Implants currently used for reconstruction of a burst vertebral body are associated with complications, including subsidence, nonunion, and substantial intraoperative blood loss. A new reconstruction device, the U-Cage (Double Engine Medical Material Ltd, Xiamen, Fujian, China), was designed to minimize complications.

Six intact adult cadaver thoracolumbar (T11-L3) spines were collected and scanned by dual-energy X-ray absorptiometry (DEXA). The stiffness of the burst spine was subsequently compared with its previous intact state during flexion/extension, lateral bending, and rotation, and then subjected to a cyclic test to predict cage subsidence and device loosening. Axial load was applied continuously until failure to test the peak load that the specimen could withstand during the cyclic test. The correlation of bone mineral density and peak load was also analyzed. The instrumented specimens were found to be equivalent to intact bone in all directions ($P > .05$), with the exception of left rotation ($P < .05$). All specimens could withstand the cyclic test, and no subsidence or loosening of the device was detected. Average peak load for the instrumented specimens was 4137.5 N, which correlated with the average bone mineral density ($r = 0.915; P = .011$).

Thoracolumbar burst fractures instrumented with a U-Cage and anterolateral D-rod fixation achieved a stiffness similar to that of intact spines. This procedure may avoid the subsidence of the cage in vivo and serve as a better option for treating thoracolumbar burst fractures.
Anterior surgery is widely used for thoracolumbar burst fractures. Through direct decompression, anterior construction, and fixation, good nerve function recovery and index level stabilization can be achieved. However, anterior surgery has not yet been perfected. Drawbacks such as malalignment or nonfusion caused by cage subsidence, loosening or fracture of the fixation device, and trauma, including increased blood loss and longer surgery time, have been reported.\(^1\)\(^-\)\(^5\) Furthermore, the optimal choices for early and effective fusion are a matter of debate.

To facilitate and improve anterior spinal surgery, a new reconstruction and fusion cage was developed. The purpose of this paper is to introduce the design of this device and demonstrate its biomechanical properties.

**Materials and Methods**

**Design and Characteristics of the U-Cage**

The U-Cage (Double Engine Medical Material Ltd, Xiamen, Fujian, China) is a rectangular stand-alone device made of titanium alloy (Ti6Al4V) with a thickness of 0.6 cm. It is a hollow cage with a ventral, dorsal, and upside wall, and the bottom and both lateral sides are left open for bone grafting. Two 45° screws can be fixed into adjacent endplates through the upper wall. Unlike cylinder mesh cages and artificial vertebral replacement devices, the thin rectangular-shaped U-Cage provides a comparatively smaller size, which allows the limited ejection of the posterior part of the middle spine column for decompression and device insertion. Corpectomy is no longer necessary, which reduces trauma while preserving most of the anterior and middle spinal column. U-Cage width ranges from 30 to 40 mm with a 5-mm interval, and its height ranges from 30 to 45 mm with a 3-mm interval. The multiple size choices facilitate its application to different vertebral dimensions.

The porous structure of the ventral wall is advantageous to fibroplasty or fibrovascularization, whereas the dorsal wall can facilitate the nonstructural bone grafting around the cage and prevent them from dropping into the spinal canal. The flanges of both ends of the ventral and dorsal walls and the two 45° screws reduce the risk of migration and implant subsidence. Two symmetrical sockets on the ventral and dorsal walls and the threaded holes on the middle of the upside wall facilitate insertion when special holding forceps are applied. Because the U-Cage is a nonexpandable device, a distractor is required (Figure 1).

**Spine Preparation**

Six intact adult cadaver thoracolumbar (T11-L3) spine specimens were harvested from cadavers at Fujian Medical University. The hospital institutional review board approved the use of cadaveric spines for biomechanical testing. The average age of the donors was 56 years (range, 47-62 years). Radiographs were taken to exclude pathologic lesions or prior surgery. Bone density was measured using dual-energy X-ray absorptiometry (DEXA), and no obvious osteoporosis was observed (range, 0.84-1.09 g/cm\(^2\)). All specimens were stored at -20°C in a double plastic bag and were thawed at room temperature for 8 hours before the test. In preparation for assessment, all surrounding soft tissue and muscle was removed with care to preserve the ligaments of the spine. T11 and L3 were potted in polymethylmethacrylate for fixation in the tester. Short screws were partially driven into the embedded bony structure to secure the anchorage of the vertebrae in the embedding material. The test was performed at room temperature on a materials testing machine (ElectroForce 3510; Bose Corporation, Eden Prairie, Minnesota), and specimens were kept moist with 0.9% sodium saline during the test.

**Fracture Model and Instrumentation**

A L1 burst fracture was simulated by destroying the integrity of the anterior and middle column with a bone chisel (Figure 2). To eliminate differences between specimens, chiseling was conducted in the same way to create equal burst severity. Specimens were laid in the lateral position, and all surgeries were performed from the left side following the manufacturer’s instructions. An approximately 80-mm-wide space was created on the posterior parts of the middle column for insertion. Adjacent diskectomy and endplate preparation were performed before placing the device. Distraction was performed, and a gauge was used to determine the proper size. Special holding forceps were used to help place the cage into the space and compress to ensure firm contact between the cage and adjacent...
endplates. Two cancellous screws were drilled into adjacent endplates at a 45° angle to further eliminate the possibility of migration (Figure 3A). Finally, the anterior plate–screw fixation system (D-rod; Double Engine Medical Material Ltd) was used (Figure 3B).

**Nondestructive Stiffness Test**

All specimens were first tested intact during flexion and extension, lateral bending, and rotation with an axially applied load to mimic the load bearing of the spine in vivo. The load was applied, starting with a preload of 50 N up to a maximum of 550 N at a rate of 10 N/second. The tests were repeated 3 times with a 10-second dwell time between loading cycles, and only the third cycle was used for data analysis. The displacement of the specimen from initial position to maximum load was measured, and the stiffness was calculated as the slope of the load displacement curve using Microsoft Excel software (Microsoft, Inc; Redmond, Washington). The L1 burst fracture and instrumentation were performed as previously described. The specimens were tested in the same protocol again, and the stiffness was calculated (Figure 3C).

**Cyclic Loading Test**

The reconstruction and fixation specimens were subjected to the cyclic loading test to predict the risk of subsidence and device loosening. The axial load was applied in each direction from 50 to 550 N at a rate of 10 N/second for 200 cycles. The displacement of the construct was recorded for each cycle to justify the loosening or migration of the device. After the test, all specimens were examined carefully at the endplates to determine if any cage subsidence existed.

**Load to Failure Test**

The reconstruction and fixation specimens were tested for maximum load bearing ability if no loosening or subsidence occurred after the cyclic loading test. The instrumented spine was placed under a constant axial load at 10 N/second, and the resultant load was recorded. The test was terminated if any endplate subsidence or device breakage occurred. The maximum load before failure was defined as the peak load of the construct. The force–displacement curve was calculated using OriginPro 8 (OriginLab Corporation, Northampton, Massachusetts) (Figure 4).

**Statistical Analysis**

A comparison of displacement and stiffness between the intact spine and the instrumented spine was performed using a paired t test. In the cyclic loading test, the displacement of each cycle was compared with 1-way analysis of variance (ANOVA) to determine any difference between cycles. The relationship between bone mineral density (BMD) and the peak load of the construct was assessed using bivariate correlation analysis. Statistical significance was set at a P level less than .05. SPSS version 16.0 software (SPSS, Inc, Chicago, Illinois) was used for statistical analysis.

**RESULTS**

The stiffness values calculated for each mode of testing are shown in the Table. Plots of stiffness values during flexion and extension, left and right bending, and left and right rotation are shown in Figure 5. After reconstruction of the U-Cage and fixation of the D-rod system, the stiffness of the specimens was equivalent to that of intact bone in all directions, with the exception of left rotation, which was significantly reduced (P<.05). All specimens were able to withstand 200 cyclic tests in each direction, and the displacement of the entire construct did not dif-
fer significantly between individual test cycles (P>.05). No cage subsidence into the endplate or device breakage was observed. The mean value of the peak load of the instrumented spine was 4137.5 N (range, 3950-4365 N). Cage subsidence into the caudal endplate occurred in all specimens by the end of the test, and no screw loosening or device breakage was detected. A bivariate correlation analysis showed that BMD had significant influence on the peak load of the construct (r=0.915; P=.011) (Figure 6).

**Discussion**

The anterior and middle columns of the spine have been shown to be the most load-bearing parts of the spine. Restoration of the load-bearing ability of fractured vertebrae is critical in the treatment of burst fractures. The results of the current study confirmed the hypothesis that U-Cage reconstruction and D-rod fixation would provide good biomechanical performance.

Anterior surgery has been demonstrated to achieve better biomechanical performance than posterior fixation in many previous in vitro studies. The biomechanical properties of different reconstruction methods have been compared. Lee et al found no significant differences in biomechanical stability between reconstructions using a polymethylmethacrylate block, a tricortical iliac graft, and a 1- or 2-mesh cage. More recently, Cardenas et al found no significant differences between thoracolumbar spine replacements using allograft bone and those using titanium cages. Buttermann et al also found that range of motion and neutral zone did not differ between strut graft and vertebral body replacement constructs following traumatic spinal injury. In a study comparing mesh cages and different types of expandable cages, Pflugmacher et al concluded that the biomechanical properties of expandable and nonexpandable cages were similar and that construct shape had no important effect on biomechanical performance. Thus, it appears that all of these reconstruction approaches are able to produce sufficient biomechanical stability.

In current study, the burst level achieved a similar stiffness after instrumentation as that in an intact spine. These results illustrate that the reduced width of a U-Cage, when used in combination with anterior fixation, does not adversely affect spine stability, in agreement with a previous study. Rohlmann et al found that loads could be transferred by the instruments allowing maintenance of the vertebral structure and that the axial loads can even be transferred by the bone implants that are used for fusion. In addition, Schmoelz et al found that less resection of the burst vertebral body allowed for

<table>
<thead>
<tr>
<th>Testing Mode</th>
<th>Intact</th>
<th>Instrumented</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>32.43±7.15</td>
<td>38.00±10.31</td>
<td>.112</td>
</tr>
<tr>
<td>Left bending</td>
<td>28.00±7.01</td>
<td>44.60±25.96</td>
<td>.0101</td>
</tr>
<tr>
<td>Right bending</td>
<td>25.47±9.50</td>
<td>26.70±11.14</td>
<td>.278</td>
</tr>
<tr>
<td>Left rotation</td>
<td>46.35±10.91</td>
<td>37.08±9.16</td>
<td>.017*</td>
</tr>
<tr>
<td>Right rotation</td>
<td>38.77±0.74</td>
<td>42.15±13.75</td>
<td>.569</td>
</tr>
</tbody>
</table>

*Significant between intact and instrumented spines.
the achievement of more biomechanical stability. According to their findings, the stiffness of instrumented specimens may be attributed to the stability of the U-Cage anterior D-rod system and the retained anterior and middle columns.\textsuperscript{15}

In the current study, only left rotation did not achieve the same stiffness as the intact spine. Less stability during rotation has been reported in several biomechanical studies. In a study by Moon et al\textsuperscript{16} that investigated the biomechanical rigidity of all-polyetheretherketone, all-titanium, and hybrid anterior thoracolumbar reconstruction constructs, all constructs had less stability during left and right rotation. Biomechanical comparison of short-segment anterolateral fixation, extended anterolateral fixation, and circumferential fixation has also shown that short-segment fixation has less rigidity during axial rotation.\textsuperscript{17} In that study, no bone ingrowth occurred between the cage and endplates, and the resistance to transverse shear was minimal, so the rigidity during axial rotation was low.\textsuperscript{17} The current study’s results support that theory.

Unlike previous studies of total resection of the vertebral body, only the posterior section of the vertebral body was resected from the left side during reconstruction in the current study, whereas the right side of the middle column was kept intact. This approach may lead to better biomechanical stability of the right axial rotation. Acosta et al\textsuperscript{18} also underscored the importance of bone fusion for providing torsional rigidity. Theoretically, the U-Cage preserves the structure and blood supply of the burst vertebral body and facilitates bone implantation in and around the cage, which may promote early and effective bone fusion. This may compensate for the decrease in stiffness during left axial rotation if the patient can achieve better fusion of the index level. Furthermore, the use of a brace may also be helpful in clinical situations.

After the cyclic test in the current study, no screws were found loosened in the specimens. The locking mechanism between screws and bones or screws and plates of the D-rod fixation system can reduce loosening. In addition, because no repeated reduction of kyphosis occurred in the screws, the chance of screw loosening would also be lower. During the test, no migration of the U-Cage was detected, which may be due to the 2 screws fixed to the adjacent vertebral body and the flanges in the implant endplate surface.

No endplate subsidence was observed at the end of the test. Several factors related to subsidence have been described in the literature, including (1) the bone quality of the endplates, (2) the contact area of the cage–endplate surface, and (3) the preparation of the endplates intraoperatively. Many studies have shown a correlation between the BMD of the vertebral body and subsidence.\textsuperscript{18-21} In the current study, all specimens had a normal BMD, which may have minimized the possibility of subsidence. Endplate resistance to compressive load differs depending on endplate area. Tan et al\textsuperscript{22} showed that placement of an interbody fusion device on the stronger regions of the endplate resulted in a stronger bone–implant interface and the avoidance of subsidence. In a study examining the maximum load to failure at 6 different endplate locations, Lowe et al\textsuperscript{23} found that the posterosuperior region of the endplate provides the greatest resistance to subsidence and the central region provides the least resistance. Polkeit et al\textsuperscript{24} found that cages placed in the posterosuperior aspect of the endplate were 20% stronger than those placed in the center of the endplate, and their findings were corroborated by Labrom et al.\textsuperscript{25}

Unlike the centrally placed mesh cage or vertebral body replacement, the U-Cage was designed to be placed on the posterior one third of the endplate, which is stronger than the central region. The careful preservation of the bony endplates\textsuperscript{17} and the contact area of the cage–endplate surface are 2 factors that helped to avoid subsidence. Hasegawa et al\textsuperscript{26} compared the mechanical properties of the interface between the endplate and different-sized mesh cages with or without an internal ring. They found that cages with augmentation of the internal end ring had better biomechanical performance. Zhang et al\textsuperscript{17} also concluded that the large contact surface of the vertebral body replacement may increase the interface strength. However, a contradiction between fusion effect and cage–endplate contact area exists.\textsuperscript{13,27} If the contact area between the implanted bone and endplate is too large, then the cage would have less contact area with the endplate, which would make it easier for subsidence to occur. Conversely, a large contact area between the cage and endplate would weaken the fusion due to a smaller corresponding contact area between the implanted bone and endplate, which may finally lead to subsidence. Therefore, the optimal size of the contact area for the cage remains unclear. In the current study, the 200 cyclic tests did not
cause subsidence of the U-Cage into the endplate, which suggests that the contact area in this study was sufficient for the U-Cage. The narrow cage allowed for more burst-fractured vertebral bone to be exposed and left more area for the bone–endplate contact, which may predict bet-
ter fusion of the burst vertebral body. The results suggest that the U-Cage may pro-
vide easy fusion with sufficient endplate surface strength to avoid subsidence.

The construct used in this study was able to withstand an axial load of approximately 4000 N. It has been shown that the maximum axial compression load needed to burst the endplate of individ-
uals between the ages of 48 and 92 is 3121 N.28 In the current study, the average age
of the collected specimens was 56 years. Therefore, the results suggest that a burst
fracture instrumented with a U-Cage and D-rod fixation system may withstand
adequate axial load in vivo before fu-
sion is fully achieved. A correlation was also found between the peak load and the
BMD of the vertebral body, which is in agreement with previous studies.27,29,30 All
specimens exhibited cage subsidence into the caudal endplates at the end of the test,
which may be explained by the anatomic properties of the cranial endplate, which
is thinner and supported by less dense tra-
becular bone.28

This study had some limitations. First,
only U-Cage reconstruction and D-rod
fixation with intact specimens was com-
pared, and because the U-Cage was de-
signed to promote fusion, further research is needed to compare its fusion effect and
biomechanical properties with that of a
mesh cage and vertebral body replace-
ment after fusion. Second, the average age
of the specimens used was not as young
as patients who generally experience tho-
racolumbar burst fractures. Although the
biomechanical results may not provide a
complete picture of the clinical situation,
they provide useful information, and fur-
ther clinical research is needed to exam-
ine the effectiveness of this construction.

Third, to minimize differences between
groups, the same burst fracture mode was
created in all specimens. The influence of
the burst degree on the biomechanical
performance will be explored in future
studies.

**Conclusion**

This biomechanical study shows that
thoracolumbar burst fractures reconstruct-
ed with a U-Cage in combination with an-
terolateral D-rod fixation can achieve similar stiffness as that of the intact spine.
This approach may effectively prevent
subsidence and withstand sufficient axial
load in vivo. In addition, the narrow
U-Cage may be advantageous compared with other devices because trauma is mini-
imized intraoperatively and fusion is con-
comitantly enhanced.

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