The Utilization Of Trabecular Metal In Combination With Autograft Bone In Acetabular Reconstruction: A Preliminary Sheep Model

A Nabavi, J Field

Citation

Abstract

Background
When confronted with acetabular bone loss at the time of primary or revision hip replacement, there are three surgical options available; the utilization of a larger cup, the use of a cage in combination with a cemented cup or the use of impaction grafting techniques. Impaction grafting is not without problems however its primary advantage is a restoration of bone stock. The current pilot study has sought to evaluate the efficacy of trabecular metal used in combination with impaction grafting of autograft bone in the repair of a simulated Type III acetabular defect in a sheep model.

Methods
A unilateral hip replacement was performed using modular cemented components. An acetabular defect was created in the cranio-dorsal wall of the acetabulum and impacted with harvested and milled autograft bone. A trabecular metal plug was applied to the graft bed prior to the cementing of a polyethylene cup using 1st generation cementing techniques. End-points measured included radiography, macrophotography, micro-radiography and histology.

Results
The planned three month duration of the in vivo assessment was interrupted at 8 weeks due to recurrent dislocation. At that time, appropriate tissues were retrieved for assessment. Macrophotographs revealed little or no fibrous tissue along the interface between the trabecular metal and underlying graft bed. Microradiographs confirmed these findings. Fluorescent microscopy and light microscopy highlighted significant amounts of new bone formation within the trabecular metal implant along its interface with the underlying autograft bone.

Conclusions
Active new bone formation was observed penetrating as much as 1-1.5 mm into the trabecular metal implant at 8 weeks following implantation. Over a longer period of time, with continued ingrowth and increasing strength, the provision of a stable mechanical environment is anticipated in response to the surgical techniques employed in this model. This preliminary study has demonstrated that trabecular metal can be successfully used in impaction grafting when it is not in contact with peri-prosthetic host bone.

INTRODUCTION

Primary or secondary acetabular bone loss, at the time of initial total hip replacement (developmental dysplasia), or revision of acetabular components with cavitatory defects in situ, continue to be problematic. Currently, there are three preferred techniques used when dealing with Type III (1-4) acetabular defects; these include over-reaming and the utilization of a larger cup (5,6), the use of a cage in combination with a cemented cup (7,8) or impaction grafting techniques (9-15).

The use of large revision cups, although technically easier, has some major disadvantages including a net loss of bone stock which is further complicated by stress shielding exacerbated by the larger, stiffer cups used (5,6). The utilization of retention cages in combination with cement has been reported to have a 20% failure rate at 5 years (16,17). Likewise, impaction grafting has problems including cup ‘spin-out’ because of a failure to integrate at the bone graft-cement interface (14,16).

Concurrent problems include inadequate initial stability and difficulty controlling cement intrusion into the bone graft. However, the advantages include augmentation of bone stock and a restoration of the centre of rotation of
The Utilization Of Trabecular Metal In Combination With Autograft Bone In Acetabular Reconstruction: A Preliminary Sheep Model

the hip (17-19).
Slooff et al (1984) first reported the successful utilization of impaction grafted bone in acetabular reconstruction; a 90% survival was achieved at 10-15 years (10). The Exeter group (20) have been unable to match these results in a study following 111 acetabular reconstructions in which grafting was utilized. Excellent to good outcomes were recorded in 87% of patients at a mean follow-up of 6 years; 25% of cases showed some degree of acetabular migration. In order to overcome this comparatively high complication rate, more vigorous impaction in combination with a stronger mesh for bone containment was recommended; the utilization of bone chips > 1 cm was also recommended although not elaborated upon (14,20). The utilization of cementless cups in combination with impaction grafting in acetabular reconstruction is not widespread. This is centred on the belief that impacted allograft bone has no or limited bone ingrowth potential (4-6). Current dogma further suggests that at least 30-50% contact with host bone is required and that the stiff, cementless cups with incite bone resorption (stress shielding) through the disparity in elastic moduli (17).

Trabecular metal has a porosity similar to bone and provides an environment more favorable to bone graft remodeling than conventional metals (7,16,17); it has also been shown to have excellent ingrowth potential (19,21). The current pilot study has sought to evaluate the efficacy of TM in combination with impaction grafting of autograft bone in the repair of a simulated Type III acetabular defect using a sheep model.

MATERIALS AND METHODS
The experimental protocol was submitted to, and approved by, the institutional Animal Welfare Committee.

A unilateral total hip replacement (THR) was performed using a 22 mm (inner diameter) polyethylene cup and a cemented, modular femoral stem and head using an already established protocol (22). With the femoral head removed a 2 cm diameter defect was created in the cranio-dorsal aspect of the left acetabulum. A retainment mesh was fashioned and secured to the labrum cranial to the acetabulum with 3.5 mm screws. Milling of the excised femoral head provided cortico-cancellous bone (4 mm chip size) which was then impacted into the defect created. Subsequently a 1.5 cm TM plug was placed onto the impacted bone surface; this plug had no contact with the surrounding host bone (Figure 1).

Figure 1
Figure 1 - Ventro-dorsal radiographic projection of the acetabular reconstruction. A retainment cage, secured by screws, is positioned on the cranial (anterior) aspect of the acetabulum. The approximate position of the autograft bone is indicated by the arrow as is the trabecular metal implant overlying the autograft bone bed. Small radio-opacities in the ilium and ischium are tantalum beads used for radiostereometric analysis.

First generation cementing techniques were then applied to both the polyethylene cup and the femoral stem.
The Utilization Of Trabecular Metal In Combination With Autograft Bone In Acetabular Reconstruction: A Preliminary Sheep Model

The sheep was recovered in a sling for the first day post-operatively after which normal weight bearing ensued. Analgesia was provided for three days postoperatively. At one week post-operatively the sheep was returned to pasture for the duration of the study.

Evaluative methods employed included radiography, macrophotographs, microradiology and histology. Radiographs were obtained post-operatively and at 6 and 8 weeks. At 7 weeks the sheep dislocated the reconstruction; this was reduced successfully under general anaesthesia. The dislocation recurred at 8 weeks and the sheep was euthanatized. (Figure 2)

Figure 2
Figure 2 - Ventro-dorsal radiographic projection of the acetabular reconstruction following dislocation. The femoral component has dislocated cranially and is resting on the retainment cage.

Five mm transverse sections were taken spanning the width of the reconstruction and placed in 10% Buffered Formalum solution. Each section was photographed for a visual assessment of bone ingrowth. Preserved sections underwent micro-radiography allowing assessment of bone-implant interface occurrences. Histological assessment included the administration of a fluorochrome (calcein green) at 6 weeks postoperatively to enable visualization of new bone formation using fluorescent microscopy. Unstained ground sections were assessed using fluorescence microscopy using a Leica DM 6000 B fluorescence microscope attached to the Quantimet Version 550 IW image analysis system. Following fluorochrome analyses, ground sections were stained with toluidine blue and examined using plain light microscopy on an Olympus BH-2 microscope (Olympus Optical Company, Japan). Representative digital microphotographs of the histology were taken.

RESULTS
No untoward effects of the procedure were observed post-operatively with the sheep released to graze at pasture at one week. The first (calcein green) of three fluorochrome injections was performed at 6 weeks uneventfully. At 7 weeks the animal was observed to be lame. Radiographic evaluation under general anaesthesia revealed a dislocation of the femoral components with the femoral head resting cranial and dorsal to the acetabulum. This was reduced manually under traction and the sheep recovered. Normal weight bearing followed. At 8 weeks post-operatively, lameness was again observed. Radiographs (Figure 2) revealed a recurrence of the dislocation; the sheep was euthanatized and appropriate specimens retrieved.

Macrophotography:

Digital macrophotographs of salient sections were recorded and enable some assessment of the extent of bone ingrowth and/or fibrous tissue formation along the
implant-autograft interface. Sections removed at the periphery of the TM implant consistently displayed a degree of fibrous tissue invasion at the interface between implant and autograft bone (Figure 3).

**Figure 3**
Figure 3 - Cross-sectional macrophotograph of the trabecular metal implant in situ. This section was removed from the periphery of the reconstruction and shows fibrous tissue ingrowth occurring at the bone-implant interface. The bed of morselized autograft bone abutting the medial wall is also depicted.

Through the majority of the sections however, little or no fibrous tissue was observed at the interface (Figure 4).

**Figure 4**
Figure 4 - Cross-sectional macrophotograph of the trabecular metal implant in situ. The section is representative of the majority of sections removed across the trabecular metal implant highlighting the directly abutting autograft bone at the interface with little or no fibrous tissue present.

Figure 5 is a higher magnification view showing cement penetration into the TM and an implant-autograft interface with no fibrous tissue evident.

**Figure 5**
Figure 5 - Cross-sectional macrophotograph of the trabecular metal implant in situ. This higher resolution macrophotograph depicts the autograft bone-TM implant interface, with little fibrous tissue evident and the cement penetration into the trabecular metal.

Microradiography:

Microradiographs obtained concur with the findings with macrophotographs. Through the majority of sections little or no fibrous tissue formation was observed at the implant-autograft interface (Figure 6).

**Figure 6**
Figure 6 - Cross-sectional microradiograph of the trabecular metal implant in situ. Fibrous tissue, as depicted in this image, projects with a light hue. Note the absence of fibrous tissue along autograft bone-TM implant interface (arrows).

Histology:

Assessment of sections under fluorescent microscopy
highlighted significant amounts of new bone formation within the autograft bed, at the implant-bone interface and within the implant itself (Figure 7,8).

**Figure 7**
Figure 7 - Cross-sectional histological section of the trabecular metal implant in situ. This section (x 40 mag), prepared with Toluidene blue and viewed under light microscopy, depicts new bone ingrowth into the pores of the trabecular metal (Ta). New bone (NB) is shown along the interface and arrows depict the new bone within the TM. Other pores contain fibrostromal tissue (FS).

**Figure 8**
Figure 8 - Cross-sectional histological sections of the trabecular metal implant in situ. This section (x 100 mag) prepared with Toluidene blue and viewed under light microscopy, depicts new bone ingrowth (NB) into the pores of the trabecular metal (Ta). Assessment of the same sections under light microscopy and stained with Toluidene blue confirmed the presence of new bone formation at all three locations (autograft, interface, implant). Bone ingrowth into the outer porous spaces (1-1.5 mm depth) of the TM implant was observed along most of the surface to varying degrees (Figures 9).

**Figure 9**
Figure 9 - Cross-sectional histological sections of the trabecular metal implant in situ. This section (x 40 mag), viewed under fluorescent microscopy, highlights the dramatic new bone ingrowth into the TM. Calcein green deposition and fluorescence within the TM corroborates the light microscopy finds in Figures 7, 8.

**DISCUSSION**
The existing bone stock and type of defect are significant factors in surgical decision making when undertaking revision of acetabular components. The intent is to restore anatomy and to achieve stable fixation of the new acetabular component (s). Unlike more traditional metal options, trabecular metal has a porosity akin to bone and confers a more favourable mechanical environment in which bone graft materials (depending on their constitution) can function; this may be osteoconductive, osteoinductive or combination thereof (7,16,17,19,21). The current pilot study has provided an opportunity to evaluate the utilization of a Trabecular Metal implant when used in conjunction with impaction of autologous bone graft material and
cement fixation of components; to this end the model has proven satisfactory. The literature (5,9) highlights concerns regarding the osseointegration of porous metal components when pressfit into a bone-deplete acetabulum. Recent studies (7,8) have evaluated the incorporation of primarily allogenic bone graft material to fill the defect followed by the placement of a cemented polyethylene cup. The current study has sought to evaluate the utilization of TM to augment the repair when used in combination with bone graft material and cemented components. Strong evidence of the early ingrowth of new bone into a trabecular metal implant has been observed, in this study, as early as six weeks post-operatively. Microradiography and histological techniques have shown good continuity of direct bone graft apposition and ingrowth along the majority of the trabecular metal implant. New bone ingrowth into the TM was observed extending as much as 1-2 mm. This is observed in the amount of fluorescent label apparent within the TM (Figure 9) and is corroborated by lightmicroscopy (Figure 7,8).

This augers well for the provision of a stable mechanical environment in which continued ingrowth and increasing strength of the fixation is anticipated. The current study was intended to proceed over a three month period with fluorochromes administered at 6, 8 and 10 weeks. Repeat dislocation necessitated euthanasia of the animal prematurely; it was believed the dislocation was a response to a significantly modified polyethylene cup which was quite shallow. Based on the significant presence of fluorochrome label at six weeks we believe all three labels, had they been administered, would have been present in the trabecular metal indicating ongoing new bone ingrowth and complimentary strength of the fixation. Anticipated future studies will involve the use of an un cemented TM cluster cup in which migration of the acetabular components will be measured using radiostereometric analysis in combination with microradiography and histological assessments.

This preliminary study has demonstrated that trabecular metal can be successfully used in impaction grafting in the absence of direct contact with peri-prosthetic host bone. New bone deposition was observed at depths of 1-3 mm inside the TM interface, in this study, as early as 6-8 weeks. This augers well for the utilization of trabecular metal to augment acetabular reconstruction in Type III scenarios. We now anticipate, that over longer periods of time, with continuing ingrowth and increasing strength, the provision of a stable mechanical environment will be achieved in response to the surgical techniques employed in this model.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of Margaret McGee, Department of Orthopaedics and Trauma, Royal Adelaide Hospital for histological preparation and Peter Self, Adelaide Microscopy, for microradiography and micro CT.

References
Author Information

Arash Nabavi
Sydney Bone and Joint Clinic Sydney, Australia

John R. Field
CORE: Comparative Orthopaedic Research Surgical Facility School of Medicine, Flinders University of South Australia