Improving Initial Acetabular Component Stability in Revision Total Hip Arthroplasty

Calcium Phosphate Cement vs Reverse Reamed Cancellous Allograft

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Abstract: A reproducible retroacetabular defect was created bilaterally in 9 cadaver pelves. The defects were filled with either an injectable, bioresorbable, calcium phosphate cement, or reverse-reamed cancellous allograft. An uncemented acetabular shell was impacted, followed by the placement of an appropriate liner. The pelves were then sectioned, and each half was loaded in a material testing machine to simulate walking on the construct over a several week period. The cement-filled defects lasted a greater number of cycles before failure and had greater cup stability and stiffness. The use of resorbable bone void filler for retroacetabular defects shows promise in this biomechanical analysis. Long-term clinical follow-up is warranted to track osseointegration of the implant and restoration of bone stock between this and other clinically accepted surgical techniques. Keywords: revision hip arthroplasty, retroacetabular defect, impacted allograft, calcium phosphate cement.

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and the host bone defect surface, can provide superior initial fixation and minimize micromotion of an implant.

A similar injection technique has shown promise in percutaneous acetabuloplasty (PCA), a minimally invasive, image-guided procedure whereby cement is injected into metastatic lesion sites. Clinically, pain relief and functional restoration have been observed with this PCA procedure [15]. In one biomechanical study of PCA, strain data were recorded from a single male pelvis under 3 conditions: without an acetabular defect, with an unfilled defect, and with a cement-filled defect [16]. These experimental data were then used to validate stress-strain relationships in a 3-dimensional finite element model constructed using computer tomography scans of the same male pelvis. This allowed the authors to study the stress concentrations that occur in the presence of a defect as well as how cements of different stiffness might affect stress propagation. The models demonstrated that cortical stresses were concentrated along the posterior column of the acetabulum, adjacent to the defect, and that filling the defect mitigated the resulting strain to a large extent. The calculated cortical stresses were greatest in the presence of transcortical defects, as compared with those involving only trabecular bone [16].

In the treatment of traumatic acetabular injuries, injectable biodegradable cements have been more well studied. Olson et al [17] tested 10 fresh-frozen cadaveric pelves (84.8 ± 6.4 years; 5 were female, 4 were male) were thawed to room temperature and prepared by removing all soft tissue. Standardized cavitary defects measuring 35-mm diameter for the larger (male) pelves and 32 mm for the smaller (female) pelves were drilled to a depth of 12 mm in the superior aspect of the posterior column of each acetabulum (Fig. 1A). The acetabula were underreamed by 1 mm, and one side was randomly chosen to be filled with the impacted, reverse-reamed, cancellous allograft. Acetabular shells (Trident; Stryker Orthopedics, Mahwah, NJ) were then inserted by a fellowship-trained orthopedic surgeon experienced in primary and revision THA. All cups were secured by two 6.5-mm cancellous bone screws, one placed bicortically into the sciatic buttress and one placed unicortically into the trabecular bone of the posterior column. The defects receiving the calcium phosphate bone substitute (Hydroset; Stryker Orthopedics) were backfilled through one of the screw holes using a large bore syringe after shell placement and before screw placement. Two screws of identical length and placement from the contralateral (allograft) side were secured, while the injectable cement was setting. After the final alignment of the shells, 32-mm polyethylene inserts (X3; Stryker Orthopedics) were impacted into each shell.

The pelves were then bisected along the midsagittal plane and potted in careful alignment so the force vector from a mating femoral component was aligned with the direction of maximum load during walking, as measured by Bergmann et al [18] (Fig. 1B). This femoral component was attached to the load arm of a custom servohydraulic testing frame (LeBlond Associates, Phoenix, Ariz) outfitted with a load cell (FR10-2.5K-B000; Tovey Engineering, Phoenix, Ariz) and electronic control system (ODIN1400; Lynx Tecnologia Eletrônica Ltda, Sao Paulo, Brazil). The cups were initially preloaded at 200 N for 10 seconds, after which a linear ramp load from 200 to 1025 N was applied. Initial stiffness was calculated from this ramp load, and a linear regression curve was fit to the pooled allograft and cemented construct data independently, to quantify differences in stiffness (slope) and predictability of stiffness for each treatment ($R^2$). The peak of this ramp is equivalent to a joint reaction force of approximately 1 to 2 times body weight (105 kg) and is representative of the loads imparted during immediate postoperative cautious ambulation (weight-bearing as tolerated). After the ramp load, a cyclic load from 200 to 2250 N (229 kg) was applied at 5 Hz for 159 600 cycles. This loading cycle peaks at approximately 3 to 4 times body weight in accordance with the joint reaction force values measured from an instrumented total hip during normal walking [18]. The number of cycles is consistent with approximately 12 weeks of walking for this demographic group, a slight reduction from the 218 000 cycle average reported for a cohort of primary THAs over a similar time period [19]. Because this portion of the

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testing had a duration of several hours, the pelves were wrapped in plastic wrap and periodically misted with saline solution to maintain consistent moisture levels.

To monitor micromotion of the cup within the acetabulum, a triad of high-resolution optical position sensors (Optotak Certus; Northern Digital Inc, Waterloo, ON, Canada) were placed around the acetabular rim and into the plastic liner. By calculating the distance and angle between planes fit to the acetabular rim triad and liner triad, respectively, the 3-dimensional vector between the centroids of the acetabulum and shell was quantified. A Wilcoxon signed rank test was applied to the micromotion data ($\alpha = .05$) for each day of simulated walking. Failure of a construct was defined as 3-mm or more motion of the acetabular component with respect to the surrounding bone or a loss of continuity in the acetabular marker triad, which indicated destruction of the rigid body constituting the acetabulum. The number of cycles before failure was statistically compared with a Wilcoxon signed rank test ($\alpha = .05$).

Results

The regression curve fit to the initial ramp loading data indicated that the average stiffness for the allograft specimens (490 N/mm) was only half of the value of the cement group (1011 N/mm) (Fig. 2). In addition, the goodness of the fit, indicated by the $R^2$ value, was much tighter in the cement group ($R^2 = 0.8$) compared with the allograft group ($R^2 = 0.24$), indicating much lower variability in stiffness between specimens in the cement group. The mean amount of micromotion per cycle over the first 2 weeks of simulated walking was 0.13 (±0.02) mm in the cement group and 0.17 (±0.02) mm in the allograft group. This amounts to a significant difference in micromotion for days 1, 3, 6, 7, and 8, with the cement approach demonstrating nearly universally lower displacements (Table 1). During cyclic loading, the defects filled with cement lasted on average 75,591 cycles before 3 mm of cup movement, whereas the defects filled with allograft lasted only 35,445 (Table 2). In only 2 of 9 pelves did the allograft-filled defect sustain a greater number of cycles than the calcium phosphate cement before failure. Although this forms a clear trend, with the cement surviving more than twice the number of cycles on average, the high variability in results between the individual pelves leads to a nonsignificant
test statistic with the limited sample of fresh-frozen cadaver pelves that were available ($P = .13$, Wilcoxon signed rank test).

**Discussion**

This is the first study comparing the stability of acetabular components using either impacted reverse-reamed cancellous allograft or a fully injectable biodegradable calcium phosphate bone cement in acetabular defects. In 7 of the 9 pelves tested, the calcium phosphate injectable cement survived a greater number of load cycles than the allograft. The allograft also showed a lower slope and $R^2$ value in the stiffness regression analysis, indicating that this material is less stiff and much less predictable than the calcium phosphate cement in how it will behave under realistic loads. This may be due to regional variation in bone quality of the pelves, quality of the allograft source, or simply how hard the allograft is compacted. The bone substitute, on the other hand, creates a highly predictable regression model, indicating more consistent performance. Coupled with the markedly higher stiffness, greater durability in cyclic loading, and lower micromotion, the bone substitute outperforms the allograft in all factors measured in this study.

Although this biomechanical study was focused on initial implant stability, clinical evidence suggests that long-term structural benefits may exist with calcium phosphate-based fillers. For example, Russell and Leighton [20] reported a significant reduction in tibial articular subsidence at 1 year when subarticular defects were filled with calcium phosphate cement rather than autograft. This difference in subsidence was not noted at earlier time points, suggesting that the gradual resorption of the calcium phosphate cement, which was still partially visible on radiographs at 1 year, continued to provide support long after the autograft had structurally resorbed. Although calcium phosphate materials may resorb more slowly and therefore potentially delay osseointegration in the local contact zone with an implant, we believe that in the revision cases simulated in this study, the improved initial structural stability of the cup will likely lead to improved overall osseous integration and therefore reduce early failures.

Most patients who are undergoing revision THA that have significant acetabular defects are typically geriatric with relatively poor bone quality. The cadaveric pelves selected for this study were of an age and bone quality representative of the population that traditionally receives these implants. The use of this cadaveric material has the potential to introduce a greater amount of variation within and between specimens than either synthetic bone or cadaver bone from younger populations. Similarly, although the surgeon author (D.J.J.) made every attempt to achieve the same fit and fill between sides, minor variations in the depth and orientation of reaming, bilateral thickness of subchondral bone, and rim fit may contribute to variation in the results. Although no clinical evidence was noted at the time of impaction, it is a possibility that microfracture of the acetabulum occurred given the age of the specimens used in the study.

In conclusion, an injectable resorbable calcium phosphate bone void filler provided markedly superior initial stability of the acetabular component compared with impacted reverse-reamed allograft and lasted far longer under cyclic loads that mimic body weight transfer during walking. Surgeons should consider using the biodegradable calcium phosphate–based bone substitutes currently on the market when managing retroacetabular defects during revision THA to improve initial stability and minimize micromotion. The in vivo effects, such as clinical implant longevity, biomaterial resorption, and failure rates of these improved biomechanical parameters, require additional long-term clinical study.

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References