reduced this motion, but this was not significant ($P = 0.0796$). The motion with TLS fixation alone was less than cage motion, but this was not significant ($P = 0.0796$)

duced motion significantly, with its median motion being 31% of cage motion ($P = 0.0277$). Motion with TLS fixation alone was significantly less than cage motion, with its median motion being 26% of cage motion ($P = 0.0277$).

Axial rotation

Cage fixation alone did not significantly change axial rotation motion from the intact level (see Fig. 6) ($P = 0.6$). Supplementary TLS fixation reduced motion significantly, with its median motion being 52% of cage motion ($P = 0.0277$). Motion with TLS fixation alone was significantly less than cage motion, with its median motion being 56% of cage motion ($P = 0.0277$).

Lateral bending

All fixation conditions decreased the lateral bending ROM to below the intact level (see Fig. 7). BAK cage fixation alone significantly reduced motion, with its median motion being 51% of intact motion ($P = 0.043$). Additional TLS fixation further reduced this motion, but this was not significant ($P = 0.0796$). The motion with TLS fixation alone was less than cage motion, but this was not significant ($P = 0.0796$).

Discussion

In the current investigation we posed three questions:

1. How effectively do anterior BAK cages stabilize the spine?
2. What is the benefit of supplementary TLS fixation on the stability?
3. How does TLS fixation alone compare to anterior cage stabilization?

In response to these questions, we made the following observations. Firstly, anterior cage fixation stabilized the spine in flexion and lateral bending, but had no effect in extension and axial rotation. Secondly, additional posterior TLS stabilized substantially in all loading directions, particularly extension and axial rotation. Thirdly, TLS fixation alone resulted in less overall motion than cage insertion and this was significant in axial rotation and extension.

Stabilization of cage alone

The poor performance of the ALIF cages in extension testing could be partly explained by the damage to the anterior annulus and the anterior longitudinal ligament during instrumentation/cage insertion. However, a recent study showed similar results for posterior interbody cages [11]. A possible explanation for the similar lack of stabilization after posterior interbody cage insertion could be the separation of the facet surfaces with distraction, which reduces the role of the facets in extension.

Comparing our results with other biomechanical papers on this topic, we are faced with the difficulty of different study designs, so only the trends could be compared. With a similar study design, Lund et al. tested three different posterior cages and presented very similar results to those found by us, especially regarding the poor stabilization effected by the cages in extension and axial rotation [11]. Many studies have investigated the stabilization provided by cages in flexion-extension, but have not separated the two directions. We feel that it is important to separate flexion and extension, since these motions are not symmetric, in contrast to left and right axial rotation or lateral bending. Virtually all published reports on combined flexion-extension motion found significant stabilization provided by the cages [2, 3]. Butts et al. found that the flexion-extension ROM decreased by 44% with cage instrumentation alone [3] and Brodke et al. found an average stiffness increase of 92% [2]. Tencer et al. reported that threaded inserts showed a trend to increase not only flexion but also extension stiffness [23]. Wilder et al. found that there was a greater increase in stiffness of the FSU instrumented by an anterior cage in extension than in flexion; however, this is probably due to different applied loading and the use of a baboon model [26]. Volkman et al. used human cadaveric specimens and found that the cage stabilized better in extension than in flexion [24]. However, their use of an eccentric compressive load and a single cylindrical device is questionable.

Brodke et al. showed that the axial rotation stiffness increased two fold by anterior cage instrumentation [2]. Tencer et al. found that cage stabilization caused a slight decrease in axial rotation stiffness; however, this change was not significant [23]. We observed only a slight decrease in the ROM in axial rotation after cage insertion, and Lund et al. presented similar results in this loading condition [11]. The lack of stabilizing effect in axial rotation after anterior cage fixation to a certain extent may be explained by the lack of a compressive force, and thus insufficient friction at the cage-endplate interface and/or facet separation. We did observe very poor rotational stability in the specimens with poor endplate contact, and therefore suggest that the quality of the endplate contact may be the most important factor for axial rotation stability.

Tencer et al. found that cages stabilized in lateral bending, but this change was not significant [23]. Butts et al. and Lund et al. found significant decreases in lateral bending ROM, which was similar to our results [3, 11].

Stabilization with cage and TLS fixation

We found that TLS fixation improved stabilization over cage instrumentation alone, particularly in the problematic extension and axial rotation loading directions. Therefore, we can conclude that anterior cage with supplementary TLS fixation limits motion in all loading directions compared to the intact condition.

In a recent paper, Volkmann et al. showed similar increased stiffness of the FSU instrumented with an anterior cage, particularly in extension, after insertion of transfacet screws [24]. Other investigators have reported a similar stabilizing effect of supplementary pedicle screw fixation [2, 11].

Stabilization with TLS fixation alone

According to our results, TLS fixation alone stabilized the spine in all loading conditions and limited axial rotation and extension motion significantly better than cage fixation alone.

Panjabi et al. and Guyer et al. tested human cadaveric spine segments and showed that transfacet and translaminar screw fixation was less effective in limiting extension than flexion [6, 18]. Panjabi et al. observed excellent overall stabilization of the transfacet screw fixation, approximately equivalent to that provided by pedicle screw fixation [18]. Heggeness and Esses tested cadaveric spines and found that the FSU stiffness increased 2.4 times in flexion after facet screw fixation [7].

Observing our data and that of other investigators, one could conclude that TLS fixation alone provides sufficient stability in flexion-extension, lateral bending and axial rotation. This may certainly be the case, as some good clinical results have been observed with TLS fixation [5, 9, 20]. However, TLS fixation alone probably results in substantial axial disc motions without anterior column support, as have been observed with the external spinal fixator during cyclic axial compression testing [12]. These micromotions may produce continued discogenic pain and may adversely affect the fusion process [25].

Limitations

This in vitro study, as with many biomechanical studies, has several inherent limitations. The physiologic loads in the lumbar spine are not completely known. We applied 10 Nm pure moments in four incremental steps. It is still possible that higher or lower loads arise in vivo. It was shown previously that these loads produce vertebral rotations typical of those measured in vivo [17]. An additional limitation is the absence of the stabilizing effect of the spinal musculature. It is well known that muscles stabilize the spine, thus exerting compressive load. Since both intact and instrumented conditions were studied without preload, the comparisons are valid. Nevertheless, it is possible that the preload would affect the performance of the four test conditions differently, and therefore, similar experiments with preload are necessary. Finally, this experiment addresses only the immediate stability of various implant configurations. The effect of bony ingrowth was not modelled and, therefore, information regarding time-related changes not obtained.

Clinical relevance

The degree of stability optimal for spinal fusion is still not known. Animal studies have documented higher fusion rates with lower micromotion levels [13], and clinical studies suggest better fusion rates for instrumented than un-instrumented posterolateral fusions [4, 28]. Holte et al. found that ALIF with posterior fixation had a 98% fusion rate compared with 75% for ALIF without fixation [8].

We feel that both extremes (too rigid and too flexible fixations) are not working. A possible answer could be in changes of the instantaneous axis of rotation after instrumentation or in the dynamic fixation (with continuously decreasing implant stiffness).

The combination of the excellent stabilizing effect of an anterior cage in axial compression, flexion and lateral bending with the stabilizing effect of TLS fixation in extension and axial rotation seem optimal from a biomechanical perspective. It is possible that laparoscopic ALIF using cages and transcutaneous TLS fixation could lead to the ideal minimally invasive spinal fusion.

Conclusion

1. Anterior cage fixation stabilized the spine in flexion and lateral bending, but had no effect in extension and axial rotation.
2. Additional posterior TLS fixation stabilized the cage condition in all loading directions, notably extension and axial rotation.
3. TLS fixation alone allowed less overall motion compared to the cage condition in all loading directions.

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