

Reconstruction options and outcomes for acetabular bone loss in revision hip arthroplasty

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different implants. The purpose of this study was to review the current literature and provide a comprehensive understanding of the available reconstruction options with their clinical outcomes.

Introduction

Revision total hip arthroplasty (THA) often involves bone loss that can represent a complex reconstructive challenge for the treating surgeon.¹⁻⁷ Considering the rising number of primary THA, with a projected growth of 174% by 2030, the number of revisions associated with acetabular bone loss will grow as well.⁸ The goals of acetabular reconstruction in the setting of bone loss are the stability of the acetabular component and the restoration of the center of rotation of the hip joint in order to obtain a stable long-term mechanical fixation and prevent component migration, loosening and dislocation.^{2,3,9-13} To achieve these goals, a correct understanding of the bone defect and its classification are mandatory for a precise preoperative planning and proper reconstruction option.

Acetabular bone defects have been reconstructed using several cemented and uncemented methods including impaction bone grafting with metal mesh, reinforcement rings and antiprotusio cage, structural allografts, cementless hemispherical cups, extra-large “jumbo cups”, oblong cups, modular porous metal augments, cup-cage constructs, custom-made triflange cups, and acetabular distraction.¹⁴ The choice to select a particular reconstruction option is often based on the defect type and severity, implants availability and surgical expertise.

The aim of this review is to provide a comprehensive understanding of the different acetabular reconstruction options and their clinical outcomes.

Classification of acetabular bone defects

There are several published classification systems for acetabular bone defects in THA.¹⁵⁻¹⁷ The two most commonly cited classifications are those by D'Antonio (AAOS classification)¹⁶ and Paprosky.¹⁵

The American Academy of Orthopedic Surgeons (AAOS) acetabular bone loss classification system was introduced in 1989 by D'Antonio and associates. In this system, defects are divided into five progressive types and based into two categories: segmental (complete loss of the sup-

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porting bone) and cavitory defects (volumetric loss of the bony substance). A type I defect is defined as a minor segmental defect and can be peripheral (superior, anterior, posterior) or central (with deficient medial wall). A type II defect is defined as a cavitory defect as well divided in peripheral (superior, anterior, posterior) or central (with an intact medial wall). A Type III defect is a combination of segmental and cavitory defects with an intact posterior column. A Type IV defect includes pelvic discontinuity, in which the superior pelvis and the inferior pelvis are separated. Type V defect termed “arthrodesis” does not imply bone deficiency but difficulty in identifying the location of the true acetabulum and it is still included since it represents a technical

Abstract

Revision total hip arthroplasty in the setting of acetabular bone loss is a challenging procedure and requires a solid understanding of current acetabular reconstruction options. Despite major developments in the field of revision hip surgery in recent decades, reconstruction of acetabular defects remains a major problem in order to achieve primary stability and durable fixation without sacrificing additional bone stock. Although there are several ways to classify acetabular bone defects, the Paprosky classification system is the most commonly used to describe the defects and guide treatment strategy. An understanding of the bone defects associated with detailed pre-operative assessment and planning are essential elements in order to achieve satisfactory outcomes. Multiple acetabular reconstructive options are currently available including impaction bone grafting with metal mesh, reinforcement rings and antiprotusio cage, structural allografts, cementless hemispherical cups, extra-large “jumbo cups”, oblong cups, modular porous metal augments, cup-cage constructs, custom-made triflange cups, and acetabular distraction. To date, debate continues as to which technique is most effective due to the lack of long-term studies of modern reconstruction systems. Further long-term studies are necessary to assess the longevity of the

deficiency. The major flaw of this classification system is that it does not address the management of these defects (Table 1).

The Paprosky classification was introduced in the early 1990's (Table 1). This classification system relies on preoperative and intraoperative evaluation and it is based on the presence or absence of and intact acetabular rim and its ability to provide initial rigid support for an implanted acetabular component. The hip center migration and the integrity of four acetabular supportive structures are evaluated on preoperative antero-posterior (AP) radiograph of the pelvis: the teardrop (medial wall), the hip center (superior dome), the Kohler's line (anterior column) and the ischium (posterior column). Type I defects have minimal focal bone loss, the hemispheric shape of the acetabulum is maintained with neither periprosthetic osteolysis nor migration of the components. Type II defects show a distortion of the acetabular shape; anterior and posterior columns are still present but is evident a deficit of the superior dome and/or the medial wall. This category is subclassified in IIA, with an ovalized acetabulum, superior lysis with a <2cm superior migration but an intact superior rim; IIB, similarly to the IIA but with a deficient superior rim so the implants migrates superolaterally; and IIC, where the implant may migrate medially due to a deficient medial wall. Type III defects involve major bone loss with >3cm migration of the implant, destruction of the acetabular rim and supportive structures. If the acetabulum is considered as a circular structure interpreted like a clock face, the IIIA pattern extends from ten o'clock to two o'clock (30% to 60% of bone stock destruction) with an intact Kohler's line (medial wall) and ischium and a superolateral migration (known as "up-and-out" deformity). The IIIB defines a major bone loss from nine o'clock to five o'clock (>60% of the bone stock) that involves both walls and both columns with severe obliteration of the

teardrop and severe lysis of the ischium with a superomedial migration (known as "up-and-in" deformity). Patients with type IIIB defect have a high risk of pelvic discontinuity (PD), defined as the loss of continuity between the superior and the inferior

hemipelvis, resulting from bone loss or fracture of the acetabulum. In addition to providing a system for describing bone loss, the Paprosky classification also guides treatment strategy (Figure 1).

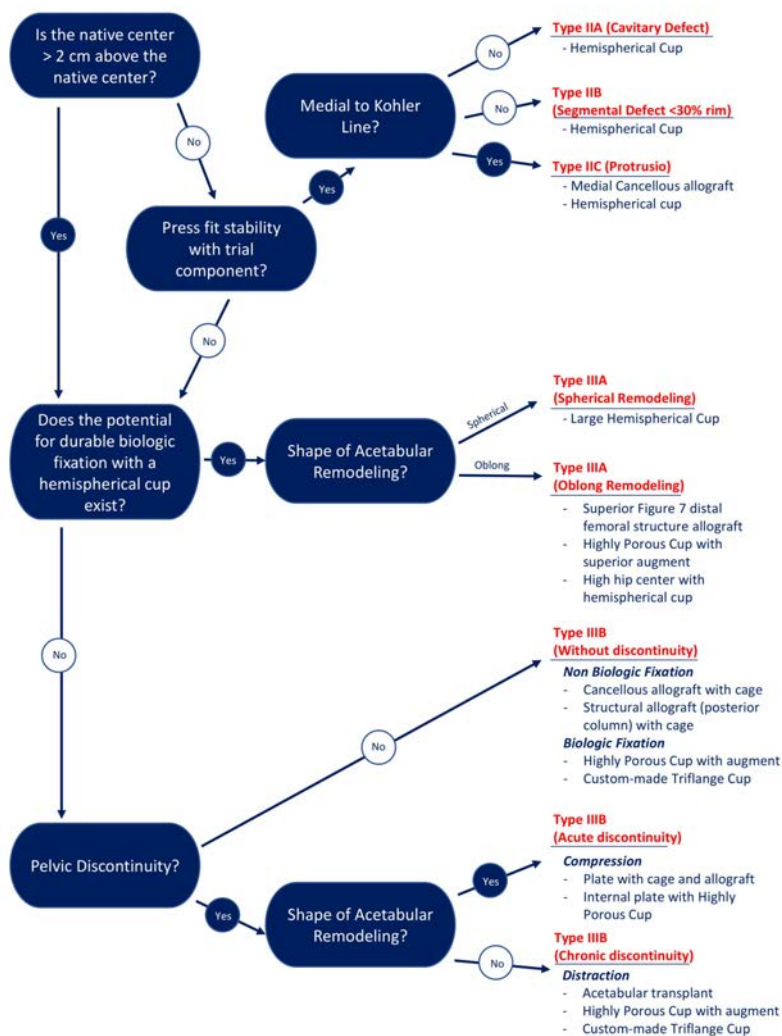


Figure 1. Algorithmic approach to acetabular reconstruction (Redrawn from Sporer SM, Paprosky WG, O'Rourke MR: Managing bone loss in acetabular revision. Instr Course Lect 55:290, 2006.).

Table 1. Classification systems for acetabular bone loss.

AAOS classification of acetabular bone loss		Paprosky classification of acetabular bone loss	
Type I	Segmental defects a. Peripheral: superior, anterior, posterior b. Central: (deficient medial wall)	Type I	Local, contained defects. Acetabular rim, anterior and posterior column intact.
		Type IIA Type IIB	<3cm superior migration. Superior lysis, intact rim. <3cm superolateral migration. Superior lysis and superior deficient rim.
Type II	Cavitory defects a. Peripheral: superior, anterior, posterior b. Central: (intact medial wall)	Type IIC	Medial migration, medial to Kohler's line. Intact rim.
Type III	Combined defects	Type IIIA Type IIIB	>3cm superolateral migration (up-and-out). >3cm superomedial migration (up-and-in).
Type IV	Pelvic discontinuity		
Type V	Arthrodesis	Pelvic discontinuity	Partial or complete fracture.

Patient evaluation and preoperative planning

Revision THA is indicated when a specific problem, caused by hip pathology, is identified and can be surgically corrected. Patient pre-operative evaluation considers the severity and the characteristics of the patient's symptoms, along with the physical examination, including range of motion, limb length discrepancies, hip musculature and ambulatory capacity.¹⁴ A detailed laboratory work-up inclusive of white blood cell count, erythrocyte sedimentation rate (ESR), and C-reactive protein level (CRP) should be mandatory in order to exclude periprosthetic joint infection (PJI) given their high sensitivity and specificity when these tests are combined.¹⁸ Hip joint aspiration with synovial fluid cell count and differential culture should be performed as well.¹⁸

Plain radiographs are essential to make the correct diagnosis.¹⁹ The anteroposterior (AP), lateral, and cross-table views of the hip are important to understand the eventual migration of the implant, ischial osteolysis and teardrop obliteration. Oblique views of the pelvis (Judet views) are crucial for assessing anterior column (obturator oblique) and posterior column (iliac oblique) bone stock.¹⁹ However, they generally tend to underestimate the degree of osteolysis.²⁰ CT-scan provides additional information despite the increased radiological exposition and its high costs.^{20,21} CT with three-dimensional reconstructions and artifact minimization is useful for planning acetabular revision in case of pelvic osteolysis and pelvic discontinuity when they are not clearly defined on plain radiographs.^{19,22} Metal artefact reduction sequence magnetic resonance imaging (MARS MRI) is inferior to CT-scan in quantifying the bone defects, however, it is an effective tool when metal-on-metal bearing or dissimilar metal junctions are present, in assessing associated soft tissue adverse reactions (pseudotumor and adverse reaction to metal debris).¹⁹ Additional studies such as angiography are suggested when the acetabular component has migrated medially to the ilio-ischial line.²³ However, in the majority of the medial migration of the cups, there is either fibrous tissue or remodeling of medial bone separating the cup from the pelvic cavity.¹⁹

Once the reason for acetabular revision is identified and bone defects are correctly quantified, the definitive acetabular reconstruction option is designated according to patient's characteristics and surgeon's experience.

Reconstruction available options

Impaction Bone Grafting with Metal Mesh

Impaction bone grafting is indicated in segmental and combined defects (Paprosky types IIIA and IIIB). In case of uncontained peripheral acetabular defects supplemental devices such as metal mesh or reconstruction ring are required to transform them into contained defects.²⁴⁻²⁸ This technique should be avoided when severe segmental defects are combined with major medial deficiencies.^{3,29,30} Failures are usually related to fracture and consequent migration of the stainless steel mesh, graft resorption and micromovement.²⁹ In a recent systematic review Baauw *et al.*,³ reported an overall reoperation rate of 7.4% (15 of 204 hips), an acetabular revision rate of 6.4% (14 of 204 hips) and an 8.8% of radiographic loosening (18 of 204 hips) at a mean 5.2 years. The main advantage of impaction bone grafting is the restoration of bone stock, especially in young patients who will eventually require a new cup revision. In addition, this technique should be avoided in patients with Paprosky type IIIB defect since it has been reported a higher risk of failure compared to type IIIA.³⁰

Reinforcement Rings and Antiprotrusion Cages

Roof-reinforcement rings and anti-protrusion cages are indicated in severe bone loss and pelvic discontinuity (Paprosky types IIB, IIIA and IIIB; AAOS types 3 and 4).³¹⁻³⁸ These devices are designed to protect morselized and structural grafts from high-stress forces avoiding early bone resorption and cup loosening when a "bridge" is required to span the defect and transfer the load to the peripheral host bone.^{39,40} Primary stability is augmented with flanges and screws allowing large contact areas between the implant and pelvic bone.³⁴ The distal side is inserted and fixed to the teardrop and superior border of the obturator foramen while the plate on the proximal side is fixed to the iliac bone.^{35,41} In a recent systematic review Baauw *et al.*,³ reported an overall revision rate of anti-protrusion cages of 3.5% (11 of 315 hips), a radiographic loosening of 7% (18 of 315 hips, with the majority due to fracture of the device or screws) and overall reoperation rate of 8.6% at mean 7.5 years. Rings and cages provide a relatively low-cost option for bridging acetabular defects with satisfactory clinical outcomes in cases of large bone defects in elderly and low demanding patients. With the advent of highly porous metal and improved cup designs, these

devices are slowly falling out of favor. In addition, rings are contraindicated in medial wall deficiency, protrusion, pelvic discontinuity and inferior bone loss.^{39,42-44} Cages may still be useful as they span the acetabular defect whilst allowing a near anatomic center of rotation and providing a high structural support in case of inferior poor bone contact.^{2,43}

Structural Allograft

Historically, Paprosky *et al.*,¹⁵ described the use of bulk structural bone grafts in conjunction with hemispherical cementless acetabular components in case of moderate-to-severe acetabular bone defects (Paprosky Type II and III). A femoral head allograft cut in "number of 7" is usually used for Paprosky Type IIA and IIB defects whilst a distal femur or proximal tibial allograft is used for Paprosky Type IIIA defects. In Type IIIB, a proximal femoral allograft can be transected in a coronal plane and laid over the defect. The authors reported no signs of major resorption or fracture of the graft with a 4% (6 out of 147 hips) of implants loosening (>3mm). DeWal *et al.*,⁴⁵ reported a 15% of implant loosening (2 out of 13 hips) with no signs of graft resorption at 6.8 years. Sporer *et al.*,⁴⁶ reported a survivorship of 78% from re-revision due to aseptic loosening in a cohort of 31 Paprosky Type IIIA bone defects at 10.3 years. Disadvantages related to bulk allografts are the risk of infection transmission, the variable mechanical characteristics, and the partial resorption or healing of the graft.^{3,47} However, given that structural allograft may enhance future bone stock, younger patients may be better candidates for structural allografts rather than porous metal augments.¹⁴

Cementless Hemispherical Cups

Cementless hemispherical cups are widely considered the recommended options in Paprosky Types I and II (AAOS 1 and 2) bone defects.¹⁵ Cancellous bone grafting can be added to fill the inner bone deficiency with satisfactory outcomes at mid-to-long term.⁴⁸⁻⁵⁰ Della Valle *et al.*,⁵⁰ reported a 15-year overall survivorship of 81%, and a 96% survivorship when considering revision due to aseptic loosening in a cohort of 138 hips. In case of a superior defects (Paprosky Type IIA) the cups can be positioned superiorly ("high hip center") and the defects filled with particulate grafts.¹⁵ However, the "high hip center" technique is associated with an increased risk of dislocation due to the modification of the abductor and adductor lever arms. Advantages of an uncemented hemispherical cup are a stable and biologic fixation in mild-to-moderate bone defects and a surgi-

cal technique familiar to many arthroplasty surgeons; however, it is accepted that provide poor results in severe acetabular bone defects (>50% of bone stock).⁵¹

Extra-Large “Jumbo” Cups

Extra-large “jumbo” cups are an option in case of major defects (Paprosky Types II and III; AAOS Types 3 and 4). They are defined as having a diameter >66mm in males and >62mm in females, approximately 10mm larger than the mean diameter of the acetabular components used in primary THA.⁵² This technique has multiple advantages: it is technically straightforward, most bone defects are filled by the socket itself obviating the need for extensive bone-graft, there is an increased contact area between the implant and the host bone and the center of hip rotation is translated to a more lateral and inferior position.^{11,52-54} Disadvantages are that a large socket limit the bone stock restoration in case of additional re-revision of the acetabular component, and large, oblong bone defects cannot be filled in an inferior-to-superior direction without marked reaming of the anterior or posterior column (vital for the implant fixation) or superior placement of the cup.⁵² Relative contraindication are previous irradiation of the pelvis and massive acetabular bone loss of the superior-lateral rim or the posterior column that can preclude the initial implant stability.^{2,52} Von Roth *et al.*,⁵³ reported a survivorship of 83% (15 of 89 hips) at 20 years. In a recent systematic review Volpin *et al.*,¹¹ reported a failure rate of 12.1% (63 of 518 hips) at 10 years, with liner exchange as the most common causes of reoperation (7.1%).

Oblong Cups

Oblong cups are indicated in large superior segmental bone defects with a prevalent superior migration and a longitudinal diameters that are greater than their transverse diameters (Paprosky Types IIA, IIB and IIIA).^{55,56} Oblongs cups adapt better to large and oblong bone defects, that cannot be filled with hemispherical cups, avoiding marked reaming of the anterior and posterior columns.^{51,55-61} Three types of Oblong Cups have been described: the bilobed oblong acetabular component, the longitudinal oblong revision cup (LOR) and the BOFOR cup.⁵⁶ In a recent systematic review, Volpin *et al.*,¹¹ reported good results for oblong cups in term of overall failure rate (5.9%, 12 of 203 hips) with an aseptic loosening rate of 3.9% (8 of 203 hips) and a dislocation rate of 2.4% (5 of 203 hips) at a mean follow-up of 7.6 years. These results are probably due to the ability of these cups to restore the hip center and achieve osseointegration through sufficient bone

implant contact.⁵¹ The main advantage of the cups is their relative ease of implantation and the oblong shape that almost enables a press-fit incorporation.

Modular Porous Metal Augments

Porous modular metal augments in conjunction with highly porous cup represent a viable option for the reconstruction of moderate-to-severe acetabular bone defects (Paprosky Types IIIA, IIIB and pelvic discontinuity).⁶²⁻⁶⁴ Porous metal augments are made with highly porous tantalum or titanium. The higher porosity (up to 80%) allows a proportionate increase in interface strength compared to conventional implants and the high coefficient of friction improves the primary stability.^{2,63} Highly porous cups, usually used alone in mild-to-moderate bone defects (Paprosky Types I and II), can be supported with porous metal augments and/or cage when bone loss is >50% of the original bone stock or in presence of pelvic discontinuity.^{48,62} Highly porous revision shells have a multi-hole configuration (8-12 screw holes) in order to position additional screws and increase stability.² Highly porous augments are usually fixed to the bone before the fixation of the acetabular cup in case of large intracavitary defects (anterosuperior and posteroinferior). In case of extracavitary defects (posterosuperior) the augments can be positioned after the acetabular cups since they provide a supplemental fixation.¹⁴ The use of metallic material, instead of bone grafts, avoid certain risks associated with allografting like transmission of infections, variable mechanical characteristics and partial resorption or healing; on the other hand it is necessary to remove some extra host bone to accommodate the metallic augment and achieve the indispensable press-fit.^{3,47} For the majority of the porous metal augment systems available in the market, the junctions between the porous metal augments and the highly porous cups need to be filled with cement, to avoid the release of metal fragments and induced metallosis.^{47,65} Jenkins *et al.*,⁶⁶ reported a survivorship from aseptic loosening of 97% (2 out of 58 hips) for aseptic loosening at a minimum 5-year follow-up and proposed variable configurations in order to achieve stability in different bone defects:

Cup + “flying buttress” augment configuration: in peripheral segmental defect, particularly in the posterosuperior quadrant (Paprosky type IIIA).

Cup + “dome” augment configuration: in elliptical, contained cavitory defects, when the anteroposterior dimension of the acetabulum precluded simply reaming up to a jumbo socket (Paprosky type IIIA).

Cup + “footing” augment: in massive medial cavitory or segmental defects to support the cup (Paprosky type IIIB).

All the junctions between tantalum components need to be filled with cement, except for the “footing” conformation. The remaining cavitory defects are filled with cancellous bone chips.⁴⁸

In case of severe medial bone defects (Paprosky Types IIC, IIIA and IIIB), Blumenfeld *et al.*,⁶⁷ described the “cup-in-cup” technique with a highly porous “Jumbo” cup combined with cementation of a similar highly porous cup into the initial jumbo cup. Webb *et al.*,⁶⁸ described the “double-cup” technique (Paprosky type IIIA, IIIB) using a highly porous cup as a “super-augment” to buttress the superior medial or lateral defect.

In a recent systematic review, Baauiw *et al.*,³ reported on the use of porous metal augments in large acetabular defects (Paprosky Types IIIA and IIIB; AAOS Types 3 and 4). They found a survivorship from re-revision of 98.4% (2 of 125 hips), a radiographic loosening of 2.4% (3 of 125 hips), an overall reoperation rate of 15.2% (19 of 125 hips) and a dislocation rate of 4.8% (10 of 125 hips) at mean follow-up of 3.8 years.

Cup-Cage Reconstruction Systems

Cup-cage reconstruction is indicated in case of severe bone defects (Paprosky Type III) and chronic pelvic discontinuity. Described by Nehme *et al.*,⁶⁴ it is a hybrid technique based on a highly porous cup with partial press-fit in combination with morselized host-bone or allograft, supported by a cage that provides load relief. The liner is then cemented into the cage and the hip center is brought back to a more physiologic position. Once the cup is well integrated the cage is offloaded preventing mechanical loosening.⁶⁹ Early outcomes reported a survivorship of more than 85%,^{70,71} and encouraging mid-term clinical and radiological outcomes have been reported in case of pelvic discontinuity.^{69,72,73} Abolghasemian *et al.*,⁶⁹ reported a survivorship of 88.5% at a mean 3.9 years (3 of 26 hips); Martin *et al.*,⁷³ reported a survivorship of 100% in a cohort of 27 hips at 5 years with 74% of healing of the discontinuity; Amenabar *et al.*,⁷² reported an overall survivorship of 91% (4 of 45 hips) at a mean follow-up of 6.4 years when cup-cage constructs were used for the treatment of pelvic discontinuity. Concerns are addressed regarding the positioning of the cup, typically placed too vertical and relatively retroverted in order to accommodate the cage; particular attention is needed in cementing the liner with the right anteversion and inclination.⁷⁴ In addition, “half

“kick-stand” technique (without the ischial flange) has been described with a “kick-stand” screw positioned in the ischium or in the superior pubic ramus in order to avoid abduction failure of the cup.¹⁴

Custom Triflange Acetabular Components

Custom triflange acetabular components (CTACs) are a valid option in massive periacetabular bone defects (Paprosky Types IIIA and IIIB). The main advantage, despite their high costs compared to other reconstruction implants, is the possibility to completely customize the implant starting from a thin-cut computed tomography scan.⁷⁵ The surgeon can decide the characteristics of the component by selecting the position of flanges, location and direction of screws, and number of holes. In addition, the surgeon is able to plan the location, inclination, and anteversion of the acetabular cup. In order to facilitate osseointegration, porous coatings and hydroxyapatite are often applied to the flanges and back-side acetabular portion of the implant. A modular liner is placed into the central hemispherical cup and engaged with either a modular locking mechanism or bone cement.^{10,22} However, if osseointegration is incomplete this implants are prone to mechanical complications, especially in case of deficient superior support or in pelvic discontinuity.¹⁰ In a recent systematic review, De Martino *et al.*²² reported that CTACs are a viable and effective way to manage complex acetabular bone defects with an overall complication rate of 29% (168 of 579 hips), reoperation rate of 17.3% (100 of 579 hips) and dislocation rates of

11% (57 of 516 hips) at mean 4.8 years showing a considerable improvement in multiple functional scores. The authors also reported that the relatively high complication rate in the CTACs may reflect the complexity of revisions and severity of acetabular bone defects. In fact, the surgical technique involves extensive soft tissue dissection with possible neuro-muscular damage¹¹ (Figure 2).

Acetabular Distraction

Acetabular distraction has been described as an alternative treatment in case of pelvic discontinuity (PD).⁷⁶ The technique is based upon the placement of an extra-acetabular distractor to allow peripheral or lateral distraction and central or medial compression at the discontinuity. The technique provides initial mechanical stability and, once bone healing occurs, biologic fixation through a highly porous cup placed into a distracted pelvic discontinuity. The presence of PD is usually confirmed intraoperatively. A stable fit of the cup with the anterosuperior and posteroinferior columns is mandatory in order to be a successful reconstruction option. Cement is apposed in the interface between the augment and the AC to reduce micromotions and the cup is additionally stabilized with cancellous screws, two of which inferiorly into the ischium or superior pubic ramus (“kickstand” screw) to avoid abduction failure of the cup. Finally, the liner is then cemented with the right version and inclination.^{74,76} Sporer *et al.*⁷⁶ reported survivorship from aseptic loosening of 95% (1 out of 20, at minimum 2 years) and 20% of early migration of the acetabular compo-

nent (4 out of 20) that stabilized with time and did not present clinical relevance. Sheth *et al.*⁷⁷ reported survivorship from re-revision due to aseptic loosening of 97% (1 failure out of 32 cases) and radiographic loosening of 6% (2 out of 32) at 5 years. Radiographically, 69% of the cases (22 out of 32) showed good healing of the discontinuity. Advantages of the acetabular distraction may result in more reproducible healing of a chronic pelvic discontinuity with a theoretically decreased risk of subsequent implant loosening. Disadvantages are its technical complexity and the not well defined magnitude of distraction required for adequate fixation.¹⁴ Further long-term high-quality studies are needed to confirm the survivorship of the implants and the clinical results.

Conclusions

Acetabular bone defects are a major concern in the setting of revision THA. Paprosky classification system is the most commonly used to describe the defects and guide treatment strategy. To date, as assessed from this review, multiple reconstruction options are available, and each technique presents advantages and disadvantages; however, the optimal method should be selected according to the surgeon’s experience, the appropriate preoperative evaluation and classification of the bone defect associated with a correct planning. Hemispherical uncemented cups supported by screw fixation are recommended to address mild and moderate defects. Highly porous metal cups and augments showed satisfactory results in enhancing bone ingrowth and fixation when used to address severe bone defects. In case of pelvic discontinuity good mid-term results have been reported with the use of cup-cage, custom triflange acetabular components and acetabular distraction technique. However, despite the overall good mid-term outcomes, there is no consensus regarding which reconstruction technique guarantees better long-term survivorship due to the lack of high-quality long-term studies on the modern reconstructive options.

Finally, the outcome of revision THAs depends on multiple factors including patient selection, appropriate preoperative evaluation of the bone defects, correct planning and templating, consideration of alternative strategies, proper reconstruction options, and good postoperative care and rehabilitation.



Figure 2. Example of highly porous cup with caudal hook and fins to ensure additional stability. (Courtesy of LimaCorporate)

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