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Original Research

Trabecular Metal Augments During Complex Primary Total Hip Arthroplasty

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ABSTRACT

Background: Trabecular metal augments (TMAs) have been extensively used in revision total hip arthroplasty (THA) to address acetabular bone defects. However, limited data exists regarding TMA utilization during primary THA. This study aims to assess the clinical and radiographic outcomes of TMAs used during primary THA.
Methods: A single-institution retrospective case series of primary THA patients treated with TMA between 2010 and 2019 was performed. Patient demographics, complications, and revisions were recorded. Cup position, center of rotation, leg length, and radiolucent lines were assessed radiographically. The Kaplan-Meier method was used to compute implant survivorship.
Results: Twenty-six patients (30 hips) were included with average age of 52.6 ± 15.3 years (range: 22-78) and mean follow-up of 4.1 ± 2.1 years (range: 2.0-8.9). Most TMAs were indicated for developmental dysplasia of the hip (n = 18; 60.0%). On average, hip center of rotation was lowered 1.5 ± 1.3 cm and lateralized 1.2 ± 1.5 cm, while leg length and global offset were increased by 2.4 ± 1.2 cm and 0.4 ± 1.0 cm, respectively. At final follow-up, 3 hips (10.0%) required revision: one (3.3%) for aseptic loosening and 2 (6.7%) for instability. No patients had progressive radiolucent lines at final follow-up. Five-year survival with aseptic loosening and all-cause revision as endpoints was 100% (95% confidence interval: 90.0%-100.0%) and 92.1% (95% confidence interval: 81.3%-100.0%), respectively. One patient required revision for aseptic loosening after the 5-year mark.
Conclusions: Trabecular metal augmentation during primary THA demonstrates satisfactory early to mid-term outcomes. TMA is a viable option for complex primary THA when bone loss is encountered or secondary support is required.
Level of Evidence: Level IV.

Introduction

Significant acetabular bone loss presents a challenging clinical scenario for arthroplasty surgeons. While more commonly encountered during revision total hip arthroplasty (THA), large acetabular defects may also be present in primary THA [1-4]. These defects can be reconstructed with various techniques, depending on their size and location. The optimal strategy, particularly in the primary setting, remains a subject of debate [1]. The increased difficulty associated with achieving initial component stability and long-term biological fixation in the presence of a large acetabular defect during complex primary THA likely contributes to an even higher incidence of acetabular component revision in this subset of patients.

Acetabular bone loss encountered in primary THA has been associated with multiple conditions. Prior studies evaluating patients with extensive bone loss requiring reconstructive methods beyond standard porous-coated cups with or without bone grafting have primarily focused on developmental dysplasia of the hip (DDH) [5-9]. In DDH, the shallow acetabulum and subluxation of

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the femoral head contribute to the development of anterolateral and superolateral acetabular defects [5,6]. Similarly, patients with a history of prior trauma or infection may also present with substantial acetabular bone loss [10-14]. Bone loss has also been documented in other conditions, including rheumatoid arthritis, rapidly progressive osteoarthritis (OA), osteonecrosis, and neoplastic periacetabular lesions [15-19]. While severe primary OA of the hip may present with bone loss, the majority of patients receive surgical treatment before the defect becomes substantial [18]. As the extent and location of the defect can vary markedly due to etiology and disease severity, a range of reconstruction options are needed to address acetabular bone loss in primary THA.

A well-described method for managing larger, uncontained defects in the setting of revision THA involves the utilization of highly porous metal components, with or without trabecular metal augments (TMAs) [20-22]. TMAs possess a high coefficient of friction against bone and have a high porosity, which helps to provide initial stability and promote osseointegration [23-25]. Moreover, TMAs are relatively straightforward to implant, and augments are available in a wide variety of shapes and sizes [22].

Previous studies have demonstrated promising results for acetabular component survival and clinical outcomes in revision THA using TMAs [21,22,26-28]. To our knowledge, only one study has evaluated the clinical and radiographic outcomes of TMAs in the setting of primary THA, reporting no revisions or complications in a cohort of 19 patients [4]. Therefore, further investigation of this technique is necessary to improve understanding of the utility of TMAs during primary THA. The purpose of this study was to assess the early to mid-term clinical and radiographic outcomes associated with the use of TMAs for reconstructing acetabular defects during primary THA.

Material and methods

Study design

After obtaining institutional review board approval (HS-19-00939), a single-institution retrospective case series of 41 consecutive primary THAs with TMAs performed in 37 patients from November 2010-October 2019 was performed. Patients were included if they were >18 years of age, had a minimum follow-up of 2 years, and underwent primary THA with the use of a TMA. Patients with a history of ipsilateral arthroplasty procedure, insufficient follow-up, or incomplete medical documentation were excluded. All primary THAs included in this study utilized the TMARS (Trabecular Metal Acetabular Revision System, Zimmer Biomet, Warsaw, IN). (Fig. 1)

Of the 37 patients (41 hips) initially identified, one patient (2.7%) died of causes unrelated to the THA, and 10 patients (27.0%) had insufficient follow-up, leaving 26 patients (70.3%, 30 hips) available for analysis. Manual chart review was performed to obtain clinical, operative, and radiographic data. Demographic variables included age, ethnicity, sex, and body mass index. Operative variables included surgical indication, date of surgery, and the size of the TMA utilized. Each patient's postoperative course was closely followed to capture all postoperative complications, need for revision surgery, and indication for revision surgery.

Radiographic evaluation

Standard anteroposterior radiographs of the pelvis, frog-leg lateral, and cross-table lateral radiographs of the operative hip were obtained preoperatively and at routine postoperative intervals. Radiographic parameters were collected using both Synapse version 4.4.3 (Fujifilm Medical Systems, Morrisville, North Carolina) and TraumaCad version 2.5.7 (Brainlab Inc., Westchester, Illinois). Radiographic evaluation consisted of acetabular inclination and anteversion, global offset, change in hip center of rotation (COR), leg-length discrepancies (LLD), degree of DDH dislocation according to Crowe type, as well as the presence of radiolucent lines [5].

Using the program TraumaCad, each radiograph was first calibrated using a standardized 25.4 mm radiopaque ball prior to the analysis of radiographic parameters [29]. Acetabular component inclination and anteversion measurements, as well as preoperative and postoperative measurements of global offset, hip COR, and LLD, were obtained using the method described by Domb et al [30]. When assessing the change in hip COR following primary THA, positive values were attributed to more medial and superior positions, while negative values were attributed to more lateral and inferior positions. Lengthening of the operative extremity was denoted using negative values. (Fig. 2) Radiographic review was performed by a single fellowship-trained orthopaedic surgeon (N.D.H.).

Surgical technique

All procedures were performed by the senior surgeon (D.A.O.) using a posterolateral approach. Circumferential exposure of the acetabulum was achieved by taking down the short external

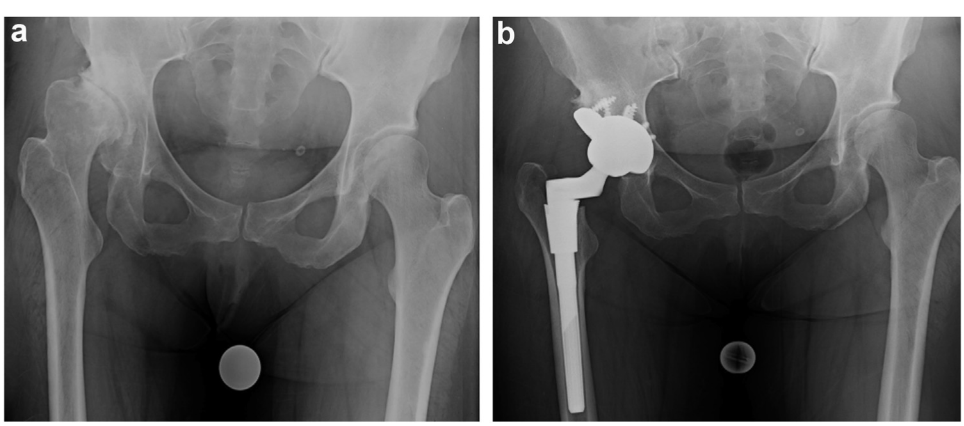

Figure 1. (a) Preoperative and (b) postoperative low anteroposterior (AP) pelvic radiographs demonstrating interval implantation of primary total hip arthroplasty (THA) with use of tantalum augments from the Trabecular Metal Acetabular Revision System (TMARS, Zimmer Biomet) to address acetabular bone defects in a dysplastic hip.

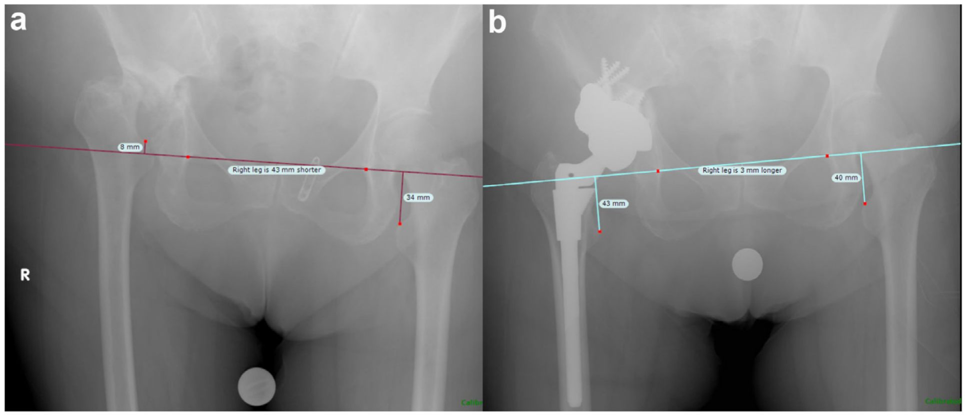

Figure 2. (a) Preoperative low anteroposterior (AP) radiograph demonstrating a 4.3 cm leg-length discrepancy in a 78-year-old female. (b) Postoperative low AP radiograph demonstrating lengthening of the right lower extremity by 4.6 cm following primary total hip arthroplasty with trabecular metal augmentation. Measurements were determined using the inter-teardrop line as a pelvic reference and the lesser trochanters as a femoral reference.

rotators, including the piriformis, and doing a standard arthrotomy through the underlying hip capsule. The short external rotators and capsule were tagged for later repair with #1 Ethibond and #1 PDS sutures (Johnson and Johnson; New Brunswick, NJ). The acetabulum was prepared with serial reaming until a hemispheric fit was achieved, ensuring that the inferior aspect of the reamer was positioned against the transverse acetabular ligament in order to maximize the anteroposterior fit within the dysplastic acetabulum. This establishes stable fixation and identifies the anterolateral and superolateral defects requiring augmentation. In all cases, a multi-hole acetabular shell was impacted into place, checked intraoperatively for stability, and subsequently anchored into place with screws. The TMA was reshaped when needed using a high-speed pneumatic drill to allow the augment to fit the corresponding acetabular defect (Midas Rex; Medtronic, Minneapolis, MN). (Fig. 3) Next, the interface between the TMA and the shell was unitized using Simplex P cement (Stryker, Kalamazoo, MI) with tobramycin and methylene blue. Prior to skin closure, the short external rotators and capsule were repaired to the posterior edge of the greater trochanter and posterior femoral neck, respectively, with #1 Vicryl suture (Johnson and Johnson; New Brunswick, NJ). Postoperatively, the majority of patients were made weight-bearing as tolerated (n = 18 hips, 60.0%). The remaining 12 patients (40.0%) were restricted to toe-touch weight-bearing of the operative extremity for a duration of 4 weeks due to the severity of the acetabular defect noted intraoperatively. Each of these 12 patients received supplementary bone grafting derived from reamings of the femoral head or acetabulum in addition to the TMA. Additionally, a femoral head structural autograft was utilized alongside the TMA in one of the 12 patients (8.3%) to provide additional support due to a significant protrusio deformity.

Statistical analysis

Clinical and radiographic data were analyzed with descriptive statistics, with the data presented as mean values with associated standard deviations and ranges where appropriate. Univariate analyses were performed to compare differences between preoperative and postoperative radiographic parameters including hip center, global offset, and leg-length discrepancy using a paired Student's t-test with a threshold for statistical significance of $P < .05$. Kaplan-Meier survival analysis was used to compute survival with all-cause revision and revision for aseptic loosening as endpoints.

Results

Patient demographics and operative variables

Of the 26 patients (30 hips) available for analysis, the majority were female (n = 15 patients; 57.7%) and White (n = 16 patients; 61.5%), with an average body mass index of 27.9 ± 4.8 kg/m^2 (range:

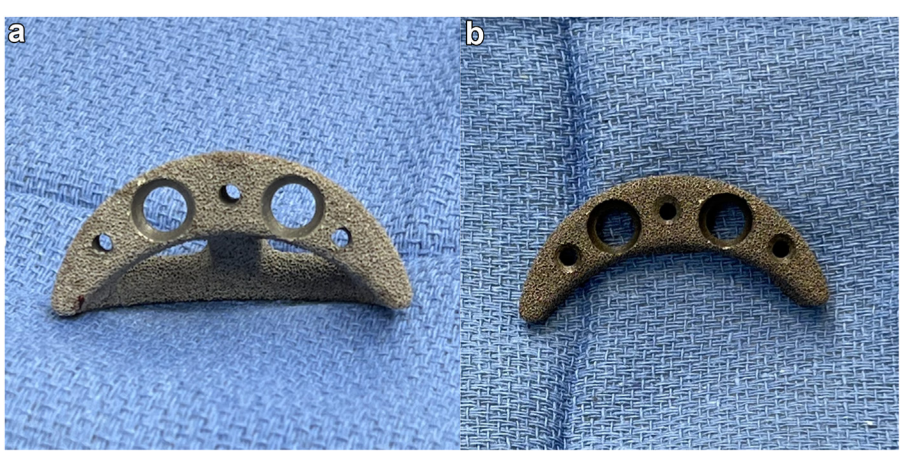

Figure 3. (a) Wedge-shaped trabecular metal augments are readily available in a variety of sizes, ranging from 50 mm to 70 mm. (b) Intraoperatively, these augments may be modified to accommodate locking screws. After placement, the augment is unitized to the acetabular components using bone cement.

Table 1
Patient demographic characteristics of the study cohort.

Demographic variable	Value	Range
Age (mean ± SD)	52.6 ± 15.3 years	(22-78 years)
BMI (mean ± SD)	27.9 ± 4.8 kg/m^2	(19.1-38.1 kg/m^2)
Sex (n, %)		
Male	11 (42.3%)	
Female	15 (57.7%)	
Operative Indication (n, %)		
Development dysplasia of the hip (DDH)	18 (60.0%)	
Post-traumatic osteoarthritis	7 (23.3%)	
Rheumatoid arthritis (RA)	3 (10.0%)	
Osteonecrosis	1 (3.3%)	
Secondary osteoarthritis (spastic diplegia)	1 (3.3%)	
Crowe classification (n, %)[a]		
Type 1	1 (5.6%)	
Type 2	7 (38.9%)	
Type 3	6 (33.3%)	
Type 4	4 (22.2%)	
Clinical follow-up (mean ± SD)	4.1 ± 2.1 years	(2.0-8.9 years)

BMI, body mass index.
[a] Crowe classification applies to dysplastic hips only (n = 18).

19.1-38.1) and a mean follow-up of 4.1 ± 2.1 years (range: 2.0-8.9) (Table 1). The average age at the time of surgery was 52.6 ± 15.3 years (range: 22-78). The most common indications for the use of a TMA in the present cohort of patients undergoing primary THA were DDH (n = 18 hips; 60.0%), post-traumatic OA (n = 6 hips; 20.0%), and rheumatoid arthritis (n = 3 hips; 10.0%). The severity of hip dysplasia according to the Crowe classification was predominantly group II (n = 7 hips; 38.9%) and group III (n = 6 hips; 33.3%), with 4 hips classified as group IV (22.2%) and one hip as group I (5.6%). Other operative indications included osteonecrosis, severe OA, and degenerative joint disease secondary to spastic diplegia, each in one hip (3.3%). In the majority of cases, a TMA sized at either 50 × 15 mm (n = 8 hips; 26.7%) or 50 × 10 mm (n = 7 hips; 23.3%) was utilized. The most common TMA shape utilized was the wedge (n = 23 hips; 76.7%) (Fig. 4). Of the remaining 7 hips, 4 (13.3%) were augmented with a disc-shaped TMA, while 3 (10.0%) were augmented with a buttress TMA.

Radiographic parameters

On average, the hip COR was lowered by 1.5 ± 1.3 cm (range: 0.1-4.3 cm, $P < .01$) and lateralized by 1.2 ± 1.5 cm [range: (−1.9 cm, lateralized)-(+3.9 cm, medialized), $P < .01$] (Table 2). Consequently, leg length of the operative extremity was increased postoperatively by an average of 2.4 ± 1.2 cm (range: 0.5-5.7 cm, $P < .01$), while global offset was increased by an average of 0.4 ± 1.0 cm [range: (−2.7 cm, decreased)-(+1.7 cm, increased), $P = .03$]. The mean acetabular inclination was 39.5° ± 9.6° (range: 17°-61°) and acetabular anteversion was 16.5° ± 6.3° (range: 3°-27°). No patients had progressive radiolucent lines at the final follow-up.

Complications and revisions

At the final follow-up, 2 patients (3 hips, 10.0%) underwent subsequent revision surgeries. One patient sustained a traumatic ground-level fall approximately 6.5 years after primary THA, resulting in the displacement of a previously well-fixed acetabular component. Notably, this patient had a history of prior acetabular fracture with pelvic discontinuity that had healed before her primary THA. This patient ultimately underwent successful revision THA for aseptic acetabular loosening at 81.0 months from index surgery with no further complications (Fig. 5).

The second patient, with a history of severe bilateral hip DDH and complex social history, underwent staged complex bilateral THAs (left prior to right). With regard to the left hip, this patient developed late multidirectional instability and was treated with femoral stem revision and conversion to a constrained articulation at 25.1 months postoperatively with no further complications. On the right side, this patient experienced recurrent anterior hip dislocations, ultimately requiring revision THA with femoral stem revision, upsizing of the femoral head, and lengthening of the femoral neck at 1.8 months from index surgery. The patient subsequently underwent a second revision of the right THA due to 2 episodes of posterior hip dislocation at 3.1 months from index surgery, requiring conversion to a constrained articulation.

Additional complications included wound dehiscence and a subsegmental pulmonary embolism, each occurring in one patient (3.3%). Five-year survival with aseptic loosening and all-cause revision as endpoints was 100.0% (95% confidence interval (CI): 90.0%-100.0%) and 92.1% (95% CI: 81.3%-100.0%), respectively (Fig. 6). One patient (3.3%) required revision for aseptic loosening after the 5-year mark. As such, the 7-year survival estimate with revision for aseptic loosening as an endpoint was 80.0% (95% CI 41.4%-100%).

Discussion

To date, a wide variety of reconstructive strategies have been implemented to address significant acetabular bone loss during

Figure 4. (a) Preoperative and (b) postoperative low anteroposterior (AP) radiographs of a patient with significant developmental dysplasia of the bilateral hips demonstrating interval bilateral primary total hip arthroplasty with use of 54 × 15 mm trabecular metal (TM) wedge augments bilaterally.

Table 2
Comparison of preoperative and postoperative variables of the study cohort, including hip center, leg length, global offset, and acetabular component position following primary THA with acetabular augmentation as measured on preoperative and postoperative radiographs.

Variable	Preoperative	Postoperative	Difference[a]	*P*-value[b]
Horizontal hip center of rotation (cm)	4.3 ± 1.3	3.1 ± 0.8	−1.2 ± 1.5 (lateral)	**<.01**
Vertical hip center of rotation (cm)	7.4 ± 1.6	6.0 ± 1.0	−1.5 ± 1.3 (inferior)	**<.01**
Leg length (cm)	1.8 ± 1.3	−0.6 ± 1.0	−2.4 ± 1.2 (lengthened)	**<.01**
Global offset (cm)	6.2 ± 0.9	6.7 ± 1.2	0.4 ± 1.0 (increase)	**.03**
Acetabular inclination (°)		39.5 ± 9.6		
Acetabular anteversion (°)		16.5 ± 6.3		

[a] With respect to the hip center of rotation, positive values denote medial and superior positions, while negative values denote lateral and inferior positions. An increase in leg length is denoted by a negative value.
[b] Statistically significant *P*-values ($P < .05$) are depicted in bold.

THA, including impaction grafting, structural allograft reconstruction, bulk femoral head autografting, and highly porous acetabular components with supplemental screw fixation [1,31-34]. However, the long-term durability of many of these techniques is varied, owing to high rates of bone graft resorption and the increased risk of aseptic loosening associated with the use of cemented acetabular components [7,35]. Acetabular reconstruction using an uncemented, hemispheric, highly porous acetabular component with supplemental TMA may be a reproducible strategy to address challenging primaries where bone loss is encountered.

The use of bulk femoral head autografts for the reconstruction of dysplastic acetabula during THA has been well-described as a reliable and potentially cost-effective alternative to the use of TMAs [36]. Taylor et al. performed a retrospective cohort study of 34 patients with hip dysplasia who underwent primary THA with femoral head autograft using a direct anterior approach, demonstrating reliable reconstruction of the true hip center, radiographic evidence of graft incorporation at a mean of 6.5 months postoperatively, and an increase in horizontal bone stock at a mean of 43.4% [37]. Similarly, Kim et al. conducted a retrospective study of 83 patients with hip dysplasia who underwent cementless THA with bulk femoral head autograft and reported a 10-year survivorship of 94% using all-cause acetabular component revision as the endpoint [38]. Nevertheless, the use of bulk femoral head autografts remains controversial due to concerns regarding long-term graft failure secondary to graft resorption [39,40]. In the present series, we elected to address the significant acetabular bone loss encountered in our cohort using TMA in lieu of bulk femoral head autografts, as TMAs are more reproducible in shape and size, provide superior fixation through compression into host iliac bone, and avoid long-term failure secondary to graft resorption. Furthermore, a significant proportion of these patients had severe dysplasia, or destruction of the native femoral head, which rendered them non-viable for use as autografts.

TMAs, which are composed of biologically inert tantalum metal organized within a porous microstructure, have demonstrated promising early clinical results for reconstructing acetabular bone defects and providing reliable osseointegration during complex hip reconstruction procedures [25]. Tantalum-based implants possess several unique material characteristics that enable optimal biologic fixation in the setting of total hip arthroplasty, including a relatively low modulus of elasticity, a high coefficient of friction, resistance to corrosion, and high volumetric porosity [41]. Prior studies utilizing canine models have demonstrated the excellent potential for bony and fibrous tissue ingrowth of porous tantalum [42-44]. Furthermore, while the microstructure of porous tantalum closely mimics that of cancellous bone, the mechanical properties and fatigue resistance of trabecular metal are superior to those of cancellous bone [45]. TMAs are available in a variety of shapes and sizes, allowing them to be utilized for a variety of acetabular defects while providing sufficient structural support for the acetabular component until bony ingrowth occurs.

Previous studies investigating the clinical and radiographic outcomes of TMAs implanted to address severe acetabular bone loss have largely focused on the revision THA setting [20,26,27,46,47]. Although several studies have documented the use of trabecular metal acetabular and femoral components in primary THA [48-55], only one prior study to our knowledge has evaluated the clinical and radiological outcomes of TMA in the setting of primary THA [4]. Ling et al. assessed 19 hips (47.4% DDH, 10.5% post-traumatic OA, 26.3% history of hip tuberculosis/infection, 15.8% severe OA) with an average follow-up of 5.1 years and found satisfactory clinical and radiographic outcomes with significant improvements in patient-reported outcome measures at final follow-up [4]. Additionally, the authors reported a high rate of stable fixation with no significant changes in mean hip center position or acetabular inclination between immediate postoperative films and final follow-up [4]. The present study investigates a

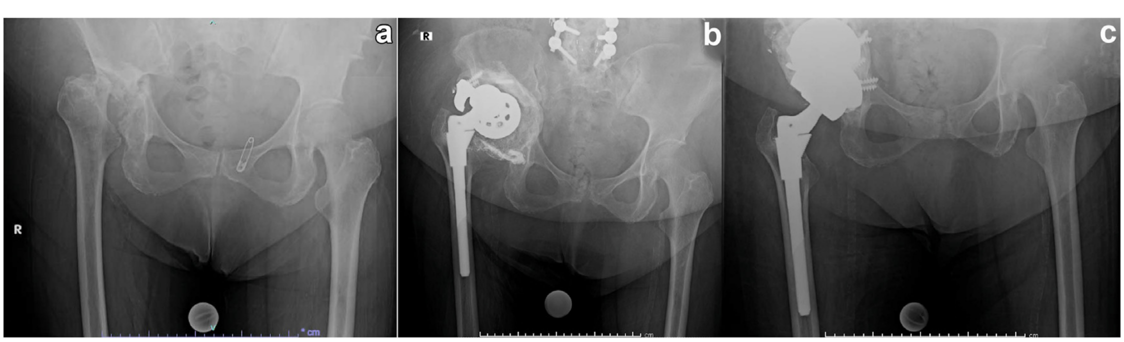

Figure 5. (a) Index preoperative, (b) revision preoperative, and (c) revision postoperative low anteroposterior (AP) radiographs demonstrating interval complex revision acetabular reconstruction for acetabular loosening at 81.0 months from index primary total hip arthroplasty with 3 acetabular shells (54 mm placed anterosuperiorly, 48 mm placed posterosuperiorly, and 60 mm placed at hip center) as well as a 58 × 30 mm trabecular metal (TM) buttress augment.

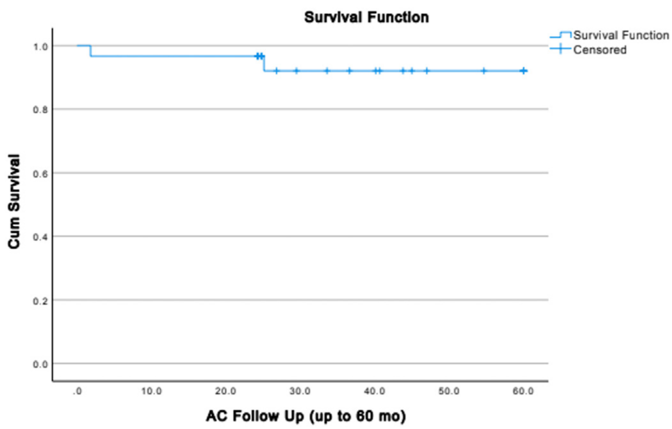

Figure 6. Kaplan-Meier survival estimate with all-cause revision as endpoint. Two-year and 5-year survival with all-cause revision as an endpoint were 96.7% (95% CI: 90.2%-100.0%) and 92.1% (95% CI: 81.3%-100.0%), respectively.

cohort of 30 primary THAs presenting with significant acetabular bone defects managed with uncemented, porous-coated, multi-hole acetabular shells with TMA, demonstrating similarly satisfactory clinical and radiographic outcomes at early to mid-term follow-up with a 5-year survivorship free from all-cause revision of 92.1%.

At a mean of 4.1 years of follow-up, 3 of 30 hips (10.0%) required revision surgery: one (3.3%) for aseptic loosening of the acetabular component following a traumatic ground-level fall, and 2 (6.6%) for recurrent multidirectional instability in a single patient with otherwise stable bilateral TMA constructs. In contrast, Ling et al. reported no revisions or complications in their series of 19 primary THA patients with TMA at an average follow-up of 5.1 years [4]. In both series, all acetabular components were fixed to the pelvis using screw fixation with unitization of the TMA to the acetabular shell using a small amount of bone cement. While none of the patients in the present series had evidence of progressive radiolucent lines at final follow-up and only one patient developed aseptic loosening of the acetabular component, further follow-up is needed to determine long-term implant survivorship.

The present study has several strengths and limitations, which warrant further discussion. To our knowledge, this is the largest series to date of patients with severe acetabular bone loss managed with TMA in the setting of primary THA. Nevertheless, the results presented herein represent our institution's experience utilizing this reconstructive technique and should be interpreted within the context of the limited sample size and lack of long-term follow-up. Specifically, 10 of the 37 patients initially identified (27.0%) had insufficient follow-up, and one patient (2.7%) died of causes unrelated to the THA. The decision was made to include patients with a minimum 2-year follow-up in order to capture early postoperative complications such as infection and instability. Furthermore, the retrospective cohort study design precludes any comparison between the use of uncemented, porous-coated, multi-hole acetabular shells with TMA against other methods of reconstructing acetabular defects during primary THA. However, the purpose of this study was to assess the clinical results, survivorship, and complication rates associated with the use of TMAs during primary THA. Additionally, all procedures were performed by a single surgeon, potentially limiting the generalizability of our results. Finally, we were unable to assess postoperative improvements in functional outcomes as patient-reported outcome measures were not routinely collected at the time of index surgery.

Conclusions

The present study demonstrates good survivorship at early to mid-term follow-up in the largest series to date of primary THA patients with large acetabular defects managed with uncemented, hemispheric acetabular components supplemented with TMA fixation. When compared to previously established techniques such as impaction grafting, structural allografting, and bulk femoral head autografting, the robust biomechanical properties of tantalum metal, resistance to absorption, and low rates of aseptic loosening warrant further investigation into the long-term viability of TMA as an alternative reconstructive option. Future studies with longer-term follow-up and patient-reported outcome measures are needed to confirm whether the use of supplemental TMA fixation to address significant acetabular bone loss is associated with improved functional outcomes and long-term implant survivorship following primary THA.

Conflicts of interest

D. A. Oakes is a paid consultant for LimaCorporate and receives royalties from them. N. D. Heckmann receives royalties from Corin U.S.A.; is a paid consultant for Intellijoint Surgical, MicroPort Orthopedics, Corin U.S.A., and Zimmer; has stock options in Intellijoint Surgical; and is a board/committee member of AAOS, AJRR, and AAHKS. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Brian C. Chung: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Nathanael D. Heckmann:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Matthew C. Gallo:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Thomas Steck:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Christian Jimenez:** Formal analysis, Writing – original draft, Writing – review & editing. **Daniel A. Oakes:** Conceptualization, Formal analysis, Supervision, Writing – review & editing.

References

[1] Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994;9:33–44.
[2] D'Antonio JA, Capello WN, Borden LS, Bargar WL, Bierbaum BF, Boettcher WG, et al. Classification and management of acetabular abnormalities in total hip arthroplasty. Clin Orthop Relat Res 1989:126–37.
[3] Clement RGE, Ray AG, MacDonald DJ, Wade FA, Burnett R, Moran M. Trabecular metal use in paprosky type 2 and 3 acetabular defects: 5-year follow-up. J Arthroplasty 2016;31:863–7.
[4] Ling T-X, Li J-L, Zhou K, Xiao Q, Pei F-X, Zhou Z-K. The use of porous tantalum augments for the reconstruction of acetabular defect in primary total hip arthroplasty. J Arthroplasty 2018;33:453–9.
[5] Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am 1979;61:15–23.
[6] Oe K, Iida H, Kawamura H, Ueda N, Nakamura T, Okamoto N, et al. Long-term results of acetabular reconstruction using three bulk bone graft techniques in cemented total hip arthroplasty for developmental dysplasia. Int Orthop 2016;40:1949–54.
[7] Kamada T, Mashima N, Nakashima Y, Imai H, Takeba J, Miura H. Mid-term clinical and radiographic outcomes of porous tantalum modular acetabular components for hip dysplasia. J Arthroplasty 2015;30:607–10.
[8] Iwase T, Morita D, Ito T, Takemoto G, Makida K. Favorable results of primary total hip arthroplasty with acetabular impaction bone grafting for large segmental bone defects in dysplastic hips. J Arthroplasty 2016;31:2221–6.

[9] Sakellariou VI, Christodoulou M, Sasalos G, Babis GC. Reconstruction of the acetabulum in developmental dysplasia of the hip in total hip replacement. Arch Bone Jt Surg 2014;2:130–6.
[10] Ranawat A, Zelken J, Helfet D, Buly R. Total hip arthroplasty for posttraumatic arthritis after acetabular fracture. J Arthroplasty 2009;24:759–67.
[11] Swanson MA, Huo MH. Total hip arthroplasty for post-traumatic arthritis after previous acetabular fractures. Semin Arthroplasty 2008;19:303–6.
[12] Oztürkmen Y, Karamehmetoğlu M, Leblebici C, Gökçe A, Caniklioğlu M. Cementless total hip arthroplasty for the management of tuberculosis coxitis. Arch Orthop Trauma Surg 2010;130:197–203.
[13] Chen C-E, Wang J-W, Juhn R-J. Total hip arthroplasty for primary septic arthritis of the hip in adults. Int Orthop 2008;32:573–80.
[14] Bauer T, Lacoste S, Lhotellier L, Mamoudy P, Lortat-Jacob A, Hardy P. Arthroplasty following a septic arthritis history: a 53 cases series. Orthop Traumatol Surg Res 2010;96:840–3.
[15] Zhen P, Li X, Zhou S, Lu H, Chen H, Liu J. Total hip arthroplasty to treat acetabular protrusions secondary to rheumatoid arthritis. J Orthop Surg Res 2018;13:92.
[16] Waljee J, Zhong L, Baser O, Yuce H, Fox DA, Chung KC. The incidence of upper and lower extremity surgery for rheumatoid arthritis among Medicare beneficiaries. J Bone Joint Surg Am 2015;97:403–10.
[17] Karayiannis P, Walls A, Cassidy R, Beverland D. Rapidly progressive osteoarthritis and acetabular bone loss outcomes for patients undergoing primary total hip replacement. Arthroplast Today 2020;6:289–95.
[18] Oe K, Iida H, Tsuda K, Nakamura T, Okamoto N, Ueda Y. Bone remodeling in acetabular reconstruction using a kerboull-type reinforcement device and structural bone-grafting in total hip arthroplasty. J Arthroplasty 2017;32:908–14.
[19] Houdek MT, Ferguson PC, Abdel MP, Griffin AM, Hevesi M, Perry KI, et al. Comparison of porous tantalum acetabular implants and harrington reconstruction for metastatic disease of the acetabulum. J Bone Joint Surg Am 2020;102:1239–47.
[20] Siegmeth A, Duncan CP, Masri BA, Kim WY, Garbuz DS. Modular tantalum augments for acetabular defects in revision hip arthroplasty. Clin Orthop Relat Res 2009;467:199–205.
[21] Nehme A, Lewallen DG, Hanssen AD. Modular porous metal augments for treatment of severe acetabular bone loss during revision hip arthroplasty. Clin Orthop Relat Res 2004:201–8. https://doi.org/10.1097/01.blo.0000150133.88271.80.
[22] Sporer SM, Paprosky WG. The use of a trabecular metal acetabular component and trabecular metal augment for severe acetabular defects. J Arthroplasty 2006;21:83–6.
[23] Black J. Biological performance of tantalum. Clin Mater 1994;16:167–73.
[24] Bobyn JD, Poggie RA, Krygier JJ, Lewallen DG, Hanssen AD, Lewis RJ, et al. Clinical validation of a structural porous tantalum biomaterial for adult reconstruction. J Bone Joint Surg Am 2004;86-A Suppl 2:123–9.
[25] Christie MJ. Clinical applications of trabecular metal. Am J Orthop 2002;31:219–20.
[26] Löchel J, Janz V, Hipfl C, Perka C, Wassilew GI. Reconstruction of acetabular defects with porous tantalum shells and augments in revision total hip arthroplasty at ten-year follow-up. Bone Joint J 2019;101-B:311–6.
[27] Van Kleunen JP, Lee G-C, Lementowski PW, Nelson CL, Garino JP. Acetabular revisions using trabecular metal cups and augments. J Arthroplasty 2009;24:64–8.
[28] Cassar-Gheiti AJ, Mei XY, Afenu EA, Safir OA, Gross AE, Kuzyk PRT. Midterm outcomes after reconstruction of superolateral acetabular defects using flying buttress porous tantalum augments during revision total hip arthroplasty. J Arthroplasty 2021;36:2936–41.
[29] Kumar PGA, Anil Kumar PG, Kirmani SJ, Humberg H, Kavarthapu V, Li P. Reproducibility and accuracy of templating uncemented THA with digital radiographic and digital traumacad templating software. Orthopedics 2009;32:815. https://doi.org/10.3928/01477447-20090922-08.
[30] Domb BG, Redmond JM, Louis SS, Alden KJ, Daley RJ, LaReau JM, et al. Accuracy of component positioning in 1980 total hip arthroplasties: a comparative analysis by surgical technique and mode of guidance. J Arthroplasty 2015;30:2208–18.
[31] Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg 2013;21:128–39.
[32] Schmitz MW, Hannink G, Gardeniers JWM, Verdonschot N, Slooff TJ, Schreurs BW. Acetabular reconstructions with impaction bone-grafting and a cemented cup in patients younger than 50 years of age: a concise follow-up, at 27 to 35 years, of a previous report. J Bone Joint Surg Am 2017;99:1640–6.
[33] Dewal H, Chen F, Su E, Di Cesare PE. Use of structural bone graft with cementless acetabular cups in total hip arthroplasty. J Arthroplasty 2003;18:23–8.
[34] Lee PTH, Raz G, Safir OA, Backstein DJ, Gross AE. Long-term results for minor column allografts in revision hip arthroplasty. Clin Orthop Relat Res 2010;468:3295–303.
[35] Callaghan JJ, Forest EE, Olejniczak JP, Goetz DD, Johnston RC. Charnley total hip arthroplasty in patients less than fifty years old. A twenty to twenty-five-year follow-up note. J Bone Joint Surg Am 1998;80:704–14.
[36] Benninger E, Zingg PO, Kamath AF, Dora C. Cost analysis of fresh-frozen femoral head allografts: is it worthwhile to run a bone bank? Bone Joint J 2014;96-B:1307–11.
[37] Taylor AJ, Runner RP, Kay RD, Najibi S. Femoral head autograft can reliably reconstruct dysplastic acetabula through the direct anterior approach for total hip arthroplasty. Arthroplast Today 2022;14:154–62.
[38] Kim M, Kadowaki T. High long-term survival of bulk femoral head autograft for acetabular reconstruction in cementless THA for developmental hip dysplasia. Clin Orthop Relat Res 2010;468:1611–20.
[39] Mulroy Jr RD, Harris WH. Failure of acetabular autogenous grafts in total hip arthroplasty. Increasing incidence: a follow-up note. J Bone Joint Surg Am 1990;72:1536–40.
[40] Gerber SD, Harris WH. Femoral head autografting to augment acetabular deficiency in patients requiring total hip replacement. A minimum five-year and an average seven-year follow-up study. J Bone Joint Surg Am 1986;68:1241.
[41] Levine B, Della Valle CJ, Jacobs JJ. Applications of porous tantalum in total hip arthroplasty. J Am Acad Orthop Surg 2006;14:646–55.
[42] Bobyn JD, Stackpool GJ, Hacking SA, Tanzer M, Krygier JJ. Characteristics of bone ingrowth and interface mechanics of a new porous tantalum biomaterial. J Bone Joint Surg Br 1999;81:907–14.
[43] Bobyn JD, Toh KK, Hacking SA, Tanzer M, Krygier JJ. Tissue response to porous tantalum acetabular cups: a canine model. J Arthroplasty 1999;14:347–54.
[44] Hacking SA, Bobyn JD, Toh K, Tanzer M, Krygier JJ. Fibrous tissue ingrowth and attachment to porous tantalum. J Biomed Mater Res 2000;52:631–8.
[45] Zardiackas LD, Parsell DE, Dillon LD, Mitchell DW, Nunnery LA, Poggie R. Structure, metallurgy, and mechanical properties of a porous tantalum foam. J Biomed Mater Res 2001;58:180–7.
[46] Abolghasemian M, Tangsataporn S, Sternheim A, Backstein D, Safir O, Gross AE. Combined trabecular metal acetabular shell and augment for acetabular revision with substantial bone loss: a mid-term review. Bone Joint J 2013;95-B:166–72.
[47] O'Neill CJ, Creedon SB, Brennan SA, O'Mahony FJ, Lynham RS, Guerin S, et al. Acetabular revision using trabecular metal augments for paprosky type 3 defects. J Arthroplasty 2018;33:823–8.
[48] Gruen TA, Poggie RA, Lewallen DG, Hanssen AD, Lewis RJ, O'Keefe TJ, et al. Radiographic evaluation of a monoblock acetabular component: a multicenter study with 2- to 5-year results. J Arthroplasty 2005;20:369–78.
[49] Baad-Hansen T, Kold S, Nielsen PT, Laursen MB, Christensen PH, Soballe K. Comparison of trabecular metal cups and titanium fiber-mesh cups in primary hip arthroplasty: a randomized RSA and bone mineral densitometry study of 50 hips. Acta Orthop 2011;82:155–60.
[50] De Martino I, De Santis V, Sculco PK, D'Apolito R, Poultsides LA, Gasparini G. Long-term clinical and radiographic outcomes of porous tantalum monoblock acetabular component in primary hip arthroplasty: a minimum of 15-year follow-up. J Arthroplasty 2016;31:110–4.
[51] Macheras G, Kateros K, Kostakos A, Koutsostathis S, Danomaras D, Papagelopoulos PJ. Eight- to ten-year clinical and radiographic outcome of a porous tantalum monoblock acetabular component. J Arthroplasty 2009;24:705–9.
[52] Malizos KN, Bargiotas K, Papatheodorou L, Hantes M, Karachalios T. Survivorship of monoblock trabecular metal cups in primary THA : midterm results. Clin Orthop Relat Res 2008;466:159–66.
[53] Matharu GS, Judge A, Murray DW, Pandit HG. Trabecular metal acetabular components reduce the risk of revision following primary total hip arthroplasty: a propensity score matched study from the national joint registry for england and wales. J Arthroplasty 2018;33:447–52. https://doi.org/10.1016/j.arth.2017.08.036.
[54] Noiseux NO, Long WJ, Mabry TM, Hanssen AD, Lewallen DG. Uncemented porous tantalum acetabular components: early follow-up and failures in 613 primary total hip arthroplasties. J Arthroplasty 2014;29:617–20. https://doi.org/10.1016/j.arth.2013.07.037.
[55] Simon J-P, Bellemans J. Clinical and radiological evaluation of modular trabecular metal acetabular cups. Short-term results in 64 hips. Acta Orthop Belg 2009;75:623–30.