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HIP ARTHROPLASTY

Clinical and radiological survivorship of the Thackray cross plate with rim reinforcement ring for cemented acetabular revision

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Abstract

Introduction Acetabular component revision surgery can be a challenging task due to the encountered bone defects. Both cemented and uncemented techniques are described. We report on the survivorship of the Thackray cross plate with rim reinforcement ring for cemented acetabular revision.

Patients and methods This is a retrospective case series of all patients treated with the implant with a minimum follow-up of 2 years. Acetabular defects were characterized according to the Paprosky classification. Data on potential risk factors for failure of the construct as well as the Oxford Hip Score (OHS) were collected. Kaplan–Meier survival analysis with radiographic aseptic loosening or revision for aseptic loosening as the end point was performed.

Results From 2000 to 2017, 35 revisions in 18 male and 17 female patients with an average age of 72 years were included. Bone allograft was used in 26 cases and additional implants (medial or supero-lateral mesh) in 13. Seven patients have deceased and the fate of all revisions is known. At an average clinical follow-up of 9.7 (2.6 to 19.6) years, there were no further re-revisions for construct failure. Five hips have demonstrated radiological evidence of aseptic loosening. Radiologically loose components were associated with more severe grades of acetabular bone defects (Paprosky Type 3) (60% vs 3%, $p=0.006$). Kaplan–Meier survival analysis demonstrates 79.8% overall survivorship at 7 years. Survivorship for Type 2 defects was significantly higher compared to Type 3 (90% vs 0% at 7 years, Logrank test $p=0.002$, Cox proportional hazards $p=0.03$). The final median OHS was 38 (12–48) and was not affected by component loosening.

Conclusion This is a cost-effective device that protects the underlying bone graft (81% complete remodeling) and prevents subsidence of the cemented cup (2 mm on average). It should be used with caution in high-grade defects and perhaps not advised.

Keywords Hip replacement · Acetabular revision · Reinforcement ring · Survival analysis · Aseptic loosening

Introduction

Total hip arthroplasty is considered one of the most successful operations in orthopaedic surgery [1]. The number of procedures performed annually is expected to rise and potentially cause a corresponding increase in revision surgery [2]. Both the Australian and British national joint registries have been reporting a stable burden of hip revisions since 2012, following worldwide mandates against the use of metal on metal articulations [3, 4]. In the United Kingdom, approximately 8,000 revision hip arthroplasty cases are being performed annually and more than two-thirds involve the acetabular component [3, 5].

The management of bone defects during acetabular revision surgery can be a challenging task [6, 7]. Anti-protrusio cages and roof-reinforcement rings combined with cemented acetabular cups have been the most popular reconstruction option during the last decades [7, 8]. Their use has been superseded lately by highly porous uncemented cups and augments, due to the potential for biological fixation and

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lower rates of aseptic loosening [6, 7, 9, 10]. On the other hand, these implants are associated with increased costs and they do not completely abolish the need for bone allograft [7, 10, 11].

The Thackray cross plate with rim reinforcement ring (DePuy, Leeds, UK) is a titanium alloy acetabular reinforcement device that has been in use since 1988 (Fig. 1). It comprises of four metal flanges in vertical angles to each other with the free surface of each flange folding at 90° to create a small rim. The flanges are perforated to allow structural bone graft to be secured with screws. The ring is designed to sit against the native bony acetabular rim and to accept a cemented acetabular component. Proposed indications for its use include revision hip replacement with a defective medial acetabular wall and primary total hip replacement in cases on protrusio acetabuli and acetabular dysplasia. The device has been used by the senior author (GJS) since 2000 to treat cavitary defects encountered during acetabular revision surgery [12]. The original design has been discontinued recently; however, a similar ring is currently available from another distributor (Merrette GmbH, Berlin, Germany) and has been used as a replacement since. Although the two devices share some minor manufacturing differences (symmetry of the flanges, number of perforations per leaf, selection of available sizes), the mechanism of function remains identical.

The purpose of this study is to describe the surgical technique and proposed benefits of the device, to report on the survivorship of the construct, to identify potential risk factors associated with failure and to report on patient-reported outcome measures.

Materials and methods

This is an anonymised, retrospective case series of implant performance. The National Healthcare System (NHS) Health Research Authority (HRA) on-line Decision Tool was consulted and as per the Governance Arrangements for Research Ethics Committees (GAfREC) 2018 edition guidelines the requirement for ethical committee review and approval was waived. The study protocol was enrolled with the department's Audit and Research Office.

Fig. 1 The Thackray cross plate with rim reinforcement ring

All patients who underwent acetabular revision surgery with the implant under investigation from 2000 to 2017 and, therefore, had a minimum clinical and radiological follow-up of 2 years were eligible for inclusion. The primary outcome measure was survivorship of the reinforcement ring with aseptic loosening as the end point.

Data on primary and revision hip replacements in our department are collected prospectively in a local database maintained by dedicated staff to ensure high quality of data collection. The department's standardized follow-up protocol comprises of annual functional assessment through telephone interviews and postal questionnaires and radiological monitoring with supine antero-posterior and lateral radiographs of the operated hip at 1, 2 and 5 years and every 5 years thereafter. For patients who describe new complaints or declining functional scores, an interim radiological evaluation is arranged. The database was interrogated for the above inclusion criteria to produce the study cohort and to identify further revision surgery involving the device. We have excluded potential revision surgery undertaken outside the hospital's catchment area by interrogating the local general practitioners' records through a dedicated electronic portal.

Patients' clinical notes (paper and electronic) and sequential radiographic imaging were retrospectively reviewed. We have collected data on a number of potential risk factors for failure of the construct [13, 14]. Post-operative complications and additional non-revision procedures were also noted. The Oxford Hip Score (OHS) is routinely collected pre- and post-operatively in our institution and this was the patient-reported outcome measure (PROM) of choice [15].

The encountered acetabular bone defects were characterized according to the Paprosky classification based on the pre-operative and immediate post-operative antero-posterior radiographs of both hips and using descriptive details from the operation note [16]. Radiographic images are uploaded on the digital imaging software PACS (Sectra Medical, Linkoping, Sweden). The known diameter of the existing femoral head was used to calibrate the magnification of the radiographs for accuracy of measurements.

The most recent radiographs for each patient were scrutinized for evidence of aseptic loosening of the ring-cemented cup construct. A construct was deemed to be radiologically loose in the following scenarios: presence of radiolucent lines (RLL) wider than 2 mm in all three DeLee and Charnley zones [7, 17]; vertical or horizontal migration of more than 5 mm as this appears to be the value most frequently referenced in the literature [8, 14, 18]; an obvious rotational shift of 5° or more [8, 14, 18]. Data from additional imaging modalities such as bone scintigraphy were also taken into

consideration. In the case that a construct was deemed to be loose, previous radiographs were inspected and the earliest imaging to demonstrate definitive features of loosening was used to set the time to radiological construct failure for the survival analysis.

The degree of bone graft remodeling was characterized according to the classification by Gie et al. [19]: no change, graft incorproration, trabecular remodeling. The presence of heterotopic ossification was noted and characterized according to the classification by Brooker et al. [20].

Surgical technique

Patients are positioned in the lateral decubitus position under general anesthetic with or without an additional spinal block, to accommodate the variable duration of these complex reconstructions. All patients are screened preoperatively for potential septic loosening with blood inflammation markers (CRP, ESR) and hip joint aspiration when required, and intravenous antibiotics are administered following collection of tissue and fluid samples for microbiology. Post-operative antibiotics are continued for 48 h until the first culture results are available. For cases with one or more positive intra-operative samples, that are not considered a contamination, suitable oral antibiotics are usually prescribed for 8–12 weeks following advice from a microbiologist; however, a second debridement is not usually required.

A posterior approach was utilized in all but one (Hardinge's). Following removal of the acetabular cup, the acetabular bed and rim are cleared from soft tissues and inspected for bony insufficiencies and any potential segmental defects. A ring of appropriate size is chosen so that it is slightly wider than the cross section of the entrance of the socket. This forces the metallic flanges to fold inwards during insertion and to recoil against the existing acetabular rim following final sitting of the ring. The ideal position is shown in Fig. 2 with the two flanges marked as superior sitting antero- and postero-superiorly. This configuration allows for the anterior wall to be free from implant material, therefore, reducing the chance of prosthetic impingement and iliopsoas tendon irritation. If primary ring stability is insufficient, an alternative position with one of the superior flanges being oriented truly caudal to cephalad and the other one anterior to posterior can be selected.

Once stability of the ring is deemed to be adequate, additional implants are utilized to convert uncontained defects to contained ones. Supero-lateral rim defects were treated with a coarse mesh (X-change; Stryker Howmedica, Staines, Newbury, UK) secured to the ilium with screws or anchors. Medial floor defects were contained with either a six-petals X-change or a fine titanium (Zimmer, Warsaw, IN) mesh without additional fixation.

The decision is then made to fill the existing bony defects with either bone allograft or polymethylmethacrylate (PMMA) cement. This decision is based on patient's age and functional status, defect severity and size, and availability of high volume bone allograft (fresh frozen femoral heads provided by the hospital's bone bank). In the majority of cases, one or two femoral heads including the articular cartilage were morcellized through a Howex bone mill (Orthosonics, Meidenhead, Berkshire, UK) with a medium grater producing bone chips from 5 to 10 mm in diameter. Grossly large pieces of retained cartilage were removed and the resulting graft was washed with saline in a sterilized strainer for delipidization. If the graft volume was suspected to be insufficient, a 15 mg pack of freeze-dried allograft (Tutobone; Tutogen GmbH, Neunkirchen, Germany) was added. The resulting graft is tightly impacted with bone punches and reamed in reverse with the biomet atraumatic acetabular reamers to reconstitute the bony bed of the acetabulum. Cement lug holes are then performed with a step-drill in exposed surfaces of the native acetabulum.

Final component insertion is then performed. The ring is reintroduced in its definitive position (Fig. 3a). A double mix of Palacos PMAA cement with Gentamycin (Heraus Medical, Newbury, Berkshire, UK) is prepared and part of it is injected in a doughy state with a cement gun behind

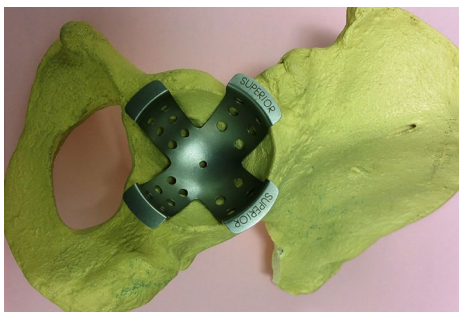

Fig. 2 Optimal orientation of the reinforcement ring against the native acetabulum

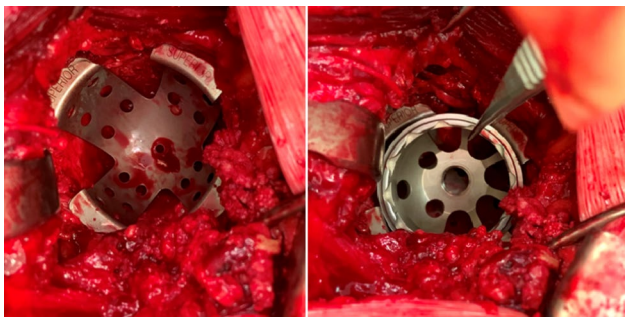

Fig. 3 **a** Placement of the ring against the reconstructed acetabulum prior to cementation; **b** a trial acetabular component demonstrating free movement of the cemented cup in relation to the ring

the ring through the openings between the metallic leaves. This is a modification from the manufacturer's proposed technique that advocates applying a full coating of cement prior to insertion of the ring. Previous experience during the senior author's learning curve has shown unsatisfactory sitting of the ring against the acetabular rim due to cement extrusion when the proposed sequence of cementation was followed, hence the requirement for this modification. The remaining cement is then applied to the ring's inner surface and pressurized with a proprietary pressurizer to allow bonding with the underlying cement layer and penetration into the bone graft and lug holes. An appropriately sized cemented acetabular component is inserted into the superficial cement mantle with full freedom of orientation to overcome any potential retroversion of the ring (Fig. 3b). As the cemented component reaches its final depth, it pushes the in-folding metallic flanges outwards and fixes their recoil against the native acetabular bone. When the cement fully sets, the displacement from the combined volume of the cemented cup and cement mantle prevents the flanges from slipping off the bony rim and falling into the acetabulum and, therefore, allows weight bearing as it is a stable construct.

Post-operative weight-bearing status is dictated by the degree of bone grafting performed and the functional status of each patient: for extensive bone grafting (two femoral heads or more), patients were asked to mobilize touch weight bearing for 6 weeks and to proceed to partial weight bear with 50% of their body weight for another 6 weeks with monitoring radiographs at each point; where just cement was used patients were allowed to fully weight bear immediately; for intermediate cases (one femoral head) weight bearing was individualized with most patients instructed to partial weight bear for 6 weeks before proceeding to full weight bearing following radiographic confirmation of component position.

Statistical analysis

Statistical analysis was performed with the statistical package R Ver. 3.5.1 (R Institute for Statistical Computing, Vienna, Austria). The Shapiro–Wilk test determined parametricity of continuous numerical variables. Normally distributed variables are expressed in mean values and range, and the Student's *t* test was used to compare differences between stable and loose constructs. Non-normally distributed continuous and discrete numerical variables are expressed in median values and the interquartile range (IQR) and differences were compared with the Wilcoxon rank sum test. Categorical variables are expressed in percentages and differences are compared with the Chi-squared and Fisher's exact tests.

Kaplan–Meier survival analysis with aseptic loosening, either clinical in the form of revision surgery or radiological according to the previously mentioned criteria, as the end point was performed. Kaplan–Maier curves with 95% confidence intervals (95% C.I) were produced for the entire cohort and were also stratified according to the identified risk factors for loosening. Differences between survival curves were compared with the logrank test and Cox proportional hazards.

Statistical significance was set at the level of $p = 0.05$.

Results

Thirty-five hip replacements in 32 patients (3 bilateral) have been revised with the device under investigation during the study period (Fig. 4). The average age at surgery was 72 (46.4–88.8) years and the average body mass index (BMI) was 28.6 (19.9–46.9). Details on the type of acetabular component removed and reasons for revision are summarized in Table 1.

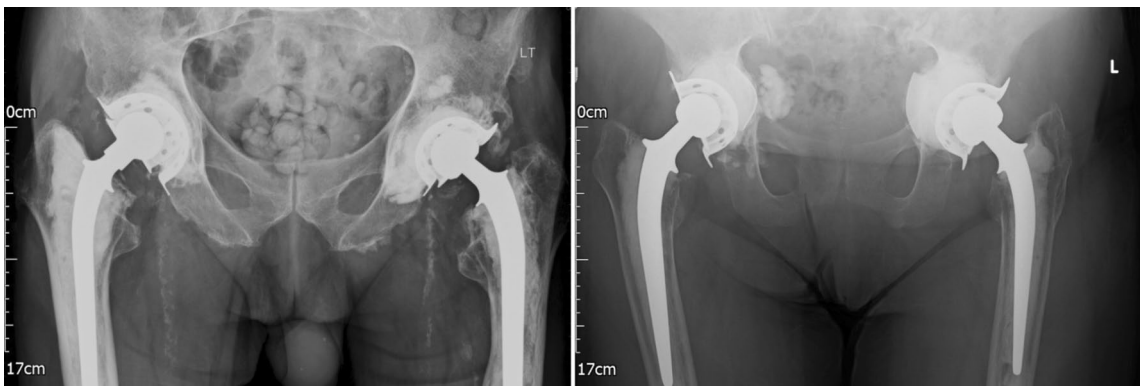

Fig. 4 Two cases of bilateral hip revisions performed with the reinforcement ring: **a** with the use of bone allograft, **b** with the use of PMMA cement as void filler

Table 1 Type of cup revised and reasons for revision

Cup revised		Reason for revision		No of previous operations	
Cemented	31	Aseptic loosening	31	One:two	28:3
Uncemented	3	Aseptic loosening	3	One:two:four	1:1:1
Uncemented MoM	1	ARMD	1	One	1

MoM metal on metal, *ARMD* adverse reaction to metal debris

Table 2 Type and volume of material used to fill acetabular bone defects

Type of defect		Void filler		Bone allograft volume	
Type 2	31	PMMA cement	7		
		Bone allograft	24	One FFFH	14
				(+) freeze-dried allograft	2 5
				Two FFFH	3
				(+) freeze-dried allograft	
Type 3	4	PMMA cement	2		
		Bone allograft	2	One FFFH	1
				Two FFFH	1

PMMA polymethylmethacrylate, *FFFH* fresh frozen femoral head

The pre-operative acetabular bone defects were classified as Type 2 according to Paprosky for thirty-one hips (fourteen 2a, five 2b and twelve 2c). The remaining four hips all presented with Type 3b defects of which two acetabuli demonstrated features of possible pelvic discontinuity. As a result, the following additional implants were required to convert uncontained defects into contained ones: for medial floor defects, a coarse X-change mesh in five hips and a fine titanium mesh in four; for superolateral defects a mesh with additional fixation in four.

Bone allograft was used for 26 cases. The remaining defects were filled with PMMA cement. A detailed description of the type and volume of void fillers utilized according to the severity of bone defect is included in Table 2.

A variety of cemented acetabular components was used: 29 Stanmore and 1 Exceed ABT cup (Biomet, Bridgend, UK), 1 Omnifit and 1 Contemporary cup (Stryker, Newbury, UK), 1 Ultima TPS and 2 Marathon cups (DePuy, Leeds, UK). The femoral component was revised in 17 cases. The distribution of femoral head sizes used was as follows: three 25 mm, twelve 28 mm, nineteen 32 mm and one 36 mm in diameter.

At an average clinical follow-up of 9.7 years (2.6–19.6), no hip has been re-revised for any reason. At the time of the final review, seven patients were deceased with their reinforcement rings still in situ and no further revision surgery planned. These patients were not excluded from the survival analysis.

Five hips presented with features of radiographic loosening at an average radiological follow-up of 9.3 years (2.1–19.4). Four hips, two type 2 and two type 3b defects (both with features of pelvic discontinuity) demonstrated marked migration or rotational shift (Figs. 5, 6). The fifth case, a non-discontinuity type 3b defect, presented with radiolucent lines in all three DeLee and Charnley zones and a positive Tc^{99m} three-phase bone scan confirming the diagnosis.

The degree of graft remodeling for the 26 hips treated with bone allograft is summarized in Table 3. The final radiograph of one patient demonstrated a Brooker Type 2 heterotopic ossification along the lateral hip capsule.

Patients with stable and radiologically loose constructs were compared with regards to the risk factors included in Table 4. A higher incidence of pre-operative Type 3

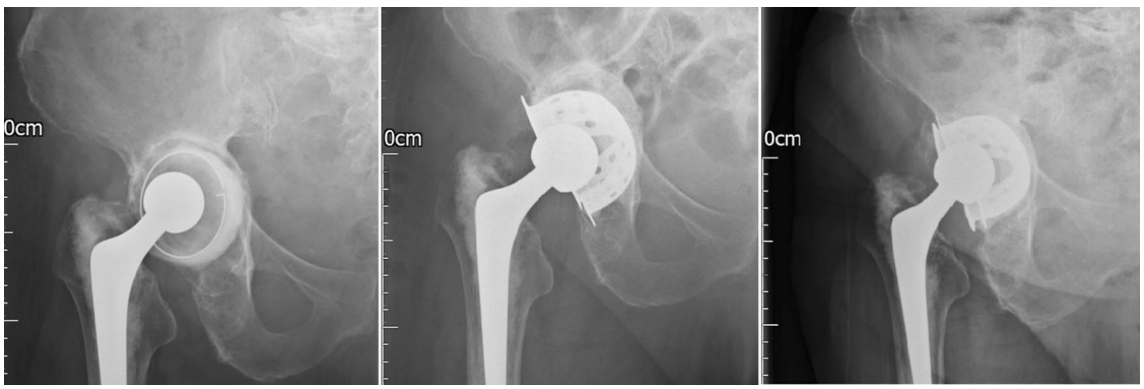

Fig. 5 **a** Type 2c defect treated with one femoral head allograft, **b** immediate post-op radiograph, **c** imaging 5.5 years post-op showing radiolucent lines and obvious rotational migration, bone graft remodeled

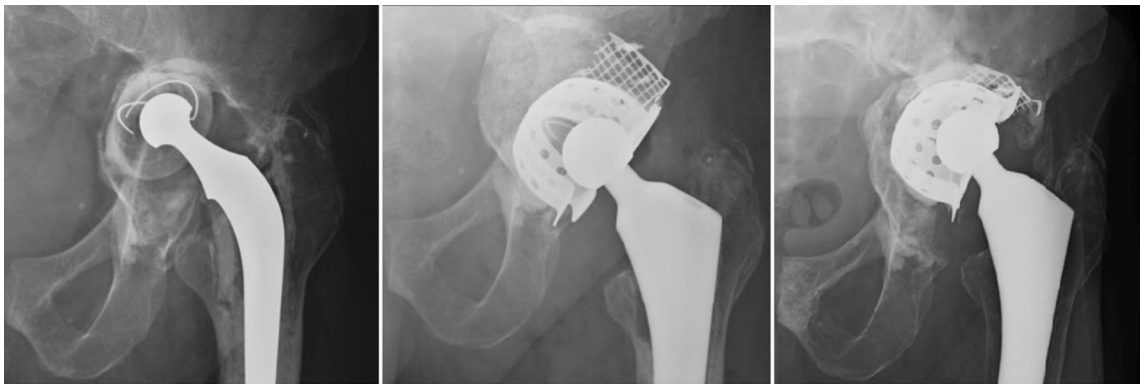

Fig. 6 **a** Type 3b defect treated with two femoral heads and supero-lateral coarse mesh, **b** immediate post-op radiograph showing features of pelvic discontinuity, **c** radiograph 7 years post-op showing bone graft resorption and ring migration

Table 3 Degree of bone allograft incorporation according to graft volume and defect severity

Grade by Gie et al		Graft volume		Defect severity	
Trabecular remodeling	21	One FFFH	14	Type 2	13
				Type 3	1
		Two FFFH	7	Type 2	7
Graft incorporation	4	One FFFH	3	Type 2	3
		Two FFFH	1	Type 2	1
No change/resorption	1	Two FFFH	1	Type 3 (discontinuity)	1

FFFH fresh frozen femoral head

Table 4 Potential risk factors for radiological loosening of the construct

Variable		Stable implants	Loose implants	*p* value
Gender	Male:female	16:14 (53%:47%)	2:3 (40%:60%)	0.658*
Age	Mean (SD):years	72.0 (11.03)	72.3 (6.45)	0.92**
BMI	Median (IQR)	28.3 (26.1–30.2)	26.6 (26.6–27.0)	0.268†
ASA grade	2:3:4	20:9:1 (67%:30%:3%)	4:1:0 (80%:20%:0)	1*
Previous ops	1:2:3	26:3:1 (87%:10%:3%)	4:1:0 (80%:20%:0)	0.561*
Cup revised	Cem:uncem:MoM	27:2:1 (90%:7%:3%)	4:1:0 (80%:20%:0)	0.477*
Femoral stem	Revised:not revised	13:17 (43%:57%)	4:1 (80%:20%)	0.177*
Defect type	Paprosky Type 2:3	29:1 (97%:3%)	2:3 (40%:60%)	**0.006***
Bone graft	Applied:no graft	22:8 (73%:27%)	4:1 (80%:10%)	1*
Graft volume	1 FFFH:2 FFFH	15:7 (68%:32%)	2:2 (50%:50%)	0.591*
Graft remodelling	Partial:complete	4:18 (18%:82%)	1:3 (25%:75%)	0.244*
Lat augmentation	Required:no	3:27 (10%:90%)	1:4 (20%:80%)	0.477*
Post-op CoR-ITL	Median (IQR):mm	21.0 (19.0–24.0)	27.0 (22.0–34.0)	0.113†
F-U duration	Median (IQR):years			
Clinical		9.05 (4.19–13.46)	13.12 (12.25–13.45)	0.421†
Radiological		7.34 (3.89–12.03)	6.64 (5.56–12.63)	0.837†

Bold value indicates a statistically significant finding

SD standard deviation, *IQR* interquartile range, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *MoM* metal on metal, *FFFH* fresh frozen femoral head, *CoR-ITL* centre of rotation of femoral head to inter-teardrop line distance, *F-U* follow-up

*Fisher's exact test, **Student's *t* test, †Wilcoxon rank sum test

acetabular defects was identified in the radiologically loose implant group. No other significant difference was identified.

Kaplan–Meier survival analysis demonstrated a 79.8% overall survivorship of the construct at 7 years and out to 16.9 years (95% C.I: 65–98%, numbers at risk: 16) (Fig. 7a). A statistically significant difference was calculated between the survival curves for Type 2 and Type 3 defects (logrank test $p < 0.001$, Cox proportional hazards $p = 0.002$): 90% at 7 years for Type 2 defects (95% C.I: 77.8–100%, numbers at risk: 19) versus 0% at 7 years for Type 3 defects (numbers at risk: 1) (Fig. 7b).

The following post-operative complications were documented: one case of wound abscess requiring surgical debridement; one case of late recurrent instability in an elderly patient who did not wish for further surgery; one case of entrapment of the sciatic nerve in posterior scar tissue with well tolerated sensory symptoms; four cases of trochanteric pain; two cases of VTE (one calf DVT and one PE).

With regards to PROMS data, the OHS significantly improved from pre-op (median: 17.5, IQR: 13–22.25) to final post-op collection (median: 38, IQR: 31–41.75) ($p < 0.001$). The final OHS was collected at an average of 6.7 years (1.5–14.5) post-operatively and did not appear to be affected by the radiological integrity of the construct with a median value of 39 (IQR: 33–42) for patients with a stable implant compared to 31 (IQR: 19–31) for those presenting with radiographic loosening ($p = 0.088$). In the latter group establishment of the diagnosis of radiological failure preceded chronologically the collection of the final OHS for all patients.

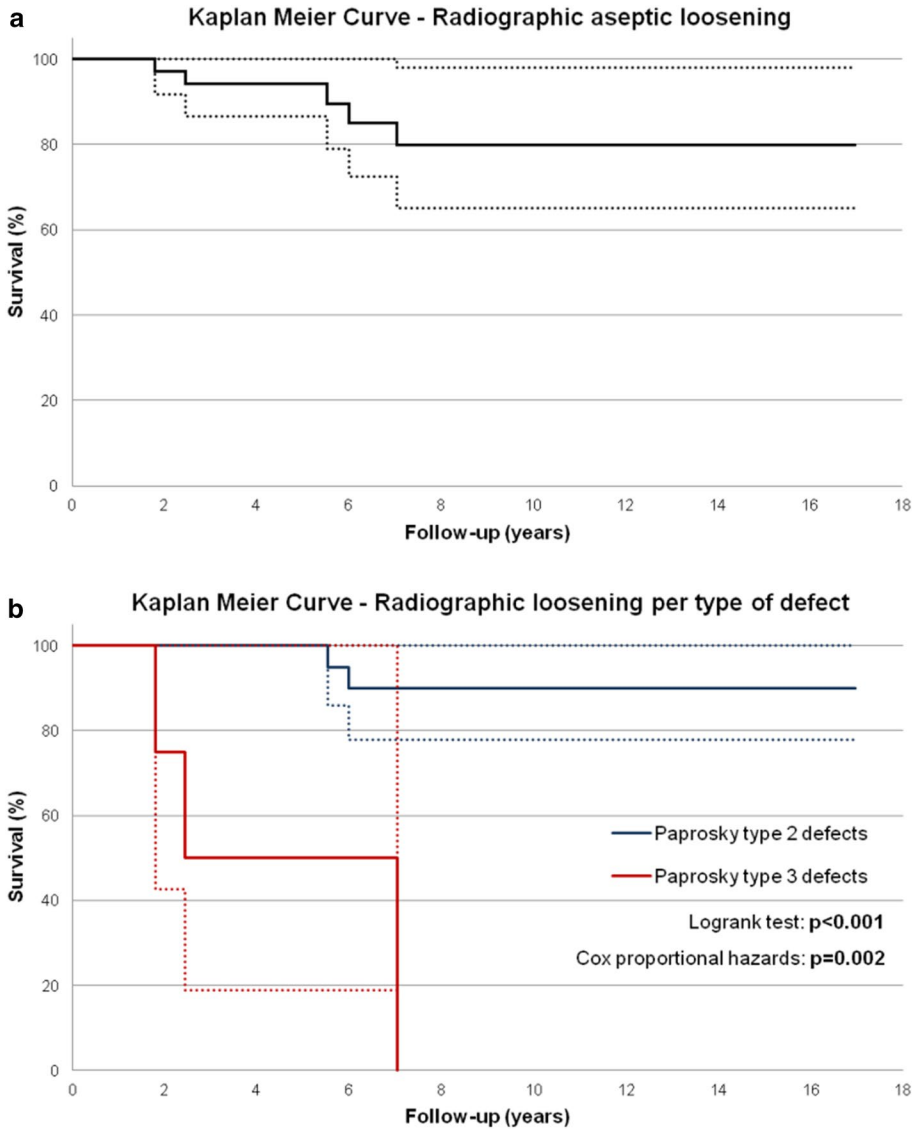

Fig. 7 Kaplan–Meier survival curves with 95% CI for radiological loosening as the end point: **a** entire cohort, **b** according to type of defect severity

Discussion

To our knowledge, this is the first study to describe the specific acetabular reinforcement device with regards to its design rationale, operative technique and results both clinical and radiological. The device has been used to treat acetabular bone defects that varied in severity from the easily reconstructible to potential pelvic discontinuities. Similarly, the device has been implanted in patients of different age and functional status groups. The underlying void filler varied from PMMA cement to conservative bone grafting to extensive volumes of bone allograft. With this variability of the treated cases in mind, the ring has demonstrated 100% clinical survivorship throughout a wide duration of follow-up extending up to 19 years. Five out of the 35 treated hips showed evidence of radiological aseptic loosening that did not however require further revision surgery, indicating potentially a controlled mode of failure of the device.

Data from the existing joint replacement registries show that the acetabular component to be involved in 31–75% of hip revision cases [4, 5]. The most common mode of failure is aseptic loosening with registry rates ranging between 24 and 48% [3, 5]. Osteolysis is recorded as an additional revision cause for 2.1–13% of cases [3, 5]. As a result, acetabular revision surgery is challenging due to the variability in the remaining bone stock and quality of bony substrate [6, 7].

The results of cemented acetabular revision have been historically poor [21]. Introduction of roof reinforcement rings and ilio-ischial anti-protrusion cages has improved survivorship. Two recent reviews have reported on cumulative revision rates of the three most common designs (Muller ring, Ganz ring, Burch–Schneider cage) for defects of all severity grades with clinical and radiological failure as the end point [7, 18]. Beckmann et al. have calculated survivorship rates from 87.7% to 92.5% at 5–7.5 years. In the review by Aprato et al. survivorship reached 85.6% at 8.8 years. We report on similar results with 79.8% clinical and radiological survivorship of the device under investigation at an average of 7 years for all types of defects. The main criticism of such a comparison is the absence of screw fixation with the design in the present study.

The Kerboull acetabular reinforcement device resembles the ring more with regards to shape and mechanism of function [22]. The main differences lie in the fact that this is a stainless steel implant and achieves partial initial stability through a superior plate accepting screws and an inferior hook. Excellent mid- to long-term results for severe defects have been described by the designing team (92% survivorship at 13 years) and Wegzyn et al. (98% survivorship at 7.5 years) [22, 23]. Other authors have reported lower mid-term survival rates for non-discontinuity defects with survivorship ranging from 81% at 6.3 to 53% at 10 years, which are comparable to the findings of the present study [24, 25].

On the basis that the ring lacks rigid fixation through screws, it supports the acetabular component like a lavatory set and acts as a protective layer to the impacted bone graft [26]. Impaction bone grafting (IBG) has demonstrated satisfactory long-term results in contained acetabular bone defects with survival rates for aseptic loosening up to 87% at 20 years [27, 28]. Subsequently, it has been combined with large metal mesh support to treat uncontained and segmental defects. Buckup et al. and Buttaro et al. [29, 30] have reported excellent short-term survivorship for Paprosky Type 3 defects. Mid-term survival rates from later studies resemble more our results. In a study by Garcia-Cimbrelo et al. [31], the revision free survivorship of 181 Paprosky Type 3 defects treated with IBG was 82% at an average of 8 years. Similarly, Gilbody et al. [14] in the largest published cohort of 304 hips have calculated survival rates of 86% at 13.5 years. The results of the present study are more relevant to the latter one as they both include defects from all severity grades, reporting similar survival rates.

The main potential advantage of implementing the reinforcement ring with IBG is protection against subsidence of the cemented cup during the graft-healing phase. Buttaro et al. [29] have reported a mean vertical migration of 5.1 mm at an average follow-up of 3 years. In our study, the average vertical migration of the center of rotation of the femoral head for stable constructs was 2 mm at an average radiological follow-up of 7.2 years.

On the other hand, application of a rigid reinforcement ring could potentially cause stress shielding of the underlying bone graft and prevent the stimuli offered by cyclic loading [32, 33]. The release of bone morphogenic proteins from bone allograft is proportional to the stresses applied [34]. A relatively flexible device could theoretically address both issues. Kerboull et al. [22] in their original study found incorporation of bone allograft in all 60 treated hips. Recently, Stigbrand et al. [33] have described the addition of a perforated titanium-alloy plate to augment IBG leading to 95% survival rates at 10 years and allograft bone resorption in just 4 out of 143 cases. In our study, complete bone graft remodeling to the surrounding trabecular bone was achieved in 81% of the treated cases (Fig. 8). There was only one case of bone graft resorption following failure of the construct when used to treat a pelvic discontinuity (Fig. 6c). We have used whole femoral head allografts including the articular cartilage. The efficacy of this graft for IBG has been previously proven [35].

For 9 out of the 35 patients, PMMA cement alone was used to fill the resulting bony defects. Satisfactory results with this technique have been previously reported in the

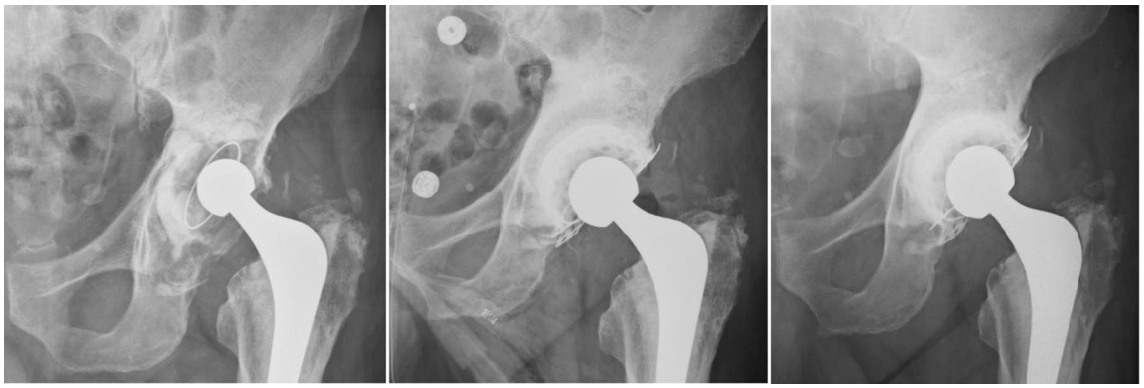

Fig. 8 **a** Type 2a defect treated with two femoral heads, **b** immediate post-op radiograph, **c** radiograph 2 years post-op showing complete graft remodeling

elderly patient population [36]. In our cohort, the average age of the treated patients was 81.2 years. Implementing cement as the sole void filler did not appear to affect implant survivorship, even when we consider that it has been used for half or the Type 3b defects. Increasing cement mantle thickness has been shown to improve its fatigue life and potentially reduce mechanical failure [37]. In our cohort when cement was used as the sole void filler, large cement volumes were required producing correspondingly thick cement mantles, which could be the reason behind the excellent clinical survivorship.

The only significant risk factor for failure of the construct was its implementation for high-grade acetabular bone defects. Three out of the five failed constructs occurred on a background of Paprosky 3b defects and two of them showed features of pelvic discontinuity. Pelvic discontinuity is a contraindication for IBG as mechanical stability is necessary for graft healing [6, 8, 29]. Similarly, reinforcement devices that do not span the ilium to the ischium have demonstrated unacceptably high failure rates when used for severe defects and pelvic discontinuity [38]. The use of metal mesh to contain supero-lateral rim defects has been suggested as a risk factor for failure of IBG; however, we were unable to prove such an association in our cohort (Table 4) [14, 39].

Of particular interest is the fact that radiological loosening of the construct did not reflect in statistically inferior clinical results. The absence of correlation between rates of radiological loosening and clinical failure requiring revision has been previously described for acetabular reinforcement devices [8, 40]. Four out of the five radiologically loose constructs presented with marked component migration. Previous studies have shown radiological migration of reinforcement devices not to be correlated with clinical outcomes and more specifically with the OHS [14, 41].

This study has a number of limitations. It is a retrospective case series of implant performance with no control group and using literature data from similar studies for comparisons and conclusions. The device has unique features and its mechanism of function does not really resemble any other available implant, with the exception of the Kerboull cage to a certain degree, and this acceptance needs to be kept in mind for all comparisons. The number of cases per type of defect severity was small and they had to be grouped in more inclusive categories for meaningful comparisons. A variety of additional implants has been used to contain uncontained defects and again these were grouped based on their function rather than physical characteristics. Although no patient was lost to follow-up, a number of them have failed to return their updated PROMs and attend the scheduled radiological follow-up as per our department's follow-up protocol. We were able to exclude, however, further revision surgery and all final PROMs were collected after the implants were deemed to be radiologically loose.

Conclusion

We believe that this is a cost-effective device that can be part of a revision implant portfolio for cavitatory defects. The surgical technique is straightforward and does not require extensive soft tissue dissections as indicated by the low incidence of heterotopic ossification. It can be useful in two scenarios: for relatively younger patients requiring IBG to restore bone stock as an intermediate stable interface to minimize subsidence; for elderly patients with the use of cement to provide them with satisfactory function and allow immediate weight bearing through a quick operation. It should be used with caution in high-grade defects (Paprosky Type 3) and perhaps not advised.

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Compliance with ethical standards

Conflict of interest The department receives financial research support from Zimmer Biomet and United Orthopaedics Corporate. The department receives financial support from DePuy Synthes to fund the position of a Clinical Fellow. One of the authors is a paid speaker at DePuy Synthes events.

Ethics approval Ethical approval was waived by the National Healthcare System (NHS) Health Research Authority (HRA) on-line Decision Tool in view of the retrospective nature of the study and all the procedures being performed as part of routine care.

Informed consent The authors affirm that human research participants provided informed consent for publication of the images in Fig. 3a, b. The requirement for additional informed consent to be obtained in retrospect has been waived, due to the anonymized retrospective nature of the study.

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