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Biomechanical Assessment of Stabilization of Simulated Type II Odontoid Fracture with Case Study

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Study Design: Researchers created a proper type II dens fracture (DF) and quantified a novel current posterior fixation technique with spacers at C1–C2. A clinical case study supplements this biomechanical analysis.

Purpose: Researchers explored their hypothesis that spacers combined with posterior instrumentation (PI) reduce range of motion significantly, possibly leading to better fusion outcomes.

Overview of Literature: Literature shows that the atlantoaxial joint is unique in allowing segmental rotary motion, enabling head turning. With no intervertebral discs at these joints, multiple ligaments bind the axis to the skull base and to the atlas; an intact odontoid (dens) enhances stability. The most common traumatic injury at these strong ligaments is a type II odontoid fracture.

Methods: Each of seven specimens (C0–C3) was tested on a custom-built six-degrees-of-freedom spine simulator with constructs of intact state, type II DF, C1–C2 PI, PI with joint capsulotomy (PIJC), PI with spacers (PIS) at C1–C2, and spacers alone (SA). A bending moment of 2.0 Nm (1.5°/sec) was applied in flexion-extension (FE), lateral bending (LB), and axial rotation (AR). One-way analysis of variance with repeated measures was performed.

Results: DF increased motion to 320%, 429%, and 120% versus intact (FE, LB, and AR, respectively). PI significantly reduced motion to 41%, 21%, and 8%. PIJC showed negligible changes from PI. PIS reduced motion to 16%, 14%, and 3%. SA decreased motion to 64%, 24%, and 54%. Reduced motion facilitated solid fusion in an 89-year-old female patient within 1 year.

Conclusions: Type II odontoid fractures can lead to acute or chronic instability. Current fixation techniques use C1–C2 PI or an anterior dens screw. Addition of spacers alongside PI led to increased biomechanical rigidity over intact motion and may offer an alternative to established surgical fixation techniques.

Keywords: Type II dens fracture; Odontoid fracture; Atlantoaxial stabilization; Cervical biomechanics; Interarticular spacer

Introduction

The atlantoaxial joint lies bilaterally between the atlas (C1) and the axis (C2). It is unique in its capacity to allow segmental rotary motion, which enables head turning, as a result of its bone morphology and gliding articulating surfaces [1,2]. This unique morphologic configuration allows greater axial rotation (AR) than occurs anywhere

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else within the cervical spine [2-4]. In the absence of intervertebral discs at this joint, multiple ligaments bind the axis to the skull base and the atlas to provide stability to the atlantoaxial joint [1,4]. These stabilizing soft tissues of the craniocervical joint include, namely, the cruciate ligament with its transverse and vertical bands, apical and alar ligaments, the tectorial membrane, and anterior and posterior atlanto-occipital membranes. Atlantoaxial stability also depends on an intact odontoid process and an intact transverse ligament, which passes from one lateral mass of the axis, moves behind the odontoid process (a.k.a. dens), and attaches to the other lateral mass. The most common traumatic injury to the craniocervical junction is a type II odontoid fracture (dens fracture, DF), in which failure of bony structures tends to occur before ligamentous failure because of the strength of the ligaments [5,6]. Transverse and alar ligaments have ultimate tensile strength of 350 N and 200 N, respectively [4]. Injury can lead to severe instability at C1–C2, requiring surgical intervention.

Standard methods used to stabilize a type II odontoid fracture injury consist of fusion techniques. Fusion in this region is important for re-stabilizing the area but can be problematic in elderly patients, who are more prone to DF. Anterior approaches generally result in high morbidity owing to difficulty in surgical access caused by placement of the atlantoaxial joint behind the mandible. Therefore, posterior approaches are used more commonly in this region [7-9]. Typical devices include transarticular screws, odontoid screws, and posterior cervical screws such as lateral mass screws or pedicle screws with rods [10-13]. Although biomechanical analysis of these methods shows adequate stability via decreased range of motion (ROM), odontoid screws have been associated clinically with a high rate of complications [8,9] resulting from infection. The rate of nonunion is an area of focus because stability is a primary concern and complications such as infection may increase the nonunion rate [8,9]. Interarticular spacers (CORRIDOR, Globus Medical Inc., Audubon, PA, USA) have been used between articulating surfaces of C1 and C2 in conjunction with posterior fixation to help stabilize the joint for treatment of basilar invagination [14]. A similar surgical technique may offer a novel solution for fixating a DF. Although both lateral mass screws and C1–C2 spacers are used during a posterior approach, comparison of these fixation methods may yield essential information with regard to stability that may lead to promotion of fusion and reduction in revision rates. In this study, researchers assessed the biomechanical instability created when a novel type II DF model was created, and quantified the contribution of C1–C2 spacers when combined with posterior instrumentation (PI). The authors hypothesized that spacers combined with PI would reduce ROM significantly, possibly leading to better fusion outcomes.

To show how results of this study can be applied in a clinical situation, we present the case of an 89-year-old female patient, which incorporates a type II DF that required surgical intervention. We describe the outcome at 1-year follow-up when this novel C1–C2 spacer was used with posterior screw and rod fixation. This case study reflects the focus of the biomechanical study by illustrating use of this novel technique in an elderly patient with type II DF.

Materials and Methods

1. Specimen preparation

Seven fresh-frozen cadaver spines from occiput (C0) to C3 were used in this study. The medical history of each donor was reviewed, along with radiographs, so that specimens with spinal trauma, malignancy, deformity, or fracture that would otherwise affect the outcome of the test could be excluded. Specimens were carefully dissected, leaving only ligaments, bones, and intervertebral discs of desired segments. Specimens were fixed at the occiput with a custom-made fixation device, which provided easy intraoperative access to the superior aspect of the dens, and were potted distally at C3 with a 2:1 mixture of Bondo Auto Filler (Bondo/MarHyde Corp., Atlanta, GA, USA) and fiberglass resin (Home-Solutions All Purpose, Bondo/MarHyde Corp.). All specimens were double-wrapped in plastics bags and were stored at –20° Celsius until the day of testing.

2. Test setup and data analysis

Each specimen was thawed overnight and was mounted on a six-degrees-of-freedom spine motion simulator. The occiput was mounted centrally to a gimble, which allowed translation in anterior-posterior and medial-lateral planes. The distal end (C3) was mounted to the base of the simulator, which allowed cranial-caudal translation

during motion. A load-control protocol was used for testing, by which the specimen continued its course of motion until the desired load was met. For flexion-extension (FE), lateral bending (LB), and AR loading modes, an unconstrained pure moment was set at ±2.0 Nm at a rate of 1.5°/sec through motors attached to the gimble. Each loading mode consisted of three load/unload cycles, and data from the third cycle were analyzed. Markers were placed at C1 and C2. With these markers, investigators assessed ROM for intact and all surgical constructs by using the Optotrak Certus motion capture system (NDI Inc., Waterloo, ON, Canada).

In this study, a displaced type II DF was simulated without transverse ligamentous injury by resection of the odontoid along the long axis of the odontoid process from above (Fig. 1). Because of difficulty involved in accessing the dens, creation of the injury required removal of additional bones and ligaments, which is not normally done in a clinical setting. Previous biomechanical studies used approaches that disrupted the anterior longitudinal ligament (ALL), the tectorial membrane, or the posterior longitudinal ligament (PLL), or investigators removed C1 and C2 just to isolate the area [15-17]. The procedure reported here began with removal of the inferior clivus with osteotomes to expose the tip of the odontoid process. Apical and alar ligaments were disrupted during this process. Then the odontoid process was hollowed from the superior process inferiorly along its internal axis to its base by a drill used along its length. Researchers used microcurettes to remove the outer shell of bone at the base of C2 to create the fracture, while taking care to preserve the transverse ligament. Fluoroscopy was used to verify complete resection of the odontoid (Fig. 1). Although the technique used to create injury in this study might have disrupted alar and apical ligaments, once the odontoid was fractured, the alar ligaments were no longer effective in limiting head rotation, as the odontoid was separated from the C2 vertebral body. All other ligaments were left intact. Clinically, this approach may be more destructive at the skull base, but in a laboratory setting, it best simulated the type II odontoid fracture without compromise of C1 and without impairment of the ALL. Other approaches to trauma involve removal of the C2 vertebral body and cannot be used to evaluate ROM [5].

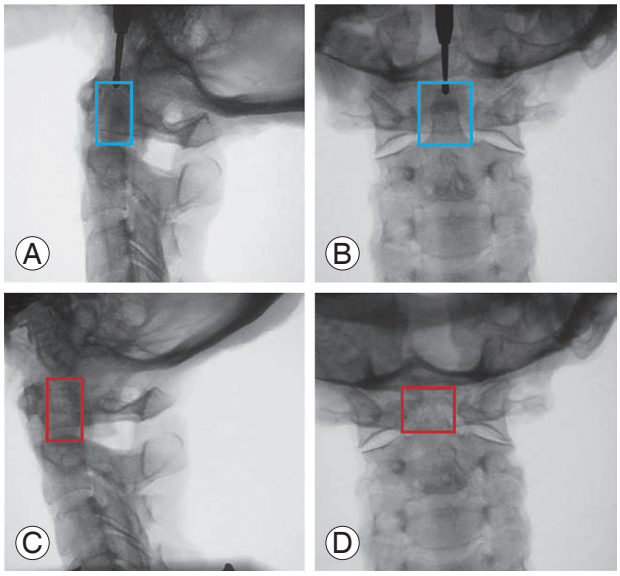

Fig. 1. (A) Lateral view of intact dens (blue box is around the dens) as drilling begins. **(B)** Anteroposterior (AP) view of intact dens (blue box is around the dens) as drilling begins. **(C)** Lateral view of fractured dens (red box). **(D)** AP view of fractured dens (red box). Statistical analysis was performed using analysis of variance with repeated measures to correlate significant (p<0.05) differences between experimental constructs.

3. Surgical reconstruction

Initially, specimens were tested for flexibility while joints were intact, so a baseline value could be determined. Subsequent to intact testing, researchers used surgical replications in the sequence presented in Fig. 2.

4. Statistical methods

Statistical analysis was performed using analysis of variance (ANOVA) with repeated measures to correlate significant (α<0.05) differences in ROM between experimental constructs. Tukey's honestly significant differences (HSD) test was used to determine statistical changes, hence p-values were not obtained. Tukey's HSD test for post-ANOVA comparisons requires a studentized range distribution statistic (Q) of the critical point (0.05), mean square error (MS), and degrees of freedom (df). The number of samples is also needed (n). Once those values are obtained, HSD can be computed by $HSD_{.05}=Q_{.05*}$ sqrt (MS/N). Significance occurs when differences between constructs are equal to or greater than this value.

Results

Mean ROM for the intact condition at C1–C2 was

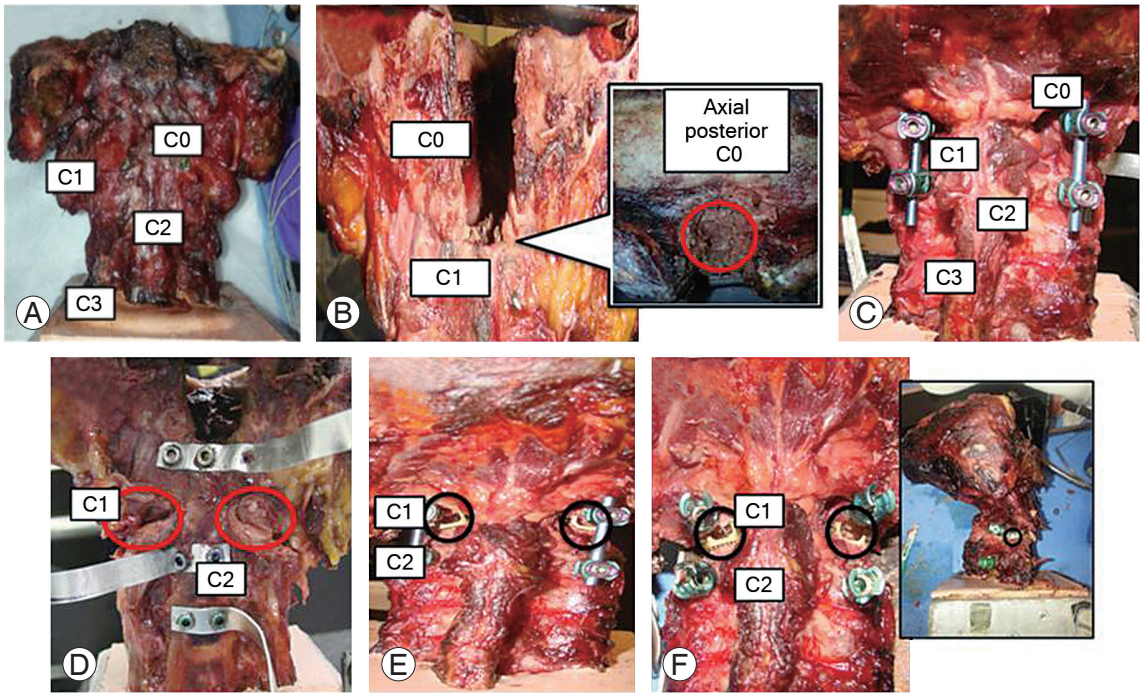

Fig. 2. Testing sequence for all specimens. **(A)** Anterior view of an intact specimen. **(B)** Dens fracture (DF) created by removal of the clivus (large image) with an axial view of the DF (small image). **(C)** Posterior view of posterior instrumentation (PI) construct. **(D)** Anterior view of joint capsulotomy during PI with joint capsulotomy. **(E)** Posterior view of PI with spacers. **(F)** Posterior (large image) and lateral views (small image) of spacers alone. Red circles represent instabilities created, and black circles indicate C1–C2 washers.

Table 1. Normalized data (as percentage of intact condition) for all constructs

Variable	Intact	DF	PI	PIJC	PIS	SA
FE (%)	100±54.6	319.6±130.8[a)]	41.0±37.1[a,b)]	45.6±53.9[a,b)]	16.2±11.4[a,b,c)]	63.6±53.5[b)]
LB (%)	100±64.7	429.3±354.5[a)]	20.7±20.7[a,b)]	27.9±20.2[a,b)]	13.9±12.7[a,b)]	24.5±31.7[a,b)]
AR (%)	100±21.9	120.3±20.6	7.8±4.3[a,b)]	8.5±5.0[a,b)]	2.9±2.9[a,b,c)]	46.7±46.5[a,b)]

DF, dens fracture; PI, posterior instrumentation; PIJC, posterior instrumentation with joint capsulotomy; PIS, posterior instrumentation with spacers; SA, spacers alone; FE, flexion-extension; LB, lateral bending; AR, axial rotation.
[a)]Significant for intact; [b)]Significant for dens fracture; [c)]Significant for spacers alone.

4.6°±2.5°, 2.2°±1.4°, and 57.3°±12.6° in FE, LB, and AR, respectively. Creating the DF significantly (p<0.05) increased motion to 14.7°±6.0° and 9.5°±7.9° in FE and LB, respectively. ROM was increased in AR to 69.9°±11.8°, but this finding was not statistically significant when compared with intact. This can be observed in the Table 1, where data have been normalized to intact (100%).

All instrumented constructs reduced motion compared with that seen in the injured construct (Fig. 3, normalized to intact). The PI construct significantly reduced motion to 2.1°±2.5, 0.6°±0.5°, and 4.5°±2.5° of intact motion in FE, LB, and AR, respectively. When joint capsulotomy was performed and PI was re-installed, ROM changed slightly to 1.9°±1.8°, 0.5°±0.3°, and 4.5°±2.5° of intact in FE, LB, and AR, respectively. The PI with spacers (PIS) construct showed the most rigid motion, which was reduced to 0.8°±0.5°, 0.3°±0.3°, and 1.6°±1.6° in FE, LB, and AR, respectively. Spacers alone (SA) proved the least stable construct of the fixation methods, with increases in FE to 2.9°±2.5° and in AR to 25.0°±26.7° of intact. This increase in motion was statistically significant when compared with PIS, and the decrease in motion was statistically significant only for the injured construct in FE, whereas all other instrumented constructs showed significantly less

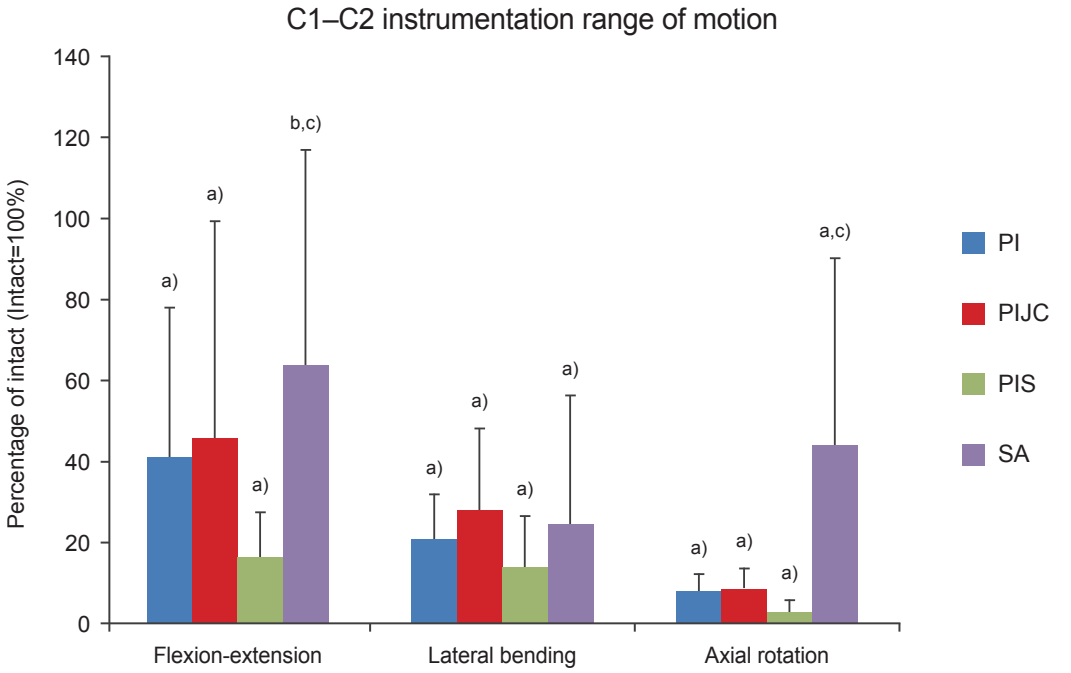

Fig. 3. Range of motion and statistical analysis of C1–C2 for each instrumented construct normalized to intact. PI, posterior instrumentation; PIJC, PI with joint capsulotomy; PIS, PI with spacers; SA, spacers alone. [a]vs. Intact and injured; [b]vs. injured only; [c]vs. PIS.

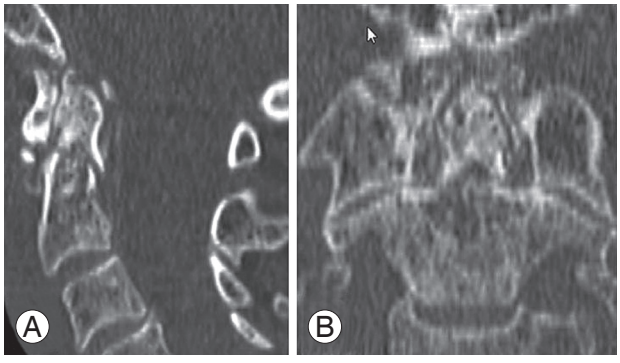

Fig. 4. Preoperative computed tomography scan shows the odontoid Anderson and D'Alonzo type II dens fracture. **(A, B)** Sagittal views.

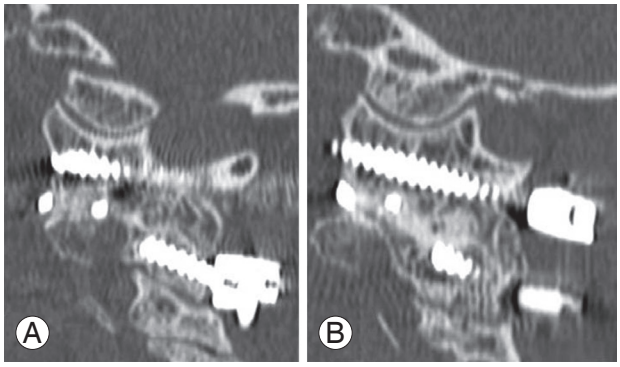

Fig. 5. Computed tomography scan 1 year after surgery. C1–C2 fusion can be observed across and posterior to the spacers. **(A, B)** Sagittal views.

motion for intact and injured. The SA construct, however, was similar to instrumented constructs in LB, with 0.6°±0.7° of motion.

1. Case study

This case study provides clinical evidence of what can occur when posterior screws are used in conjunction with C1–C2 spacers. An 89-year-old female patient who had sustained a type II odontoid fracture was treated with a sternal occipital mandibular immobilizer brace without signs of consolidation with secondary displacement (Fig. 4). The patient reported severe neck pain. Surgery was uneventful, as was postoperative hospitalization, and during follow-up, the patient demonstrated complete elimination of pain. Findings on neurologic examination were completely normal, except for limitations in neck movement, which did not disturb the patient. Radiologic investigation performed with spiral, thin-sliced computed tomography with multiplanar reconstruction revealed solid fusion across the spacers bilaterally, as well as solid bone behind the spacers (Figs. 5, 6). Functional cervical

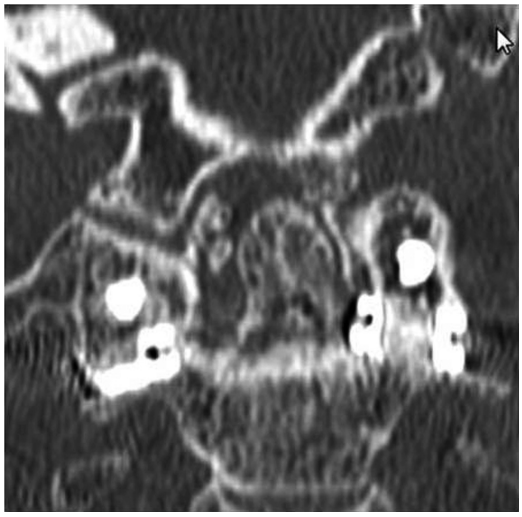

Fig. 6. Computed tomography scan 1 year after surgery. Coronal view shows solid bone fusion across the spacers in an almost pillar-like shape.

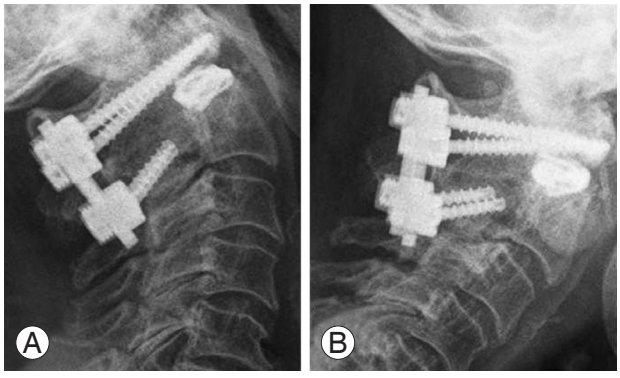

Fig. 7. Cervical functional X-rays show no detectable motion between C1 and C2 vertebrae. **(A)** Extension view. **(B)** Flexion view.

radiography with FE did not show movement between C1 and C2 (Fig. 7).

Discussion

DF injuries are difficult to create *in vitro* because access to the dens is limited. The injury model in the current study involved axial drilling of the dens with all ligaments left intact, with the exception of apical and alar ligaments. This model is similar to that used in a previous biomechanical study performed to test craniocervical dislocations [18,19]. It might accurately mimic a type II odontoid fracture because the base of the dens can be properly fractured without affecting the ALL, the PLL, or the C1 vertebral body. The clivus had to be removed by this technique, which caused disruption of the alar ligaments; however, once the dens was fractured, the contribution of alar ligaments to stability was considered moot. The injury as created in this model resulted in different outcomes than were reported by McCabe et al. [16], for whom a significant increase in AR preceded DF. In the current study, ROM was increased in AR, but this finding was not significant. The authors believe that this difference was due to use of different moments for testing. McCabe et al. [16] used ±1 Nm, which may have resulted in decreased intact motion while increasing the injured state, as less force is required to move that construct. Also, the larger sample size would achieve better statistical power. FE and LB in this study showed significant increases—a finding that was also reported by McCabe et al. [16] and Ivancic et al. [20]. Results indicate that this unique injury creation model led to instability comparable with that described in previous work.

PI limits atlantoaxial joint movement to achieve bony union posteriorly between posterior elements, or laterally within atlantoaxial joints, or within the fracture itself. A type II DF is most commonly treated through posterior C1–C2 fixation or by insertion of a single lag screw through the C2 body into the dens from an anterior approach. Currently, appropriate treatment is determined on the basis of spinal injury characteristics and surgeon experience and preference [11,16,21,22]. Anterior surgery, however, can lead to complications such as dysphagia and dysphonia [23]. Although odontoid screws have been associated with excellent outcomes in terms of bony union and motion preservation, access is more difficult to achieve than with posterior fixation [10,24-26]. Indications for odontoid screw fixation are much more limited than for posterior fixation, and fusion outcomes change drastically with elderly patients [8,9]. Alignment of the fracture is crucial, as is patient anatomy, in the decision of whether anterior screw placement is the best option [11]. The degree of separation may make use of anterior screws difficult because of lagging complications [26]. Furthermore, preserving motion may not always be a crucial issue, especially when elderly individuals are treated. In a DF study, Lakshmanan et al. [27] concluded that 56% of patients suffered from osteoporosis. ROM can be severely limited by osteoarthritis at the C1–C2 joint.

Although biomechanical researchers have reported no statistically significant differences in ROM, they have found that some methods provide greater reduction in ROM than others [11-13,20]. Deviations within each

spine and limited sample size have resulted in lack of significant differences between PI and constructs with spacers. The novel approach of using intervertebral spacers at C1–C2 takes advantage of intact ligaments by maintaining tension onto the spacers, thus stabilizing joints. Differences have been observed between PI alone and PIS in all loading modes; the latter approach is most effective in FE and AR. This research, although not clinical, also tested PI with joint capsulotomy, allowing quantitative analysis of how spacing created between C1 and C2 affects motion.

Daniel et al. [14] used the same spacer and screw construct to test biomechanical stability in a case of basilar invagination. In the Daniel et al.'s [14] study, SA led to great reduction in motion—a finding that is contradictory to outcomes reported in the present study. This difference in results could be due to lax transverse and alar ligaments (caused by the DF injury) that allow the joints to move freely. However, Daniel et al. [14] did not create an injury and thus left additional stabilizing elements in place. Robertson et al. [28] performed a similar study and used a novel approach with C1–C2 interface fixation. Investigators found statistical equivalence to all constructs, with the interface fixation device reducing motion to the greatest extent. Again, changes to injury methods may have led to outcomes different from those reported here. In the current study, spacers were sufficient for providing stability, but results were inconsistent in that some specimens demonstrated motion, leading to higher averages and higher standard deviations. SA produced significantly lower averages than were noted in the injured construct in FE, indicating that use of SA is not sufficient.

Type II DF generally happens in the elderly as a result of weakened bone [16,29]. The average person is living longer, and the prevalence of this injury may increase. Complications of nonunion, particularly in anterior correction of type II DF, are frequently reported among the elderly [11]. In the case study presented, the patient was 89 years old, yet fusion was achieved in a columnar fashion through the use of spacers; this may have been difficult to accomplish through other techniques. The approach described here provides a rigid construct with greater potential for bone growth. The authors of the present study believe that scraping and preparing the articular joint promotes bone growth, as has been seen in discectomy and endplate preparation techniques used in interbody fusion, but that construct rigidity, in terms of motion, remains stable until fusion occurs. Concerns regarding vertebral artery complications can be addressed by care and repositioning, as was discussed in previous clinical cases reported by Bobinski et al. [30], in which spacers as large as 10 mm were used in the C1–C2 articular joint. Finally, this technique allows use of a posterior approach only, thereby reducing the number of surgical incisions.

In the present study, researchers performed a biomechanical test with inherent limitations. No loads were included to simulate the weight of the head, and motion was applied at C0 rather than at each individual vertebral body. The clivus was removed to gain access, but this would not occur during repair of a type II fracture in a clinical setting. All muscles were removed as well, making forces different from those encountered in an *in vivo* setting.

Conclusions

A type II DF can cause segmental instability predominantly in FE and AR. A biomechanical simulation of this injury model has been created, in which the transverse ligament, the ALL, and the PLL were kept intact. Although current anterior methods with fairly narrow indications are available, PI is used more frequently to treat C1–C2 instability. Even though this technique provides adequate fixation, a novel approach in which spacers are used to stabilize the C1–C2 joint provides additional rigidity over posterior screws used alone and may allow bone growth. Rigidity and joint preparation may allow bone growth even in the geriatric population, for whom fusion rates can be problematic. This theory is supported by the clinical case provided; however, this case represents only one example. A larger clinical study would better reveal potential clinical benefits.

Conflict of Interest

Authors M.M.H., N.K., S.S.Y., and B.S.B. are salaried employees of Globus Medical Inc. Authors RTD, LB, and JMD have no relationships to disclose. All biomechanical testing was performed at Globus Medical Inc.

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