An Overview about Tantalum Metal Augments for Acetabular Fractures

Ahmed Ashraf Abd el-salam Mohamed[1], Aly Tawfique Elalfy [2], Mohamed Mahmoud El-Hefnawy[2], Mohamed Kotb[2]

1 Orthopedic Surgery Resident, Faculty of Medicine, Zagazig university

2 Orthopedic Surgery Department, Faculty of Medicine, Zagazig university

Email: **ahmed.ashraf11095@gmail.com**

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Abstract

Background: Tantalum implants have demonstrated excellent biocompatibility with physical and mechanical properties best suited for enhanced biological incorporation and greater structural integrity. In addition, tantalum has shown good corrosion resistance secondary to a stable oxidation layer and it can be used either as a bulk implant or as a surface coating on implants. These characteristics of tantalum make it an attractive biomaterial for incorporation in total joint replacement component designs or as a bone void filler and osteoconductive scaffold in the management of extensive bone defects in revision reconstructive surgery. Moreover with an increasing number of revision joint replacement surgeries in the future, the inclusion of such a biomaterial in the surgeon's armamentarium may greatly assist in the management of these difficult clinical conditions.

Keywords: Tantalum Metal Augments, Acetabular Fractures

Introduction

Tantalum implants have demonstrated excellent biocompatibility with physical and mechanical properties best suited for enhanced biological incorporation and greater structural integrity. In addition, tantalum has shown good corrosion resistance secondary to a stable oxidation layer and it can be used either as a bulk implant or as a surface coating on implants. **(1)**

These characteristics of tantalum make it an attractive biomaterial for incorporation in total joint replacement component designs or as a bone void filler and osteoconductive scaffold in the management of extensive bone defects in revision reconstructive surgery. Moreover with an increasing number of revision joint replacement surgeries in the future, the inclusion of such a biomaterial in the surgeon's armamentarium may greatly assist in the management of these difficult clinical conditions **(2).**

Over the past two decades, the porous tantalum augment has emerged as a versatile and reliable option for reconstructing uncontained acetabular defects during revision THA . Porous tantalum has several unique mechanical properties that facilitate acetabular reconstruction.**(3)**

First, the porosity of tantalum is two to three times greater than that of cobalt chrome and titanium mesh, which results in increased potential for bony and fibrous ingrowth after implantation.**(4)**

Second, the modulus of elasticity of porous tantalum is similar to that of subchondral bone. This allows for a more physiologic implant-to-bone load transfer and helps preserve host bone by minimizing stress shielding. **(5)**

Third, tantalum has greater yield and ultimate strength than subchondral bone, which decreases the risk of fracture and graft resorption in comparison with structural allograft. **(6)**

Finally, tantalum's high coefficient of friction results in improved implant stability compared with traditional uncemented titanium implants . In addition to favorable biomechanical properties, porous tantalum augments greatly increase the intraoperative versatility of acetabular reconstruction as they allow for on-table customization of cup-augment configuration in accordance with the type of acetabular defect to be addressed(7).

BIOMATERIAL CHARACTERISTICS OF TANTALUM

Tantalum is a transition metal (atomic number 73; atomic weight 180-05); an open cell tantalum structure consisting of repeating dodecahedrons with an appearance similar to cancellous bone. Porous tantalum implants are fabricated through a multistage process of pyrolization of polyurethane foam to create a vitreous carbon scaffold followed by chemical deposition of tantalum metal. Typically this process yields a tantalum coating consisting of 99% tantalum and 1% vitreous carbon by weight, ranging from 40 to 50 lm in thickness with an average pore size ranging from 500 to 600 lm and a volume porosity of 75–80%. **(8)**

The porosity and pore size of tantalum is superior to that of conventional porous coatings (30–40%). There is also higher interconnectivity between the pores of the threedimensional structure of tantalum. The elastic modulus of tantalum (3 GPa) compares favorably to subchondral (2 Gpa) or cancellous bone (1.2 GPa), yet its yield strength and ultimate strength are greater than cancellous bone or most of the bone graft substitutes **(9).**

Laboratory studies have shown that the osseointegration potential of porous tantalum can be enhanced by the application of surface coatings (e.g. calcium phosphate A study studied the interaction of porous tantalum with osteoblast-like cells. They concluded that the tantalum metal may offer a favorable conductive bioenvironment for growth and differentiation of human osteoblasts. Experimental studies have consistently shown tantalum biomaterial as an effective scaffold for bone ingrowth comparable with conventional porous materials**. (10)**

It was revealed complete tissue ingrowth with concomitant presence of blood vessels at the tissue implant interface. The high porosity of porous tantalum may suggest a potential for enhanced transport of wear debris to the bone implant interface. However, enhanced bone ingrowth into this material appears to function as a barrier to particle migration. **(11)**

For example, in a recent canine study, it was observed that less polyethylene particles had migrated around the porous tantalum implant compared with glass bead blasted titanium alloy cylinders, which were inserted with a peri-implant gap due to superior gap healing and bone ingrowth potential of tantalum implants.**(12)**

CLINICAL APPLICATIONS

Primary Total Hip Arthroplasty

The monoblock porous tantalum cup with direct compression-molded polyethylene has been used for primary total hip replacement (THR). Direct compression molding allows polyethylene to penetrate 1.5–2 mm into the tantalum cup thus eliminating backside micromotion and its related problem of wear and osteolysis. (129)

The hemiellipsoid geometry of these components permits optimal interference fit thus obviating the need for adjunctive fixation with screws in the majority of the cases. **(13)**

A monoblock tantalum acetabular cup comprised of polyethylene with tantalum surface coating that allows supplemental fixation with screws at the periphery of the component and a modular acetabular component of titanium with porous tantalum coating with multiple screw options are available for use in primary hip replacement surgeries. Porous tantalum has demonstrated excellent fibrous tissue ingrowth throughout the pores in animal models in regions without bone ingrowth. This phenomenon may have potential implications in acting as a mechanical barrier to fluid and particulate material access to the bone implant interface and help mitigate wear particulate-induced osteolysis.**(14)**

Fig. (1). Preoperative radiograph of left hip in a patient of juvenile rheumatoid arthritis with poor bone stock.**(14)**

Fig. (2). Postoperative radiograph of the patient showing reconstruction of left hip using a tantalum acetabular component and impaction bone grafting.**(14)**

The Harris hip score averaged 90 points and there was no evidence of radiographic osteolysis or implant migration. Similar encouraging results were observed in another study of 112 primary THRs using the same acetabular device. The authors reported satisfactory clinical and radiological outcomes with high patient satisfaction rate [99%] at a mean follow up of 32 months. **(15)**

Porous tantalum cups appear to be a viable option in reconstructive hip surgery following radiation therapy. After irradiation, the pelvic bone is comprised of patches of avascular bone interspersed with islands of viable vascularized bone. The potentially better mechanical fixation coupled with good biological fixation secondary to rapid tissue ingrowth from viable areas of host bone may potentially yield better clinical results compared with conventional porous-coated acetabular components in these challenging clinical scenarios. In a case series of 12 THRs following therapeutic pelvic radiation,.**(16)**

Radiolucencies ([1 mm) were seen in 5 hips, which regressed or remained unchanged at the latest follow-up. However, the commonly used monoblock acetabular component has some potential disadvantages. First is the inability to visualize the dome during implantation of the monoblock component. The rough external surface of the shell adheres strongly to soft tissues, which might inhibit full seating of the component in the acetabular cavity. This may manifest in the form of zone 2 gaps or radiolucencies ranging from 2 to 5 mm in width on the immediate postoperative X-rays in some clinical series. **(17)**

However, because of excellent potential for bone and fibrous tissue ingrowth into this novel biomaterial, these radiolucencies have been found to diminish with further follow-up. Secondly, inherent to the design of the monoblock component, such cups do not provide the option for isolated replacement of bearing surface should polyethylene wear and osteolysis occur. Thirdly, given the enhanced potential of porous tantalum for bone and fibrous tissue in growth it is likely that extraction of these components may present difficulties during revision surgery.**(18)**

Lastly, the prominent rim of the polyethylene liner associated with the monoblock component may potentially contribute to impingement and instability. **(19)**

Revision Hip Replacement

Acetabular revision surgeries present challenging clinical situations with bone loss ranging from small, contained defects to extensive segmental defects encompassing the anterior or posterior columns, to pelvic discontinuity. The clinical results described with allografts, impaction grafting with cemented components, reconstruction rings, or jumbo cups have been rather inconsistent and sometimes suboptimal.**(20)**

Tantalum implants offer a wide array of options in these situations including the monoblock acetabular components for uncomplicated cases of osteolysis and cup loosening or a tantalum acetabular shell with screw mentation followed by cementing the polyethylene liner into the implanted shell. Additionally, standard and custom acetabular augments are available in various shapes and sizes, which can be used to reconstruct the acetabular defect. **(21)**

The surgical procedure consists of primarily fixing the appropriate augments to the pelvic bone with multiple screws and subsequently implanting the revision shell with a thin layer of bone cement in between the augment and the shell. Bone cement is placed at this site to prevent metal-on-metal fretting. **(22)**

Finally the tantalum acetabular shell is fixed to the pelvis with multiple screws. The augments function in a manner to support the cup similar to a structural allograft without undergoing resorption, a phenomenon sometimes observed with allografts. It is thought that the current generation of reconstruction cages do not provide biologic fixation and are subject to eventual loosening and breakage. **(23)**

Hence A study have proposed a tantalum cup and reconstruction cage construct for extensive acetabular defects. The construct is based on the philosophy that in situations of suboptimal host bone contact, the cage would protect the tantalum metal cup until morselized or structural allograft is united thus later shifting the stress off the cage onto the tantalum cup; having an enhanced potential for biologic fixation even in the presence of a compromised bioenvironment.**(24)**

Fig. (3). Preoperative radiograph of a patient demonstrating failure of acetabular reconstruction ring fixation.**(25)**

Fig. (4). Postoperative radiograph showing the use of tantalum acetabular component and augment in revision hip surgery of the patient.**(142)**

Several clinical studies have reported the results of tantalum implants in acetabular revision surgeries. It was evaluated the results of monoblock porous tantalum cups with or without ancillary screw fixation in 60 acetabular revision cases at a mean follow up of 42 months. Serial radiographs demonstrated excellent osseointegration; the Harris Hip score improved from 74.8 preoperatively to 94.8 postoperatively. **(26)**

One patient with Paprosky III b acetabular defect required re-operation for component loosening at 18 months postoperatively. Interestingly, all of the bone grafts, which included 80% allografts placed adjacent to tantalum implant united. However, the ingrowth potential of allograft into the porous tantalum may be questionable and needs to be elucidated in future studies. . Pelvic discontinuity is characterized by the separation of superior and inferior hemi-pelvis with either loss of host bone or a fracture through acetabular columns. **(27)**

The tantalum augments were commonly placed on the medial aspect of the pelvis or stacked in with the wide base facing laterally and apex medially. A burr or reamer was used to remove portions of augments to ensure optimum contact between revision shell and the augments. Particulate bone graft was introduced to fill any residual cavities before placement of the final acetabular component. All 12 patients treated by this technique with a tantalum metal shell, augments, and bone graft had satisfactory clinical and radiographic outcome at 2.1 years of follow up, whereas 8/12 patients managed with structural allografts and reconstruction cages had either radiographic evidence of aseptic loosening or required revision surgery. **(28)**

Implantation of a revision acetabular component made of tantalum demands great care because of compromised bone stock. A study recently reported seven cases of transverse acetabular fractures following implantation of a porous tantalum acetabular component for revision surgery of failed acetabular implants. Two fractures were undisplaced and treated conservatively. Five patients required internal fixation for fracture stabilization. The authors attributed the occurrence of fractures to possible weakening of acetabular walls during reaming for the revision procedure further compounded by the stresses imposed by activities of daily living. All the tantalum cups were found to be well fixed to one of the pelvic fragments intraoperatively. **(29)**

Hence they advocated restricting the amount of columnar support that is removed during reaming of the acetabulum and observing a protected weight bearing protocol postoperatively in cases of acetabular revision cases associated with extensive bone defects. **(30)**

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