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STABILITY DIFFERENTIALS FOR PROXIMAL VERSUS DISTAL FUSION OF THA FEMORAL IMPACTION GRAFTS

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Abstract

In impaction grafting for revision joint arthroplasty, the morselized cancellous bone (MCB) ideally remodels into a new contiguous lattice. However, the use of biologically active factors may sometimes be indicated to enhance fusion. The purpose of this study was to determine the stability of femoral impaction graft constructs for which either only the proximal or distal half of the MCB volume was modeled as fused. Fusing the proximal half of the impaction graft volume resulted in a higher femoral stem stability than did fusing the distal half. This proximal graft fusion also resulted in a stem stability that was similar to that of fusing the entire graft. These results emphasize the importance of proximal fixation of an impaction grafted femoral stem.

Introduction

Impaction grafting for revision joint arthroplasty involves compacting morselized cancellous bone (MCB) into a cavitary defect, to build up bone stock lost to osteolysis or to prosthesis removal. Ideally, the impaction graft MCB remodels into a new contiguous cancellous lattice throughout the construct, with this restoration of host bone increasing the strength of the graft and the stability of the construct [1–5]. However, biomechanically sufficient remodeling of the impaction graft MCB is not necessarily guaranteed, and incomplete or insufficient MCB remodeling is a possible contributor to stem subsidence or postoperative femoral fracture [6–8].

A recent laboratory model of MCB fusion allowed simulating an impaction graft construct in the ideal clinical state of contiguous remodeled bone [9]. An earlier study used this MCB fusion model to determine the relative stability of femoral impaction graft constructs for full fusion of the MCB, versus for the freshly-impacted nonfused condition, by measuring three-dimensional motion between the femoral stem and the femur both proximally and distally [10]. That study found that the fused femoral impaction graft constructs were much more stable than the unfused graft constructs at the proximal stem location, but that MCB fusion had a much smaller effect on distal stem stability. This implied that most of the opportunity to increase impaction graft femoral stem stability was proximal, and therefore that steps to

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enhance MCB fusion – for example, using biologically active factors such as bone morphogenic proteins [11–16] – might be most effectively focused proximally.

The purpose of the current study was to determine the stability of femoral impaction graft constructs for which only half of the MCB volume was fused, with the fused half being located either proximally or distally. In previous studies of the stability of impaction grafted stems and uncemented stems, both proximal fixation [17–22] and distal fixation [23–26] techniques have been associated with improved stem stability and better clinical results. Based on the results from the earlier study of simulated MCB fusion [10], it was hypothesized that fusing only the proximal half of the impaction graft volume would be more effective in improving construct stability than would fusing only the distal half.

Materials and Methods

Specimen preparation is described in detail elsewhere [10], so will be only briefly summarized here. Composite femurs (model 3306, Pacific Research Laboratories, Vashon, WA) were prepared in a standardized manner. A nylon abductor strap was attached to each femur. Cavitary defects were created by overdrilling the femoral diaphysis to 17 mm and removing all proximal cancellous bone (foam) analog. Femoral impaction graft constructs were then created by impacting human MCB into the femur, following a standardized protocol based on the intraoperative practice of an experienced orthopaedic surgeon [9]. A polished, collarless, triple-tapered femoral stem (C-Stem, Size 3, DePuy Orthopaedics, Warsaw, IN) was then cemented into the impaction graft.

Both nonfused and fused MCB were used for the impaction grafts. The MCB, from fresh-frozen human bones, was cut into 4–5 mm cuboidal pieces [9]. The MCB to be used nonfused was defatted by saline rinsing, per typical surgical practice. The MCB to be used fused was defatted by rinsing first with saline and then with chloroform, followed by dehydration. Just before the impaction grafting process, this MCB was mixed with an amine-based epoxy adhesive (Hysol E-120HP, Loctite Corp., Rocky Hill, CT) to coat the MCB particles with a thin layer of epoxy. After the impaction grafting (and implant cementing) process was complete, the MCB-epoxy mixture fused into a contiguous structure biomechanically comparable to intact cancellous bone in compression [9], thus simulating the desired remodeled end-stage of an impaction graft.

The impaction grafts were constructed with either the proximal half of the MCB fused (hereafter referred to as proximally fused) or the distal half of the MCB fused (hereafter referred to as distally fused) ($n = 6$ each). Equivalent volumes of fused and nonfused MCB were used in each femur. Because the diaphyseal portion of a femur has a smaller transverse cross-section as compared to the metaphyseal portion of a femur, the distal half of the MCB filled a longer length of the femur, and covered a greater length of the femoral stem, than did the proximal half of the same MCB volume (Figure 1).

After three days (to allow time for epoxy and bone cement cure), each impaction graft construct was tested in an MTS 858 materials testing machine (MTS Systems Corp., Eden Prairie, MN). The constructs were loaded with 250,000 three-dimensional physiologic duty cycles for level walking and stair climbing [27], which were converted to axial and torsional loads for the MTS machine to apply [19]. Loading was at 50% full-scale. The duty cycles were applied as repetitions of 490 level walking cycles followed by 10 stair climbing cycles, a functionally realistic proportion [28].

Three-dimensional motion between the femoral stem and the femur was measured at the proximal and distal stem with a total of six differentially variable reluctance transducers (SG-DVRT-8, MicroStrain, Burlington, VT) having a resolution of better than 3 μm . The proximal

stem measurement location was 20 mm below the resection level, along the axis of the femoral neck. The distal stem measurement location was 20 mm above the tip of the stem, along the axis of the femoral stem (Figure 1). DVRT motion was measured around logarithmic cycle intervals as described in an earlier study [10].

Micromotion and migration of the stem within the femur were both calculated. Micromotion refers to the amount of motion that occurs over a single cycle of loading; in vivo, excessive micromotion can inhibit bone revascularization and remodeling. Micromotion was calculated as the stem's maximum minus minimum position value for each loading cycle measured. Migration, also called subsidence, refers to the amount by which the (unloaded) position of the stem within the bone changes over time; in vivo, excessive migration can result in loosening, femoral fracture, or limb length discrepancy. Migration was calculated from the stem's minimum (least-loaded) position value for each loading cycle measured. Statistical comparisons using the 1-tailed two-sample Student's t-test (or Wilcoxon rank-sum test, where appropriate) were carried out on the final micromotion and migration values, and on the final migration rate (calculated between 100,000 and 250,000 cycles).

Results

At the proximal stem location (Figure 2a), the proximally fused graft constructs had a considerably smaller final level walking micromotion ($p = 0.001$), final stair climbing micromotion ($p = 0.003$), final migration ($p = 0.003$), and final migration rate ($p = 0.038$) than did the distally fused graft constructs. At the distal stem location (Figure 2b), there was no significant difference detected between the proximally fused and distally fused graft constructs for final level walking micromotion ($p = 0.261$), final stair climbing micromotion ($p = 0.288$), final migration ($p = 0.091$), or final migration rate ($p = 0.370$).

Discussion

Fusing only the proximal half of the impaction graft volume resulted in a higher proximal construct stability than did fusing only the distal half, but showed no significant effect on distal construct stability. The hypothesis that proximal impaction graft fusion would be more effective in improving construct stability than distal impaction graft fusion was therefore supported for the proximal region. Previous studies have suggested the desirability of proximal fixation for femoral stems, in terms of impaction graft containment [17,18,21], proximal fit (rather than distal fit) of uncemented stems [19,22], and a calcar collar in uncemented stems [20]. However, several authors have argued in favor of distal fixation, albeit on the basis of indirect evidence, namely, directly cementing an impaction graft distal stem to the host bone [23], using an uncemented stem designed for distal rather than proximal stability [24], having a tight distal fit [25], or having a beaded surface fully rather than proximally coated with HA [26].

As a point of reference, the proximally fused and distally fused impaction graft constructs were also compared to the fully fused and nonfused constructs from the earlier study [10] (Figure 3). Fusing only the proximal half of the impaction graft volume resulted in a construct stability that was nearly as high as when the entire graft was fused. For both the proximal and distal stem, fusing the entire impaction graft resulted in the least final micromotion, final migration, and final migration rate out of the four construct groups; however, these amounts for the fully fused grafts were similar to those for the proximally fused grafts. Also, the stability measures for the nonfused and distally fused groups were similar to one another.

This study also corroborates a concept suggested by the findings of the earlier study [10]: to increase the stability of an impaction grafted femoral stem, the proximal region of the construct

should receive the most emphasis. While the absolute results in this study are specific to the femoral stem design used, this general result should extrapolate to other polished, collarless, tapered femoral stem designs (such as the Exeter). Against the backdrop of spiraling health costs, a disadvantage of currently available biologically active factors is their considerable expense [29–31]. The use of these factors, when deemed appropriate to enhance MCB fusion, might therefore be economized by preferentially applying them to MCB that will be impacted into the proximal portion of the graft.

References

1. Grimm B, Hassaballa M, Mehendale S, et al. Stem subsidence in impaction grafting revision hip arthroplasty: Comparing results from a clinical follow-up study with in-vitro experimental models. *Trans 51st ORS* 2005;30:1173.
2. Inoue H, Irie H, Kuroda K, et al. Porous beta-TCP as a bone graft substitute. *Trans 30th SFB* 2005;27:361.
3. Tsiridis E, Narvani AA, Haddad FS, et al. Impaction femoral allografting and cemented revision for periprosthetic femoral fractures. *J Bone Joint Surg Br* 2004;86:1124. [PubMed: 15568524]
4. van Doorn WJ, ten Have BL, van Biezen FC, et al. Migration of the femoral stem after impaction bone grafting. First results of an ongoing, randomised study of the Exeter and Elite Plus femoral stems using radiostereometric analysis. *J Bone Joint Surg Br* 2002;84:825. [PubMed: 12211672]
5. Voor MJ, White JE, Grieshaber JE, et al. Impacted morselized cancellous bone: Mechanical effects of defatting and augmentation with fine hydroxyapatite particles. *J Biomech* 2004;37:1233. [PubMed: 15212929]
6. Heliotis M, Tsiridis EE. Fresh frozen bone in femoral impaction grafting: Can developments in bone regeneration improve on this? *Med Hypotheses* 2001;57:675. [PubMed: 11918425]
7. Kamineni S, Pearse M. Early stem stability following impaction grafting – A case matched analysis. *J Bone Joint Surg Br* 1999;81B:238.
8. Ullmark G, Obrant KJ. Histology of impacted bone-graft incorporation. *J Arthroplasty* 2002;17:150. [PubMed: 11847612]
9. Heiner AD, Callaghan JJ, Brown TD. A laboratory simulation for morselized bone graft fusion: Apparent modulus under operatively based femoral impaction kinetics. *J Biomech* 2005;38:811. [PubMed: 15713302]
10. Heiner AD, Callaghan JJ, Brown TD. Stability of fused versus nonfused THA femoral impaction grafts. *J Orthop Res* 2007;25:351. [PubMed: 17143908]
11. Jeppsson C, Astrand J, Tagil M, et al. A combination of bisphosphonate and BMP additives in impacted bone allografts. *Acta Orthop Scand* 2003;74:483. [PubMed: 14521303]
12. Lind M, Overgaard S, Jensen TB, et al. Effect of osteogenic protein 1/collagen composite combined with impacted allograft around hydroxyapatite-coated titanium alloy implants is moderate. *J Biomed Mater Res* 2001;55:89. [PubMed: 11426402]
13. McGee MA, Findlay DM, Howie DW, et al. The use of OP-1 in femoral impaction grafting in a sheep model. *J Orthop Res* 2004;22:1008. [PubMed: 15304273]
14. Soballe K, Jensen TB, Mouzin O, et al. Differential effect of a bone morphogenetic protein-7 (OP-1) on primary and revision loaded, stable implants with allograft. *J Biomed Mater Res A* 2004;71:569. [PubMed: 15505829]
15. Tagil M, Jeppsson C, Aspenberg P. Bone graft incorporation. Effects of osteogenic protein-1 and impaction. *Clin Orthop Relat Res* 2000;371:240. [PubMed: 10693571]
16. Cook SD, Barrack RL, Shimmin A, et al. The use of osteogenic protein-1 in reconstructive surgery of the hip. *J Arthroplasty* 2001;16:88. [PubMed: 11742457]
17. Saito J, Aslam N, Tokunaga K, et al. Bone remodeling is different in metaphyseal and diaphyseal-fit uncemented hip stems. *Clin Orthop Relat Res* 2006;451:128. [PubMed: 16770282]
18. Jazrawi LM, Della Valle CJ, Kummer FJ, et al. Catastrophic failure of a cemented, collarless, polished, tapered cobalt-chromium femoral stem used with impaction bone-grafting. A report of two cases. *J Bone Joint Surg Am* 1999;81:844. [PubMed: 10391549]

19. Barich, F. Ph.D. Dissertation. University of Iowa; 1998. Global micromotion of noncemented components used in total hip arthroplasty.
20. Whiteside LA, Amador D, Russell K. The effects of the collar on total hip femoral component subsidence. *Clin Orthop Relat Res* 1988;231:120. [PubMed: 3370866]
21. van Doorn WJ, van Biezen FC, Prendergast PJ, et al. Fracture of an Exeter stem 3 years after impaction allografting--a case report. *Acta Orthop Scand* 2002;73:111. [PubMed: 11930977]
22. Einsiedel T, Arand M, Gebhard F, et al. Hip arthroplasty with proximal transmission of force: First clinical results with a new partially cemented femoral stem. *Arch Orthop Trauma Surg* 2007;127:147. [PubMed: 17151852]
23. de Thomasson E, Williams JB, Marmorat JL, et al. Modified Exeter technique in revision hip surgery: Does distal fixation of the stem affect allograft transformation? *J Arthroplasty* 2005;20:473. [PubMed: 16124963]
24. Incavo SJ, Beard DM, Puppato F, et al. One-stage revision of periprosthetic fractures around loose cemented total hip arthroplasty. *Am J Orthop* 1998;27:35. [PubMed: 9452834]
25. Whiteside LA, Easley JC. The effect of collar and distal stem fixation on micromotion of the femoral stem in uncemented total hip arthroplasty. *Clin Orthop Relat Res* 1989;239:145. [PubMed: 2912614]
26. Al Hertani W, Waddell JP, Anderson GI. The effect of partial vs. full hydroxyapatite coating on periprosthetic bone quality around the canine madreporic femoral stem. *J Biomed Mater Res* 2000;53:518. [PubMed: 10984700]
27. Kotzar GM, Davy DT, Goldberg VM, et al. Telemeterized in vivo hip joint force data: A report on two patients after total hip surgery. *J Orthop Res* 1991;9:621. [PubMed: 1870027]
28. Benson LC, DesJardins JD, Harman MK, et al. Effect of stair descent loading on ultra-high molecular weight polyethylene wear in a force-controlled knee simulator. *Proc Inst Mech Eng [H]* 2002;216:409.
29. Phillips FM, Bolt PM, He TC, et al. Gene therapy for spinal fusion. *Spine J* 2005;5:250S. [PubMed: 16291120]
30. Dahabreh Z, Dimitriou R, Giannoudis PV. Health economics: A cost analysis of treatment of persistent fracture non-unions using bone morphogenetic protein-7. *Injury* 2007;38:371. [PubMed: 17070526]
31. Delloye C, Cnockaert N, Cornu O. Bone substitutes in 2003: An overview. *Acta Orthop Belg* 2003;69:1. [PubMed: 12666283]

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Figure 1. Impaction grafted femoral stem, and the resection level, average height at which the MCB types (fused or nonfused) transitioned (86 mm above the tip of the distal stem), and the proximal and distal stem locations at which stem-femur motion was measured.

Figure 2.

Series-average micromotion and migration results for proximally fused and distally fused impaction graft constructs for the a) proximal and b) distal stem locations ($n = 6$). The solid lines indicate level walking cycles, and the dashed lines indicate stair climbing cycles (these lines are not always distinguishable from one another). Note that the first stair climbing cycle was at overall cycle #491. Standard deviations are indicated on selected cycle numbers.

Figure 3.

Average final micromotions, migrations, and migration rates for the proximally fused and distally fused femoral impaction graft constructs, and the averages for the fully fused and nonfused femoral impaction graft constructs from our previous study [10], at the a) proximal and b) distal stem locations ($n = 6$). The final micromotion and migration values were at 250,000 cycles. The final migration rate was calculated between 100,000 – 250,000 cycles, and is expressed per order-of-magnitude change in the number of loading cycles. Lines indicate standard deviations. The medians (and lower and upper quartiles) for those variables requiring use of the Wilcoxon rank-sum test are as follows: Final proximal stem stair climbing micromotion: proximally fused 2.4 (2.0, 4.6) μm , distally fused 44.2 (29.2, 54.7) μm ; final distal stem level walking micromotion: proximally fused 2.3 (1.8, 3.2) μm , distally fused 1.8 (1.7, 2.6) μm ; final distal stem stair climbing micromotion: proximally fused 3.0 (2.0, 3.8) μm , distally fused 2.4 (2.3, 2.9) μm .