In vitro evaluation of a lateral expandable cage and its comparison with a static device for lumbar interbody fusion: a biomechanical investigation

Laboratory investigation

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Object. Through in vitro biomechanical testing, the authors compared the performance of a vertically expandable lateral lumbar interbody cage (EC) under two different torque-controlled expansions (1.5 and 3.0 Nm) and with respect to an equivalent lateral static cage (SC) with and without pedicle screw fixation.

Methods. Eleven cadaveric human L2–3 segments were evaluated under the following conditions: 1) intact; 2) discectomy; 3) EC under 1.50 Nm of torque expansion (EC-1.5Nm); 4) EC under 3.00 Nm of torque expansion (EC-3.0Nm); 5) SC; and 6) SC with a bilateral pedicle screw system (SC+BPSS). Load-displacement behavior was evaluated for each condition using a combination of 100 N of axial preload and 7.5 Nm of torque in flexion and extension (FE), lateral bending (LB), and axial rotation (AR). Range of motion (ROM), neutral zone stiffness (NZS), and axial rotation NZS, in which it was comparable (p > 0.66, Friedman test) with that of all other constructs; and 3) AR EZS, in which a marginal (p = 0.05) difference greater (p ≤ 0.01) NZS in flexion, extension, and LB as well as EZS in flexion, LB, and AR. When comparing the torque expansions, the EC-3.0Nm condition had smaller (p < 0.01) FE and AR ROM and greater (p ≥ 0.04) flexion NZS, extension EZS, and AR EZS. The SC condition performed equivalently (p ≥ 0.10) to both EC conditions in terms of ROM, NZS, and EZS, except for EZS in AR, in which a marginal (p = 0.05) difference was observed with respect to the EC-3.0Nm condition. The SC+BPSS was the most rigid construct in terms of ROM and stiffness, except for 1) LB ROM, in which it was comparable (p = 0.08) with that of the EC-1.5Nm condition; 2) AR NZS, in which it was comparable (p > 0.66, Friedman test) with that of all other constructs; and 3) AR EZS, in which it was comparable with that of the EC-1.5Nm (p = 0.56) and SC (p = 0.08) conditions.

Conclusions. A 3.0-Nm torque expansion of a lateral interbody cage provides greater immediate stability in FE and AR than a 1.5-Nm torque expansion. Moreover, the expandable device provides stability comparable with that of an equivalent (in size, shape, and bone-interface material) SC. Specifically, the SC+BPSS construct was the most stable in FE motion. Even though an EC may seem a better option given the minimal tissue disruption during its implantation, there may be a greater chance of endplate collapse by over-distracting the disc space because of the minimal haptic feedback from the expansion.

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Key Words • expandable cage • spine biomechanics • lumbar • lateral interbody fusion

Lumbar interbody fusion is a common treatment option for disc height loss, alignment correction, and restoration of segmental stability after neural decompression.16 Minimally invasive lateral interbody fusion has gained popularity among fusion techniques. Potential complications associated with other approaches, such as major vessel injury (anterior approach),18 significant retraction and manipulation of nerves (posterior approach),20 and dural leaks (transforaminal approach),3 are minimized using a minimally invasive lateral approach. However, this approach requires transpsoas dissection, which can lead to several complications, such as iliopsoas weakness and quadriceps muscle weakness.24

An ideal lateral fusion surgery should include an interbody cage that maximizes the area in contact with the

Abbreviations used in this paper: AR = axial rotation; BMD = bone mineral density; BPSS = bilateral pedicle screw system; EC = vertically expandable lateral lumbar interbody cage; EZS = elastic zone stiffness; FE = flexion and extension; LB = lateral bending; NZS = neutral zone stiffness; ROM = range of motion; SC = lateral lumbar static cage.
endplate and an incision that minimizes tissue disruption. Hybrid approaches (anterolateral) can be used to minimize psoas disruption, but the cage dimension still defines the incision size. An interbody cage with a variable-height (expandable) feature is an attractive option for any interbody fusion device. The amenability of a vertically expandable cage to implantation in a disc space in its “collapsed” form reduces the amount of tissue disruption and nerve root retraction in comparison with that encountered using a static interbody cage, making the expandable cage a less invasive alternative that could even have applications in endoscopic surgery. Moreover, controlling the cage height allows the surgeon to optimize cage expansion (final height) after its implantation instead of trying to select the “best-fit” height available in an implant set.

Expandable cages have been widely used for corpectomy reconstruction and have been recently introduced to single-level interbody fusion. Their application in posterior and transforaminal interbody fusion have been discussed; however, little information is available for lateral approaches. To the best of our knowledge, expandable cages for lateral interbody fusion have not been biomechanically compared with an equivalent device (that is, a static cage) in vitro models.

Optimal cage expansion can play an important role in the performance of the device: under-expanding the device increases the chances of cage migration, and over-expanding can increase the risk of cage subsidence. Thus, investigating the effects that different expansions may have in the biomechanical performance of an interbody cage could help to characterize the optimum expansion. To our knowledge, no biomechanical studies have addressed this concern.

The purpose of our investigation was to biomechanically compare through in vitro testing the performance of a vertically expandable lateral lumbar interbody cage (EC) under two different torque-controlled expansions (1.5 and 3.0 Nm) and with respect to an equivalent lateral lumbar static interbody cage (SC) with and without pedicle screw fixation. We hypothesized that 3.0 Nm of torque expansion provides greater immediate stability than 1.5 Nm in flexion and extension, and that the EC’s biomechanical performance is comparable to that of an equivalent (in size, shape, and bone-device interface material) SC.

### Methods

#### Specimen Preparation

Eleven lumbar segments (L2–3) were harvested from 6 female and 5 male cadaveric human spines (average age at death 64 years, range 50–77 years). Excessive muscular and adipose tissue was removed, and all ligaments, joint capsules, and intervertebral disc of the spinal segment were preserved. None of the specimens had a history of spinal pathology, trauma, or surgery, which was verified macroscopically and through fluoroscopic images before specimen dissection. Average bone mineral density (BMD) of the L1–4 segments was available for all specimens included in the study (average 1.353 g/cm², range 1.003–1.720 g/cm²).

Spinal segments were affixed in a mixture of Bondo autobody filler (Bondo Corp.) and fiberglass resin (3M) via 2-inch self-tapping screws in the free endplates and/or facets of the L2–3 segments. Horizontal alignment of the intervertebral joint was verified during curing of the Bondo-fiberglass mixture by using a series of leveling tools and customized potting frames, as described previously, to ensure proper force transmission during biomechanical testing. Dissection and testing were performed at room temperature (21°C ± 2°C) in a period no longer than 48 hours. Specimens were smeared with petroleum jelly to minimize dehydration effects during testing and were placed in a refrigerator (4°C ± 2°C) and covered with 4 × 4 gauzes soaked in 0.9% saline solution when not being tested.

#### Biomechanical Testing

A customized four-degree-of-freedom testing apparatus, described in previous publications, was used to perform flexion and extension (FE), lateral bending (LB), and axial rotation (AR) tests. The machine consisted of a servo-hydraulic system (MTS 858 MiniBionix modified by Instron) that allows dynamic axial rotation and translation and two custom-made frames (superior and inferior) that allow quasi-static bending moments (in one axis) through pulley systems (Fig. 1).

The combination of an axial preload of 100 N and a 7.5 Nm of torque for each direction (FE, left and right LB, and left and right AR) was selected for the flexibility tests. Six cycles of dynamic AR at 0.125 Hz were delivered by the hydraulic system, while 3 cycles of quasi-static FE and LB were delivered through 2-kg masses in a pulley system with a radius of 0.68 m, which represented steps of 1.5 Nm that were separated by 10 seconds each and held for a total of 5 seconds. The last 2 cycles of each test were averaged and analyzed. The number of cycles selected was based on the delivery method and motion direction; thus, a reduced rate and number of cycles was selected for FE and LB to minimize creep effects since these motions heavily rely on the disc space.

Infrared light-emitting diode markers were affixed to the frames that were embracing the L-2 and L-3 vertebral bodies to measure angular displacement (± 0.1°) via an Optotrak Certus motion capture system (Optotrak 3020, Northern Digital Inc.). Load-displacement behavior was evaluated from the flexibility tests performed after each treatment.

#### Analysis of Biomechanical Variables

The FE, LB, and AR ranges of motion (ROMs) were estimated as the change in angular displacement from the minimum (–7.5 Nm) to the maximum (+7.5 Nm) torque applied. Neutral zone stiffness (NZS) and elastic zone stiffness (EZS) were calculated as the inverse of the slope of the load–displacement graphs. Right and left stiffness values for bending and rotation were averaged and represented as LB and AR stiffness accordingly.

#### Surgical Treatments

Attending surgeons performed all surgical proce-
dures using standard techniques and surgical tools. Specimens were tested under the following conditions: 1) intact; 2) discectomy; 3) EC under 1.50 Nm of torque expansion (EC-1.5Nm); 4) EC under 3.00 Nm of torque expansion (EC-3.0Nm); 5) SC; and 6) SC with a bilateral pedicle screw system (SC+BPSS). The discectomy procedure consisted of removing the lateral annulus fibrosus, complete nucleus pulposus, and cartilaginous endplate. Torque expansion of the EC was performed sequentially (1.5 and then 3.0 Nm) after cage implantation by using a calibrated nonsurgical digital (accuracy of 0.01 Nm) torque wrench (Westward Mini Torque Wrench 1/4-inch, Grainer) to ensure precise and accurate torque measurements. The EC remained inside the disc space during its expansion and was expanded slowly until the static impeding motion torque matched the desired torque. Implantation of the SC required retraction and then removal of the EC, which was assumed to have a negligible effect in the SC condition since this technique allowed preservation of the endplates, which would not have been possible if the SC had been tested (implanted and removed through its regular “tapping” process) before the EC condition.

The sizes of the implanted EC (Caliber-L, 45–60 mm in length and 9–11 mm in height, nonlordotic, Globus Medical Inc.) and BPSS (REVERE system, 6.5-mm diameter and 45-mm length, Globus Medical Inc.) were selected for each specimen according to the surgeons’ criteria to simulate surgical scenarios. The length of the EC was specifically selected to cover the endplate’s periphery and extend a few millimeters laterally, whereas the length of the SC (TransContinental spacer system, 45–60 mm in length, 13–15 mm in height, Globus Medical Inc.) was chosen to be identical to that of the EC. On the other hand, the SC’s height was selected to match the EC’s height after 3.0 Nm of torque expansion, which generally implied rounding to the closest height available in the SC implant set; however, the surgeon also verified that the selected SC fulfilled the “good fit” criterion. The torque expansion of 3.0 Nm was based on the torque wrench limit available in the implant set, which was also the manufacturer’s recommended torque, whereas 1.5 Nm was intended to simulate the clinical scenario of a surgeon’s haptic satisfaction, by expanding to half of the maximal torque.

Fluoroscopic images were taken throughout the testing conditions (Fig. 2), including before and after each interbody cage testing, to evaluate any evidence of cage subsidence, which was defined as a compromised endplate during radiographic inspection. Additionally, intervertebral discs were dissected after the last test (SC+BPSS condition) to visually examine the condition of the endplates (Fig. 3). If cage subsidence was observed at any point, biomechanical testing was completed when possible, but specimen data were dropped from the statistical analysis.

**Statistical Analysis**

Range of motion, NZS, and EZS variables were normalized with respect to the intact condition (100%) to reduce variability among specimens. Since normalized data did not comply with normal distribution of the residuals according to the Shapiro-Wilk test, nonparametric approaches were selected for statistical comparisons. Friedman tests were performed for each motion (FE, LB, and AR) to evaluate differences among conditions in terms of normalized ROM, NZS, and EZS. If significance was achieved, paired comparisons were estimated through post hoc Wilcoxon signed-rank tests. Lastly, normal distribution of the differences in height between the lateral cage constructs (the EC-1.5Nm, EC-3.0Nm, and SC conditions) was verified using a Shapiro-Wilk test, and paired t-tests were used to compare the cage heights between the constructs. All statistical tests were performed at a 0.05 significance level.

**Results**

All experimental values are summarized in Table 1, and normalized results with respect to the intact condition used in the statistical analyses are shown in graphs. Cage subsidence was identified in 1 of the specimens (Fig. 4), and it occurred at the inferior endplate of the specimen (from a female) with the highest average BMD (1.720 g/cm²). Some subsidence occurred after implantation of the EC previous to its expansion (Fig. 4, EC-no expansion), but it intensified after the 3.0 Nm of torque expansion. This specimen was dropped from the biomechanical analysis; thus only 10 specimens were considered for statistical comparisons.

The average (± standard deviation) cage height in the EC-1.5Nm, EC-3.0Nm, and SC conditions was 12.1 ± 0.9, 13.9 ± 1.1, and 13 ± 1 mm, respectively. The height differ-

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**Fig. 1.** The L2–3 spinal segment in the testing apparatus before the flexion and extension test.
ence between the two torque expansions (1.8 ± 0.7 mm) was significant (p < 0.0001). Moreover, the difference in the SC height with respect to the EC-1.5Nm and the EC-3.0Nm heights was 1.3 ± 0.7 mm (p < 0.001) and -0.5 ± 1.0 mm (p = 0.14), respectively.

Range of Motion

All instrumentation reduced (p < 0.01) ROM with respect to the injury (discectomy) in all directions (Fig. 5). When comparing the 1.5 with the 3.0 Nm torque expansion, FE and AR were smaller (p < 0.01) in the latter condition. Moreover, the ROM in the SC condition was comparable (p ≥ 0.19) with both EC conditions in all motions. The most stable condition (p < 0.01) in all directions was the SC+BPSS, except in LB where its performance was comparable (p = 0.08) with that in the EC-1.5Nm condition.

Stiffness

All fixation constructs increased (p ≤ 0.01) flexion, extension, and LB stiffness around both the neutral (Fig. 6) and the elastic (Fig. 7) zones, except for extension, for which the EZS of the EC-1.5Nm (p = 0.38), EC-3.0Nm (p = 0.73), and SC (p = 0.92) conditions were equivalent to that of the injury condition (discectomy). In terms of AR, there was not enough evidence (p = 0.66, Friedman test) to state any difference in the NZS among conditions; however, all instrumentations increased AR EZS (p < 0.01) with respect to the injury.

When comparing the torque-expansion conditions, the EC-3.0Nm condition was significantly stiffer around...
Expandable lateral cage for lumbar fusion

TABLE 1: Range of motion and stiffness values from biomechanical testing of the L2–3 segment under various conditions*

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>Condition</th>
<th>Flexion</th>
<th>Extension</th>
<th>LB</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROM (°)</td>
<td>intact</td>
<td>7.6 (6.5)</td>
<td>10.0 (6.1)</td>
<td>3.7 (4.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>discectomy</td>
<td>9.3 (7.3)</td>
<td>15.1 (15.1)</td>
<td>6.4 (5.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EC-1.5Nm</td>
<td>2.8 (2.0)</td>
<td>3.2 (6.0)</td>
<td>2.3 (2.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EC-3.0Nm</td>
<td>2.4 (1.8)</td>
<td>2.4 (4.4)</td>
<td>1.9 (1.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SC</td>
<td>2.5 (4.7)</td>
<td>1.9 (4.9)</td>
<td>1.8 (2.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SC+BPSS</td>
<td>1.1 (0.8)</td>
<td>1.5 (2.5)</td>
<td>1.2 (1.3)</td>
<td></td>
</tr>
<tr>
<td>NZS (Nm/°)</td>
<td>intact</td>
<td>0.7 (1.8)</td>
<td>1.1 (1.7)</td>
<td>0.6 (1.1)</td>
<td>2.2 (1.7)</td>
</tr>
<tr>
<td></td>
<td>discectomy</td>
<td>0.9 (1.5)</td>
<td>1.2 (1.4)</td>
<td>0.4 (0.4)</td>
<td>1.8 (2.5)</td>
</tr>
<tr>
<td></td>
<td>EC-1.5Nm</td>
<td>5.0 (5.4)</td>
<td>5.0 (5.0)</td>
<td>3.9 (5.9)</td>
<td>2.9 (9.2)</td>
</tr>
<tr>
<td></td>
<td>EC-3.0Nm</td>
<td>5.8 (7.6)</td>
<td>5.3 (10.9)</td>
<td>6.3 (13.5)</td>
<td>4.7 (10.2)</td>
</tr>
<tr>
<td></td>
<td>SC</td>
<td>6.3 (13.3)</td>
<td>6.3 (5.8)</td>
<td>6.3 (10.2)</td>
<td>2.2 (11.4)</td>
</tr>
<tr>
<td></td>
<td>SC+BPSS</td>
<td>13.3 (8.4)</td>
<td>13.1 (5.1)</td>
<td>8.4 (16.4)</td>
<td>6.2 (12.6)</td>
</tr>
<tr>
<td>EZS (Nm/°)</td>
<td>intact</td>
<td>5.9 (16.1)</td>
<td>6.7 (14.8)</td>
<td>4.9 (2.8)</td>
<td>7.2 (4.9)</td>
</tr>
<tr>
<td></td>
<td>discectomy</td>
<td>5.6 (8.3)</td>
<td>7.6 (15.2)</td>
<td>3.8 (5.8)</td>
<td>5.1 (3.3)</td>
</tr>
<tr>
<td></td>
<td>EC-1.5Nm</td>
<td>9.6 (8.2)</td>
<td>6.0 (5.7)</td>
<td>9.2 (8.7)</td>
<td>10.7 (4.0)</td>
</tr>
<tr>
<td></td>
<td>EC-3.0Nm</td>
<td>11.0 (14.2)</td>
<td>8.5 (9.9)</td>
<td>11.3 (9.4)</td>
<td>12.6 (4.6)</td>
</tr>
<tr>
<td></td>
<td>SC</td>
<td>9.6 (9.1)</td>
<td>8.6 (10.4)</td>
<td>11.9 (10.2)</td>
<td>10.6 (3.9)</td>
</tr>
<tr>
<td></td>
<td>SC+BPSS</td>
<td>18.6 (12.6)</td>
<td>17.2 (11.2)</td>
<td>14.9 (12.1)</td>
<td>12.7 (9.6)</td>
</tr>
</tbody>
</table>

* Values represent the median (range expressed as the difference between maximum and minimum).

the neutral zone for flexion (p = 0.04) and around the elastic zone for extension (p = 0.02) and AR (p = 0.03). Moreover, the stiffness provided by the SC condition was comparable with that of the EC-1.5Nm condition (p > 0.13) and EC-3.0Nm condition (p ≥ 0.38) in all motions, except for EZS in AR, in which a marginal (p = 0.05) difference was observed between the EC-3.0Nm and the SC condition (Fig. 7). The SC+BPSS condition was the stiffest fixation (p < 0.05) in all directions, except in AR, in which AR NZS was comparable with that of all the other constructs (as mentioned before) and AR EZS was comparable with that of the EC-1.5Nm (p = 0.56) and SC (p = 0.08) conditions.

Discussion

One of the major advantages of ECs over static devices is the minimal endplate disruption during their implantation, especially since endplate integrity acts in favor of device stability and against subsidence. The potential

Fig. 4. Fluoroscopic images showing evolution of cage subsidence; (pre) and (post) state indicate before and after biomechanical testing, respectively.
disruption of the lateral aspect of the endplate and the cortical bone during SC implantation could have deleterious effects on cage stability and strength, especially in degenerated cases in which the strength of the central aspect of the endplate is compromised and cage stability relies mainly on the periphery (lateral endplate for extreme lateral interbody fusion) of the endplate. Moreover, cage breakage by forcing an SC into a collapsed disc has been reported, and its incidence can be significantly reduced by selecting a smaller cage that can be expanded after its implantation. Another major advantage of expandable devices is the reduction of tissue disruption, not just by less endplate damage, but also by offering the possibility of both a smaller incision for its implantation and the use of an endoscopic approach that could significantly reduce the invasiveness of the procedure.

Conversely, ECs are more radio-opaque than SCs because the inner mechanism of the expandable device is made out of titanium, which can interfere with postoperative radiological evaluation when, for example, supplemental (radio-opaque) fixation is implanted at the same spine level (Fig. 2D and G). An EC may also have a shorter fatigue life than an SC since the expandable mechanism entails a more complex construct with more articulations.
and points of stress concentration, which also restricts the amount of bone packaged; however, failure after interbody cage implantation is expected to occur in the bone-device interface before it occurs in the device’s mechanics. Moreover, there may be a higher risk of endplate collapse by over-distracting the disc space when an expandable device is used since the haptic feedback from its implantation is minimal as compared with the “tapping” process of inserting an SC. This over-distraction risk is probably the biggest concern when using ECs for interbody fusion, and this issue demands further investigation to better understand the clinical outcomes it could trigger.

The case of subsidence in this investigation was presumably attributable to a compromised endplate. Initial radiography (intact condition) revealed hyperconcavity of the inferior endplate (Fig. 4 Intact), and it is presumed that this anatomical condition predisposed cage subsidence by promoting stress concentration on the bone-device interface; however, a single incident is not enough to support any hypothesis. Nevertheless, it was shown how in vitro subsidence can occur in cases in which the length of the lateral cage covers the periphery of the endplate and also extends a little beyond it laterally. Moreover, it can occur at the inferior endplate in a specimen with normal BMD, although the inferior endplates seem to have higher failure loads than the superior endplates, and clinical subsidence is thought to be higher in patients with low BMD. The reduction in ROM, with respect to the intact condition, following implantation of an SC (FE = 31.1%, LB = 23.3%, and AR = 49.3%) in our study was similar to that reported by Cappuccino et al. (FE = 31.6%, LB = 32.5%, and AR = 69.4%). Likewise, the effects of incorporating a BPSS into the SC construct, as observed by the same group (FE = 13.0%, LB = 14.4%, and AR = 41.7%), were validated in our investigation (FE = 14.8%, LB = 18.9%, and AR = 33.5%), confirming that the SC+BPSS construct contributed the least to AR motion. Some differences were expected between the results of Cappuccino et al. and our findings since different testing protocols were used: whole lumbar spines versus single-segment testing, L3–4 versus L2–3 operative level, 0 N versus 100 N of axial preload, and a smaller average BMD (0.83 ± 0.12 vs 1.35 ± 0.20 g/cm²); however, the similarities between the two studies reduces the possibility of a testing bias toward the EC condition by preceding it with the SC condition in our investigation.

The optimal height of an implanted expandable interbody spacer is debatable. Over-expansion has been defined in terms of changes in the spine’s curvature that leads to excessive tension on the (anterior and/or posterior) longitudinal ligament(s). This tension causes significant compression of the cage, which could increase the chance of subsidence. Analyzing the immediate biomechanical effects of different expansions may help to predict possible clinical outcomes. Surgically, reaching 3.0 Nm of torque when expanding a (Caliber-L) lateral cage is recommended; however, it is the surgeon’s haptic feedback, satisfaction, and intuition that determine the final cage height, especially when optimal expansion is achieved before the specified torque.

The results of our investigation suggest that the 3.0 Nm of torque expansion offers higher immediate stability than the 1.5 Nm in FE and AR (Fig. 5). Biomechanically
speaking, longitudinal ligaments offer the greatest resistance to the expansion mechanism in this in vitro model, implying that the greater the expansion the greater the tensile forces on the ligaments. However, ligament stiffness is nonlinear, and greater strain is expected to induce greater stiffness and hence lower ROM. Furthermore, LB ROM was not affected by the amount of expansion since the majority of the stability in this motion relies on the length of the cage, which did not change with the torque expansion and presumably because changes in transverse ligament strain were negligible between the two torque-expansion conditions.

Extrapolating the effects of torque-controlled expansion to clinical scenarios can be challenging since spinal ligament strain is not the only factor affecting this mechanism. Muscle contractions, body position, segmental balance, BMD, cage location, and endplate integrity are some of the in vivo anatomical constraints determining the maximal height per controlled torque. However, the lack of difference between the heights of the EC (at 3.0 Nm) and the SC, as well as the equivalent testing protocols used for their biomechanical evaluation, allowed us to establish valuable comparisons between constructs while attempting to minimize the gap between in vivo and in vitro interpretations.

The equivalent performance of the EC-3.0Nm and SC conditions reveals how a similar shape, dimensions, and bone-interface area and material can provide comparable immediate stability. The SC’s performance was expected to be equivalent to that of the EC-3.0Nm condition but not that of the EC-1.5Nm condition, although this last hypothesis was rejected. A possible explanation for the equivalent performance of the low torque-expansion construct (1.5 Nm) and the SC construct may be the small (but significant) difference in cage height between the two conditions, smaller than the (significant) difference between the two torque-expansion constructs. Selection of the SC height was based on the maximum torque expansion (3.0 Nm), as well as on the availability of the implant size, which occasionally forced the use of a cage smaller (not significantly) than the EC at maximum torque expansion (3.0 Nm).

Stiffness

The NZS may have greater clinical relevance than the EZS since patients are usually advised to avoid strenuous activities postoperatively, which generally implies loads underlying the neutral posture. On the other hand, EZS is used to describe deformation sensitivity by large moments and may be good for comparing different implant rigidities (intrinsically related to the mechanical properties of the device). Stiffness analyses provide deeper examination than ROM analyses since localizing the differences between treatments or conditions may provide additional information in terms of biomechanical performance.

Lateral cages have been recommended as stand-alone devices and NZS findings corroborate how they can provide significant immediate stability in all directions around the neutral posture; however, when exposed to large moments in extension (extension EZS), only the incorporation of a BPSS increases the rigidity of the segment after discectomy. The increased kyphosis triggered by the expansion explains how greater distraction in the posterolateral area of the disc space can reduce the segment’s flexibility around the neutral posture in extension and around the elastic zone in flexion and AR. Likewise, the poor contribution of the BPSS to the SC construct in AR was also evident in terms of NZS and EZS.

This study can only imply the effects of the two torque expansions under in vitro conditions; however, the notion that greater expansion is the preferred option must be carefully considered. It has been demonstrated that the amount of torque expansion plays a crucial role in the immediate stability of the construct during in vitro biomechanical testing. Although an expandable device may be a more attractive option than an SC because of its less invasive implantation, the reduced haptic feedback from an EC implantation may increase the risk of endplate collapse and hence the risk of subsidence.

Study Limitations

There are several limitations to this study. The testing order was not randomized among cage conditions. The EC was assumed to have a negligible effect in the SC condition because 1) retraction of the EC for its implantation and before its removal significantly reduced the chance of endplate damage, 2) the small-load protocol used through a small number of cycles was considered to have minimal fatigue effects, and 3) fluoroscopic images were taken before and after each biomechanical test to evaluate any evidence of endplate damage (subsidence) that could have compromised cage stability. Moreover, our ROM findings for the SC condition were similar to those reported in previous publications, as mentioned in the Discussion. If the testing order had been alternated, the tapping process used during insertion and removal of the SC would have compromised the endplate’s integrity and probably affected the EC performance. Spinal functional units were used in this investigation, which limits extrapolation of results to multisegmental behavior. Lordotic lateral cages are widely used in lumbar interbody fusion, but this study was limited to cages with 0 angulation that allowed parallel anteroposterior expansion. In vivo anatomical constraints encountered during interbody cage implantation or expansion were not considered; thus, extrapolating results of this study should be limited to expansion in terms of height differences. Fatigue effects were not investigated and may provide useful information in terms of subsidence incidence when comparing different torque expansions.

Conclusions

Demonstrating that 3.0 Nm of torque expansion in a lateral interbody cage provides greater stability than that of 1.5 Nm in FE and AR for a single spinal segment during in vitro testing has proved the theory that more expansion provides greater immediate rigidity to the construct. However, it is presumed that the chance of subsidence increases exponentially with the amount of distraction, but only further clinical investigations in terms of the amount of expansion and surgical outcomes will determine the true benefits or disadvantages of different expansions for
Expansible lateral cage for lumbar fusion

lateral interbody devices. Moreover, a static and a vertically expandable lateral device with an equivalent shape, size, and bone-interface material provides comparable immediate stability to a single spine segment, and the incorporating a BPSS in the SC made the SC+BPSS the most stable construct in FE. An EC may be an attractive option because of the minimal tissue disruption during its implantation, but the risk of endplate collapse by over-distracting the disc space can be higher.

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Disclosure

Globus Medical Inc. sponsored this study and provided the implants used in the investigation; however, the authors initiated the study proposal. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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