Clinical Use of Porous Tantalum in Complex Primary Total Knee Arthroplasty

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Orthopedic implants have historically been manufactured from various materials including cobalt chrome (Co-Cr), titanium, and stainless steel. Regardless of the material, the ultimate goal for implantation has always been to achieve adequate fixation and stability in order to maximize the longevity of the prosthesis. With an increasing number of young, active patients undergoing total joint arthroplasty, the need for optimal biologic fixation and maintenance of bone stock over time is apparent. During the past decade, technological advances have included the development of surface coatings to enhance the stability of the bone-implant interface; however, biomechanical property limitations of traditional materials have resulted in the production of a porous tantalum, Trabecular Metal (TM) (Zimmer, Trabecular Metal™ Technology, Parsippany, NJ), that can be effective in a variety of clinical scenarios.[1]

Trabecular metal is constructed from tantalum (atomic number 73), which behaves in a relatively inert manner in vivo.[2] The structure of the material is based upon repeating dodecahedron units, yielding the appearance of native trabecular bone.[3] Its safety record as a biocompatible material, high degree of volumetric porosity, high frictional characteristics, and low Young's modulus have expanded its use in orthopedic surgery to offset issues such as peri-implant stress shielding and the inability for immediate weight bearing.

TM has experienced widespread popularity in the arena of craniofacial and dental reconstruction, spinal implant fixation, and total hip and knee reconstruction.[4] In the field of total joint arthroplasty, the literature is abundant on the use of TM for both primary and revision surgery, especially as it applies to primary total hip arthroplasty (THA), pelvic bone loss, and acetabular revision. However, the utilization of TM for total knee arthroplasty (TKA) has been underrepresented in the literature. Principles generated for the use of TM in THA have been extrapolated to address issues in simple primary and difficult revision TKA. To the authors' knowledge, there have been no studies discussing the use of TM in the setting of complex primary TKA.

We propose to demonstrate the clinical use and specific indications for using TM in complex primary total knee arthroplasty.

Biomaterial Property Overview

Tantalum orthopedic implants possess a porosity of 400 to 600 µm with a volume porosity of 75% to 85%,[5] which is significantly higher than Co-Cr (30%-35%) and fiber metal (40%-50%).[6] Its frictional characteristics demonstrate that a tantalum–cancellous bone interface may maintain higher initial stability when compared with bone interfaces with bone grafts and conventional porous metal surfaces.[5] Tantalum has a modulus of elasticity on the order of 3 GPa (similar to subchondral bone). In conjunction with its fatigue failure properties and endurance limit under loading conditions, tantalum is ideal for orthopedic applications requiring physiologic load transmission and biologic fixation.[7]

The most significant contribution of porous tantalum is that it allows for bone and soft-tissue ingrowth. Some traditional options for addressing bone loss in revision TKA permit immediate weight bearing and stable component fixation. However, restoring deficient bone has not been successfully resolved. Bobyn and colleagues[1] demonstrated bone ingrowth in a canine model using TM acetabular components via histology, radiography, and electron

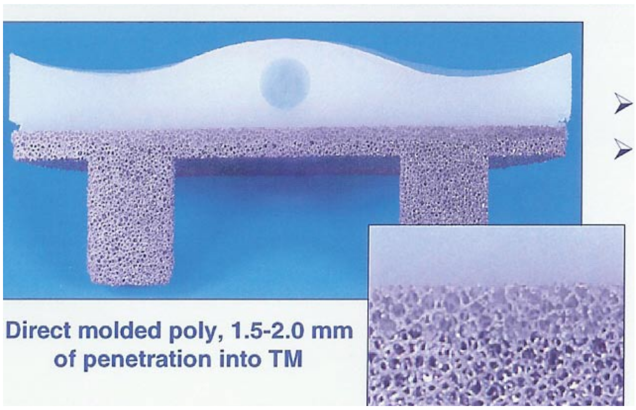

Figure 1. Compression-molded tibial monoblock total knee arthroplasty component. The monoblock design helps to minimize backside polyethylene wear. Abbreviation: TM, Trabecular Metal. Image courtesy of Zimmer Holdings, Inc.

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Am J Orthop. 2009;38(10):526-530.

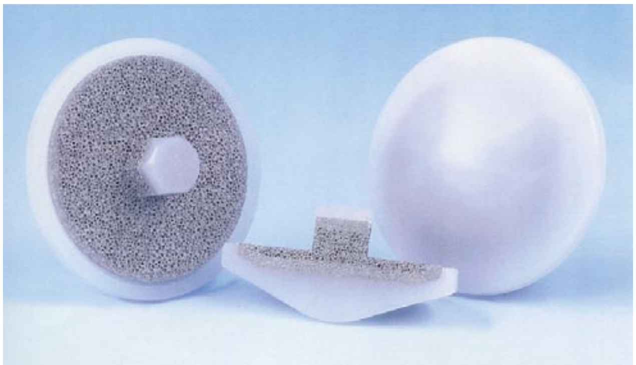

Figure 2. The porous tantalum hexagonal peg press-fit primary patellar implant. This device also utilizes monoblock technology to reduce articular stress and minimize backside polyethylene wear. Image courtesy of Zimmer Holdings, Inc.

Figure 3. A proximal tibial porous tantalum cone used to reconstruct large cavitary bone defects, provide structural support of the endosteal cavity, and enhance biologic fixation. Image courtesy of Zimmer Holdings, Inc.

microscopy, with surface integration of 16.8% and 25.1% in all sections and the periphery, respectively. This mimics previous studies that showed titanium fiber metal and Co-Cr to encounter 21.5% and 13.4% surface bone ingrowth in all sections and the periphery, respectively.[8] Hacking and colleagues[9] assessed fixation strength of porous tantalum to fibrous tissue in an in vivo canine model. Histology showed neovascularization with complete fibrous tissue ingrowth. The attachment strength values were 3- to 6-fold higher than strength measurements seen with sintered beaded porous coatings and Co-Cr. This is most likely a function of porosity.

Component Design Specifics

Tantalum Monoblock Tibial Component

Engh and colleagues[10] introduced the concept of tibial component backside wear and concluded that the increased incidence of proximal tibial osteolysis may result from modularity between the polyethylene insert and tibial baseplate secondary to increased polyethylene wear from excessive motion.[10] The tantalum monoblock tibial component addresses backside wear because the polyethylene is compression molded directly onto the underlying TM baseplate with a total of 1.5 to 1.0 mm of penetration (Figure 1).

The TM monoblock tibial component is also designed with two 16-mm hexagonal pegs, allowing for symmetric load transfer to the proximal tibia. The minimal modulus mismatch between tantalum and the metaphysis leads to a lesser degree of stress shielding.

Bobyn[11] prospectively followed 101 primary TM total knee arthroplasties. Seventy-two implants were cementless and 29 cemented just below the baseplate, excluding the fixation pegs. At 2-year follow-up, there was no evidence of new or progressive radiolucent lines and there were no revisions required. The authors concluded that decreased stress-shielding led to better maintenance of proximal tibial bone stock.

Florio and colleagues[12] evaluated the effect of tantalum monoblock tibial component liftoff in response to lateral and medial tibial loading. The TM monoblock tibia exhibited 22 µm of liftoff compared with 65 µm for the tibial tray with a keel. The keel acts as a fulcrum for the tibial component, allowing it to pivot, resulting in liftoff and decreased stability.

Primary Porous Tantalum Patella

The use of tantalum patellar implants for primary TKA adheres to many of the same principles that underlie use of the TM monoblock tibial component. The TM monoblock patellar component is compatible with either cementless or cemented fixation. The monoblock feature allows for an additional decrease in backside wear between the metal-backed patella and the compression-molded, nonmodular polyethylene. A central hexagonal post design is also available, allowing for press-fit initial stability and minimizing the degree of periarticular stress and wear (Figure 2). Overall, the patellar component allows for physiologic loading of the remaining patellar bone stock and decreased stress shielding. One concern unique to many metal-backed patellar designs, which is not a consideration in all-polyethylene patellar components, is the risk of edge loading causing wear, exposing the metal backing and predisposing to metallosis.

A multicenter prospective trial evaluated 60 patients undergoing 69 primary TKAs with a TM patellar component. Over a 2-year period, the average Knee Society scores were 92 and 95 at the 1- and 2-year time points, respectively.[13] There was no radiographic evidence of loosening, component migration, or progressive radiolucent lines.

Tantalum Augments, Wedges, and Cones

Porous tantalum augments and wedges have been developed to address distal femoral and proximal tibial bone deficiency that may be encountered in revision TKA scenarios. TM can be used as an alternative to bone graft and bone-graft substitutes, allowing for enhanced biologic fixation. Augments and wedges are available for the distal and posterior femur and offer thickness options. Full and half-block tibial augments

Figure 4. Preoperative standing anteroposterior radiograph demonstrating proximal medial tibial bone loss of the right knee.

counter contained bone-loss defects in the proximal tibia. Stulberg[14] demonstrated 1- to 4-year follow-ups of 35 femoral and 2 tibial cases utilizing augments. Two cases required the use of both. At final follow-up, all reconstructions were stable radiographically and Knee Society scores improved from 54 to 87 postoperatively. There were no reported augment-related complications.[14]

Large cavitary bone defects pose a more difficult challenge in revision TKA. Porous tantalum femoral and tibial cone fabrications offer an effective alternative for managing these types of defects by reinforcing the endosteal cavity, maintaining viable bone, providing immediate structural support, and enhancing biologic fixation (Figure 3). Cones are compatible with standard TKA components and allow for compressive loading of the surrounding host bone.

These concepts can be extrapolated to apply to the arena of complex primary TKA. The following 4 clinical vignettes have been chosen to demonstrate complex primary TKA scenarios managed with a combination of TM primary components, augments, wedges, and cones. The authors have obtained verbal informed consent from the patients for print and electronic publication of their case reports.

Case Reports

Case 1

A 52-year-old woman with diabetes mellitus and peripheral vascular disease presented with posttraumatic arthritis of the right knee 1 year after sustaining a displaced medial tibial plateau fracture. She complained of medial-sided discomfort. The patient exhibited 0° to 90° range of motion of the right knee with overall varus alignment and slight medial-lateral laxity. Peripheral pulses were absent, but sensation to light touch was intact. Radiographs demonstrated medial joint posttraumatic arthritis with collapse of the medial hemiplateau (Figure 4). It was unclear whether this was a manifestation of Charcot arthropathy. The decision was made to perform a right TKA. Intraoperatively, there was considerable deficiency of the medial hemiplateau secondary to posttraumatic arthritis. The deficiency measured approximately 20 mm in depth at its greatest point. A TM cone was used to fill this defect. The medial edge of the TM was used to buttress the uncontained defect. The lateral edge of the cone was embedded within the intact lateral proximal tibial metaphysis. A stemmed component was utilized. The patient's postoperative course was uneventful. Her pain improved dramatically. At her most recent follow-up, 2 years after surgery, the knee had maintained neutral alignment and range of motion from 0° to 95° (Figure 5). The patient was able to ambulate without the use of any assistive devices.

Figure 5. Postoperative standing anteroposterior radiograph after primary total knee arthroplasty using a cemented, stemmed constrained condylar knee with a proximal tibial cone.

Alternative methods of treatment could have included impaction grafting with wire mesh containment,[15] structural autografting or allografting,[16,17] or use of stacked tibial augments. In this particular case, a maximum defect of 20 mm was encountered, making the use of structural autografting unfeasible and standard metal augments (typically with a maximal thickness of 10 mm) impractical. A final option, reinforced cement augmentation of the tibial hemiplateau, would be unpredictable in its strength, given the size of the defect. Therefore, in this case, the use of a TM cone was considered advantageous, given its provision for buttressing of the uncontained medial defect and its biomechanical properties.

Case 2

A 60-year-old man presented with insidious onset of left knee pain with progressive disability. Several years earlier, he had undergone a left TKA with early failure at 1 year postoperatively. Extensive workup revealed that the patient

Figure 6. Postoperative anteroposterior radiograph of the right knee after cementless porous tantalum total knee arthroplasty for a history of cement allergy.

Figure 7. Preoperative anteroposterior radiograph of the right knee demonstrating severe tricompartmental degenerative joint disease with an intramedullary tibial nail in place.

had a cement allergy. This was treated with successful revision with a cementless revision arthroplasty. Based on the patient's history, the decision was made to proceed with a right TKA using a cementless implant. The implant chosen was a monoblock TM tibial tray, TM-backed patellar component, and a porous cementless femoral component. At his 2-year postoperative visit, the patient exhibited a range of motion from 0° to 115° with excellent alignment (Figure 6). The radiographs demonstrated good biologic incorporation of the implant with the absence of any radiolucent lines surrounding the prosthesis. The patient is quite active and satisfied with his clinical outcome.

Case 3

A 59-year-old man presented with progressive right knee pain 3 years after an intramedullary nailing of a right tibia fracture. The patient had progressive and painful right knee arthritis that failed a variety of nonoperative interventions, including injections, physical therapy, and bracing. The patient had no pain at the interlocking screws of the tibial nail or in his leg. The right knee range of motion was 10° to 95° with an overall 20° of varus alignment. There was no evidence of ligamentous instability on physical exam. Radiographs showed advanced arthritis with varus deformity and a tibial nail, which was well fixed with interlocking screws (Figure 7).

A TKA was performed, using a two-pegged TM monoblock tibial component, to avoid removal of the tibial nail. The use of a traditional tibial component with a central keel would have required removal of the intramedullary device. At 3 years following TKA, the components were well fixed with good incorporation of the implant. There was no radiographic evidence of loosening or progressive radiolucent lines (Figure 8). The patient plays golf frequently and ascends stairs without hindrance. His right knee range of motion is from 0° to 135° with excellent stability.

Figure 8. Postoperative anteroposterior radiograph demonstrating a successful porous tantalum total knee arthroplasty implanted without removal of the intramedullary tibial nail required.

Case 4

A 62-year-old man was referred for evaluation of a painful right knee. One year prior, he had undergone a right proximal tibial osteotomy, which was complicated by an infected nonunion requiring multiple débridements, hardware removal, and bone grafting and casting. The infection was eventually cleared after thorough débridement and intravenous antibiotic therapy; however, the patient had persistent right knee pain. A bone stimulator had been utilized without success. He had difficulty ascending and descending stairs and ambulating more than 2 or 3 city blocks. On physical exam, the patient stood 5'6" tall and weighed 223 lbs. The right knee range of motion was 0° to 120° with diffuse crepitus. There was a well-healed midline incision. The preoperative leg length discrepancy measured 0.5 cm, and the knee was stable to varus and valgus stress on physical exam. Radiographs showed arthritis of the knee with a nonunion of the right proximal tibial osteotomy with a probable avascular segment of proximal tibia (Figures 9A, 9B). The knee was aspirated and culture results were negative. The

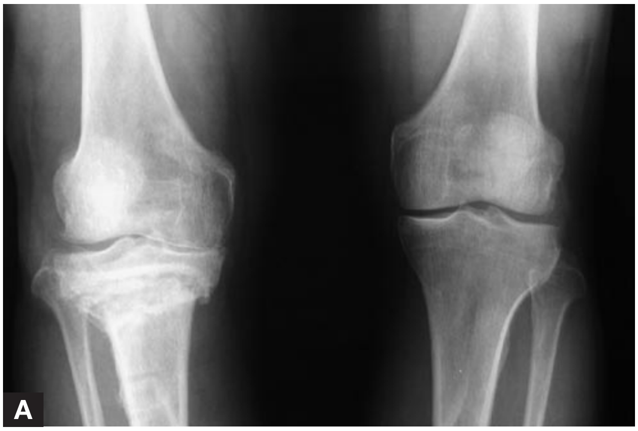

Figure 9. Preoperative anteroposterior (A) and lateral (B) radiographs demonstrate a right knee proximal tibial metaphyseal nonunion with a probable avascular segment of bone. There is evidence of severe medial compartment degenerative joint disease.

Figure 10: Postoperative anteroposterior radiograph following primary total knee arthroplasty using a cemented, offset-stem constrained condylar knee with a proximal tibial cone.

preoperative C-reactive protein and erythrocyte sedimentation rate were 0.19 and 1.0, respectively. The nonunion was confirmed by a white-blood-cell–labeled bone scan, which showed no evidence of infection. Computed tomography demonstrated a large, fibrous nonunion and a thin wafer of residual proximal tibial articular surface. The decision was made to perform a right TKA.

Grossly, the proximal tibia appeared avascular with a large area of fibrous nonunion, which was excised. The avascular proximal tibial segment was completely excised and replaced with a 15-mm trabecular cone augment. A stemmed component was utilized as well as a 17-mm constrained condylar polyethylene insert (NexGen Legacy Constrained Condylar Knee, Zimmer, Warsaw, Ind) (Figure 10). The patient was allowed immediate weight bearing and experienced an uneventful postoperative recovery. At most recent follow-up, the knee range of motion was 0° to 120°. The patient denied any pain, actively played golf, and ascended stairs without any difficulty.

Conclusions

While the use of highly porous TM metaphyseal cones and convex patellae have been described for massive defects of the distal femur and proximal tibia or patellar deficiency in revision procedures, little has been written about the use of TM implants for complex situations in primary TKA. TM technology allows for physiological load transfer to the host bone with predictable bony ingrowth and stress distribution. The implant is virtually isoelastic with bone, and biomechanical studies have shown excellent early stability that encourages bone ingrowth, minimizes the risk of liftoff, and reduces mid-term and long-term stress shielding that may be seen with more rigid implants.

The case scenarios presented in this article have shown a variety of clinical applications of TM technology for complex primary total knee replacements, including patients with uncontained metaphyseal bone loss and cement allergy. In addition, the unique 2-pegged design of the monoblock tibial component makes it a favorable alternative to the standard tibial design when there is hardware within the intramedullary canal of the tibia. TM/porous tantalum can be used effectively for a variety of clinical situations in primary and revision TKA. Long-term data will be necessary to prove durability of the material.

Authors' Disclosure Statement

Dr. Sheth reports no actual or potential conflict of interest in relation to this article. Dr. Lonner wishes to note that he is a paid consultant to Zimmer.

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This paper will be judged for the Resident Writer's Award.