The Journal of Arthroplasty Vol. 26 No. 7 2011

A Preclinical Study of Stem Subsidence and Graft Incorporation After Femoral Impaction Grafting Using Porous Hydroxyapatite as a Bone Graft Extender

Donald W. Howie, MBBS, PhD, FRACS,*† Margaret A. McGee, BSc, MPH,*† Stuart A. Callary, BAppSc,* Angelo Carbone, BSc,† Roumen B. Stamenkov, MD, MS,* Warrick J. Bruce, BVSc, MVN, DSAS Ortho, MRCVs,‡ and David M. Findlay, MSc, PhD†

Abstract: This preclinical *in vivo* screening study compared bone graft incorporation and stem subsidence in cemented hemiarthroplasty after femoral impaction bone grafting with either morselized allograft bone (n = 5, control group) or a 1:1 mix of allograft and porous hydroxyapatite ceramics (HA) granules (n = 5, HA group). At 14 weeks, there was excellent bone graft incorporation by bone, and the stems were well fixed in both groups. The median subsidence at the cement-bone interface, measured using radiostereometric analysis, was 0.14 and 0.93 mm in the control and HA groups, respectively. The comparable histologic results between groups and good stem fixation in this study support the conduct of a larger scale investigation of the use of porous HA in femoral impaction bone grafting at revision hip arthroplasty. **Keywords:** bone graft, revision hip arthroplasty, femoral, histology, radiostereometric analysis.

Despite the success of total hip arthroplasty, failure requiring revision surgery is a major problem. Revision may be necessary for several reasons, but it is usually due to loss of prosthesis fixation because of periprosthetic bone loss. In patients with a good life expectancy, there is not only the increased probability of re-revision but also at re-revision, there will be even less bone available to support a new prosthesis. Thus, with the trend to perform joint arthroplasty on younger patients and the increasing life expectancy of patients in general, there is a need for techniques that reconstitute bone at revision surgery. Impaction grafting of the femur at revision total hip arthroplasty is a reconstructive procedure suitable for younger patients or patients with extensive loss of periprosthetic bone. After removal of the failed femoral stem, the femur is impacted with morselized cortico-cancellous allograft bone before cementing a stem within the allograft bed, or less commonly, a cementless stem is used. Impaction of bone graft into the bone bed aims to improve initial stability of the prosthesis and provide a mechanical environment conducive to revascularization and osteogenesis. With this, the allograft bone is incorporated and remodeled into the host bone structure by new bone formation, as observed in animal and human studies [1-7].

Although impaction grafting is technically demanding and although there have been adverse reports, improvements in bone graft preparation and the surgical technique have reduced complications, particularly periprosthetic fracture and gross subsidence seen in early series [8,9]. Using the end point aseptic loosening of the stem, survival of 99% at 10 to 11 years [9] and 99% at 15 years [10] has been reported. The use of allograft bone tissue may, however, be limited because of a restrictive supply of bone, variability in its mechanical properties, the processing costs, and the risk of viral and bacterial disease

*From the *The Department of Orthopaedics and Trauma, Royal Adelaide Hospital, Adelaide, South Australia, Australia; †Discipline of Orthopaedics and Trauma, University of Adelaide, Adelaide, South Australia, Australia; and ‡Pet Practice, Hamilton and Massey University, Palmerston North, New Zealand.*
Submitted January 5, 2011; accepted May 9, 2011.
The Conflict of Interest statement associated with this article can be found at doi:10.1016/j.arth.2011.05.007.
Funding for this study was received from ApaTech Ltd, Bristol-Myers Squibb Zimmer, and the University of Adelaide.
Reprint requests: Margaret McGee, BSc, MPH, Department of Orthopaedics and Trauma, L4 Bice Bldg, Royal Adelaide Hospital, North Terrace Adelaide, SA 5000 Australia.

0883-5403/2607-0013$36.00/0
doi:10.1016/j.arth.2011.05.007

transmission [11]. Hence, there is a clinical need for biomaterials that can extend or replace allograft bone graft for these important bone reconstruction procedures. Porous hydroxyapatite ceramics (HA), which have the advantage of macroporosity and microporosity, have been well described for use as a synthetic bone graft substitute [12,13]. The inclusion of HA or tricalcium phosphate ceramic particles with allograft bone in *in vitro* simulated impaction grafting studies has been shown to result in significantly greater initial mechanical stability of the stem at the cement-bone graft interface when compared with allograft bone alone [14-17]. This has been attributed to the greater stiffness (minimum, 300%) upon compression and lower relaxation (minimum, 50%) after compression of the ceramic when compared with human allograft bone [16]. Favorable bioperformance of mixtures of allograft bone and HA in femoral impaction grafting at hip arthroplasty has been demonstrated in 2 ovine studies [6,7]. For these studies, ground reaction forces were used as a measure of hip function and, thus, an indirect measure of stem fixation and the mechanical stability of the bone-graft-cement construct. Although favorable results were reported in both studies, no clinically relevant *in vivo* sensitive measure of stem fixation was used that could be related to the biologic response determined histologically.

Radiographic monitoring of hip arthroplasty is routine, as progressive stem subsidence is indicative of loss of fixation leading to clinical failure [18]. Radiostereometric analysis (RSA) is the most accurate radiographic method for measuring stem subsidence [19] and is thus the quality standard for clinical studies of joint arthroplasty. This standard should also be used in preclinical *in vivo* studies to better understand stem performance and how the biologic response to graft materials affects this. The aim of this study was, therefore, to examine whether by 14 weeks, a 1:1 mix of allograft bone and HA incorporate into a new bone, to a similar extent as allograft bone alone and to relate the biologic observations to *in vivo* subsidence of the femoral stem, as measured by RSA.

Methods

The study was approved by the institution's animal ethics committee. Ovine bone was aseptically harvested from the femoral and humeral heads and the femoral and tibial metaphyseal bone. After removing the cortex, the bone was morselized in a laminar flow cabinet using a surgical bone mill (Tracer Designs Inc, Santa Paula, Calif) using the coarse and medium drum to produce a gradient of allograft bone chips ranging in size between 0.3 to 4.0 mm in diameter. The morselized bone was then sieved to separate out the 3 to 4 mm bone chips. After confirmation of sterility by swab culture, the bone was pooled, aliquotted, and stored at −80°C. Ten skeletally mature Merino wether sheep, selected from a single flock to ensure uniform genetic background, were randomized and underwent a left hip cemented hemiarthroplasty with a polished double taper stem (Exeter Ovine stem V-40 and 26 mm head; Stryker-Howmedica Inc., Benoist Girad, France) after impaction of fresh-frozen morselized cancellous allograft bone alone in 5 sheep (control group) or with a 1:1 volume mix of allograft bone and porous HA granules (Apapore-60; ApaTech Ltd, Elstree, UK) in 5 sheep (HA group) (Fig. 1) using an established surgical technique [5,20]. Allograft bone was washed with warmed saline to remove fat and marrow and sieved and gently compressed in a syringe to remove excess fluid. A 20-mL pack of HA granules was mixed with 4 mL of fresh blood and then combined with 20 mL of the washed allograft to make the homogenous admixture for the HA group. Antimicrobial and analgesia medication was administered over 3 days postoperatively, and the sheep were placed in a sling for 24 to 48 hours to allow hoof-touching weight-bearing. Thereafter, the sheep were transferred to paddocks and allowed free activity with veterinary surveillance of gait and general health.

For RSA, customized stems had a tantalum bead marker tower on the lateral shoulder and at the distal tip. Tantalum beads (0.8-mm diameter; RSA Biomedical, Umea, Sweden) were also placed into the centralizer and proximally and distally in the cement mantle, in the trabecular bone of the greater and lesser trochanters and in the cortex. Because RSA assessment of graft-bone subsidence had yet to validated in the sheep model, beads were not placed in the graft. Radiostereometric analysis radiographs were taken immediately after closure and postoperatively at 6 and 14 weeks. These time points were selected based on previous studies using this model [5]. At 6 weeks, there is early bone graft incorporation activity, including graft resorption and an osteogenic tissue response. By 14 weeks, there is extensive bone graft incorporation and early remodeling activity. For RSA, the stifle joint was held in maximal extension and the sagittal plane of the tibia was held in external rotation so that it forms an angle of approximately 80° to the table top. Radiographs were analyzed using RSA software (UmRSA v6.0; RSA Biomedical). Subsidence of the stem within the cement (prosthesis-cement) was distinguished from subsidence of the stem and cement composite within the bone (cement-bone). Subsidence was calculated relative to the pair of RSA radiographs taken immediately after the operation. The measurement precisions (95% confidence interval) were −0.064 to 0.011 mm and −0.029 to 0.014 mm for prosthesis-cement and cement-bone subsidence, respectively, similar to that reported for *in vitro* RSA [21].