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REVIEW ARTICLE

Acetabular reinforcement rings associated with allograft for severe acetabular defects

Emmanuel Gibon[1] · Luc Kerboull[1] · Jean-Pierre Courpied[1] · Moussa Hamadouche[1]

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Abstract

Acetabular revisions with severe bone defects can be challenging procedures. Several grading systems have been set into place to help the surgeon adequately gauge the degree of bone loss within the acetabulum. Internationally innovative research in orthopedics and bio-engineering has helped with progression of successful techniques and rings to re-establish the normal anatomy of the hip. The purpose of this review is to evaluate the outcomes of the different acetabular reinforcement rings in the setting of severe acetabular defects. A successive report of relevant data from the literature of multiple techniques will be provided. The procedures include the cup-cage, the Müller ring, the Ganz Ring, the Kerboull acetabular reinforcement device (KARD), the graft augmentation prosthesis (GAP) ring, and the Burch-Schneider ring. The main focus of this overview is rings only; other devices such as trabecular augments, custom-made cages, or oblong cups are not discussed. Furthermore, a special emphasis on the surgical technique of the KARD is also given. Procedures using these rings are usually associated with bone grafts either bulk or morselized. When considering the available data on these various rings used for reconstruction of the severely damaged acetabulum, the cup-cage, the KARD, and the Burch-Schneider ring appear to be reliable options for more successful long-term outcomes.

Keywords Cup-cage · Müller ring · Ganz ring · Kerboull acetabular reinforcement ring · GAP ring · Burch-Schneider ring

Introduction

The demand for total lower limb joint arthroplasty is rising at a frenetic rate. Data from previous studies [1, 2] and projection studies [3, 4] show that the number of revision total hip arthroplasty (THA) will increase 137% over the next 25 years in the USA. Similar trends have been reported in the UK and Australia [5, 6]. Among revision THA, Bozic et al. [7] have shown that acetabular component revision represents the third most common procedure (12.7%) following femoral component revision (13.2%) and all-component revision (41.1%). Major advances have been made in design and manufacturing of bearing surfaces. Among these, ceramics and first- and second-generation highly crossed-linked polyethylene (HXLPE) are marketed and available for primary THAs, markedly reducing wear and osteolysis [8–15]. However, despite dramatic alleviation, osteolysis is still accountable in up to 11% of the revision THAs [7, 16]. Occult intra-operative fractures of the acetabulum may also impair implant survival [17]. The extent of the osteolysis can be characterized through different classifications (Table 1).

Reconstruction techniques of the obliterated acetabulum are driven by the extent of bone loss. Studies have shown that when contact between a viable bleeding host bone is greater than 50% of a porous-coated acetabular component along with initial mechanical stability can be acquired, then a dependable osseointegration is expected [24–28]. On the other hand, when 50% of contact cannot be obtained between the host bone and the acetabular component, studies show that an acetabular reinforcement ring is warranted [29–31] or another acetabular reconstruction device (i.e., tantalum cones, tantalum cups).

In this review, we discussed the outcomes of acetabular reinforcement rings (only) used for reconstruction of the severely damaged acetabulum following primary THA (Fig. 1), with an emphasis on the Kerboull ring. Allografts alone have shown their high failure rate in these circumstances [23,

✉ Moussa Hamadouche
moussah@club-internet.fr

[1] Clinical Orthopaedics Research Center, Department of Orthopaedic and Reconstructive Surgery, Centre Hospitalo-Universitaire Cochin-Port Royal, 27 Rue du Faubourg St Jacques, 75014 Paris, France

Table 1 Current classifications for acetabular defects

Classification	Assessment
Engh et al. [18]	Is based on the integrity of the rim and the bed
Gustilo and Pasternak [19]	Is based on the integrity of the acetabular walls
D'Antonio et al. [20] (a.k.a. AAOS)	Is based on acetabular segmental and cavitary deficiencies
Gross et al. [21]	Is based on contained/uncontained bone loss including the percentage of bone defect of the acetabulum
Saleh et al. [22]	Is based on bone defects after removal of the acetabulum implant
Paprosky et al. [23]	Is based on the presence or absence of key supporting structures of the acetabulum

32–35]. Jasty and Harris [32] reported a failure rate of 32% at six years with a mean time to failure of 5.4 years. Failure was attributed to marked resorption of the graft in all but one of the failure cases. Interestingly, the study showed that the extent of the acetabular cover provided by the allograft had a positive correlation with acetabular implant loosening. Moreover, the more severe the resorption was, the more frequent the loosening was. Paprosky et al. [23] emphasized those outcomes showing as high as 70% failures at a mean of 5.1 years in revision THAs with Paprosky IIIB acetabular defects. Garbuz et al. [36] in a series of 38 hips showed successful results at a mean of 7.5 years when an acetabular reinforcement device supported the structural allograft whereas most of the reconstructions without such a device failed.

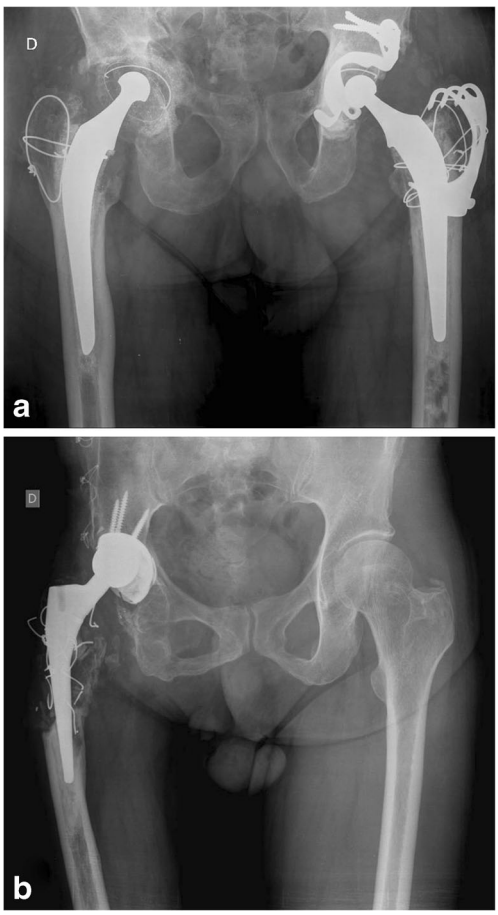

Fig.1 **a**, **b** Pre-operative AP radiographs showing massive acetabular bone defects Paprosky type III of the right hips. Ischial lysis and obliteration of the teardrop are present in both cases

Cup-cage

This technique was first developed by Hanssen and Lewallen and reported in 2005 [37]. It consists of a trabecular metal (TM) acetabular shell and an ilioischial antiprotusio cage placed over the cup (full cup-cage construct) (Fig. 2). The technique has been altered and can be used in a half cup-cage version. It resembles the reverse technique of a cage placed initially in the acetabulum followed by a cup cemented into place. The desired outcome of this construct was based on the fact that no bone ingrowth could be obtained into the cage whereas a TM acetabular shell enables and promotes bone ingrowth when placed first. Kosashvili et al. [38] reported on a series of 26 cases of acetabular revision including 24 patients with pelvic discontinuity (PD) and severe acetabular bone defects (a mean of 15.8% contact with bleeding host bone). After filling the defects with morselized bone graft, the cup and the cage were put in place. A polyethylene component was then cemented into the cage. At a mean of 3.7-year follow-up, the authors reported three (11.5%) migrations. Later on, the same group presented an extended follow-up study of the initial series and compared it with a group of PD cases reconstructed with a conventional cage (without trabecular metal) [39]. The cup-cage group had a survivorship of 87.2% whereas the conventional cage group had a survivorship of 49.9% at 5.75 and 6.8 years respectively. Similar outcomes were reported by Amenabar et al. [40] who treated Gross type IV (uncontained loss of bone stock involving > 50% of the acetabulum and affecting both columns) and Gross type V (PD) acetabular deficiencies. The authors showed a ten year survival rate of 85%. As aforementioned, the full cup-cage construct can be modified to a half cup-cage construct by removing the inferior flange of the cage. This adaptation was reported by Sculco et al. [41]. The reasons for such an

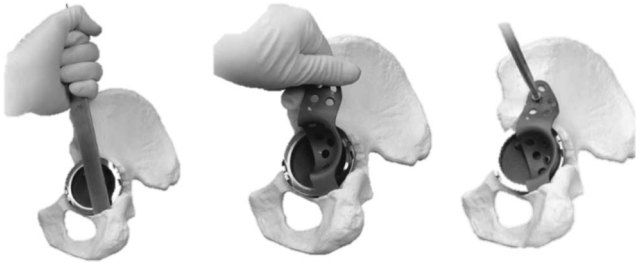

Fig. 2 The cup-cage construct (courtesy of Zimmer-Biomet)

evolution, as mentioned by the authors, are various: (1) slotting the ischial flange of the cage into the ischium may lead to a PD, (2) the ischium might be obliterated, and (3) the risk of damaging the sciatic nerve while dissecting the ischium. To analyze the outcomes of the half cup-cage construct, the authors compared 27 revision THAs performed with this technique to 30 revision THAs with the full cup-cage construct. Acetabular defects were graded as Paprosky IIB through IIIB including 60% of PD. No significant differences were found between the two groups. Two sciatic nerve injuries occurred in the full cup-cage group whereas none were reported in the half cup-cage group. At a mean follow-up of 4.6 years, the survivorship was 83% and 96% for full and half cup-cage groups, respectively. Although a relatively new technique, the cup-cage construct appears to be a viable and reliable method for revision THAs with major acetabular bone loss.

The Müller ring

The design of the ring is cup-shaped with a flange around the posterior two thirds of the cup edge. The ring accepts screw fixation on its superior lip. Three to five 6.5 fully threaded cancellous screws are generally warranted. To ensure a strong fixation, the ring must have support from the posterior pillar, the medial wall, and the superior acetabular lip [42]. Therefore, bone grafting is routinely required to meet these requirements. There is limited literature regarding the use of the Müller ring in revision THA with severe bone loss. Early studies [42, 43] showed promising results, but the follow-up was limited to three to four years and accurate description of the extension of bone loss in revision cases was not provided. At this time, it is uncertain to draw any inferences from those studies. Later, Zehntner and Ganz investigated the outcomes of the Müller ring in AAOS type III (combined cavitary and segmental defects) acetabular defect associated with structural allograft from a fresh frozen femoral head. Their results showed that at a mean of 7.2 years of follow-up, 45% of the component failed and migrated. The authors concluded that additional internal fixation should be used in case of AAOS type III defects. Thereafter, Korovesis et al. [44] revealed no failure at a mean of nine years of follow-up after revision THA using the Müller ring and bone allograft. However, the study size was small with only eight hips having AAOS type III defects. Similar results were found by van de Linde and Tonino [45], but again, their series was limited to 13 cases of AAOS type III acetabular defects and they randomly used either the Müller ring or the Burch-Schneider cage. Schlegel et al. [46] followed a series of 164 revision THAs reconstructed with fresh frozen femoral head allograft and the Müller ring. Among them, 56% had AAOS type III acetabular defects and 5% had AAOS type IV acetabular defects (pelvic discontinuity). The survival rate was 98% at five years but no difference was observed regarding the severity of the acetabular defects. Massin et al. [47] used the Müller ring in combination with structural allograft to treat segmental or important cavitary roof defects. Using aseptic loosening as the end point, the authors showed a survival rate of 55% at 11 years. They reported that mechanical failures were related to the resorption of structural bone grafts.

The Müller ring has not been extensively investigated to treat major acetabular defects. From the small data available in the literature, the Müller ring appears to be insufficient for revision THAs with severe acetabular defects.

The Ganz ring

The design of the Ganz ring is comparable to the Müller ring. The additional feature of the Ganz ring is an inferior hook meant to be placed under the teardrop (Fig. 3). The Ganz ring was initially used for primary THAs in developmental dysplasia of the hip [48]. The first study of its use for revision THAs was performed by Siebenrock et al. [49]. The authors revised 57 hips, among them, 36 hips had enough data to be included in the study and most of them ($n = 19$) had a combined segmental and cavitary defect and three hips had a pelvic discontinuity. At a mean follow-up of 11.4 years, 8% of the hips underwent re-revision, two for aseptic loosening and one for septic loosening. Later on, Gerber et al. [50] used the Ganz ring for AAOS types II, III, and IV acetabular defects. Fifty hips were analyzed and defects were filled with morselized

Fig. 3 The Ganz® ring (courtesy of Zimmer-Biomet)

Fig. 4 The original Kerboull device (courtesy of Zimmer-Biomet)

allografts. Their results showed seven failures due to aseptic loosening and the survivorship at ten years was 81%. Additional analysis showed that inadequate fixation of the ring at the revision was the only significant predictor of failure and the authors also concluded that the ring might not be suitable for AAOS type IV defects or segmental defects affecting the medial wall. Recently, Hourscht et al. [51] investigated the outcomes of the Ganz ring with structural allograft in revision THAs with AAOS type III and IV acetabular defects. Additionally, the type IV was reinforced with a plate. The authors showed that the AAOS type of acetabular defect was the only independent risk factor of failure according to a multivariate Cox regression, the type IV being at a significant higher risk for failure. The five year survival rate using revision for any reason was 86% and 57% in types III and IV, respectively. Therefore, the authors concluded the Ganz ring should not be used when there is a pelvic discontinuity.

Taken together, the data [50, 51] shows that the Ganz ring should not be used for major acetabular defects or segmental defects affecting the medial wall.

The GAP ring

Published data on the outcomes of the GAP ring (graft augmentation prosthesis) are seldom. The design of this ring is unique by combining an inferior hook to be placed under the teardrop and two superior plates for screw fixation to the pelvis (Fig. 13). The outside surface is made of grit-blasted titanium with HA (hydroxyapatite) coating. Duffy et al. [52] investigated the GAP ring in revision THA. Within their series of 17 patients, they had 11 cases of severe acetabular defects graded AAOS type III. The average follow-up was 6.5 years. The authors concluded that "this device should not be used unless it is adequately supported by the host bone." Similarly, Buttaro et al. [53] reviewed 24 cases of AAOS type III and IV acetabular. At 34 months, the survival rate was 67%. The authors discontinued its use for the treatment of severe acetabular defects, especially AAOS type IV.

Based upon these data, the GAP ring appears to be unsuitable for severe acetabular bone defects.

Table 2 Comparative data for the Kerboull ring used in severe acetabular bone loss reconstruction

Authors	Year	Defect type (number of hip)	Mean follow-up (years)	Ring	Survival/end point*
Gibon et al. [64]	2018	Paprosky III ($n = 37$)	8.2	Kerboull ring	95.3%/aseptic loosening
Makita et al. [65]	2017	Paprosky IIIA and IIIB ($n = 65$)	11.2	Kerboull ring + bulk allograft	90.7%/revision for any reason
Kim et al. [66]	2015	AAOS II and III ($n = 40$)	12.8	KT + bulk allograft + HA	94.9%/revision for loosening (type III)
Hori et al. [67]	2012	AAOS III and IV ($n = 32$)	7.5	KT + bulk or morselized allograft	92.3%/revision for loosening or rx loosening
Akiyama et al. [68]	2011	AAOS II and III ($n = 40$)	6.7	KT + bulk or morselized allograft	87%/revision for loosening or rx loosening
Okano et al. [69]	2010	AAOS II and III ($n = 31$)	6.3	KT + bulk or morselized allograft	NA
Kawanabe et al. [70]	2007	AAOS II, III, and IV ($n = 42$)	8.7	KT + bulk or morselized allograft	53%/failure of acetabular implant (morselized allograft) 82%/failure of acetabular implant (bulk allograft)
Tanaka et al. [62]	2003	AAOS II and III ($n = 21$)	5.3	KT + HA ± morselized allograft	NI
Kerboull et al. [71]	2000	AAOS III and IV ($n = 60$)	8	Kerboull ring + bulk allograft	92.1%/loosening of the acetabular implant

NA non available, *KT* Kerboull-type ring, *HA* hydroxyapatite, *rx* radiographic

*Survival rate at the mean follow-up of the series

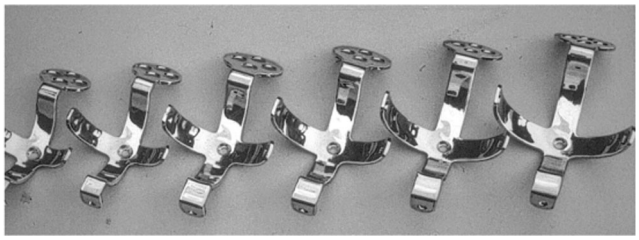

Fig. 5 The original KARD displayed in a series of six sizes

The Burch-Schneider ring

The Burch-Schneider (BS) ring was first designed by Burch and later modified by Schneider during the 1970s [54]. The ring has two flanges: the superior one rests against the ilium while the inferior one is slotted into the ischium (Fig. 14). These two flanges can be bended to comply with the individual anatomy of the acetabular region. The ring is riddled with numerous screw holes for further fixation. Hsu et al. [55] reported on a series of Paprosky type III acetabular defects and PD reconstructed with the BS ring and structural allograft. The authors showed survival rates of 76% and 57% at five and ten years respectively. Similarly, Regis et al. [56] investigated the outcomes of 65 THAs revised with the BS ring and structural allograft as well for Paprosky III acetabular defects. Their results showed a survival rate of 84.6% at 18.9 years. Likewise, Jones et al. [57] used allograft and autograft along with the BS ring to revise 30 hips rated Paprosky III. Their results showed a survival rate of 91% at nine years. Ilyas et al. [58] in a series of 33 hips with acetabular defects rated AAOS III and beyond showed a survival rate of 72.2% at 10.3 years. Van Koeveringe and Oschner also re-

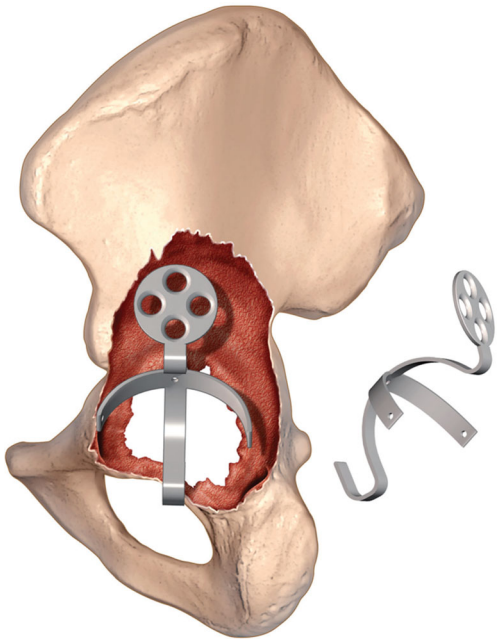

Fig. 7 The hook of the KARD must be placed under the teardrop in its posterior portion, near the ischium

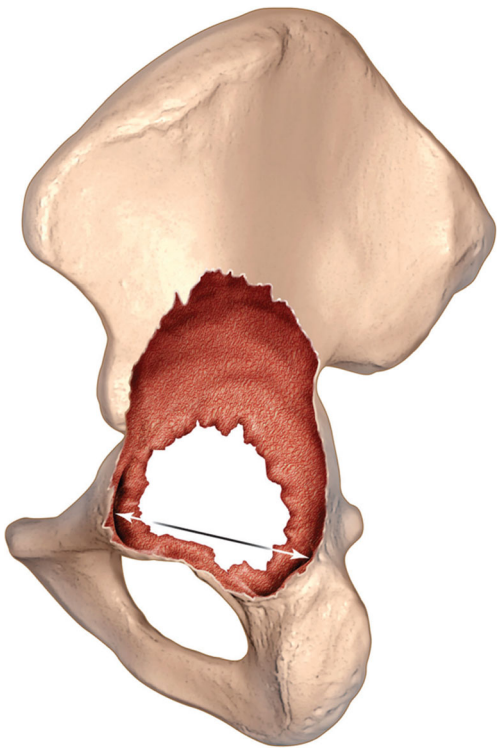

Fig. 6 Assessing the anatomic osseous size of the acetabulum

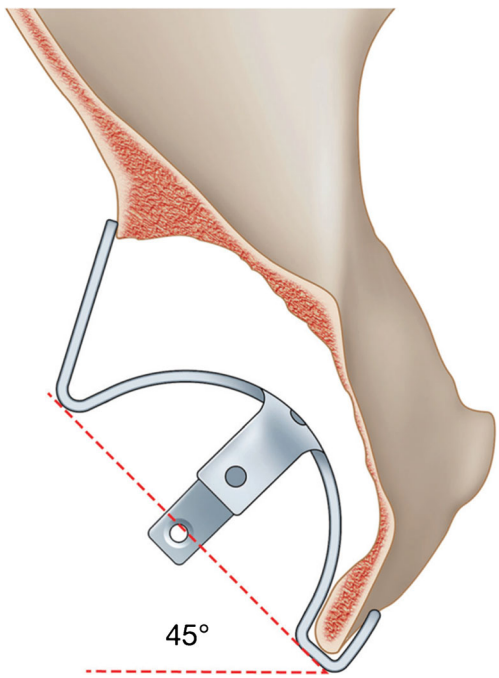

Fig. 8 The acetabular device is tilted 40° to 45° of abduction

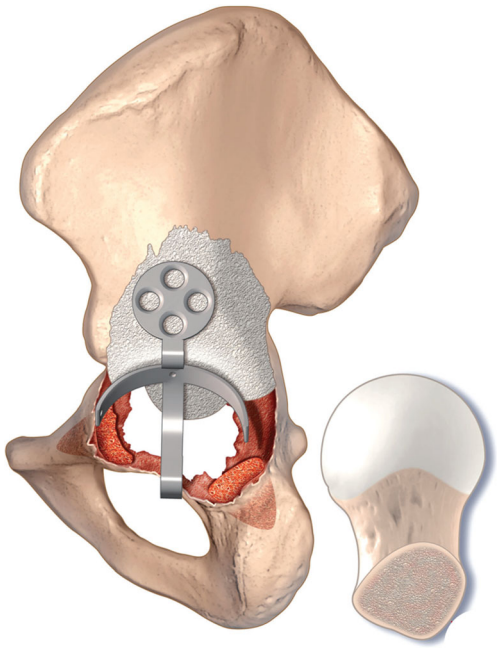

Fig. 9 The superior bone defect is reconstructed whenever possible, by a structural allograft

ported satisfactory results at five years [59]. Other studies confirmed that the BS ring can be highly successful in managing severe acetabular defects [60, 61].

Through this review, it has been determined the BS ring is a viable option to reconstruct severely damaged acetabuli.

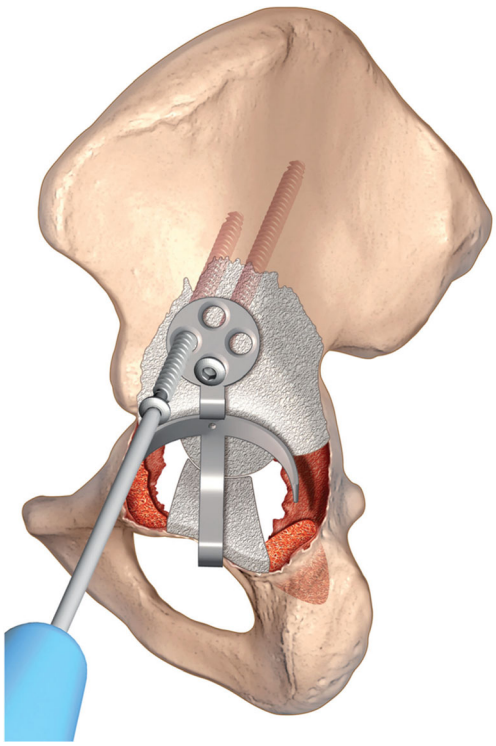

Fig. 10 The plate is fixed to the iliac host bone with 5-mm screws. At least two screws are used to obtain sufficient stability, always starting with the inferior screw

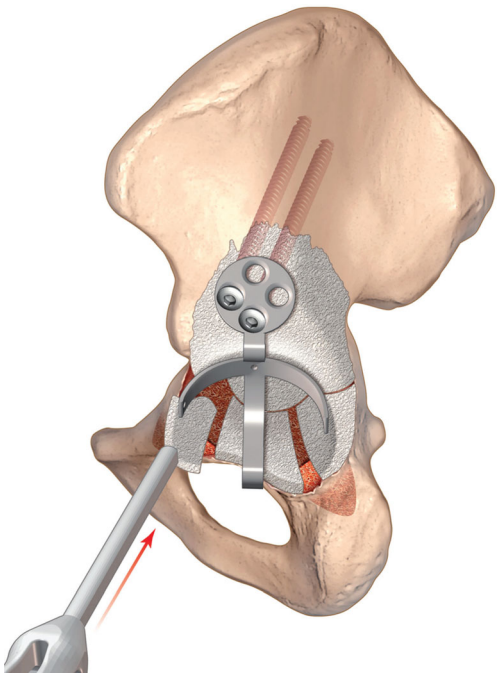

Fig. 11 Reconstruction of the anterior and posterior walls is performed using allograft fragments wedged in between the residual walls and the horizontal branches of the acetabular device

The Kerboull acetabular reinforcement device

In the early 1970s, pelvic discontinuities associated with acetabular bone loss were present in some cases of metal on metal total hip replacement. Marcel Kerboull designed a special acetabular ring as shown in Fig. 4. First intended for this indication, this ring was used later as a guide and reinforcement with structural allografts in almost all acetabular revisions. This device can also be employed in primary THAs when facing weak bone or altered anatomy as it is often the case after an acetabular fracture or a pelvic osteotomy. Studies reporting the use of the original Kerboull acetabular

Fig. 12 The modified Kerboull device (courtesy of Medacta)

Fig. 13 The Gap II® ring (courtesy of Stryker)

reinforcement device (KARD) have been mainly reported from France. A design modification has been made by Chiaki Tanaka [62] in Japan, with favourable outcomes [63]. It should be emphasized that most of the early failures are related to inadequate surgical technique. Comparative data regarding the KARD used in major acetabular defects are displayed in Table 2.

The original KARD (Fig. 4) consists of a four-branched hemispheric cross, made of 316L stainless steel. Its shape results from the orthogonal crossing of two hemispheric plates. The vertical plate ends distally with a hook, which must be placed under the teardrop, and proximally with a rounded plate perforated by four holes for iliac screw fixation above the acetabulum. The horizontal plate is asymmetric: its posterior branch being longer than the anterior determines a 10° anteversion angle. A left and a right series of the device are available in six sizes in which sockets with an outer diameter of 37 to 54 mm can be cemented (Fig. 5). Three holes, one at the crossing of the plates and one at each extremity of the horizontal plate, allow direct fixation of the allograft fragments to the device with 3.5-mm screws.

Fig. 14 The Burch-Schneider® ring (courtesy of Zimmer-Biomet))

Surgical technique

A large exposure of the acetabulum is required to completely remove the loosened component and the cement fragments when present. Complete excision of the fibrous membrane adherent to cavity and the granulation tissue filling in the defects is paramount. Also, osteophytes and fibrous tissue present around the teardrop should be completely excised in order to accurately visualize this region. The acetabulum is thereafter cleansed with pulsatile lavage. No reaming of the cavity is performed because of the weakness of the acetabular walls secondary to the bone loss.

Pre-operative templating on the opposite hip (when unoperated) allows choosing the appropriate size of the KARD. Otherwise, the size should be chosen intraoperatively based on the anatomic osseous size of the acetabulum (Fig. 6).

The hook of the KARD must be placed under the teardrop in its posterior portion, near the ischium (Fig. 7). The KARD then is tilted 40° to 45° of abduction (Fig. 8). Once placed in its correct position, the KARD allows assessing the extent and location of bone defects and the required shape of bone graft. The plate must never be opened or bent to adapt to the bone loss. Bone loss reconstruction routinely begins with acetabular roof grafting. This superior bone defect is reconstructed whenever possible, by one allograft block shaped from a fresh frozen femoral head allograft (Fig. 9). Then the reconstruction of the medial wall is performed with an adequate piece cut from a femoral head. The plate is then fixed to the iliac host bone with 5-mm screws (Fig. 10). At least two screws are used to obtain sufficient stability, always starting with the inferior screw. The latter must be tightened again, once all screws are placed. Reconstruction of the anterior and posterior walls is performed using allograft pieces wedged in between the residual walls and the horizontal branches of the KARD (Fig. 11). Finally, the reconstruction is completed by morselized cancellous bone packed in the cavitary defects of the pubis, the ischium, and in the gaps between the different allograft fragments to avoid any cement leak.

When Paprosky III acetabular defects involving the teardrop require its reconstruction to place the socket in an anatomic situation, we have observed a high risk of proximal and medial migration of the KARD. Indeed, primary stability of the KARD—and especially the hook—is the leading factor for long-term survival. For this reason, the KARD has recently been redesigned (Kerboull Cage, Medacta International SA,

Table 3 Comparative data on survival rates between the different rings used for reconstruction of the severely damaged acetabulum

Ring	Last follow-up (years)	Survival at last follow-up (%)
Cup-cage [39–41]	5.3 to 10	83 to 96
Müller ring [46, 47]	8 to 11	55 to 90
Ganz [50, 51]	5 to 10	57 to 81
KARD [64–68, 70, 71]	10 to 15.2	82 to 95.3
GAP [53]	2.8	67
BS [55–58, 60]	9 to 21	57 to 92

Castel San Pietro, Switzerland). The general design and the number of sizes have not been modified, as can be seen on Fig. 12. However, based upon the results from Tanaka et al. [62], this new device is made of grade 4 titanium (ASTM F67) in order to increase the resistance to fatigue, while keeping the same rigidity. This is accomplished by slightly increasing its thickness from 2 to 2.5 mm and remove the holes that were present on the arms and at their crossing.

In addition, the outer convex surface of the device has a sand-blasted finish in order to promote fixation to host bone where direct contact occurs. The hook of the device has been made wider to increase its stability, in particular when the latter is thin or partially obliterated by the osteolytic process (Figs. 13 and 14).

Overall, the Kerboull device is reliable option for revision THA with severe acetabular bone loss. However, its main disadvantage at mid and long term is a 21.6% rate of migration when the teardrop is obliterated [64, 71].

Comparative data on survival rates between the different rings for reconstruction of the severely damaged acetabulum are shown in Table 3.

When these reconstructions fail, the re-revision procedure represents a complex surgery. Kosashvili et al. [72] investigated the use of TM cups for these particular situations. They showed that TM cups performed well at an average of four years with 12 patients out of 15 free of another revision. Similarly, Tangsataporn et al. [73] compared TM cups and rings for salvage of failed cages. The authors showed a significantly higher survival rate of 60% for TM cups at eight years whereas rings had a survival rate of 20%. López-Torres et al. [74] also validated promising results of TM systems for severe acetabular defects. Nodzo et al. [75] have studied the effect of bone morphogenic protein-2 in revision THA. Their results showed modest clinical benefit. Interestingly, Amirouche et al. [76] used a finite element analysis to show that a defect in the columns is a risk factor for cup instability.

Conclusion

Reconstruction of severe acetabular bone loss is a surgical challenge. Currently, there are various acetabular reinforcement rings available on the market as well as numerous reconstruction techniques, with or without bone graft. Other devices are also available (i.e., TM augments, tantalum cones and cups, customized components) to reconstruct a severely damaged acetabulum. The top priorities are to restore the anatomic centre of rotation of the hip and ensure a long-term success of the revision. Several solutions based upon the literature review and depending on the surgeon's own experience can be proposed to deal with these complex cases.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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