

## Use of allograft bone for posterior C1–2 fusion

### Clinical article

**VIRANY HUYNH HILLARD, M.D., DANIEL R. FASSETT, M.D., MICHAEL A. FINN, M.D.,  
AND RONALD I. APFELBAUM, M.D.**

*Department of Neurosurgery, University of Utah, Salt Lake City, Utah*

**Object.** An iliac crest autograft is the gold standard for bone grafting in posterior atlantoaxial arthrodesis but can be associated with significant donor-site morbidity. Conversely, an allograft has historically performed suboptimally for atlantoaxial arthrodesis as an onlay graft. The authors have modified a bone grafting technique to allow placement of a bicortical iliac crest allograft in an interpositional manner, and they evaluated it as an alternative to an autograft in posterior atlantoaxial arthrodesis.

**Methods.** The records of 89 consecutive patients in whom C1–2 arthrodesis was performed between 2001 and 2005 were reviewed.

**Results.** Forty-seven patients underwent 48 atlantoaxial arthrodeses with an allograft (mean follow-up 16.1 months, range 0–49 months), and 42 patients underwent autograft bone grafting (mean follow-up 17.6 months, range 0–61.0 months). The operative time was 50 minutes shorter in the allograft (mean 184 minutes, range 106–328 minutes) than in the autograft procedure (mean 234 minutes, range 154–358 minutes), and the estimated blood loss was 50% lower in the allograft group than in the autograft group (mean 103 ml [range 30–200 ml] vs mean 206 ml [range 50–400 ml], respectively). Bone incorporation was initially slower in the allograft than in the autograft group but equalized by 12 months postprocedure. The respective fusion rates after 24 months were 96.7 and 88.9% for autografts and allografts. Complications at the donor site occurred in 16.7% of the autograft patients, including 1 pelvic fracture, 1 retained sponge, 1 infection, 2 hernias requiring repair, 2 hematomas, and persistent pain.

**Conclusions.** The authors describe a technique for interpositional bone grafting between C-1 and C-2 that allows for the use of an allograft with excellent fusion results. This technique reduced the operative time and blood loss and eliminated donor-site morbidity. (DOI: 10.3171/2009.5.SPINE08662)

**KEY WORDS** • atlantoaxial arthrodesis • iliac crest allograft • fusion rate • donor-site morbidity • complication

**P**OSTERIOR atlantoaxial fusion is commonly performed with C-1 and C-2 screw fixation and an iliac crest autograft. An autograft is harvested from the posterior iliac crest and wired into position at C1–2. The goal is to achieve a bony fusion because, as with all spinal fusions, the spinal instrumentation may eventually fail unless fusion takes place. Traditionally, autografting has been used for fusion because it provides both an osteoconductive and osteoinductive environment that results in very high rates of fusion.<sup>1</sup> The harvesting of an autograft for atlantoaxial arthrodesis requires a separate incision at the iliac crest, however, which increases operative time, blood loss, risk of infection, and postoperative pain.<sup>10</sup> Pelvic fractures<sup>21</sup> and the herniation of abdominal contents,<sup>19</sup> although uncommon, can occur with the harvesting of an iliac crest autograft, and chronic donor-site pain (in 18–39% of patients)<sup>10</sup> is common even with uncomplicated autograft harvesting.

The use of allograft (prepared cadaveric) bone in

other procedures, such as an ACDF, has proved to be successful<sup>4,20,23,25</sup> and has replaced autograft bone in these procedures at many institutions. In these procedures, the graft can be placed in an interpositional manner, such as between 2 vertebral bodies, where it is under compressive loading. Historically, C1–2 grafts have been applied as an onlay fusion where the graft bone is laid over the 2 adjacent vertebrae or has limited interposition in compression between these 2 bones without wide appositional decorticated surfaces.<sup>5,8,11</sup> In such constructs, allograft bone has not yielded acceptable fusion rates, primarily because of fusion failure at the graft–C-1 interface.

Therefore, we have modified the technique of placing a bone graft to increase the area of decorticated surface contact between the graft and C-1 and the graft and C-2, and instead we place the graft in a true interpositional manner held in compression between the posterior elements of C-1 and C-2. In this study, we investigated the fusion rates, overall surgical time, EBL, and donor-site complications in consecutive patients who underwent posterior atlantoaxial arthrodesis using autograft or allograft iliac crest bone placed in a similar manner.

*Abbreviations used in this paper:* ACDF = anterior cervical discectomy and fusion; EBL = estimated blood loss; LOS = length of stay.

# Allograft bone for C1–2 fusion

## Methods

### *Patient Population and Study Variables*

Between January 1, 2001, and September 31, 2005, 89 patients underwent posterior C1–2 fusion at the University of Utah Health Sciences Center. For the atlantoaxial arthrodeses an iliac crest autograft was used in the initial 42 patients, whereas an iliac crest allograft was used in the subsequent 47 patients. There were no exclusion criteria in this study, and patients of all ages, sexes, and diagnoses were eligible for participation.

Under an institutional review board–approved protocol, we retrospectively reviewed the radiographs, clinic records, and hospital charts for the patients identified. Preoperative symptoms, clinical findings, operations performed, combined procedures, and results were noted along with patient characteristics. The rate of fusion, percentage of patients in whom fusion was achieved, operative time, and EBL were also recorded.

Fusion was defined as the presence of bone bridging between the graft and both C-1 and C-2 and a lack of motion between the posterior elements and graft on flexion and extension cervical spine radiographs. We reviewed anteroposterior, lateral, and flexion and extension radiographs, which were routinely obtained at 3, 6, 12, and 24 months after surgery.

The hospital LOS was based on the admission and discharge dates. Preoperative indications and follow-up clinical results were found in the surgeon's office charts. Operative time and EBL were determined from the anesthesia and surgical nursing records. Surgical time was calculated according to the operative record from the time of skin incision until closure. Some patients underwent combined surgery involving anterior transoral decompression, occipitocervical fusion, or combinations with more extensive subaxial fusions. The patients who had undergone combined operations were excluded from the analysis of EBL and operative time because we were unable to separate the various components of their operations, which were recorded under one anesthesia and surgical nursing record.

### *Surgical Technique and Bone Grafting*

A modified Magerl technique<sup>15</sup> for C1–2 transarticular screw placement using a guide tube system has been described,<sup>2</sup> and the usual technique of iliac crest autograft harvest and placement (tricortical/bicortical) with wiring techniques has been described as well.<sup>5,7,11</sup> In patients who did not have suitable anatomy for C1–2 transarticular screw placement, the C-1 lateral mass was coupled to the C-2 pars by using a screw-rod technique described by Goel and Laheri<sup>14</sup> and Harms and Melcher.<sup>17</sup>

The interpositional graft is shaped to fit tightly between C-1 and C-2 while maximizing the surface contact with decorticated surfaces on C-1 and C-2. For the allograft we use bicortical iliac crest graft supplied by the Musculoskeletal Transplant Foundation. They provide sterile-harvested graft materials that have not been subjected to high-dose terminal irradiation. At our request, they have prepared the material in a 3 × 3.5–cm size (Fig. 1), which we shape and trim to fit the patient's anatomy.

The posterior arch of C-1 is decorticated and shaped by squaring its posterior and caudal surfaces with a high-speed drill. The graft is notched horizontally across the undersurface of the superior portion of the graft so that its edges contact the posterior and inferior surfaces of C-1. On C-2 the sides of the spinous process are decorticated, the laminae are decorticated, and a squared-off groove is made bilaterally at the junction of the lamina and spinous process (Fig. 2). A triangular notch is placed in the bone graft to accommodate and snugly contact the spinous process of C-2. It may take several trial placements to optimize the graft shape for maximal contact with C-1 and C-2 before the graft is situated into its final interpositional location between C-1 and C-2. We also impregnate the graft with demineralized bone matrix before its final placement. A lateral fluoroscopic image can be helpful in confirming a good interpositional location of the graft with good surface-to-surface contact. We secure the bone graft between C-1 and C-2 by using a braided titanium cable that is passed in the manner described by Dickman and colleagues<sup>8</sup> before we place the interpositional bone graft. A single cable is passed from the superior aspect of C-1 under the lamina of C-1 on one side, then behind the spinous process of C-2 through the interspinous ligament and again under the contralateral lamina of C-1 from its inferior aspect. The cable is again passed through the interspinous ligament behind the C-2 spinous process and through the crimping mechanism. Once the graft is situated, the cable is tensioned to 20–30 in-lbs and crimped. The cable passes above and below the graft, essentially encircling it, and keeps it compressed between the posterior elements of C-1 and C-2. It also resists flexion while the graft itself prevents extension. The interspinous ligaments between C-2 and C-3 are left intact to help secure the cable behind the C-2 spinous process. Postoperative lateral radiography and CT show the contact of the graft and C1–2 (Fig. 3).

### *Statistical Analysis*

The statistical significance of the differences in fusion rates, operative time, EBL, and hospital LOS between the 2 graft groups was determined using the Student t-test and ANOVA. Statistical significance was defined as  $p < 0.05$ .

## Results

Eighty-nine patients (55 women and 34 men) were included in the study. The mean age of patients in the allograft group was 60 years (range 21–89 years) and that of those in the autograft group was 55 years (range 15–89 years). Operative indications in the allograft group included trauma (29.8%), rheumatoid arthritis (38.3%), congenital anomaly (4.3%), os odontoideum (2.1%), neoplasm (2.1%), and chronic degenerative instability (23.4%). The operative indications in the autograft group included trauma (45.2%), rheumatoid arthritis (23.8%), congenital anomaly (9.5%), os odontoideum (2.4%), neoplasm (2.4%), and chronic degenerative instability (16.7%).

Anesthesia and nursing records of the operations were available for all patients except 1 in the autograft

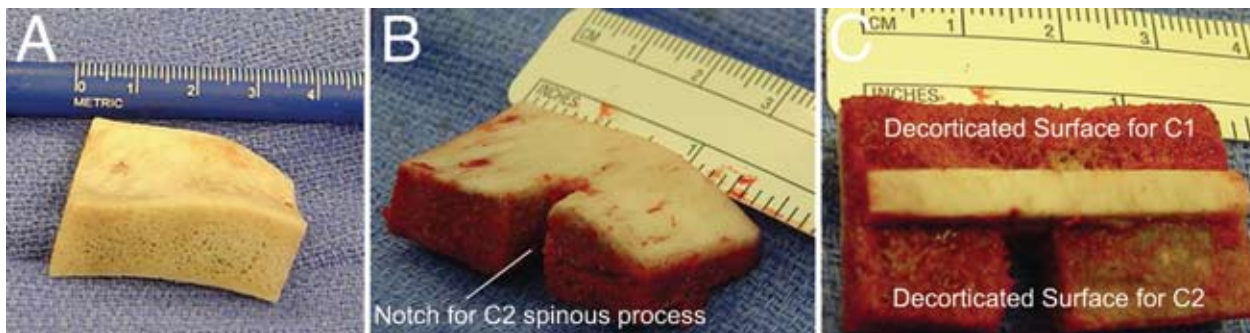


FIG. 1. Intraoperative photographs showing the 3 × 3.5-cm piece of bicortical iliac crest bone allograft (A) and the prepared graft trimmed to size with decorticated surfaces to abut the decorticated portions of the patient's C-1 and C-2 (B and C) posterior elements.

group. Several patients, mainly those with trauma and those from out of state, made no postoperative office visit, although some of them had radiographic studies sent for review during the follow-up period. The mean duration of follow-up in the allograft group was 16.1 months (0–49 months) and in the autograft group was 17.6 months (0–61 months). Nine patients in the allograft group and 5 in the autograft group had < 3 months of follow-up. No perioperative deaths were recorded in either group, but 4 patients in the allograft group and 1 in the autograft group died within 6 months of causes unrelated to surgery, namely, respiratory failure, systemic cancer, multiorgan failure due to trauma, stroke, and aftermath of a motor-vehicle accident. Thirty-seven (79%) of the allograft patients and 32 (76%) of the autograft patients had at least 6 months of follow-up. Thirty-three allograft patients and 25 autograft patients had at least 12 months of follow-up.

Combined operations were performed in 18 of the 48 allograft procedures, including atlantoaxial arthrodeses after attempted odontoid screw fixation in 2 cases, Chiari decompression and occipitocervical fusion in 1 case, and combined transoral odontoid resections and posterior atlantoaxial arthrodeses in 9 cases. There were also 1 case each of transoral odontoidectomy and laminectomy of C-1, anterior cervical corpectomy and posterior occipitocervical fusion, subaxial laminectomy, C1–T2 fusion, neoplasm, and occipitocervical fusion. In the autograft group, combined procedures were performed in 17 of 42 patients: failed odontoid screw placement in 2 cases, Chiari decompression and occipitocervical fusion in 1 case, combined transoral decompressions in 6 cases, and occipitocervical fusions in 8 cases. As indicated in *Methods*, these patients were excluded from an analysis of EBL and operative time since these parameters were not recorded for the separate components of the surgeries.

The mean operative time was reduced by 50 minutes ( $p = 0.0004$ ) in the allograft patients (mean  $\pm$  SD,  $184 \pm 9.6$  minutes, range 106–328 minutes) relative to the autograft group ( $234 \pm 10.2$  minutes, range 154–358 minutes; Fig. 4). The mean EBL was reduced by 50% ( $p = 0.0005$ ) in the allograft group ( $103 \pm 8.4$  ml, range 30–200 ml) relative to the autograft group ( $206 \pm 21.5$  ml, range 50–400 ml).

The hospital LOS was analyzed for all 89 patients. There was a trend toward a shorter LOS in the allograft

group ( $5.2 \pm 0.7$  days vs  $6.5 \pm 1.3$  days), but no statistically significant difference ( $p = 0.119$ ) was found between the 2 groups (Fig. 4). When examining patients who underwent only atlantoaxial arthrodesis, there was no difference in the LOS, with autograft and allograft patients staying for  $3.4 \pm 2.2$  and  $3.1 \pm 1.2$  days, respectively.

Fusion rate analysis included data from all patients tracked to fusion or at least 24 months posttreatment. Two patients in the autograft and 1 in the allograft group had documented fusion at the long-term follow-up but lacked intermediate follow-up data; these patients were not used in our analysis. Fusion rates increased as expected over time, with earlier fusion occurring in the autograft group. At 3 months postgrafting, no fusion was observed in either group. At 6 months after treatment, however, 48% of patients with an autograft showed fusion, whereas only 14% of the allograft group did. After 12 months of follow-up, the rates of fusion were similar between the 2 groups, with fusion in 73% of the autograft group and 68% of the allograft group. At 24 months posttreatment, 96.7% of the autograft patients had achieved fusion and 88.9% of those with an allograft had achieved fusion (Fig. 5). At the final follow-up, 91.9% of allograft patients and 96.9% of autograft patients demonstrated solid fusion.

Complications related to harvesting an iliac crest autograft occurred in 16.7% of the 42 patients in the au-

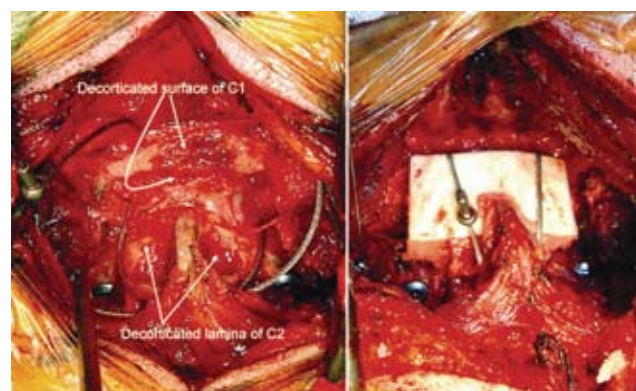


FIG. 2. Intraoperative photographs showing preparation of the C-1 and C-2 surfaces for increased contact with bone grafting (left) and final interpositional graft placement between C-1 and C-2 (right).

## Allograft bone for C1–2 fusion

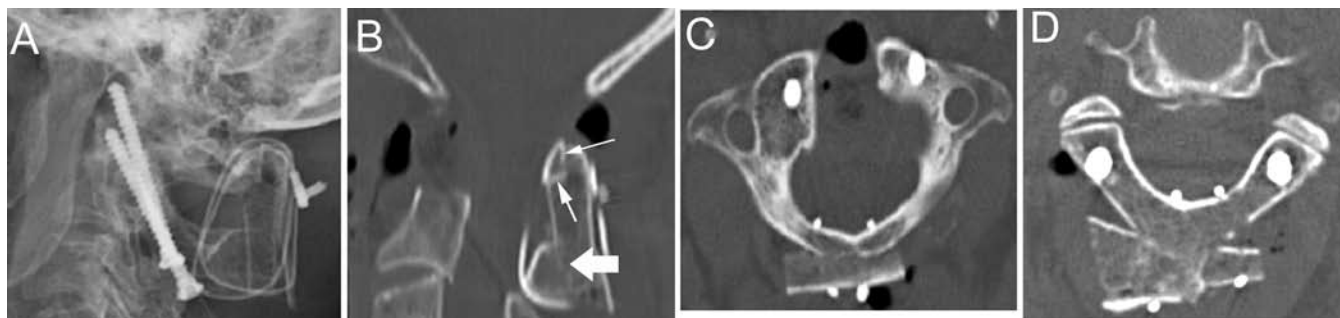


FIG. 3. Lateral radiograph (A) of the C1–2 transarticular screw and bone graft/wiring technique showing good contact between the graft and C-1 and C-2. Sagittal reconstruction CT (B) demonstrating a squared-off C-1 arch in contact with the graft (*thin arrows*) and the graft mortised into the arch of C-2 (*bold arrow*). Axial CT scans showing the decorticated surface of C-1 contacting the graft (C) and the C-2 decorticated lamina and spinous process with the notch in the graft fitting around C-2 (D).

tograft group and included 1 pelvic fracture, 1 retained sponge requiring surgical removal, 1 infection, 2 hernias requiring repair, and 2 hematomas. Although pain was not quantified in this study, it is our experience that patients undergoing these grafting procedures commonly experience significant persistent pain at the iliac crest donor site during the perioperative and follow-up periods. Other complications in the autograft group included a partially backed-out transarticular screw that was asymptomatic and did not require revision at the 43-month follow-up. In the allograft group, atlantoaxial transarticular screw breakage occurred in 1 patient in whom we had used a 3.5-mm polyaxial screw coupled to a long subaxial construct (our usual transarticular screws are 4 mm in diameter). Bone fusion failed to occur in this patient, who had severe degenerative disease and osteopenia, when the contralateral screw failed to hold. Occiput–C-1 instability developed, and the patient underwent revision to an instrumented occiput–to–C-2 arthrodesis with an

allograft again and ultimately demonstrated a solid fusion. Other complications in this group included 1 partial screw backout that did not require operative intervention, 1 postoperative myocardial infarction in an elderly patient after a combined transoral/occipitocervical fusion, and 1 emergency tracheostomy in a patient who was extubated immediately after a combined transoral/occipitocervical fusion.

## Discussion

Atlantoaxial arthrodesis surgeries combining screw fixation (C1–2 transarticular screws or C-1 and C-2 polyaxial screw constructs) and iliac crest autograft wired between the posterior elements of C-1 and C-2 have been very successful, with fusion rates around 95%.<sup>12,13,16</sup> Harvesting an iliac crest bone graft is not a benign procedure, however, as it is associated with complications such as infections, pelvic fractures, and chronic pain at the iliac

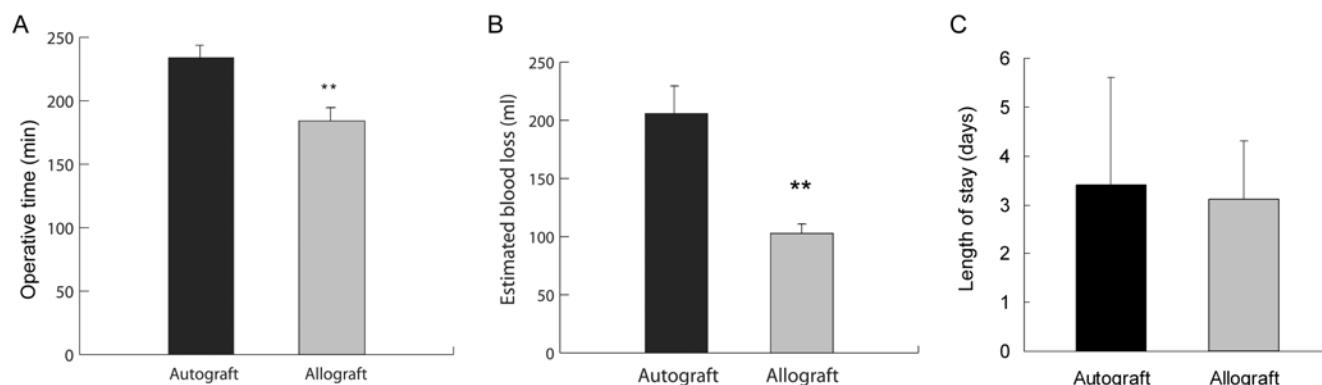


FIG. 4. Bar graphs showing operative time in minutes (A), EBL (B), and LOS (C) for procedures using allograft versus autograft. Allograft procedures were significantly quicker than autograft procedures (\*\* $p = 0.0004$ ). The EBL for the allograft group was significantly lower than for the autograft group (\*\* $p = 0.0005$ ). The LOS was not significantly shorter for allograft procedures. Thirty-four patients who underwent this surgery as part of a combined procedure were excluded from an analysis of operative time, EBL, and LOS. min = minutes.

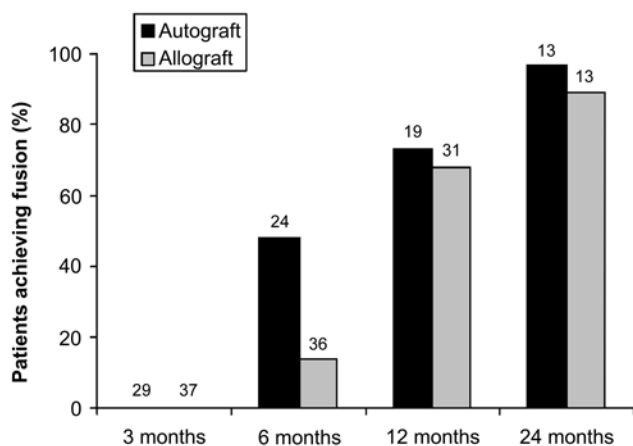


FIG. 5. Bar graph demonstrating fusion rates at various time points in patients who underwent procedures involving allografts and those who underwent procedures involving autografts. The number above each bar represents the number of patients evaluated at each time point.

crest donor site. Rates of donor-site morbidity associated with anterior or posterior iliac crest autograft harvesting range from 0.6 to 35% in the literature.<sup>3,4,19</sup> In a retrospective questionnaire-based study of anterior iliac crest bone harvest for single-level ACDF, Silber et al.<sup>24</sup> reported numerous complications, including ambulation difficulty (50.7%), extended antibiotic usage (7.5%), persistent drainage (3.7%), wound dehiscence (2.2%), reoperation with incision and drainage (1.5%), cosmetic dissatisfaction (92.5%), and pain at the donor site (26.1%). Similarly, in posterior spinal fusion operations requiring a posterior iliac crest bone graft, Robertson and Wray<sup>22</sup> found that the major morbidity is chronic donor-site pain, which is most severe at ~ 6 months after surgery and decreases by 12 months after surgery. These authors also noted that sensory loss around the donor site was described by 10% of their patients. Banwart et al.<sup>3</sup> have evaluated the cases of 261 patients who underwent iliac crest harvesting and found that the rate of major complications was 10% and that of minor complications was 39%. In our series, we found similar major complication rates (16.7%) associated with the harvesting of posterior iliac crest bone graft for atlantoaxial arthrodesis.

In addition to donor-site-related morbidities, we found that blood loss and operative time were both significantly greater when an autograft was harvested for atlantoaxial arthrodesis. Although not a statistically significant difference, the hospital LOS was slightly longer with the use of an autograft. We speculated that allograft patients have less pain postoperatively, which could lead to an earlier discharge from the hospital, but we did not evaluate postoperative pain in this retrospective study.

We began to use allografts after encountering multiple graft-site complications. Many of the patients requiring atlantoaxial arthrodesis, such as those on steroid treatment for rheumatoid arthritis, have poor bone quality, which predisposes to pseudarthrosis and complications associated with the harvesting of an autograft. In a review of the literature, Casey et al.<sup>6</sup> have demonstrated a

low cumulative average rate of fusion (68%) for atlantoaxial arthrodesis in patients with rheumatoid arthritis. In our series, 31% of the patients had rheumatoid arthritis, but we did not see significant rates of pseudarthrosis. We speculate that this finding is attributable to the careful bone carpentry technique (autograft or allograft) used by the senior author (R.I.A.). In patients with rheumatoid arthritis who have poor bone quality and other comorbidities (for example, drugs that prevent healing), the risk of complications associated with an iliac crest bone graft may be higher, and thus the use of an allograft could be even more beneficial in these patients.

We found that the autograft patients tended to show fusion earlier, with a greater percentage having apparent fusion 6 months after grafting. However, at 12 and 24 months of follow-up, no difference in the fusion rates was apparent between allograft and autograft patients, with > 88% of patients in both groups demonstrating fusion by 24 months after surgery. Similar results have been found with ACDF, in which a structural bone graft is placed interpositionally in a load-bearing environment, with fusion rates of ~ 95% by using an allograft.<sup>23,25</sup> Prolonged periods of time required for graft incorporation have been seen with the use of an allograft in ACDF.<sup>9,18,20,26</sup> In their cases of 1- and 2-level ACDFs, Kao et al.<sup>18</sup> have found similar clinical results and fusion rates with autografts, allografts, and cages—although they have noted that union in the autograft group occurred at 4 months after treatment, whereas union in the allograft group occurred later, at 5.54 months after treatment.

Our prior use of autograft bone for atlantoaxial fusions has shown successful fusion in many patients by 4 months,<sup>12</sup> but the data in the present study show that allograft bone fusion takes longer (only 14% of cases will appear fused at 6 months). Because patients undergoing atlantoaxial fusion procedures have excellent internal fixation, which results in immediate stability that has proved to be very durable, we do not use external orthoses. The longer times to fusion are therefore just a radiological parameter and have no clinical significance as long as fusion occurs eventually.

We speculate that most allograft failures are attributable to graft placement in an unloaded environment where it is absorbed because it is not under the influences of loading according to Wolff's law. Our bone grafting technique enlarges the amount of cancellous bone contact between the graft and both C-1 and C-2 and places the graft in an interpositional fashion where loads can be transferred through the graft to enhance the bone healing process.

## Conclusions

The use of a bicortical iliac crest bone allograft for instrumented C1–2 posterior fusion, when placed as an interpositional graft rather than an onlay graft, led to fusion rates comparable to those following autograft surgeries, although the fusion took longer to achieve. With the elimination of iliac crest autograft harvesting, the EBL and operative time were decreased and donor-site morbidity was eliminated.

# Allograft bone for C1–2 fusion

## Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

## Acknowledgments

We thank Kristin Kraus for her editorial assistance in preparing this manuscript.

## References

1. Ahlmann E, Patzakis M, Roidis N, Shepherd L, Holtom P: Comparison of anterior and posterior iliac crest bone grafts in terms of harvest-site morbidity and functional outcomes. **J Bone Joint Surg Am** **84**:716–720, 2002
2. Apfelbaum RI: Posterior C1-2 screw fixation for atlantoaxial instability, in Rengachary SS, Wilkins RH (eds): **Neurosurgical Operative Atlas, vol 4**. Baltimore: Williams and Wilkins, 1995, pp 19–28
3. Banwart JC, Asher MA, Hassanein RS: Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. **Spine** **20**:1055–1060, 1995
4. Bishop RC, Moore KA, Hadley MN: Anterior cervical interbody fusion using autogeneic and allogeneic bone graft substrate: a prospective comparative analysis. **J Neurosurg** **85**:206–210, 1996
5. Brooks AL, Jenkins EB: Atlanto-axial arthrodesis by the wedge compression method. **J Bone Joint Surg Am** **60**:279–284, 1978
6. Casey AT, Madawi AA, Veres R, Crockard HA: Is the technique of posterior transarticular screw fixation suitable for rheumatoid atlanto-axial subluxation? **Br J Neurosurg** **11**:508–519, 1997
7. Dickman CA, Sonntag VK: Posterior C1-C2 transarticular screw fixation for atlantoaxial arthrodesis. **Neurosurgery** **43**:275–281, 1998
8. Dickman CA, Sonntag VK, Papadopoulos SM, Hadley MN: The interspinous method of posterior atlantoaxial arthrodesis. **J Neurosurg** **74**:190–198, 1991
9. Ducker TB: Anterior cervical fusion. **J Neurosurg** **98** (1 Suppl):114, 2003
10. Fernyhough JC, Schimandle JJ, Weigel MC, Edwards CC, Levine AM: Chronic donor site pain complicating bone graft harvesting from the posterior iliac crest for spinal fusion. **Spine** **17**:1474–1480, 1992
11. Gallie WE: Fractures and dislocations of the cervical spine. **Am J Surg** **46**:495–499, 1939
12. Gluf WM, Brockmeyer DL: Atlantoaxial transarticular screw fixation: a review of surgical indications, fusion rate, complications, and lessons learned in 67 pediatric patients. **J Neurosurg Spine** **2**:164–169, 2005
13. Gluf WM, Schmidt MH, Apfelbaum RI: Atlantoaxial transarticular screw fixation: a review of surgical indications, fusion rate, complications, and lessons learned in 191 adult patients. **J Neurosurg Spine** **2**:155–163, 2005
14. Goel A, Laheri V: Plate and screw fixation for atlanto-axial subluxation. **Acta Neurochir (Wien)** **129**:47–53, 1994
15. Grob D, Magerl F: [Surgical stabilization of C1 and C2 fractures]. **Orthopade** **16**:46–54, 1987 (Ger)
16. Haid RW Jr, Subach BR, McLaughlin MR, Rodts GE Jr, Wahlig JB Jr: C1-C2 transarticular screw fixation for atlanto-axial instability: a 6-year experience. **Neurosurgery** **49**:65–70, 2001
17. Harms J, Melcher RP: Posterior C1-C2 fusion with polyaxial screw and rod fixation. **Spine** **26**:2467–2471, 2001
18. Kao FC, Niu CC, Chen LH, Lai PL, Chen WJ: Maintenance of interbody space in one- and two-level anterior cervical interbody fusion: comparison of the effectiveness of autograft, allograft, and cage. **Clin Orthop Relat Res** **430**:108–116, 2005
19. Kurz LT, Garfin SR, Booth RE Jr: Harvesting autogenous iliac bone grafts. A review of complications and techniques. **Spine** **14**:1324–1331, 1989
20. Malloy KM, Hilibrand AS: Autograft versus allograft in degenerative cervical disease. **Clin Orthop Relat Res** **394**:27–38, 2002
21. Porchet F, Jaques B: Unusual complications at iliac crest bone graft donor site: experience with two cases. **Neurosurgery** **39**:856–859, 1996
22. Robertson PA, Wray AC: Natural history of posterior iliac crest bone graft donation for spinal surgery: a prospective analysis of morbidity. **Spine** **26**:1473–1476, 2001
23. Samartzis D, Shen FH, Goldberg EJ, An HS: Is autograft the gold standard in achieving radiographic fusion in one-level anterior cervical discectomy and fusion with rigid anterior plate fixation? **Spine** **30**:1756–1761, 2005
24. Silber JS, Anderson DG, Daffner SD, Brislin BT, Leland JM, Hilibrand AS, et al: Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical discectomy and fusion. **Spine** **28**:134–139, 2003
25. Yue WM, Brodner W, Highland TR: Long-term results after anterior cervical discectomy and fusion with allograft and plating: a 5- to 11-year radiologic and clinical follow-up study. **Spine** **30**:2138–2144, 2005
26. Zdeblick TA, Cooke ME, Kunz DN, Wilson D, McCabe RP: Anterior cervical discectomy and fusion using a porous hydroxyapatite bone graft substitute. **Spine** **19**:2348–2357, 1994

Manuscript submitted October 1, 2008.

Accepted May 7, 2009.

*Current address for Dr. Hillard:* Department of Neurosurgery, University of Washington, Seattle, Washington.

*Current address for Dr. Fasset:* Department of Neurosurgery, University of Illinois College of Medicine at Peoria, Illinois.

*Address correspondence to:* Ronald I. Apfelbaum, M.D., Department of Neurosurgery, University of Utah School of Medicine, 175 North Medical Drive East, Salt Lake City, Utah 84132. email: ronald.apfelbaum@hsc.utah.edu.