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CLINICAL ARTICLE

Mid- to Long-term Follow-up of Severe Acetabular Bone Defect after Revision Total Hip Arthroplasty Using Impaction Bone Grafting and Metal Mesh

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Objective: In revision total hip arthroplasty (THA), reconstruction of severe acetabular bone defect continues to be problematic for orthopedic surgeons. This study reports the mid- to long-term survivorship, radiological outcomes, and complications of impaction bone grafting (IBG) and metal mesh with a cemented acetabular component in the reconstruction of severe acetabular bone defects in revision THA.

Methods: This retrospective consecutive study included 26 patients (29 hips: type II B, four; type II C, three; type III A, 10; and type III B, 12) who underwent revision THA, which was performed using IBG and metal mesh, between 2007 and 2014 in our institution. All patients were followed up regularly for clinical and radiographical assessments. Migration and loosening of prosthesis graft integration and complications were observed and analyzed. Survival analysis was performed using a Kaplan–Meier survival analysis.

Results: At the time of revision, 75.9% of the hips (22 hips) were classified as type III bone defects. The average follow-up period was 9.4 ± 2.8 (range, 2.4–14.0) years. Of the 29 hips, four hips (13.8%) were assessed as clinical failures; at the last follow-up, two had undergone re-revision THA, and two had not been scheduled for re-revision THA despite radiological failure of the acetabular component. Among them, three clinical failures (10.3%) were due to aseptic loosening, and one (3.4%) was due to infection. Radiographic evaluation showed bone graft integration in all hips during the follow-up. The Kaplan–Meier survivorship analysis revealed an acetabular reconstruction survival rate of 86.5% (95% confidence interval, 61.4%–95.7%) at 10 years.

Conclusion: IBG and metal mesh with a cemented acetabular component for revision THA is an effective technique for treating severe acetabular bone defects, with effective mid- to long-term outcomes due to the solid reconstruction of the acetabular bone defect and restoration of the hip rotation center.

Key words: Acetabular bone defects; Cemented acetabular component; Impaction bone grafting; Metal mesh; Revision total hip arthroplasty

Introduction

Total hip arthroplasty (THA) has achieved great success in orthopedic surgery in the last few decades. THA can reduce pain and restore the joint function of patients with severe joint diseases.[1] However, with the popularity of primary THA in recent years, a subsequent increase in revision THA has been observed. Currently, revision surgeries accounted for 10%–15% of THA cases in the Unites States.[2] By 2030, the demand for revision THA is estimated to increase by 137% to 96,700.[3] The etiology of acetabular implant failure includes aseptic loosening, infection, instability, wear, trauma, and osteolysis. The most common reason

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for revision THA is aseptic loosening. Aseptic loosening of the acetabular components can lead to increased bone loss around the acetabular component.[4] For the acetabulum, bone defects may adversely influence the possibility of achieving adequate fixation and stability of the acetabular component. Therefore, reconstruction of the acetabular bone defect is crucial for the stability and restoration of hip biomechanics.

In revision THA, reconstruction of severe acetabular bone defect continues to be problematic for orthopedic surgeons. Several techniques have been developed for the treatment of acetabular bone defects, including impaction bone grafting (IBG) with cement cup,[5] acetabular reconstruction cages and support rings,[6] acetabular reconstruction cup-cage,[7] porous trabecular metal components and augments,[8] custom triflange components,[9] and custom-made acetabular components.[10] Disadvantages to their use include failure due to breakage or loosening of cages and support rings.[11] Custom triflange components require wide exposure and the use of advanced imaging studies, and they involve waiting for custom implant manufacturing.[9] Although porous trabecular metal components and augments have shown good early clinical results without the risk of graft resorption, partial bone mass may be sacrificed to match the shape of the augments and cost–benefit issues may prevent the routine use of this technique.[8] The impacted bone allows good initial stability of the cemented acetabular component and restoration of bone stock.[12] Although irradiated bone is mechanically weak, its advantage is the reduced possibility of disease transmission, and the clinical follow-up results of IBG using irradiated fresh-frozen allograft in acetabular reconstruction are acceptable.[13] In particular, the combination of IBG and metal mesh with a cemented acetabular component has been successfully employed in redesigning acetabular anatomy.[14] Furthermore, good results have been reported after revision THA when IBG is combined with uncemented components or tantalum augments.[15] Although acetabular IBG with metal mesh for restoring acetabular bone defects in revision THA is a well-established method with good outcomes,[16,17] the clinical results of severe acetabular bone defects, especially type III B defects with pelvic discontinuity, using IBG and metal meshes remain controversial.[18]

Therefore, the purpose of this study was to: (i) evaluate mid- to long-term clinical results and radiological outcomes of revision THA using IBG and metal mesh with a cemented acetabular component; (ii) report the validity of this surgical technique in patients with severe acetabular bone defects; and (iii) analyze the factors which influenced the clinical outcomes using this surgical technique.

Methods

Ethics Approval

The study design was approved by the local ethics committee (approval no. 2019–134).

Patient Data

Inclusion criteria included: (i) patients with a failed THA; (ii) patients with severe acetabular bone defects; (iii) patients who had undergone revision THA with IBG and metal mesh with a cemented acetabular component between 2007 and 2014 at our institution; and (iv) the main evaluation indicators included survivorship, complications, and radiographic outcomes.

Exclusion criteria included acetabular defects that were reconstructed: (i) with cementless acetabular components; (ii) with a structural allograft or metal augment; or (iii) using other techniques.

We retrospectively analyzed the prospectively collected data of patients who underwent revision THA with IBG and metal mesh with a cemented acetabular component for severe acetabular bone defects between 2007 and 2014 at our institution. Isolated acetabular reconstruction was performed in 30 hips (27 patients). Unfortunately, one patient was lost to follow-up and excluded from the analysis; thus, 26 patients (13 males and 13 females; mean age, 59.3 [range, 29–81] years at the time of THA revision; 29 hips) were included in the final analysis (Fig. 1). There were 19 patients aged ≥60 years and seven patients aged <60 years at the time of the surgery. Furthermore, the average body mass index (BMI) of the patients was 24.2 ± 2.8 kg/m^2 (range, 18.5–29.3). The indications for revision THA were aseptic loosening in 28 hips and periprosthetic fracture in one hip. Based on the Paprosky classification,[19] acetabular bone defects were identified and categorized by senior orthopedic surgeons using radiographic and CT images. These results are presented in Table 1.

Surgical Technique

Preparation

Femoral head allograft bone, obtained from a bone bank, was used for each procedure after irradiation with 25 kGy

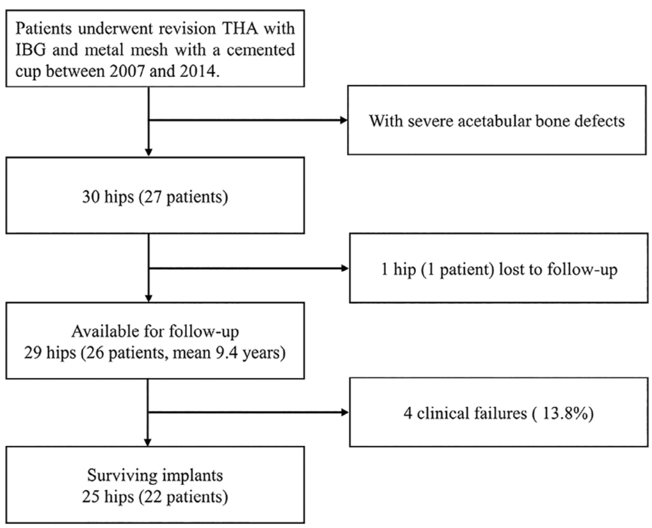

Fig. 1 Flowchart to demonstrate surviving patients and outcomes. THA, total hip arthroplasty; IBG, impaction bone grafting.

TABLE 1 Demographics of patients included in the study

Variable	29 hips (26 patients)
Mean age, years (range)	59.3 ± 13.7 (29 to 81)
≥60	19
<60	7
Mean BMI (kg/m^2)	24.2 ± 2.8 (18.5 to 29.3)
Sex, n (%)	
Male	13 (50.0)
Female	13 (50.0)
Operation side, n (%)	
Right	14 (48.3)
Left	15 (51.7)
Mean FU, years (range)	9.4 ± 2.8 (2.4 to 14.0)
Indications for revision surgery, n (%)	
Aseptic loosening	28 (96.6)
Periprosthetic fracture	1(3.4)
Paprosky type, n (%)	
Type IIB	4 (13.8)
Type IIC	3 (10.3)
Type IIIA	10 (34.5)
Type IIIB	12(41.4)

and freezing at −80°C. After thawing, the fibrous tissue, cartilage, and subchondral bone on the surfaces of the femoral heads were cleaned. These femoral head allografts were morcellated with a rongeur to create bone chips between 0.5–1.0 cm^3 that would provide a substantial layer of bone graft with a thickness of ≥5 mm. The bone graft was defatted by repeated rinsing in warm saline solution.

Position

All surgical procedures were performed by a senior orthopedic surgeon (QW). The procedures were performed using a standard posterolateral approach with patients in the lateral decubitus position.

Surgical Procedures

First, previously implanted components were removed. Then, all fibrous membranes were removed from the acetabular bone bed using curettes and reamers to correctly identify the acetabular bone defects. Segmental, peripheral, or combined acetabular bone defects were converted into contained defects using a metal mesh cut to the appropriate dimensions and screwed to the anterior and posterior walls and iliac bone. The number of screws required, usually five to seven, was generally determined by the extent of the acetabular bone defects and firmness of the fixation. For severe osteolysis that causes extensive segmental or acetabular column defects, one or two plates were used to reconstruct the acetabular wall or column. After fixation of the metal mesh with screws, layers of allograft bone chips were vigorously impacted into the cavitary bone defects using an impactor. This procedure converted the oblong shape of the revised acetabular cavity into a hemisphere. The transverse ligament and tear drop of the acetabular were identified, and efforts were made to restore the center of rotation of the hip. Finally, a polyethylene cup was fixed in the correct position with bone-cement containing antibiotics, and pressure was maintained on the cup until polymerization was complete.

Assessment

All patients were allowed toe-touch weight-bearing with a walker for 6 weeks following surgery. The patients underwent progressive partial weight-bearing mobilizations as tolerated until full weight-bearing without walking aids, usually within 12 weeks. All patients were followed-up clinically and radiologically at 0 weeks, 3 months, 6 months, and yearly thereafter. All complications and re-revision THA related to the operated hips were recorded.

Radiological assessments included allograft incorporation, radiolucent lines, and component migration. Graft incorporation was assessed using the radiographic criteria described by Slooff *et al.*[20] Full allograft incorporation was defined as identical radiodensity of the graft and host bone, with a continuous trabecular pattern throughout. Radiolucent lines at the bone-cement interface were recorded using the three zones described by DeLee and Charnley.[21] We evaluated vertical and horizontal acetabular component migration by measuring the vertical distance from the center of rotation of the hip to the teardrop line and the horizontal distance from the center of rotation of the hip to the pelvic axis.[22] Radiologic failure was defined as a component migration of >2 mm or the presence of circumferential radiolucent lines. Radiological failure or reoperation was considered clinical failure. All radiographs were assessed based on the consensus of two orthopedic surgeons.

Statistical Analysis

The follow-up period began on the day of revision THA and ended on the day of prosthetic loosening, infection, re-revision, death, or last available follow-up measurement. All data were analyzed using SPSS software (version 17.0; IBM, Armonk, NY, USA) and expressed as means ± standard deviations (SDs). Kaplan–Meier survival analysis was performed with 95% confidence intervals (CI), using mechanical loosening of the acetabular component or reoperation for any reason as the endpoint.

Results

Characteristics of the Study Population

Of the 27 patients (30 hips), one patient was lost to follow-up and excluded from the analysis. The remaining 26 patients (29 hips) were reviewed both clinically and radiographically at a mean follow-up duration of 9.4 ± 2.8 (range, 2.4–14.0) years. According to the Paprosky classification, four hips (13.8%) had type II B, three hips (10.3%) had type II C, 10 hips (34.5%) had type III A, and 12 hips (41.4%) had type III B defects (Table 1). Type III acetabular defects accounted for 75.9% (22 hips) of all hips. Furthermore, three patients had already undergone a revision THA before this surgery, so they underwent a re-revised THA at the time of the surgery.

Clinical Outcomes and Complications

Of the 29 hips, four hips (13.8%) were assessed as clinical failures at the final follow-up; three clinical failures (10.3%) were due to aseptic loosening, and one (3.4%) was due to infection (staphylococcus aureus). Of the three aseptic loosening hips, one patient had type II B defects and underwent a re-revision THA at 9.5 years post-surgery (Fig. 2). Additionally, one patient with type III A defects was diagnosed with prosthetic loosening in the operated hip after 10.8 years, and the patient planned a revision THA at the time of the last follow-up. Another patient had type III B defects, assessed as radiological failure of the acetabular component, but the patient had no obvious discomfort and was not scheduled for re-revision THA at the time of the last follow-up. Furthermore, one patient (type III B) underwent a re-revision surgery for periprosthetic infection in the operated hip after 6 years. Also, one patient had quadriceps weakness, which was treated with mecobalamin for 3 months and returned to normal 1 year after the operation. None of the patients experienced hip dislocation. Of the 29 hips, 25 acetabular reconstructions in 22 patients (86.2%) survived at the time of the last follow-up. Of the 22 severe acetabular reconstructions cases, 19 hips (86.4%) were still functioning satisfactorily. Post-revision complications data are shown in Table 2.

Radiographic Outcomes

Follow-up radiographs were available for all patients. At the final follow-up, the graft-bone border was integrated without any radiological signs of aseptic loosening or other pathological changes in the 22 patients. As shown in Fig. 3, severe bilateral acetabular bone defects and the hip rotation center were successfully restored using IBG and metal mesh with a cemented acetabular component. Of the four clinical failures, three acetabular components appeared radiologically loose and showed migrations of 8, 10, and 12 mm. Of the three aseptic loosening hips, two patients showed superolateral migration of the acetabular component, and one patient showed superomedial migration. As shown in Fig. 2, although the acetabular component failed at 9.5 years post-surgery, the graft was completely incorporated with the host bone, and the condition of the acetabular bone bed was better than that observed at the first revision THA. Therefore, a tantalum metal acetabular cup (Zimmer, Warsaw, IN, USA) was used for the re-revision surgery without bone grafting. Fig. 4 shows a severe acetabular bone defect with pelvic discontinuity, in which two reconstruction plates were used to reconstruct the continuity of the acetabular column. The anterior, posterior, and medial walls were restored with metal mesh, and the acetabulum was reconstructed using IBG and a cemented acetabular component. The radiograph showed successful acetabular revision surgery with IBG combined with plates and metal mesh at 6 years post-surgery.

TABLE 2 Post-revision complications

Complications	Numbers (n)	Percentage (%)
loosening	3	10.3
Infections	1	3.4
NV injury	1	3.4
Dislocations	0	0
LLD Felt	0	0

Survival Rate

The Kaplan–Meier survival analysis curve of the acetabular component survival with aseptic loosening or reoperation as the endpoint is shown in Fig. 5, indicating a cumulative survivorship of 86.5% (95% CI, 61.4%–95.7%) at 10 years.

Discussion

Treatment of Acetabular Bone Defects

The follow-up results indicated that the use of IBG and metal mesh with a cemented acetabular component for revision THA is an effective technique for treating severe

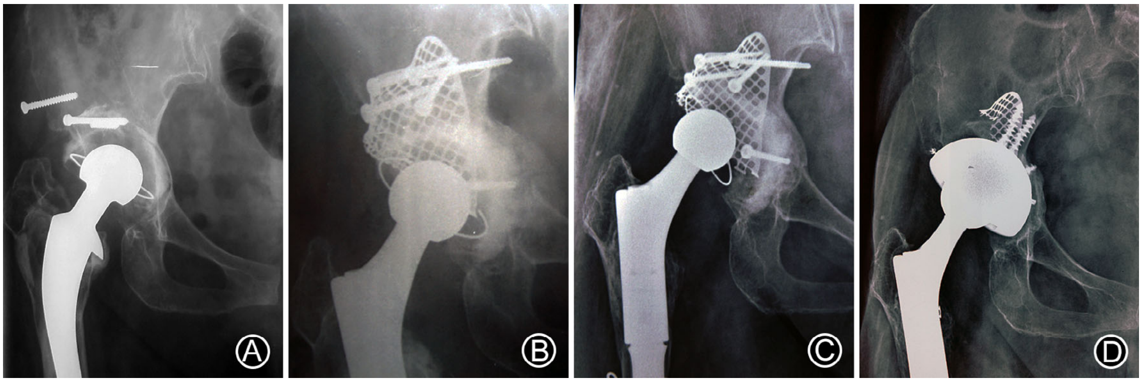

Fig. 2 Female patient (aged 66 years) with type II B acetabular bone defect. (A) Preoperative radiograph; (B) Immediate postoperative radiograph; (C) Superolateral migration of the acetabular component at 9.5 postoperative years; and (D) Radiograph after re-revision THA with a tantalum metal acetabular cup.

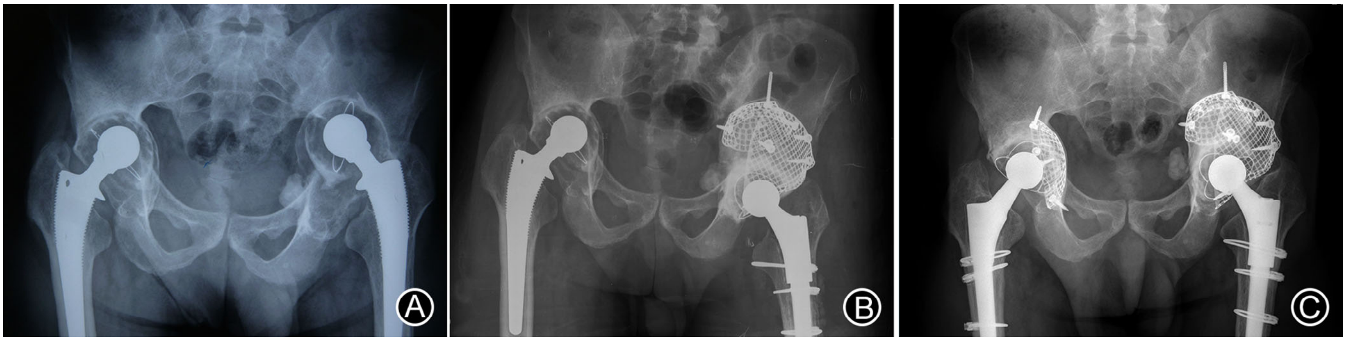

Fig. 3 Male patient (aged 35 years) with type III A acetabular bone defect in the right hip and type III B defect in the left hip. (A) Preoperative radiograph; (B) Immediate postoperative radiograph in the left hip; and (C) Immediate postoperative radiograph in the right hip.

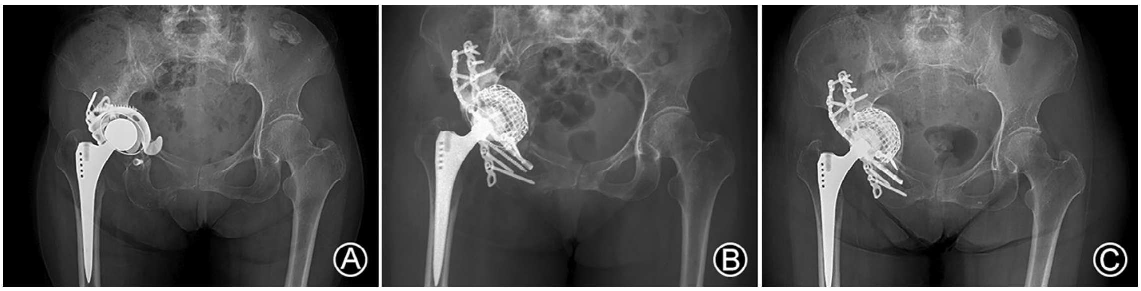

Fig. 4 Female patient (aged 67 years) with type III B acetabular bone defect and pelvic discontinuity. (A) Preoperative radiograph; (B) Immediate postoperative radiograph; (C) Radiograph showing a successful acetabular revision surgery with IBG combined with plates and metal mesh at 6 postoperative years.

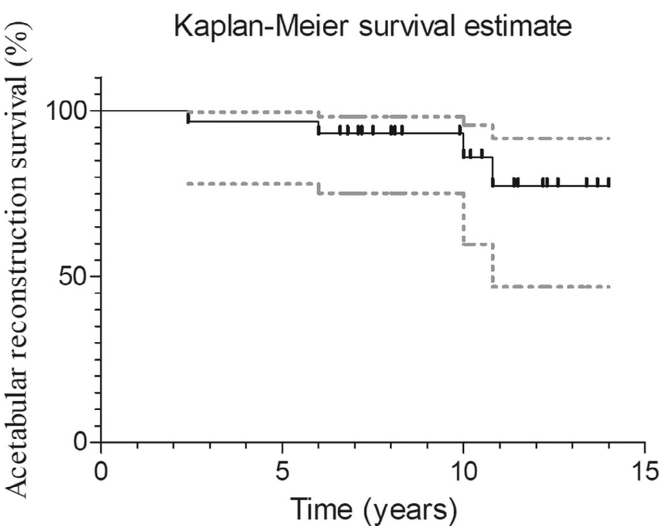

Fig. 5 Kaplan–Meier survivorship analysis with aseptic loosening or acetabular re-revision for any reason as the end point. Dotted lines are 95% confidence intervals.

acetabular bone defects. However, the reconstruction of acetabular bone defects remains a major challenge during revision hip arthroplasty.[23] Thus, preoperative assessment of acetabular bone defects before revision THA is crucial, as the location and amount of acetabular osteolysis can determine the type and success of revision surgery. Based on acetabular bone defect classification,[19] type I defects have minimal bone loss; type II defects have supportive columns, but a distorted acetabulum; and type III defects demonstrate significant bone loss and have inadequate column support. Cases with mild bone loss can be treated with surgical options, such as IBG with uncemented acetabular components or a Jumbo cup. For type III acetabular bone defects, cage, ring, or even structural acetabular allografts were once recommended, but they were associated with inferior long-term results. In the past decade, porous trabecular metal components and augments with different features and shapes have been designed to treat moderate to severe acetabular bone defects and have shown good early clinical results without the risks of graft resorption. However, the irregularity and expansion of osteolysis sometimes result in matching problems between the prosthesis and bone defect, as the shape and choice of metal augments are limited. More bone mass may be sacrificed to firmly fit and fix metal augments.[18] In contrast, IBG with metal mesh can be applied in patients with different severities of acetabular bone defect.[15,24] Segmental or uncontained acetabular bone defects can be converted into contained defects using metal mesh cut to the appropriate dimensions and screwed to the acetabulum.[18,25] After reshaping the acetabulum with IBG and metal mesh, the implant can be fitted as planned to restore the hip rotation center and biomechanical functions.[18] This technique has undeniable advantages because severe acetabular bone defects can be repaired while the bone stock is being restored, regardless of the extent and irregularity of osteolysis. The bone graft and metal mesh can effectively restore bone stock, facilitating re-revision THA in severe bone defect cases. As shown in Fig. 2, the preoperative severity of bone loss improved after re-revision THA, compared with observations after the first revision. In our study, 25 acetabular reconstructions in 22 patients survived (86.2%) at the time of the last follow-up. Furthermore, 75.9% of the hips (22 hips) were classified as type III, especially type III B, which accounted for 41.4% (12 hips) of the defects, at the time of revision THA. Of the 22 type III cases, 19 hips (86.4%) were still functioning satisfactorily. With the advent of trabecular metal acetabular components and augments as well as custom-made acetabular components to treat moderate to severe acetabular bone defects, IBG and metal mesh with a cemented acetabular component might become less commonly used. However, our study indicates that this technique remains valid for the treatment of severe acetabular bone defects with satisfactory long-term results.

Selection of Bone Grafting

IBG for the acetabulum has been advocated as an effective method, with excellent long-term survival, for reconstructing acetabular bone defects.[13] Autologous bone remains the best source of bone for reconstructing bone defects because it is osteoconductive and osteogenic.[26] However, because autologous bone is not always accessible, allograft bone is also considered a good option for the restoration of acetabular bone defects is considered a good option.[17,27] Although allograft bone has excellent biological properties, it lacks structural resistance; hence, the morselized allograft bone must be filled with cavitary defects and requires impaction to increase the mechanical strength of the grafted area, which is necessary to ensure the stability of graft-cement and graft-native bone interfaces. Irradiation of allograft bone is an effective sterilization method. Moreover, the mechanical strength of the allograft bone is not affected by low-dose irradiation (25 kGy), but higher doses of 60 kGy cause adverse effects.[28] A series of 123 reconstructions (110 patients) using IBG yielded survival rates of 87.8% at 5 years and 83.3% at 10 years.[29,30] Green *et al.* reported longer term survivorship of 80.6% at 15 years.[13] Furthermore, Gerhardt *et al.* reported that the bone mineral density of the allograft gradually increased after IBG for acetabular reconstruction arthroplasties at 2 years follow-up.[31] In the present study, irradiated frozen allograft was used, and a satisfactory result was achieved with a survival of 86.5% at 10 years.

Reconstruction of Severe Acetabular Bone Defects

IBG with metal mesh is technically demanding, and different orthopedic surgeons may not have the same outcomes. Studies have reported good long-term results with IBG and a cemented acetabular component in minor and contained defects, with which good initial implant fixation can be achieved. When the technique is used for type III bone defects, implant survival rates appear inferior unless non-contained defects are reinforced with a metal mesh.[32] However, we observed only two clinical failures with type III B bone defects. From a mechanical point of view, 50% host bone contact might indirectly influence implant survival, given that initial stability is more difficult to achieve in more complex defects. Poor initial stability in primary and revision acetabular components results in an increased risk for later revision.[33] Therefore, rigid reconstruction of the acetabulum is important for initial stability of the component in revision THA. The higher rates of graft resorption and migration in type III B acetabular defects might be caused the localization of the defect at the 9 to 5 o'clock acetabular regions. Moreover, the acetabular component is not supported by the solid iliac bone and cannot protect the graft from compressive forces.[34] In segmental defects, containment is provided exclusively by metal mesh fixed with screws, which guarantee the correct reconstitution of the hip center of rotation and protects the graft, facilitating correct integration and transformation into the new trabecular bone.[35] Pelvic discontinuity presents the most severe defects in this classification and requires careful evaluation and planning for successful reconstruction. Irrespective of the chosen method, the goal of THA is to achieve stable fixation and anatomical reconstruction of the center of rotation as well as healing of the discontinuity. In our study, we used metal mesh to reconstruct the acetabular wall and enhance acetabular stability. For severe acetabular column defects with pelvic discontinuity or column defects, we used one or two reconstruction plates to reconstruct acetabular column and then combined the metal mesh and IBG to restore the acetabular wall (Fig. 4). In our series, the IBG and metal mesh technique proved to be a reliable strategy for reconstructing severe acetabular bone defects.

Restoration of the Hip Rotation Center

Both the surgical technique and type of acetabular bone defect determine the migration of the acetabular component. Two hips were assessed as radiological failures, with superolateral migration of the acetabular component (Fig. 2). The failure may have occurred because the hip center of rotation was reconstructed more superolateral than the position of the normal acetabular. Restoration of normal biomechanics decreases stress and increases longevity of the reconstructed acetabulum. Linde *et al.* demonstrated a higher rate of mechanical loosening when the acetabular cemented component was placed above the roof of the true acetabulum, and 42% of the cemented components were loose after a mean of 9 years.[36] Compared with the anatomic hip center, superolateral relocation theoretically results in higher hip joint forces, and this occurs in cemented acetabular components, resulting in an increased clinical failure rate.[37] Furthermore, biomechanical analysis showed that higher joint contact forces occurred with lateral placement of the acetabular cup.[38] Therefore, we do not recommend the superolateral placement of a cemented component for acetabular reconstruction. In contrast, type III B acetabular defects had lower rates of superolateral migration, which might be because the defects show complete destruction of the medial wall and severe destruction of the anterior column. In type III B defects, the hip center migrates in an "up and in" pattern. One study showed that even after reconstruction, the load on the hip was significantly reduced by placing the acetabular component at the most medial and inferior position.[39] For revision THA, it is important to lower and medialize the high hip center into the original acetabular. Overall, the aim of this technique should be to reconstruct acetabular bone defects and correct the hip center of rotation to restore hip biomechanics and obtain an enduring prosthetic implant.

Strengths and Limitations

Thus, we believe that rigid reconstruction of the mechanical structure of the acetabulum and restoration of the hip rotation center are key to the success of this surgical technique. However, the present study also has some limitations. First, it was a retrospective consecutive study of a single-center series involving a relatively small number of patients. From a single institution, it is difficult to obtain a larger number of patients who have undergone rare and severe acetabular reconstruction using IBG and metal mesh with cemented components. Second, a control group of patients with similar acetabular bone defect types which had been reconstructed using other techniques was not included in this study. Third, the Paprosky classification did not fully depict the bone condition. Mild or moderate bone defects may be accompanied by poor condition of the acetabular bone, which greatly increases the difficulty of revision THA.

Conclusion

The use of IBG and metal mesh with a cemented acetabular component is an effective technique for the treatment of severe acetabular bone defects in revision THA and achieves longevity. This technique showed satisfactory clinical and radiological outcomes in this study, with an acetabular component survival of 86.5% at 10 years. The success of this technique for severe acetabular bone defects was mainly attributed to the reconstruction of the acetabular bone defect and restoration of the hip rotation center.

Authors Contributions

Qi Wang and Qiaojie Wang designed the study. Chao Yang and Kechao Zhu contributed equally to this study. Chao Yang, Kechao Zhu and Huiyong Dai analyzed the data and drafted the manuscript. Xianlong Zhang helped revise the manuscript.

Authorship Declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

Ethical Approval

The study design was approved by research ethics committee of the Sixth People's Hospital affiliated with the Shanghai Jiao Tong University (approval no. 2019–134).

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