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Laboratory studies

Vertebroplasty plus short segment pedicle screw fixation in a burst fracture model in cadaveric spines

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ABSTRACT

The current project investigates the role of vertebroplasty in supplementing short segment (SS) posterior instrumentation, only one level above and below a fracture. In the treatment of thoracolumbar burst fractures, long segment (LS) posterior instrumentation two levels above and below the fracture level has been used. In our study, burst fractures were produced at L1 in eight fresh frozen human cadaveric spines. The spines were then tested in three conditions: 1) intact, 2) after LS (T11–L3), 3) SS (T12–L2) instrumentation with pedicle screws and rods, and 4) short segment instrumentation plus cement augmentation of the fracture level (SSC). LS instrumentation was found to significantly reduce the motion at the instrumented level (T12–L2) as well as the levels immediately adjacent in flexion, extension and lateral bending. Similarly, SSC augmentation was found to significantly reduce the motion compared to intact at T12–L2 but still maintained the adjacent level motion. However, SS instrumentation alone did not significantly reduce the motion at T12–L2 except for left lateral bending. While LS instrumentation remains the most stable construct, SS instrumentation augmented with vertebroplasty at the fracture level increases rigidity in flexion, extension and right lateral bending beyond SS instrumentation alone.

1. Introduction

Surgical intervention is indicated in the treatment of burst fractures when the individual presents with neurological deficit, pain or spinal instability [1–10]. The type of surgical intervention may include anterior column decompression and reconstruction via an anterior approach, or a posterior approach with decompression and instrumentation. Failure, however, to adequately support the anterior column may lead to hardware failure, progressive kyphosis and chronic pain.

Corpectomy for burst fractures through an anterolateral approach is by no means a simple procedure and can carry morbidities of 5–10% [6,8,10–12]. This morbidity includes wound infection, iliopsoas weakness, cerebrospinal fluid leaks and vascular injuries. Anterior column reconstruction with cement such as ActivOs (90% polymethylmethacrylate [PMMA] + 10% hydroxyapatite cement by weight; Medtronic Sofamor Danek, Memphis, TN, USA) is a potentially attractive option in patients with multiple comorbidities, poor bone quality and in those who do not require ventral decompression.

Previous biomechanical studies have shown that transpedicular vertebral body reconstruction with hydroxyapatite cement reduced pedicle screw-bending moments and increased initial stiffness in flexion-extension in a human cadaveric burst fracture model [3,9,13–15]. Prospective studies have shown that anterior column reconstruction with hydroxyapatite supplemented with pedicle screw fixation showed improvement in neurological function, maintenance of the vertebral body height and stable alignment [13,16–18].

The above results suggest that vertebroplasty potentially augments stability imparted by short posterior instrumentation in burst fractures. The current study is designed to investigate the rigidity conveyed by cement vertebroplasty with short segment (SSC) posterior instrumentation in a cadaveric model of burst fracture.

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2. Methods

2.1. Specimen preparation

Eight fresh frozen human cadaveric spine specimens were obtained from the Department of Anatomy and Cell Biology Deeded Body Program at The University of Iowa. Age, sex and bone mineral density (BMD) were recorded. The specimens were radiographed in both the anteroposterior and lateral planes to ensure the absence of fractures, deformities and any metastatic disease. BMD was measured using peripheral quantitative CT scan, with measurements taken at two different slices. The specimens were stored in double plastic bags at –20°C and allowed to thaw at room temperature prior to any manipulation. Thawed specimens were denuded of paravertebral musculature avoiding disruption of spinal ligaments, joints and discs. Specimens were potted at T10 and L4 using polymer resin (Bondo; 3M Corporation, St. Paul, MN, USA). Prior to potting, wood screws were inserted into the endplates to improve interdigitation with the potting material.

2.2. Experimental setup

Each specimen was mounted in a biaxial servo-hydraulic materials testing machine (858 Bionix II; MTS Corporation, Eden Prairie, MN, USA) retrofitted with two spine gimbals and a passive XZ table. Custom made rigid body markers comprised of three infrared light-emitting diodes affixed between two small aluminum plates were placed on each vertebral body and the two gimbals to track the segmental motion. Nondestructive flexibility tests were performed about each axis of rotation (flexion and extension, right and left lateral bending [RLB; LLB], and right and left axial rotation [RAR; LAR]) by applying an isolated ±6 N.m (Newton meter) moment about each of the primary axes. Each test initiated and concluded in the neutral position with zero load. Three loading and unloading cycles were performed with motion data collected on the third cycle (the first two cycles serve as preconditioning). The displacement of each vertebra was measured using an optoelectronic motion capture system (OptoTrak 3020; Northern Digital, Waterloo, Ontario, Canada), the output of which was synchronized with that of the 858 Bionix II machine. Moment-rotation curves were plotted for each scenario and the motions are reported for the greatest moment loading (6.0 N.m).

2.3. Testing paradigm

Testing, as described above, was performed in the following order: 1) intact spines; 2) burst fractures were created at L1; 3) specimens were instrumented and tested after each fixation technique (posterior T11–L3 long segment instrumentation [LS]; posterior T12–L2 short segment instrumentation [SS]; posterior SSC [L1]).

2.4. Burst fracture

For the production of the L1 burst fracture, the body was cored out with a high speed drill and a matchstick bit. The specimen was then secured on the 858 Bionix II machine using custom rigid fixation. The spine was placed in slight flexion and axially loaded in compression until failure of the anterior cortex was noted (Fig. 1).

2.5. Posterior SS and LS instrumentation

Using anatomical landmarks, the cortical surface was penetrated with an awl. A pedicle probe was used to engage the pedicle down to a depth of 30 mm. A ball tip probe was used to ensure that the cortex of the pedicle was intact on all sides. Next, a 5 mm tap was used to prepare the pedicle. A 6 $\times$ 45 mm polyaxial screw was then inserted into the pedicle. Screw purchase seemed to correlate with the known bone mineral density for each specimen but this was not quantified. For SS constructs, screws were placed at T12 and L2. For LS constructs, screws were placed at T11, T12, L2, and L3. Following placement of the pedicle screws, appropriate length 5.5 mm titanium rods were cut and placed in the screw heads. The rods were fixed with set screws and all instrumentation was tightened prior to testing. No cross-connector was used for posterior instrumentation in order to keep the results of the study applicable in the setting of percutaneous pedicle screws.

2.6. Cement augmentation

ActivOs bone cement was prepared according to manufacturer recommendations. Cement (5 ± 2 mL) was then injected directly into the fractured L1 body. The cement was allowed to harden for 120 min prior to testing.

2.7. Statistical analysis

The rotational displacement in response to the 6 N.m moment was compared at each level for the intact state and fixation techniques. Statistical analysis was conducted using the general linear model procedure for analysis of variance. Pairwise comparisons were made using Tukey's studentized range test. Statistical significance was determined at the 0.05 alpha level.

3. Results

The specimens were obtained from people aged 34–95 years with a mean age of 76.1 ± 20.2 years (standard deviation [SD]). The bone mineral densities ranged from 111.4–201.4 mg/cm^3 with a mean of 130.8 ± SD 29.5 mg/cm^3.

The results are presented starting at the area of interest, T12–L2, followed by the adjacent levels of T11–T12 and L2–L3 and the next adjacent levels of T10–T11 and L3–L4. In both flexion and extension at T12–L2 (Fig. 2), motion with SSC was not statistically different from SS and LS, however, SSC and LS were both significantly less than intact motion. In LAR and RAR, there was no significant difference between any of the interventions and the intact state. In LLB, all interventions were significantly less than intact motion. Additionally, LS was significantly less than SSC and SS. In RLB, both SSC and LS were significantly less than intact motion. LS was also significantly less than SS motion.

In flexion at T11–T12 (Fig. 3), SSC was similar to SS and intact, and only LS was significantly more rigid than intact and other interventions. In extension and axial rotation, there was no significant difference between any of the interventions and intact. In LLB and RLB, LS was significantly stiffer than intact and other interventions, and SSC was similar to SS and intact.

At L2–L3 (Fig. 4) in flexion, extension and RLB and LLB, SSC was similar to SS and intact, and LS was significantly more rigid than the intact and the other interventions. In LAR and RAR there was no significant difference between any of the interventions and the intact state.

At T10–T11 and L3–L4 (Fig. 5, 6), there were no significant changes between any of the interventions and the intact state.

In summary, LS significantly reduces the motion at the instrumented level (T12–L2) as well as the levels immediately adjacent in flexion, extension and lateral bending. Similarly, SSC significantly reduces the motion compared to intact at T12–L2 but still maintains the adjacent level motion. However, SS alone does not significantly reduce the motion at T12–L2 except for LLB.