DONTOID fractures are common cervical injuries accounting for 10 to 20% of all cervical fractures in some reported series. This type of injury is often associated with a high rate of morbidity. Most commonly, these fractures occur at the C-2 dens–VB junction (Type II) or in the upper portion of the C-2 VB (Type III). Different treatment options exist for these fractures: rigid orthotic immobilization, posterior transarticular screw fixation, and anterior odontoid screw–assisted stabilization.

Recent trends in Type II odontoid fracture surgery tend to focus on the anterior fixation method involving odontoid screws because this procedure has been reported in a large series to result in an 88% fusion rate for recent fractures.2 This technique provides immediate stability, promotes healing through fracture reduction and compression, and maintains normal C1–2 motion. The anterior odontoid screw fixation technique was first reported in the literature in 1982.13 It involves the placement of one or two screws into the odontoid process via an anterior approach and it is usually used for stabilization of Type II and shallow Type III odontoid fractures.

Object. The authors tested the ability of a resorbable cannulated lag screw composed of a polylactide copolymer to repair Type II odontoid fractures. The resorbable screw was evaluated for its ability to restore strength and stiffness to the fractured odontoid process compared with traditional titanium screws.

Methods. Type II odontoid fractures were created in 14 human cadaveric C-2 vertebrae by applying a posterolaterally directed load and piston displacement was measured. Seven of these specimens were repaired using metal screws and seven were repaired using resorbable screws. Specimens were reinjured using the same mechanism as the initial fracture. Values of ultimate strength and stiffness during failure were statistically compared between metal and resorbable screws and between initial fracture and reinjury.

Conclusions. The stiffness and ultimate strength during initial fracture were significantly greater than those during reinjury in specimens repaired using resorbable screws or titanium screws (p < 0.001). The resorbable and titanium screws both restored 31% of the initial ultimate strength of the intact specimen (p = 0.95). The stiffness of the fractured odontoid process was restored to 15 and 23% of its initial value by repair with resorbable and metal screws, respectively (p = 0.07). The mode of failure in resorbable screws was usually breakage or bending, whereas that in metal screws was consistently cutout of the proximal shaft of the screw through the anterior C-2 vertebral body.

Key Words • odontoid process • Type II fracture • bioresorbable screw • biomechanical study

Abbreviations used in this paper: BMP-2 = bone morphogenetic protein–2; PLDLA = poly(L-lactide-co-D,L-lactide); SD = standard deviation; VB = vertebral body.
In addition, several types of fractures—oblique frontal and sagittal fractures, deep Type III fractures, irreducible fractures, and pathological fractures—are contraindications for odontoid screw placement. The patient’s bone quality and size of odontoid process should be considered because of the potential for screw migration. Investigating characteristics in a cadaveric model, Sasso, et al., reported that one or two screws are biomechanically equivalent in terms of fracture stabilization. Because the screw required for repairing the odontoid fracture is no longer beneficial after fusion has occurred and, in fact, may limit (secondary to stress shielding) the extent of desirable bone remodeling, an odontoid repair technique in which the screw disappears after fusion is theoretically desirable. A bioresorbable odontoid screw made of 70:30 poly(L-lactide-co-D,L-lactide), or PLDLA, was developed as an alternative to a metallic screw designed for direct fixation of Type II and shallow Type III odontoid fractures (Fig. 1). The screw is cannulated using a series of 45°-angled pores placed where the screw crosses the fracture site to permit the injection of osteotransductive cement or BMP-2 and its carrier after insertion. The polymer resorbs completely over 18 months, permitting the complete bone remodeling through the cross-sectional area previously occupied by the screw. Type II fracture (i), screw insertion (ii), reduced fracture (iii), cross-section (iv), injection of cement or growth factor carriers (v), and healed fracture after screw resorption and replacement by bone (vi).

Materials and Methods

Cadaveric Specimens
Fourteen human cadaveric C-2 vertebrae were studied. Seven specimens (obtained in three men and four women whose mean age at the time of death was 53 ± 8 years) received resorbable screws to repair the fractured odontoid process and seven specimens (obtained in two men and five women whose age at the time of death was 62 ± 7 years) received titanium screws to repair the odontoid fracture. In early-treated specimens, household wood screws were embedded in C-2 lateral masses and joint articulations away from the location of the fracture and odontoid screw to reinforce potting.
Fracture Repair Techniques

After the odontoid was fractured, the fractures were repaired by screw fixation. Seven of the specimen received resorbable 4.5-mm-diameter 70:30 PLDLA screws (MacroPore, San Diego, CA) and seven were repaired using 3.5-mm-diameter cannulated titanium screws (UCSS; Medtronic Sofamor Danek, Memphis, TN). For screw insertion, a 1.25-mm end-threaded stainless steel guidewire was first inserted in the anterocaudal margin of the C-2 VB and drilled through the body in a trajectory that allowed it to exit in the middle of the fracture site. While drilling the guide wire into the odontoid fragment, the fragment was then held in place manually because all surrounding tissue had been removed. Once the guidewire was in place, a cannulated 2.7-mm-diameter drill bit was used to create a pilot hole. In specimens receiving metallic screws, a 3.6-mm-diameter drill bit was then used to enlarge the proximal screw hole (in the C-2 VB) to allow the screw to pass through readily. In specimens receiving the resorbable screws, both the distal and proximal holes were enlarged to a slightly greater diameter to accommodate the slightly larger (4.5-mm) diameter resorbable screws. The screw length was 40 mm in all cases. Each repaired specimen was refraughtured under the same conditions used to generate the initial fracture.

Determination of Stiffness and Ultimate Strength

From the recorded load and displacement data, stiffness and ultimate strength were determined (Fig. 3). Stiffness was obtained by measuring the slope of the steepest linear portion of the early part of the load–displacement curve by using the least-squares method. The ultimate strength was defined as the maximum force sustained by the construct before failure (the peak value on the load–displacement curve). Stiffness and ultimate strength during initial fracture were compared with failure after repair by using paired two-tailed Student t-tests for each type of screw. Stiffness and ultimate strength were compared according to screw type by conducting nonpaired two-tailed Student t-tests. In all statistical comparisons, probability values less than 0.05 were considered significant. In addition to quantitative analysis, the mode of failure was recorded for both screw types. Data are presented as the means ± SDs.

Results

Both the metal and resorbable PLDLA screws were able to create a lag effect that drew the odontoid fragment in tight apposition with the C-2 VB. On radiography, the resorbable screw was nearly invisible except for the embedded tantalum beads on the head and tip.

Both the resorbable screw and the metal screw exhibited highly significantly (p < 0.0006) lower ultimate strength after repair than in their initial intact condition (Table 1, Fig. 4 left). In the bioresorbable screw group, the mean initial ultimate strength was 1239 ± 419 N, whereas after repair it was 356 ± 140 N. The bioresorbable screws therefore restored 31 ± 16% of intact strength. In the titanium screw group, the mean initial ultimate strength was 1192 ± 377 N, whereas after repair it was 351 ± 80 N. The metal screws therefore restored 31 ± 8% of intact strength. The stiffness of the fractured odontoid process was restored to 15 and 23% of its initial value by repairing it with resorbable and metal screws, respectively (Fig. 4 right). In both groups, the difference in stiffness between initial failure and postrepair failure was highly statistically significant (p < 0.009; Table 1).

No statistically significant difference in strength or stiffness was detected when comparing specimens repaired using resorbable and metal screws (p > 0.06; Table 1, Fig. 4). The resorbable screw–repaired specimens tended to fail at lower stiffness than specimens repaired using titanium screws. This difference approached significance (p = 0.067; Table 1).

The mode of failure in resorbable screws was breakage in four screws, bending in two screws, and posterior rotation of the screw in one case, which caused the proximal shaft to break through the anterior C-2 VB. This rotational failure mode was the mode of failure in all seven cases in the metal screw group.

Discussion

Both resorbable and metal screw constructs were significantly weaker than the anatomy itself in an uninjured state, and both screw types were weaker by the same amount (31% of the initial value). The stiffness after metal screw repair, however, was 23% of the original value,
whereas that after resorbable screw repair was 15% of the original value \( (p = 0.0667) \). The power or probability of avoiding a false-negative error in this biomechanical comparison was only 0.35 \( (\text{desired power} / H_1 = 0.8) \). Therefore, additional testing of a larger number of specimens might have resulted in a statistical difference. Regardless of the statistical significance, it is unclear whether this difference would result in a different outcome clinically. Although less stiff than a metal screw, the resorbable PLDLA exhibits greater stiffness than that of the surrounding bone.

Resorbable screws usually failed as a result of breakage or bending, which is consistent with the decreased stiffness of the resorbable material. Although constructs incorporating the resorbable material were as strong as those involving metal screws, the material properties of the polymer are very different from those of titanium. The mode of failure in the metal screws was always pushing of the proximal shaft of the screw through the anterior C-2 VB.

In the future course of development of the resorbable screws, special attention will be paid to increasing the polymer strength and stiffness. Current research is also focusing on increasing the efficiency of the release kinetics of proteins contained within and bound to the polymer matrix.

An advantage of resorbable polymer–based implants is that they may function as growth factor carriers. Richards, et al.,10 reported on development of biodegradable devices, fabricated from poly(L-lactic acid) and poly(D,L-lactic-co-glycolic acid), that could provide multidose drug delivery. The authors stated that the drug of interest is released in pulses at different time intervals after clinical implantation by using different molecular masses or materials for the membrane of the carrier device. One implication of this potential is that resorbable polymers may be used to develop implants into which bone morphogenetic factors (such as those for the family of BMP and transforming growth factor molecules) can be packaged. Their additional advantage is that their resorption allows the instrumentation cavity to be filled with normal host bone, which is then capable of remodeling in response to natural biomechanical stresses. Eventual remodeling and resorption should eliminate stress shielding–induced local osteoporosis. Furthermore, the decreased stiffness related to the low modulus of elasticity of the resorbable instrumentation may decrease the incidence of screw cutout through C-2, which currently is the most common mechanism of screw failure, particularly in cases of osteoporot-

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\text{Ultimate Strength}
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<table>
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<tr>
<th>Comparison</th>
<th>p Value</th>
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<tr>
<td>repaired vs uninjured specimens*</td>
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* Based on results of nonpaired t-tests.
† Indicates statistical significance \( (p < 0.05) \).
‡ Based on results of paired t-tests.

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\text{Stiffness}
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FIG. 4. Bar graphs. \textit{Left}: Mean ultimate strength of intact and repaired odontoid specimens. \textit{Right}: Mean stiffness during failure of intact and repaired odontoid specimens. Error bars show SDs.
It is unknown whether this decrease in stiffness and presumed increase in micromotion at the fracture site would result in decreased resorbable screw–assisted fusion rates, but this is at least a potential problem related to the decreased stiffness. It should also be noted that we are comparing the stiffness and strength of the resorbable screw to the metallic screw at implantation (initial state). The difference in stiffness and strength between the two materials is likely to increase with time because the DLPLA screw slowly resorbs and the metal screw retains stable. The rate of this decrease in stiffness and strength with time for this indication and screw design is unknown; however, studies have been performed to characterize the material strength degradation characteristics for other screws, plates, and cages (Fig. 5). It is also important to note that in the current study we do not address the issue of repetitive cyclic loading of this screw. Standard fatigue testing would need to be performed prior to clinical application.

The extent to which the cement injection, growth factor delivery, increased cross-sectional area for fracture healing, and decreased stress shielding may affect fusion rates in the setting of decreased stiffness is also unknown. It is also unclear how strong and stiff an odontoid screw needs to be to achieve acceptable fusion rates. It is clear from our study and previous work that screw fixation only restores 50% or less of the strength in relation to the intact condition. This is not characteristic of most instrumentation for spinal fixation, which usually produces much stronger and stiffer constructs compared with the intact condition. Perhaps, in cases of odontoid fracture fixation, the screw really functions more as a reduction mechanism, especially when combined with postoperative immobilization, making the ultimate material strength and stiffness less critical. Bioresorbable odontoid screws also are radiolucent on x-ray films, which is not the case with metallic screws. Thus, it is easier to evaluate the extent of reduction when the former are used. This radiolucent quality may also have a serious potential drawback in that an early screw fracture may not be demonstrated on plain x-ray films. Future design improvements that contain a continuous linear radiodense stripe along the length of the screw may address this present limitation.

**Conclusions**

The strength achieved using the resorbable screw to repair Type II odontoid fractures is equivalent to that conferred by metal screws. Because the resorbable material is less stiff than metal, hardware failure after Type II fracture fixation with a resorbable screw would manifest as bending at the fracture junction and possible screw breakage, whereas metal screws would likely fail by a push-through phenomenon. Because they performed similarly biomechanically to the presently used metal screws, resorbable screws may be a feasible alternative to metal screws for repairing Type II and some Type III odontoid fractures. The resorbable material has the advantage that space for new bone formation across the fracture area would eventually become available and stress shielding would be eliminated.

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**References**

Bioresorbable odontoid screw


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