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Review Article

Treatment of Bone Losses in Revision Total Hip and Knee Arthroplasty Using Trabecular Metal: Current Literature

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Revision Total Knee or Hip Arthroplasty is challenging procedures for surgeons usually characterized by bone loss. There are different options available to treat those bone losses. However, there is still a concern on the stability of bone-implant interface, which is mandatory to achieve good long-term results in prosthetic implants. Recently, porous tantalum has been introduced, with the aim of improving the bone-implant interface fixation and implant primary stability. Different solutions for the treatment of bone defects in both revision Total Knee and Hip Arthroplasty have been proposed. In revision Total Hip Arthroplasty (THA) tantalum shells can be used to treat Paprosky type III defects also, because of their mechanical properties. Similarly, trabecular metal has been proposed in revision Total Knee Arthroplasty (TKA), being considered a viable option to treat severe type 2 or 3 defects. The aim of this paper is to review the mechanical properties and characteristics of tantalum. Furthermore, we will discuss its role in treating bone defects in both revision THA and TKA, as well as the outcome reported in literature.

1. Introduction

Osteointegration in orthopedic implants can be compared to bone healing in fractures. Stability at the bone-implant interface is mandatory for implant's success. Excessive micromovements result in fibrous attachment fixation with a collagen structure throughout the porous network [1], while bigger movements can even produce a pseudocapsule [2] surrounding the implant that can lead to early failure. The limits for implant integration have been established in some studies [2, 3] showing bone ingrowth for movements smaller than 50 microns, pseudoligamentous healing from 50 to 150 microns, and pseudocapsule formation for movements bigger than 150 microns. However, a small mechanical stimulation at the interface can enhance implant healing in the first phase after surgery.

Another important aspect in implant integration is pore size; recent studies by Bobyn and associates [3] showed the relationship between pore size and bone ingrowth rate. This may be related to different microenvironments present within different sizes pores and their effect on osteogenesis [4].

Traditionally, orthopedic implants have been produced with titanium, stainless steel, and cobalt-chromium (Co-Cr). However, the limits of these materials in porosity, high elastic modulus, and low frictional characteristics have pushed researchers to develop new materials with better performances. One of the answers to this search is tantalum, firstly introduced by Zimmer (Warsaw, IN). The excellent resistance to erosion-corrosion and high frictional characteristics associated with its bioactivity make tantalum a promising material for orthopedic implants.

2. Basic Science

Tantalum is an elemental metal with great characteristics of biocompatibility, corrosion resistance, and a porous geometry. Tantalum has a uniform and continuous structure that allows for greater strength, lower stiffness, higher volumetry porosity, and a higher coefficient of friction compared to other porous metals [5].

Porous tantalum structure is produced by pyrolysis of thermosetting polymer foam; it creates a low-density vitreous

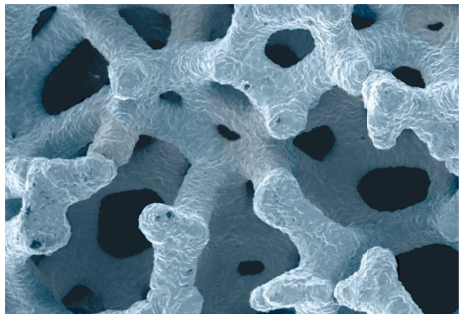


Figure 1: Porous structure of the trabecular metal.

carbon skeleton characterized by a repeating dodecahedron that produces a regular structure with interconnecting pores [6]. Tantalum is then deposited on this structure by vaporization or infiltration [7–9]. The production process usually produces coverage that ranges between 40 and 60 μm in thickness. However, designers and engineers can vary all parameters of implants regarding shape and pores dimension acting on the skeleton production and metal apposition. For these reasons, tantalum mechanical properties can be changed varying the thickness covering the polymer skeleton (Figure 1).

In common orthopedic application, tantalum pore dimension ranges from 400 to 600 μm resulting in a 75% to 85% porosity. At the end of the process, 99% of weight is due to tantalum and 1% to the skeleton [6]. The porous structure has higher porosity than other materials used in orthopedic implants like sintered beads (30–35%) and fiber metal (40–50%) [8], providing a great increase in elasticity and making porous tantalum mechanical properties very close to those of the subchondral bone.

The great number of pores and their dimension positively affects stability of the implant, increasing friction coefficient, up to even three times higher than sintered beads materials [10].

In the long period, primary stability is enhanced by tantalum bioactivity that produces a stable oxide component (Ta_2O_5) on the surface forming a bone-like apatite layer [11]. These characteristics represent a great improvement compared to conventional materials. Classically, implants' bioactive coatings applied to the surface of the implant grant bone integration. The effect is to bond bone; however, they showed to degrade over time and debond from the implant surface with possible loosening.

Tantalum morphology provides a scaffold for bone growth and osteoblast interaction [2, 7, 12, 13], producing a bone ingrowth that has been measured to be 0.2 to 2 mm in 4 weeks [12]. For these reasons, pullout tests demonstrated that tantalum could resist doubled shears forces, compared to conventional materials (18.5 MPa versus 9.3 MPa of the Co-Cr sintered beads) [3, 7, 12]. Complete incorporation into the bone is usually achieved around 16 weeks after implant and no major variations can be observed at one year [7].

The association of great friction rate and the subsequent osteointegration makes tantalum the perfect material for bone loss managing and defect filling.

In addition, tantalum is relatively inert in vivo and can be compared to titanium; by the way, tantalum can produce occasional macrophage reaction at the implant-tissue interface [14]. At our knowledge, there are no studies reporting inflammatory reaction to tantalum.

3. Treatment of Bone Deficiency in Revision Total Hip Arthroplasty

The number of Total Hip Arthroplasties (THA) is increasing, as well as life expectancy. Consequently, the number and complexity of revision THA continue to increase, with a further increase expected in 2030 of 137% compared to 2005 [15]. Revision THA are usually challenging for surgeons, particularly on the acetabular side, which is more commonly characterized by bone loss. In socket revisions, the surgeon has to manage bone defects and provide a stable construct; in these cases an accurate preoperative planning is mandatory to achieve good results [16].

Different classification systems have been used for acetabular defects to describe the severity of bone losses. Paprosky et al. developed a classification evaluating the acetabular defect type, size, and location, pointing at the appropriate reconstructive options' selection. The classification is based on four radiographic measures obtained through an anteroposterior radiograph of the pelvis: (1) superior hip center migration, (2) ischial osteolysis, (3) position of the implant relative to the Kohler (ilioischial) line, and (4) teardrop osteolysis (Table 1) [17].

Bone losses are consequently classified depending on the support for the new acetabular cup of the acetabulum: completely supportive (type I), partially supportive (type II), or unsupportive (type III). The reconstruction options for acetabular revision include hemispherical cementless cup, jumbo cup, structural or morselized allograft, custom or triflanged implants, and antiprotrusio cage [18]. Trabecular metal implant or augments can be useful to treat major bone defects, allowing for increased biological fixation, primary stabilization, and easier surgical technique, also when compared to structural allograft.

3.1. Reconstructive Options Using Trabecular Metal. Highly porous metal components are popular options for both primary and revision THA. Conversely to titanium components, which require at least 50% of supporting bone stock, these cups can be used also in Paprosky type III defects, because of their mechanical properties [18, 19]. Using trabecular metal cups allows for good osteointegration and primary stability of the system [20]. There are two types of tantalum cups: with incorporated locking mechanism for the polyethylene insert or predisposed for cementation of the polyethylene insert. The second option allows a greater malleability of implant by positioning it in the area of the defect not considering its position and orientation that can be compensated by reorienting the insert at the time of cementation [18]. When less than 50% of bone stock is available, structural allograft or metal augments may be required to allow stability of the cup. Porous metal augments can be assembled intraoperatively acting as

Table 1: The Paprosky classification.

Defect type	Superior hip center migration	Ischial osteolysis	Kohler line	Teardrop
I	Minimal	None	Intact	Intact
IIA	Mild	Mild	Intact	Intact
IIB	Moderate	Mild	Intact	Intact
IIC	Mild	Mild	Disrupted	Moderate lysis
IIIA	Severe	Moderate	Intact	Moderate lysis
IIIB	Severe	Severe	Disrupted	Severe lysis

a structural allograft. The surgical technique includes securing the augments to the pelvis with multiple screws and then securing the revision shell to the augment with bone cement. The shell is then secured to the pelvis with multiple screws [6, 21, 22]. When the augment is secured to the acetabular shell, the surface area of the cup available for bone ingrowth can be raised up to 30 or 40% of the surface more than the implant with no augments [16]. However, care should be used implanting trabecular metal cups: Springer et al. detected 7 transverse acetabular fractures in a series of 37 trabecular metal cup revisions; all fractures likely occurred intraoperatively [23].

Trabecular metal augments can be also useful for type III defect; in presence of massive contained or uncontained defects involving more than 50% of the acetabulum, a protective cage may be necessary. Particularly, if morselized or structural grafts are used and the necessary amount of contact is not achievable, the bone graft should be protected by a cage [24]. These cages have different advantages: they can be used as a template for bone stock restoration and they allow placing the hip center in an anatomic position independently by the cage position. However, the surgical technique is demanding and the cages do not allow for bone integration [24]. Different authors reported poor results using cages, with a high failure rate, particularly in those cases with insufficient column or superior dome bone stock to support the cage and the graft or in case of pelvic discontinuity [16, 25, 26]. For this reason, different authors proposed using trabecular metal in these cases as well. Some authors proposed to use a "cup-cage" system. The trabecular metal cup, because of its properties, allows for a better healing environment for the graft. If an adequate amount of bone is not available, a cage can protect the cup. The cage protects the cup until bone graft remodeling is complete, and then the stress leaves off the cage and is transferred on the trabecular metal cup [16, 24, 27, 28].

When the anterior and posterior walls are insufficient in a pelvic discontinuity, trabecular metal cups and augments can be used to restore acetabular ring integrity. The augments are placed in the inferior and superior aspect of the acetabular defect, secured to the bone with screws, and the cup is then inserted press-fit into the contained bone defect of host bone. To provide rigid fixation, multiple screws can be placed in both the superior and inferior hemipelvis. This construct can be used as an internal plate to stabilize discontinuity [25, 28, 29].

3.2. Clinical Outcomes. Different studies focused on clinical outcomes of trabecular metal constructs in revision THA (Table 2). Given that most of these studies are characterized by short-term follow-up or small population, good clinical and radiological outcomes are reported, despite a considerable complication rate related to the complexity of the surgery [19–21, 25, 28–41].

Van Kleunen et al. in 2009 [42] reported 90 patients with Paprosky type 2 or more acetabular bone defects, treated with revision shell associated with metal augments. There were 8 cases of infection and one revision for dislocation. No revisions for aseptic loosening were detected. The authors concluded that revision shells associated with metal augments are a viable option to treat moderate to severe bone losses in acetabular revision. Jafari et al. [43] compared the outcomes of titanium and tantalum cup in 283 hip revisions with mixed acetabular bone defects; the authors concluded that there was a higher failure rate in massive bone deficiency for titanium cups compared to tantalum cups, which showed radiographical better fixation. Similarly, Fernández-Fairen et al. [44] evaluated 263 patients treated with monoblock or revision tantalum shell, with 85.9% subjective satisfaction, and no aseptic loosening at 73-month follow-up. Skyttä et al. [45] evaluated 827 patients treated with trabecular metal shell in revision hip arthroplasty with patterns of bone loss, representing the biggest population described in literature. The authors observed a 92% overall survivorship at 3-year follow-up, with 2% of aseptic loosening. Furthermore, each additional year in age decreased the risk of revision by 2.4%. Recently, Long et al. [46] evaluated 599 revision shells at a minimum of 24 months of follow-up reporting 7.8% of reoperation, with 2.3% of removed cup but without any case of aseptic loosening.

In the recent years, some authors described their experience using cup-cage constructs. Abolghasemian et al. [47] evaluated 26 patients affected by pelvic discontinuity and treated with cup-cage construct and 16 patients treated using standard cages. The authors reported a reduced complication and revision rate in the cup-cage group, with a higher pelvic discontinuity healing-rate compared to the standard cages. Recently, Amenabar et al. [48] described their results on 64 patients affected by Paprosky types 3 and 4 defects with 61% of pelvic discontinuity and treated using cup-cage constructs. The 5- and 10-year cumulative survivorship was, respectively, 93% and 85%. The authors concluded that cup-cage constructs are a viable option in the treatment of major acetabular bone losses.

4. Treatment of Bone Deficiency in Revision Total Knee Arthroplasty

Similar to THA, also the number of revision Total Knee Arthroplasties (TKA) is increasing [15]. Revision TKA can

Table 2: Results for revision THA using porous tantalum acetabular components (THA: Total Hip Arthroplasty, N/A: not reported).

Author	Year	Number of cases (F/M)	Average age (SD)	The Paprosky classification of bone defect	Type of implant	Follow-up months (SD)	Outcome
Nehme et al. [30]	2004	16	N/A	2 and 3	Revision shell and modular augments	31.9	No implant had evidence of migration or loosening Good clinical and radiological outcomes at early follow-up; 1 revision for pelvic discontinuity, 1 dislocation, 1 sciatic nerve palsy
Unger et al. [31]	2005	60	N/A	N/A	Tantalum cup with screws	42	7 cases of dislocation and 1 case of aseptic loosening
Paprosky et al. [25]	2005	12 (versus 12 patients reconstructed with cage)	61	3 (all pelvic discontinuity)	Trabecular metal cup with or without augments	25.2	11 patients with no or moderate pain in tantalum group versus 8 patients in cage group; 1 aseptic loosening case in the tantalum group versus 8 cases in the cage group
Sporer and Paprosky [32]	2006	28	64	3A	Trabecular metal cup plus superior augment	37.2	All hips radiographically stable; no revision; good clinical outcome
Sporer and Paprosky [33]	2006	13	N/A	3B (pelvic discontinuity)	Revision shell with/without augments	31.2	1 possible radiographic loosening; no revision surgery Reliable and reproducible short-term results in pelvic discontinuity
Weeden and Schmidt [29]	2007	43	N/A	3A, 3B (10 pelvic discontinuity cases)	Trabecular metal cup with or without augments	33.6	1 septic loosening case 98% success rate; excellent option in revision TKA
Malkani et al. [34]	2009	25 (16/9)	71.7 (10.5)	2 or 3	Revision shell with/without augments	39 (11)	21 well-fixed and functioning implants, with ingrowth along the tantalum surface; no dislocation or aseptic loosening
Flecher et al. [35]	2008	23	58.2	3A, 3B (8 pelvic discontinuity cases)	Revision shell with or without augments	35	No mechanical failure Suitable options for type III defects and alternative options to bone graft and cages
Van Kleunen et al. [42]	2009	90 (50/40)	59	Minimum 2A	Revision shell with/without augments; 2 antiprotrusio cage cases	45	8 revisions for infection and 1 case for instability; no revision for aseptic loosening
Siegmeth et al. [21]	2009	34 (19/15)	64	2, 3 (2 pelvic discontinuity cases)	Trabecular metal shell with augments and screws	34	2 aseptic failures; good clinical and radiological outcomes at short-term follow-up
Lakstein et al. [36]	2009	53 (24/29)	63	Less than 50% of contact	Trabecular metal cups	45	2 failed cup cases (4%); other 2 cups with radiological signs of aseptic loosening; 4 dislocation cases, 1 sciatic nerve palsy case

Table 2: Continued.

Author	Year	Number of cases (F/M)	Average age (SD)	The Paprosky classification of bone defect	Type of implant	Follow-up months (SD)	Outcome
Jafari et al. [43]	2010	283 (128/155)	69	Mixed	Tantalum cup (79) versus titanium cup (207)	43.6	Failure rate: titanium 8%, tantalum 6% Higher failure rate in massive bone deficiency for titanium cups Radiographically better fixation for tantalum cups
Flecher et al. [37]	2010	71 (41/30)	60	Mixed	Tantalum cup with/without augments	48	No radiolucent lines, 3 revisions for instability Good restoration of rotation center of the hip
Fernández-Fairen et al. [44]	2010	263 (150/113)	69.5	Mixed	Monoblock or revision shell with or without augments	73.6	85.9% of satisfied patients All cups were stable, no revision, no radiolucent lines
Lachiewicz and Soileau [19]	2010	37 (19/18)	65.1	3	Tantalum cups and augments	39.6	97% of well-fixed component; 1 mechanical failure; 7 revisions (dislocation, infection, periprosthetic fracture)
Ballester Alfaro and Sueiro Fernandez [27]	2010	19 (12/7)	63	3A and 3B	Cup-cage constructs	26	No mechanical failures Buttress tantalum augments, with cup-cage construct for severe bone defects can be a viable option
Skyttä et al. [45]	2011	827 (522/447)	69.1	N/A	Trabecular metal revision shell	36	The 3-year overall survivorship was 92%; 2% revision for aseptic loosening; each additional year in age decreased the risk of revision by 2.4%
Davies et al. [38]	2011	46 (24/22)	66.7	2C or 3	Tantalum cups with or without augments or buttress plate	50	1 infection, 2 dislocations, and 1 arterial bleeding Good clinical outcomes; no loosening
Del Gaizo et al. [39]	2012	36	60	3A	Tantalum cups and augments	26	One aseptic loosening; 7 revisions (dislocation, infection, periprosthetic fracture) Reasonable function with low rates of loosening at midterm follow-up
Gehrke et al. [40]	2013	46 (28/18)	65	2B, 3A	Tantalum cups and augments	46	4 hips of dislocation; 2 revisions because of early loosening; tantalum implants were radiographically stable and osteointegrated
Batuyong et al. [28]	2014	24	67	3, 4	Trabecular metal shell with/without augments and cage	37	92% osteointegration; 2 failures for septic loosening

Table 2: Continued.

Author	Year	Number of cases (F/M)	Average age (SD)	The Paprosky classification of bone defect	Type of implant	Follow-up months (SD)	Outcome
Moličnik et al. [20]	2014	25 (11/14)	69.7	Minimum 2A	Trabecular metal shell with/without augments	20.9	No aseptic loosening; 1 revision for traumatic dislocation; it is a suitable option in revision THA with good short-term outcomes
Abolghasemian et al. [47]	2014	26 (20/4) versus 19 (18/1) treated with cage	65	All pelvic discontinuity	Cup-cage construct versus cage	82	4 major complications in cup-cage group versus 9 in the cage group; all discontinuity healed in cup-cage group, only 3 in the cage group; 3 early migrations in the cup-cage group
Long et al. [46]	2015	599 (345/254)	65.5	N/A	Revision shell	24	7.8% of reoperations; 2.3% of cup removal (12/14 for septic loosening); no revision for aseptic loosening
Amenabar et al. [48]	2016	64 (50/14)	66	3 and 4 (61% of pelvic discontinuity)	Cup-cage construct	74	93% and 85% of, respectively, 5 and 10 years of cumulative survivorship; it is a suitable option in pelvic discontinuity

be a demanding procedure for both the patients and the surgeons. Usually, the surgeons have to deal with bone losses, ligamentous deficiencies, and loss of adequate fixation. Engh and Ammeen [49] proposed the "Anderson Orthopaedic Research Institute" (AORI) classification of bone defects. Femoral and tibial bone losses are classified into three types, according to the extent and severity of the defect. Type 1 defects are characterized by intact metaphyseal bone stock, without subsidence of the components nor osteolysis. In type 2 defects the metaphyseal bone is damaged in one (A) or both (B) condyles. On the femoral side these defects are usually distal to the epicondyles, and on the tibial side they are up to or below the fibular head. Type 3 defects include major bone losses, generally associated with ligamentous insufficiency, proximal to the epicondyle in the femur and distal to the tibial tuberosity at the tibia.

Furthermore, bone defects can be divided into cavitary or segmental, depending on the status of the cortical ring surrounding the defect [50]. The bone defects should be reclassified after removal of the components, as their amount usually increases much during surgery. A minimum defect theoretically involves less than 50% of a single condyle, with a depth of less than 5 mm. A moderate defect involves 50% to 70% of a single condyle with a depth of 5 to 10 mm. An extensive defect involves more than 70% of a condyle with a depth over 10 mm. Finally, a massive cavitary defect is characterized by the total disruption of one or both femoral condyles and can be either associated with an intact cortical rim or not [50].

In this scenario, obtaining a stable fixation of the revision implant is mandatory. Morgan-Jones et al. [52] recently defined the "zonal fixation" concept. The femur and tibia can be divided into three zones: the joint surface or epiphysis, the metaphysis, and the diaphysis. The authors suggest that solid fixation should be achieved in at least two out of the three zones.

4.1. Surgical Options Using Trabecular Metal and Techniques. Available options to treat bone defects are bone cement, autograft, morselized or structural allograft, metal augments, cones, and sleeves [53]. The chosen technique depends on patient age, life expectancy, bone loss classification, need for diaphyseal fixation, and ligamentous insufficiency. Radnay and Scuderi [51] developed an algorithm to deal with bone losses (Table 3). If the defects are small and cavitary and involve less than 1/4 of the cortical rim, they can be filled using cement or bone grafts. Conversely, if the defect involves more than 1/4 of the cortical rim or it is segmental, metal augments must be considered. Metal augments should also be considered if more than 40% of the implant interface is not supported by host bone. Metal augments resulted to be particularly useful in 5 to 10 mm type 2 defects. Major bone defects, particularly type 3 defects, are the most demanding to treat. Allograft, metal augment, hinged implant, and long stems may turn out to be useful in obtaining adequate fixation and stability in these cases. Trabecular metal is indicated in treating major bone loss, providing adequate fixation and stability. Trabecular metal has been proposed in revision TKA

Table 3: Radnay's algorithm for bone loss treatment in revision TKA [51].

Type 1 defects	Type 2 defects	Type 3 defects
Cement	Defects < 5 mm: cement	Unicondylar: metal augments
Morselized bone graft	Defects 5–10 mm: metal augment	Bicondylar: metal augments, tantalum cones, structural allograft, hinge/tumor prosthesis
Metal augment	Defects > 10 mm: structural allograft or metal augments	

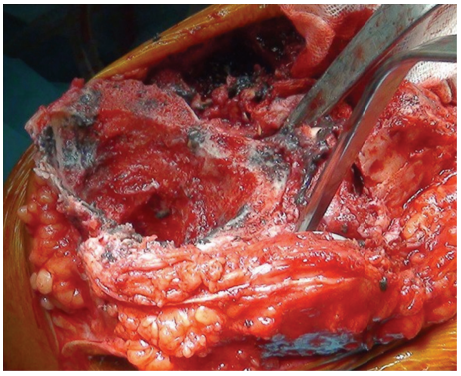


Figure 2: Tibial bone defect at the end of the preparation for implanting a tantalum cone.

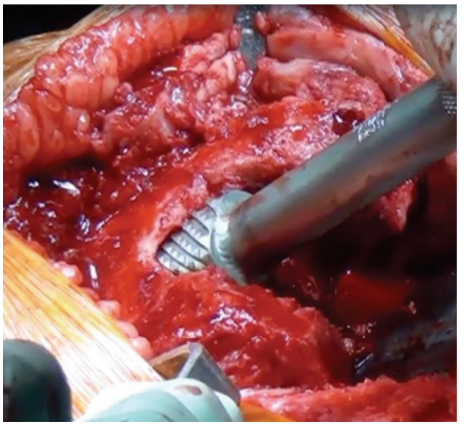


Figure 3: Preparation with rasp for a femoral tantalum cone.

because of its properties, such as increased osteointegration and structural stability. Tantalum cones can be a viable option to treat severe type 2 or 3 bone defects and can be used in association with tantalum augments to increase primary fixation [50]. Stepped cones are also available when the bone defect is greater on one side of the tibial plateau compared to the other [51].

4.1.1. Tantalum Cones' Surgical Technique. Bony surfaces have to be completely debrided from necrotic bone and residual cement, and the bone defect is sized. The residual bone has to be prepared for the tantalum cones. Dedicated instrumentation with trial is available. Once the surgeon has chosen the size of the cone, the defect is prepared using high speed burr, to reach the shape of the cone (Figure 2). On the femoral side, dedicated rasp can be used, but carefully in order to avoid fracturing the impacted bone (Figure 3). Both on the tibial and on femoral side, care should be taken not to overresect the bone, because the cones have to be inserted with a tight press-fit. If there is still a defect between the cone and the host bone, it can be filled using morselized grafting (Figure 4). Once the cone is impacted into the host bone, the final tibial or femoral component is cemented into the cone. Association of a tibial or femoral stem is useful to guarantee better stability and fixation of the construct (Figure 5) [50, 51, 54, 55].

Trabecular metal has also been proposed to treat severe patellar bone defect in revision TKA. Porous tantalum patellar component allows for implantation of a polyethylene patellar component. However, using a patellar tantalum component as an alternative to bone grafting requires sufficient

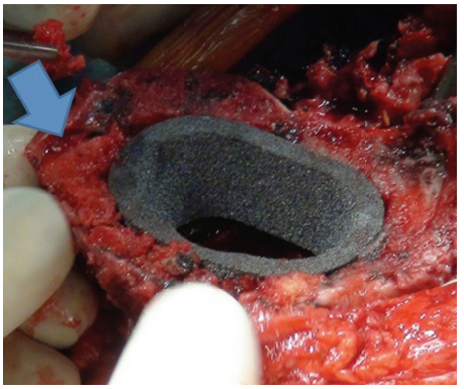


Figure 4: Tibial tantalum cone implanted. The blue arrow shows the filling of the remaining defect with morselized bone.

blood supply to allow for the incorporation of the new component in the residual patellar bone [56].

4.2. Clinical Outcomes. Considering the recent introduction of tantalum materials, only short-term follow-up studies are available (Table 4) [54, 57–63].

Most of these studies reported good clinical and radiological outcomes with low revision rate for aseptic loosening (0.9%), despite an increased revision rate for infection (2.2%) [55].

Howard et al., in 2011 [66], reported 24 femoral cones used to fill type 2 or 3 femoral bone defects. The authors reported a high reoperation rate, but without any aseptic loosening or mobilization of the tantalum cone at short-term

Table 4: Results for revision TKA or patellar replacement using porous tantalum components (TKA: Total Knee Arthroplasty, N/A: not reported).

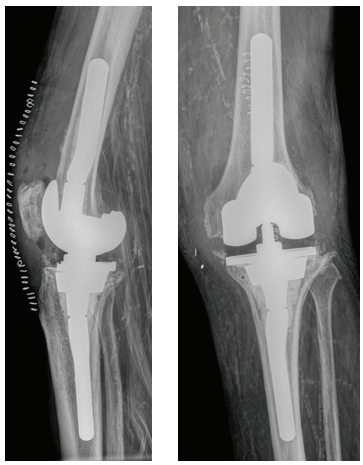
Author	Year	Number of cases (femoral/tibial)	Average age (SD)	Bone defect classification (AORI)	Type of implant	Follow-up months (SD)	Outcomes
Nelson et al. [64]	2003	20	70	N/A	Porous tantalum (PT) patellar components	23	Good or excellent results in 17 patients; 3 polar patellar fractures postoperatively; no sign of loosening
Nasser and Poggie [65]	2004	11	66	N/A	Porous tantalum (PT) patellar components	32	All implants stable, high patients' satisfaction
Meneghini et al. [57]	2008	15	68.1	Types 2 and 3	Femoral and tibial tantalum cones	34	All cones were osteointegrated at the follow-up; no loosening or migration
Long and Scuderi [58]	2009	16 (all tibial)	66.1	2 T2A, 3 T2B, 4 T3A, 7 T3B tibial bone defects	Tantalum tibial cones	31	2 cases of reinfections; in the remaining cases no reoperations and no signs of loosening; good short-term results were achieved in complex revisions, with these new cones
Howard et al. [66]	2011	24 (all femoral)	64	Types 2 and 3	Femoral tantalum cones	33	21% required subsequent surgery (no aseptic loosening); all femoral cones appeared well-fixed radiographically, with no evidence of complications related to the cone
Lachiewicz et al. [59]	2012	33 (9/24)	64.6	N/A	Femoral or tibial cone	39.6	2 cones removed for infection at 12 months, 1 revision for loosening Metaphyseal fixation with tantalum cones can be achieved
Kamath et al. [56]	2012	23	62	N/A	Porous tantalum (PT) patellar components	92.4	All patellae had less than 10 mm residual thickness; in 2 cases direct sutures to the tendons; 4 revision surgeries; 83% of survivorship; failures were associated with avascular necrosis of the residual bone and direct suture to the extensor apparatus
Villanueva-Martínez et al. [60]	2013	21 (18/11)	73.3	Types 2 and 3	Femoral and tibial tantalum cones	36	All metaphyseal cones showed evidence of stable osteointegration; good or excellent results in 17 cases
Schmitz et al. [61]	2013	44	72	Types 2 and 3	Femoral and tibial tantalum cones	37	2 rerevisions for aseptic loosening; favorable clinical and radiological outcomes using tantalum cones in managing significant bone losses in revision TKA

Table 4: Continued.

Author	Year	Number of cases (femoral/tibial)	Average age (SD)	Bone defect classification (AORI)	Type of implant	Follow-up months (SD)	Outcomes
Rao et al. [62]	2013	29	72	Types 2 and 3	Femoral and tibial tantalum cones	36	No radiolucent lines; good osteointegration one year after surgery; no evidence of collapse or loosening
Jensen et al. [67]	2014	36 (all tibial)	69	Types 2 and 3 (75%)	Tantalum tibial cones	47	4 rerevisions (2 infections, 1 aseptic loosening, 1 hyperextension); 27 patients had no radiological loosening
Derome et al. [63]	2014	29	70	Types 2 and 3	Femoral and tibial tantalum cones	33	No evidence of loosening or migration of the constructs; no complication
Boureau et al. [54]	2015	7 (all femoral)	65	Types 2 and 3	2-tantalum-cone technique	17	No complication; no migration of the femoral cones
De Martino et al. [68]	2015	26 (13/13)	73	Types 2 and 3	Femoral and tibial tantalum cones	72	2 reoperations for infection, but cones were osteointegrated; no evidence of loosening; tantalum cones for reconstruction of massive bone defects provided secure fixation and outcomes at average follow-up of 6 years
Brown et al. [69]	2015	83	69	Types 2 and 3 (primary and revision surgery)	Femoral and tibial tantalum cones	40	12% revision (one aseptic loosening); of the unrevised knee, 99% had complete osteointegration 45% experienced at least one complication
Kamath et al. [70]	2015	66	67	Types 2 and 3	Tibial tantalum cones	70	Improvement of mean Knee Society Score; one patient had progressive radiolucent line; 3 cones were revised: 1 infection, 1 aseptic loosening, 1 periprosthetic fracture; revision-free survival of the tibial cone component was >95% at the time of the latest follow-up

follow-up; this has to be considered a good outcome in a cohort of patients with a lot of comorbidities and enhances the good integration properties of this material. Recently, Jensen et al. [67] reported their results using tantalum cones to treat major tibial bone losses; at a short-term follow-up only 1 revision for aseptic loosening was necessary, while most of the patients showed well integrated cones. In 2015 three papers with considerable population and midterm follow-up were published. De Martino et al. [68] described their results with 26 (both femoral and tibial) cones at 72 months of follow-up. No evidence of loosening of the cones was detected, and the authors stated that tantalum cones for reconstruction of massive bone defects provided secure fixation and outcomes at average follow-up of 6 years. Brown et al. [69] described one of the biggest populations of femoral and tibial cones at short-term follow-up, reporting a 12% revision rate, but only one case of aseptic loosening. 99% of the remaining unrevised knees had complete osteointegration.

Kamath et al. [70] recently reported a midterm follow-up (70 months) of tibial tantalum cones used to fill major bone defects in revision TKA. The authors described one case of progressive radiolucent line, with a revision-free survival



(a) (b)

Figure 5: Postoperative X-ray showing (a) lateral view of a revision TKA with a tibial tantalum cone and (b) anteroposterior view of a revision TKA with a tibial tantalum cone.

of the tibial cone component higher than 95% at the latest follow-up.

Few papers described the result of porous tantalum patellar component in revision TKA [56, 64, 65]. Nasser and Poggie described their results on 11 patients affected by severe patellar bone losses and treated using porous tantalum patellar component. The authors concluded about good clinical and radiological short-term outcomes, with high patients' satisfaction [65]. Kamath et al. in 2012 [56] described their results in 23 patients in which a porous tantalum patellar component was used due to severe patellar bone defects. All patellae had less than 10 mm residual bone thickness. The survivorship rate was 83% at the final follow-up.

5. Conclusion

The use of tantalum in revision total hip replacement provides a higher integration potential in a shorter time: this helped reducing surgeons' fears when addressing a pelvic discontinuity or big acetabular bone losses. Tantalum provides a good and reliable substitute of bone, even in the very first period after implantation.

Big bone losses can be reduced to normal and easier to handle dimensions, decreasing the surgical challenge; however, in pelvic discontinuity, the problem still can be worrisome. In these cases, tantalum osteoinductive characteristics enhance acetabular ring healing potential, representing a very effective structure and scaffold and providing a good long-term outcome.

In revision total knee replacement, as well as for hips, the osteoinductive potential of tantalum is of paramount importance in the long period, associated with the excellent structural support and defect filling characteristics provided in the first phase after surgery.

In conclusion, tantalum showed to be a very effective material in orthopedic surgery, especially in revision surgery, thanks to the great ductility of the material and its intrinsic characteristics. High porosity, elasticity, bioactivity, biocompatibility, and osteoinductivity are of paramount importance in orthopedic implants and tantalum is actually the state of the art for all these aspects.

Competing Interests

The authors declare that they have no competing interests.

References

[1] J. A. Szivek, G. C. Weatherly, R. M. Pilliar, and H. U. Cameron, "A study of bone remodeling using metal-polymer laminates," *Journal of Biomedical Materials Research*, vol. 15, no. 6, pp. 853–865, 1981.

[2] D. M. Findlay, K. Welldon, G. J. Atkins, D. W. Howie, A. C. W. Zannettino, and D. Bobyn, "The proliferation and phenotypic expression of human osteoblasts on tantalum metal," *Biomaterials*, vol. 25, no. 12, pp. 2215–2227, 2004.

[3] J. D. Bobyn, R. M. Pilliar, H. U. Cameron, and G. C. Weatherly, "The optimum pore size for the fixation of porous surfaced metal implants by the ingrowth of bone," *Clinical Orthopaedics and Related Research*, vol. 150, pp. 263–270, 1980.

[4] W. J. Gordon, M. G. Conzemius, E. Birdsall et al., "Chondroconductive potential of tantalum trabecular metal," *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, vol. 75, no. 2, pp. 229–233, 2005.

[5] R. Cohen, "A porous tantalum trabecular metal: basic science," *American Journal of Orthopedics*, vol. 31, no. 4, pp. 216–217, 2002.

[6] B. R. Levine, S. Sporer, R. A. Poggie, C. J. Della Valle, and J. J. Jacobs, "Experimental and clinical performance of porous tantalum in orthopedic surgery," *Biomaterials*, vol. 27, no. 27, pp. 4671–4681, 2006.

[7] J. D. Bobyn, G. J. Stackpool, S. A. Hacking, M. Tanzer, and J. J. Krygier, "Characteristics of bone ingrowth and interface mechanics of a new porous tantalum biomaterial," *The Journal of Bone & Joint Surgery—British Volume*, vol. 81, no. 5, pp. 907–914, 1999.

[8] L. D. Zardiackas, D. E. Parsell, L. D. Dillon, D. W. Mitchell, L. A. Nunnery, and R. Poggie, "Structure, metallurgy, and mechanical properties of a porous tantalum foam," *Journal of Biomedical Materials Research*, vol. 58, no. 2, pp. 180–187, 2001.

[9] S. A. Hacking, J. D. Bobyn, K.-K. Toh, M. Tanzer, and J. J. Krygier, "Fibrous tissue ingrowth and attachment to porous tantalum," *Journal of Biomedical Materials Research*, vol. 52, no. 4, pp. 631–638, 2000.

[10] A. Shirazi-Adl, M. Dammak, and G. Paiement, "Experimental determination of friction characteristics at the trabecular bone/porous-coated metal interface in cementless implants," *Journal of Biomedical Materials Research*, vol. 27, no. 2, pp. 167–175, 1992.

[11] J. Black, "Biologic performance of tantalum," *Clinical Materials*, vol. 16, no. 3, pp. 167–173, 1994.

[12] J. D. Bobyn, K.-K. Toh, S. A. Hacking, M. Tanzer, and J. J. Krygier, "Tissue response to porous tantalum acetabular cups: a canine model," *Journal of Arthroplasty*, vol. 14, no. 3, pp. 347–354, 1999.

[13] H. Matsuno, A. Yokoyama, F. Watari, M. Uo, and T. Kawasaki, "Biocompatibility and osteogenesis of refractory metal

implants, titanium, hafnium, niobium, tantalum and rhenium," *Biomaterials*, vol. 22, no. 11, pp. 1253–1262, 2001.

[14] C. B. Johansson, H. A. Hansson, and T. Albrektsson, "Qualitative interfacial study between bone and tantalum, niobium or commercially pure titanium," *Biomaterials*, vol. 11, no. 4, pp. 277–280, 1990.

[15] S. Kurtz, F. Mowat, K. Ong, N. Chan, E. Lau, and M. Halpern, "Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002," *The Journal of Bone & Joint Surgery—American Volume*, vol. 87, no. 7, pp. 1487–1497, 2005.

[16] W. G. Paprosky, S. S. Sporer, and B. P. Murphy, "Addressing severe bone deficiency. What a cage will not do," *Journal of Arthroplasty*, vol. 22, no. 4, supplement 1, pp. 111–115, 2007.

[17] W. G. Paprosky, P. G. Perona, and J. M. Lawrence, "Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation," *The Journal of Arthroplasty*, vol. 9, no. 1, pp. 33–44, 1994.

[18] E. D. Taylor and J. A. Browne, "Reconstruction options for acetabular revision," *World Journal of Orthopaedics*, vol. 3, no. 7, pp. 95–100, 2012.

[19] P. F. Lachiewicz and E. S. Soileau, "Tantalum components in difficult acetabular revisions," *Clinical Orthopaedics and Related Research*, vol. 468, no. 2, pp. 454–458, 2010.

[20] A. Moličnik, M. Hanc, G. Rečnik, Z. Krajnc, M. Rupreht, and S. K. Fokter, "Porous tantalum shells and augments for acetabular cup revisions," *European Journal of Orthopaedic Surgery & Traumatology*, vol. 24, no. 6, pp. 911–917, 2014.

[21] A. Siegmeth, C. P. Duncan, B. A. Masri, W. Y. Kim, and D. S. Garbuz, "Modular tantalum augments for acetabular defects in revision hip arthroplasty," *Clinical Orthopaedics and Related Research*, vol. 467, no. 1, pp. 199–205, 2009.

[22] J. B. Stiehl, "Trabecular metal in hip reconstructive surgery," *Orthopedics*, vol. 28, no. 7, pp. 662–670, 2005.

[23] B. D. Springer, D. J. Berry, M. E. Cabanela, A. D. Hanssen, and D. G. Lewallen, "Early postoperative transverse pelvic fracture: a new complication related to revision arthroplasty with an uncemented cup," *The Journal of Bone & Joint Surgery—American Volume*, vol. 87, no. 12, pp. 2626–2631, 2005.

[24] A. E. Gross and S. B. Goodman, "Rebuilding the skeleton: the intraoperative use of trabecular metal in revision total hip arthroplasty," *The Journal of Arthroplasty*, vol. 20, no. 4, supplement 2, pp. 91–93, 2005.

[25] W. G. Paprosky, M. O'Rourke, and S. M. Sporer, "The treatment of acetabular bone defects with an associated pelvic discontinuity," *Clinical Orthopaedics and Related Research*, no. 441, pp. 216–220, 2005.

[26] S. Goodman, H. Saastamoinen, N. Shasha, and A. Gross, "Complications of ilioischial reconstruction rings in revision total hip arthroplasty," *Journal of Arthroplasty*, vol. 19, no. 4, pp. 436–446, 2004.

[27] J. J. Ballester Alfaro and J. Sueiro Fernandez, "Trabecular Metal buttress augment and the Trabecular Metal cup—cage construct in revision hip arthroplasty for severe acetabular bone loss and pelvic discontinuity," *Hip International*, vol. 20, supplement 7, pp. S119–S127, 2010.

[28] E. D. Batuyong, H. S. Brock, N. Thiruvengadam, W. J. Maloney, S. B. Goodman, and J. I. Huddleston, "Outcome of porous tantalum acetabular components for paprosky type 3 and 4 acetabular defects," *Journal of Arthroplasty*, vol. 29, no. 6, pp. 1318–1322, 2014.

[29] S. H. Weeden and R. H. Schmidt, "The use of tantalum porous metal implants for Paprosky 3A and 3B defects," *Journal of Arthroplasty*, vol. 22, no. 6, supplement 2, pp. 151–155, 2007.

[30] A. Nehme, D. G. Lewallen, and A. D. Hanssen, "Modular porous metal augments for treatment of severe acetabular bone loss during revision hip arthroplasty," *Clinical Orthopaedics and Related Research*, no. 429, pp. 201–208, 2004.

[31] A. S. Unger, R. J. Lewis, and T. Gruen, "Evaluation of a porous tantalum uncemented acetabular cup in revision total hip arthroplasty: clinical and radiological results of 60 hips," *Journal of Arthroplasty*, vol. 20, no. 8, pp. 1002–1009, 2005.

[32] S. M. Sporer and W. G. Paprosky, "The use of a trabecular metal acetabular component and trabecular metal augment for severe acetabular defects," *Journal of Arthroplasty*, vol. 21, no. 6, supplement 2, pp. 83–86, 2006.

[33] S. M. Sporer and W. G. Paprosky, "Acetabular revision using a trabecular metal acetabular component for severe acetabular bone loss associated with a pelvic discontinuity," *Journal of Arthroplasty*, vol. 21, no. 6, supplement 2, pp. 87–90, 2006.

[34] A. L. Malkani, M. R. Price, C. H. Crawford III, and D. L. Baker, "Acetabular component revision using a porous tantalum biomaterial: a case series," *The Journal of Arthroplasty*, vol. 24, no. 7, pp. 1068–1073, 2009.

[35] X. Flecher, S. Sporer, and W. Paprosky, "Management of severe bone loss in acetabular revision using a trabecular metal shell," *The Journal of Arthroplasty*, vol. 23, no. 7, pp. 949–955, 2008.

[36] D. Lakstein, D. Backstein, O. Safir, Y. Kosashvili, and A. E. Gross, "Trabecular Metal™ cups for acetabular defects with 50% or less host bone contact," *Clinical Orthopaedics and Related Research*, vol. 467, no. 9, pp. 2318–2324, 2009.

[37] X. Flecher, W. Paprosky, J.-C. Grillo, J.-M. Aubaniac, and J.-N. Argenson, "Do tantalum components provide adequate primary fixation in all acetabular revisions?" *Orthopaedics and Traumatology: Surgery and Research*, vol. 96, no. 3, pp. 235–241, 2010.

[38] J. H. Davies, G. Y. Laflamme, J. Delisle, and J. Fernandes, "Trabecular metal used for major bone loss in acetabular hip revision," *The Journal of Arthroplasty*, vol. 26, no. 8, pp. 1245–1250, 2011.

[39] D. J. Del Gaizo, V. Kancherla, S. M. Sporer, and W. G. Paprosky, "Tantalum augments for paprosky IIIA defects remain stable at midterm followup," *Clinical Orthopaedics and Related Research*, vol. 470, no. 2, pp. 395–401, 2012.

[40] T. Gehrke, Y. Bangert, B. Schwantes, M. Gebauer, and D. Kendoff, "Acetabular revision in THA using tantalum augments combined with impaction bone grafting," *HIP International*, vol. 23, no. 4, pp. 359–365, 2013.

[41] R. G. Clement, A. G. Ray, D. J. MacDonald, F. A. Wade, R. Burnett, and M. Moran, "Trabecular metal use in paprosky type 2 and 3 acetabular defects: 5-year follow-up," *The Journal of Arthroplasty*, vol. 31, no. 4, pp. 863–867, 2016.

[42] J. P. Van Kleunen, G.-C. Lee, P. W. Lementowski, C. L. Nelson, and J. P. Garino, "Acetabular revisions using trabecular metal cups and augments," *Journal of Arthroplasty*, vol. 24, no. 6, pp. 64–68, 2009.

[43] S. M. Jafari, B. Bender, C. Coyle, J. Parvizi, P. F. Sharkey, and W. J. Hozack, "Do tantalum and titanium cups show similar results in revision hip arthroplasty?" *Clinical Orthopaedics and Related Research*, vol. 468, no. 2, pp. 459–465, 2010.

[44] M. Fernández-Fairen, A. Murcia, A. Blanco, A. Meroño, A. Murcia, and J. Ballester, "Revision of failed total hip arthroplasty

acetabular cups to porous tantalum components. A 5-Year Follow-Up Study," *Journal of Arthroplasty*, vol. 25, no. 6, pp. 865–872, 2010.

[45] E. T. Skyttä, A. Eskelinen, P. O. Paavolainen, and V. M. Remes, "Early results of 827 trabecular metal revision shells in acetabular revision," *The Journal of Arthroplasty*, vol. 26, no. 3, pp. 342–345, 2011.

[46] W. J. Long, N. O. Noiseux, T. M. Mabry, A. D. Hanssen, and D. G. Lewallen, "Uncemented porous tantalum acetabular components: early follow-up and failures in 599 revision total hip arthroplasties," *The Iowa Orthopaedic Journal*, vol. 35, pp. 108–113, 2015.

[47] M. Abolghasemian, S. Tangsaraporn, M. Drexler et al., "The challenge of pelvic discontinuity: cup-cage reconstruction does better than conventional cages in mid-term," *Bone and Joint Journal*, vol. 96, no. 2, pp. 195–200, 2014.

[48] T. Amenabar, W. A. Rahman, B. M. Hetaimish, P. R. Kuzyk, O. A. Safir, and A. E. Gross, "Promising mid-term results with a cup-cage construct for large acetabular defects and pelvic discontinuity," *Clinical Orthopaedics and Related Research*, vol. 474, no. 2, pp. 408–414, 2016.

[49] G. A. Engh and D. J. Ammeen, "Classification and preoperative radiographic evaluation: knee," *Orthopedic Clinics of North America*, vol. 29, no. 2, pp. 205–217, 1998.

[50] M. Vasso, P. Beaufils, S. Cerciello, and A. Schiavone Panni, "Bone loss following knee arthroplasty: potential treatment options," *Archives of Orthopaedic and Trauma Surgery*, vol. 134, no. 4, pp. 543–553, 2014.

[51] C. S. Radnay and G. R. Scuderi, "Management of bone loss: augments, cones, offset stems," *Clinical Orthopaedics and Related Research*, vol. 446, pp. 83–92, 2006.

[52] R. Morgan-Jones, S. I. S. Oussedik, H. Graichen, and F. S. Haddad, "Zonal fixation in revision total knee arthroplasty," *Bone and Joint Journal B*, vol. 97, no. 2, pp. 147–149, 2015.

[53] J. M. Cuckler, "Bone loss in total knee arthroplasty: graft augment and options," *The Journal of Arthroplasty*, vol. 19, no. 4, supplement 1, pp. 56–58, 2004.

[54] F. Boureau, S. Putman, A. Arnould, G. Dereudre, H. Migaud, and G. Pasquier, "Tantalum cones and bone defects in revision total knee arthroplasty," *Orthopaedics and Traumatology: Surgery and Research*, vol. 101, no. 2, pp. 251–255, 2015.

[55] N. A. Beckmann, S. Mueller, M. Gondan, S. Jaeger, T. Reiner, and R. G. Bitsch, "Treatment of severe bone defects during revision total knee arthroplasty with structural allografts and porous metal cones—a systematic review," *Journal of Arthroplasty*, vol. 30, no. 2, pp. 249–253, 2015.

[56] A. F. Kamath, A. O. Gee, C. L. Nelson, J. P. Garino, P. A. Lotke, and G.-C. Lee, "Porous tantalum patellar components in revision total knee arthroplasty. Minimum 5-year follow-up," *The Journal of Arthroplasty*, vol. 27, no. 1, pp. 82–87, 2012.

[57] R. M. Meneghini, D. G. Lewallen, and A. D. Hanssen, "Use of porous tantalum metaphyseal cones for severe tibial bone loss during revision total knee replacement," *The Journal of Bone & Joint Surgery—American Volume*, vol. 90, no. 1, pp. 78–84, 2008.

[58] W. J. Long and G. R. Scuderi, "Porous tantalum cones for large metaphyseal tibial defects in revision total knee arthroplasty: a minimum 2-year follow-up," *Journal of Arthroplasty*, vol. 24, no. 7, pp. 1086–1092, 2009.

[59] P. F. Lachiewicz, M. P. Bolognesi, R. A. Henderson, E. S. Soileau, and T. P. Vail, "Can tantalum cones provide fixation in complex revision knee arthroplasty?" *Clinical Orthopaedics and Related Research*, vol. 470, no. 1, pp. 199–204, 2012.

[60] M. Villanueva-Martínez, B. De la Torre-Escudero, J. M. Rojo-Manaute, A. Ríos-Luna, and F. Chana-Rodriguez, "Tantalum cones in revision total knee arthroplasty. A promising short-term result with 29 cones in 21 patients," *Journal of Arthroplasty*, vol. 28, no. 6, pp. 988–993, 2013.

[61] H.-C. R. Schmitz, W. Klauser, M. Citak, H. Al-Khateeb, T. Gehrke, and D. Kendoff, "Three—year follow up utilizing tantal cones in revision total knee arthroplasty," *Journal of Arthroplasty*, vol. 28, no. 9, pp. 1556–1560, 2013.

[62] B. M. Rao, T. T. Kamal, J. Vafaye, and M. Moss, "Tantalum cones for major osteolysis in revision knee replacement," *Bone and Joint Journal*, vol. 95, no. 8, pp. 1069–1074, 2013.

[63] P. Derome, A. Sternheim, D. Backstein, and M. Malo, "Treatment of large bone defects with trabecular metal cones in revision total knee arthroplasty: short term clinical and radiographic outcomes," *Journal of Arthroplasty*, vol. 29, no. 1, pp. 122–126, 2014.

[64] C. L. Nelson, J. H. Lonner, A. Lahiji, J. Kim, and P. A. Lotke, "Use of a trabecular metal patella for marked patella bone loss during revision total knee arthroplasty," *The Journal of Arthroplasty*, vol. 18, no. 7, supplement 1, pp. 37–41, 2003.

[65] S. Nasser and R. A. Poggie, "Revision and salvage patellar arthroplasty using a porous tantalum implant," *Journal of Arthroplasty*, vol. 19, no. 5, pp. 562–572, 2004.

[66] J. L. Howard, J. Kudera, D. G. Lewallen, and A. D. Hanssen, "Early results of the use of tantalum femoral cones for revision total knee arthroplasty," *Journal of Bone and Joint Surgery—Series A*, vol. 93, no. 5, pp. 478–484, 2011.

[67] C. L. Jensen, N. Winther, H. M. Schrøder, and M. M. Petersen, "Outcome of revision total knee arthroplasty with the use of trabecular metal cone for reconstruction of severe bone loss at the proximal tibia," *Knee*, vol. 21, no. 6, pp. 1233–1237, 2014.

[68] I. De Martino, V. De Santis, P. K. Sculco, R. D'Apolito, J. B. Assini, and G. Gasparini, "Tantalum cones provide durable mid-term fixation in revision TKA," *Clinical Orthopaedics and Related Research*, vol. 473, no. 10, pp. 3176–3182, 2015.

[69] N. M. Brown, J. A. Bell, E. K. Jung, S. M. Sporer, W. G. Paprosky, and B. R. Levine, "The use of trabecular metal cones in complex primary and revision total knee arthroplasty," *Journal of Arthroplasty*, vol. 30, no. 9, suppleme, pp. 90–93, 2015.

[70] A. F. Kamath, D. G. Lewallen, and A. D. Hanssen, "Porous tantalum metaphyseal cones for severe tibial bone loss in revision knee arthroplasty: a five to nine-year follow-up," *The Journal of Bone & Joint Surgery—American Volume*, vol. 97, no. 3, pp. 216–223, 2015.