Chapter 9
Revision Arthroplasty of the Acetabulum Using Structural Allograft and a Cage: State-of-the-Art

E. Gibon, L. Kerboull, and M. Hamadouche

Introduction

The demand for total lower limb joint replacement is increasing at a staggering rate. Data from past studies [1, 2] and projection studies [3, 4] shows that the number of revision total hip arthroplasty (THA) will increase 137% over the next 25 years in the US. Similar trends have been observed in the UK and Australia [5, 6]. Among revision THA, Bozic et al. [7] have shown that acetabular component revision was the third most common procedure (12.7%) after femoral component revision (13.2%) and all-component revision (41.1%). Major breakthroughs have been made in manufacturing new bearing surfaces. Among these, ceramics and first- and second-generation highly crossed-linked polyethylene (HXLPE) are now available for primary THAs dramatically decreasing wear and osteolysis [8–11]. However, although markedly mitigated, osteolysis is still responsible for up to 11% of the revision THAs [7, 12]. DeLee and Charnely created a way to locate osteolysis on the acetabular side by dividing it in three different zones [13]. This classification is still in use today. Two lines, one vertical and one horizontal, cross at the center of the prosthetic femoral head. Zone I is superolateral, zone III is inferomedial and zone II is in between. Chiang et al. [14] have shown that the pattern of osteolysis differs between cemented and cementless acetabular component. For cemented components, osteolysis predominantly occurs in DeLee zones III and I whereas it is mostly observed in DeLee zones II and III for cementless components.

The severity of the osteolysis can be categorized through different classifications. The Engh classification focuses on the integrity of the rim and the bed [15]. The Gustilo and Pasternak classification is based on the integrity of the acetabular

E. Gibon (✉) · L. Kerboull · M. Hamadouche
Clinical Orthopaedic Research Center, Centre Hospitalo-Universitaire Cochin-Port Royal, Paris, France
e-mail: moussah@club-intrnet.fr

E. García-Rey, E. García-Cimbrelo (eds.), *Acetabular Revision Surgery in Major Bone Defects*, https://doi.org/10.1007/978-3-319-98596-1_9

walls [16]. D'Antonio et al. described a classification based on acetabular segmental and cavitary deficiencies with special types for pelvic discontinuity and arthrodesis as well [17]. This classification is now known as the AAOS classification [18]. Gross et al. [19] described a classification with contained/uncontained bone loss including the percentage of bone defect of the acetabulum. The Saleh classification [20] describes bone defects after removal of the acetabulum implant. Finally, the Paprosky classification [21] relies on the presence or absence of key supporting structures of the acetabulum. Those classifications are further detailed in Chap. 2.

Reconstruction techniques of the damaged acetabulum are guided by the extension of the bone loss. Studies have shown that when a contact between a viable bleeding host bone greater than 50% of a porous-coated acetabular implant and initial mechanical stability can be obtained, then a reliable osseointegration is expected [22–26]. On the other hand, when 50% of contact cannot be achieved between host bone and the acetabular implant, studies showed that an acetabular reinforcement ring is indicated [27–29].

In this chapter, we will be reviewing different techniques of reconstruction of the severely damaged acetabulum (Paprosky III) following primary THA. First, we will discuss the use of a structural allograft only. Second, we will present techniques using a structural allograft and an acetabular reinforcement ring with proximal fixation. And in the last section, we will review the use of a structural allograft and an acetabular reinforcement ring with proximal and distal fixation.

Structural Allografts Only

The use of a structural allograft alone for acetabular reconstruction in revision THAs has been studied since the 1990s. Different results have been reported depending on the severity of the initial bone loss. The major concern is the fate of the allograft with subsequent risk of failure due to resorption and collapse leading to implant loosening. When used for minor acetabular bone defects (involving less than 50% of the acetabulum), results are controversial. Morsi et al. [30] reported a successful rate of 86% at mean of 7.1 years, Woodgate et al. [31] showed a cup survival of 80.6% at almost 10 years and Lee et al. [32] had survival of 61% and 55% at 15- and 20 years, respectively.

For major acetabular deficiencies (more than 50% of the acetabulum) a structural allograft needs to be use. This allograft is provided by a bone bank and can be either a femoral head, as described by Harris [33, 34] or part of the distal femur [35]. Early on, Harris and colleagues warned of catastrophic failures. Jasty and Harris [36] reported a failure rate of 32% at 6 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, they also 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. Similarly, in a minimum 2 year follow-up study, Pollock et al. [37] showed 28.6% of migration and 30% of gross loosening. Further studies [38, 39] confirmed early

catastrophic failures. Paprosky et al. [40] 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. [41] 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. Therefore they advocated the use of an acetabular reinforcement ring in association with a structural allograft. Latest reports showed a survival of 74% and 72% at a mean 10- and 21 years, respectively, for Paprosky type IIIA acetabular defects revised with a structural allograft only [42, 43].

Cup Cage

This technique was first developed by Hanssen and Lewallen and reported in 2005 [44]. It consists in a trabecular metal (TM) acetabular shell and an ilioischial antiprotusio cage placed over the cup (full cup-cage reconstruction) (Fig. 9.1). The technique has been later modified and can be used in its half cup-cage version. It is somehow the reverse technique of a cage placed first in the acetabulum and then a cup is cemented into it. The rational of this construct was based on the fact that no bone ingrowth could be achieved into the cage whereas a TM acetabular shell allows and promotes bone ingrowth when placed first. Kosashvili et al. [45] reported on a series of 26 cases of acetabular revision including 24 patients with pelvic discontinuity (PD) and severe acetabular bone loss (a mean of 15.8% contact with bleeding host bone). After filling the defects with morsellised bone graft, the cup-cage contruct was put in place and a polyethylene liner 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 [46]. At a mean follow-up of 6.8 years and 5.75 years for the cup-cage and conventional cage

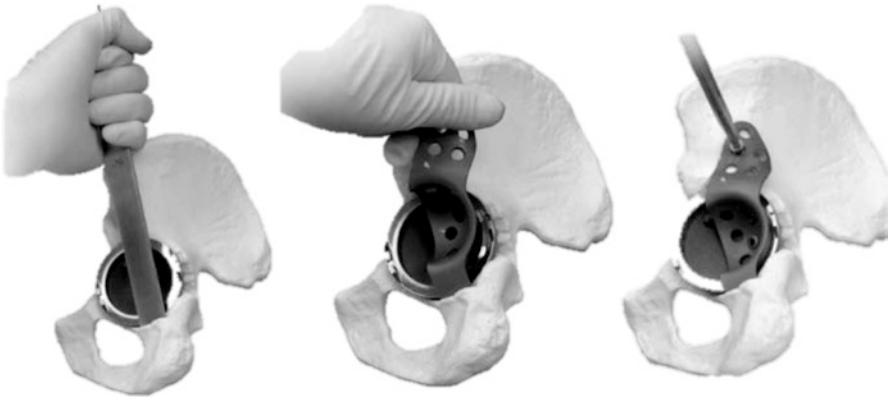

Fig. 9.1 The cup-cage construct. (Courtesy of Zimmer-Biomet)

groups respectively, the survivorship was significantly different. The cup-cage group had a survivorship of 87.2% whereas the conventional cage group had a survivorship of 49.9%. Four migrations occurred in the cup-cage group and three of them were revised. Similar results were reported by Amenabar et al. [47] 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 10-year survival rate of 85%. As stated earlier, the full cup-cage construct can be modified to a half cup-cage construct by removing the inferior flange of the cage. This evolution was reported by Sculco et al. [48]. The reasons for such an evolution, as mentioned by the authors, are numerous: (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 investigate 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 defects.

Proximal Fixation

The Müller Ring

The Müller ring became available in the 1980s and is still in use by some teams across the world. The Müller ring can be used either in primary or revision THA. 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 necessary. To ensure a strong fixation, the ring must have support from the posterior pillar, the medial wall and the superior acetabular lip [49]. Therefore, bone grafting is most of the time mandatory to achieve these requirements. The literature is very scarce regarding the use of the Müller ring in revision THA with severe bone loss. Early studies [49, 50] showed good and promising results but the follow-up was limited to 3–4 years and accurate description of the extension of bone loss in revision cases was absent. Therefore it is uncertain to draw any conclusions from those studies. Later, Zehntner and Ganz [51] 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. [52] showed no failure at a mean of 9-year of follow-up after revision THA using the Müller ring and bone allograft. However, their series was very small with only eight hips having AAOS type III defects. Similar results were found by van de Linde and Tonino [53] 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 Shneider cage. Schlegel et al. [54] 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 5 years but no difference was made between regarding the severity of the acetabular defects. Massin et al. [55] 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 large acetabular defects. From the small data available in the literature, the Müller ring appears to be insufficient for revision THAs with severe acetabular defects.

Proximal and Distal Fixation

The Ganz Ring

The design of the Ganz ring is similar to the Müller ring. The additional feature of the Ganz ring is an inferior hook meant to be placed under the inferior margin of the acetabulum providing a reliable way to restore the anatomic center of the hip (Fig. 9.2). The Ganz ring was initially used for primary THAs in developmental dysplasia of the hip [56]. The first study of its use for revision THAs was performed by Siebenrock et al. [57] in Germany, a group including Dr. Ganz, the designer of the ring. The authors revised 57 hips, among them, 36 hips had enough data to be incorporated in the study and most of them (n = 19) had a combined segmental and cavitary defect and three cases had a pelvic discontinuity. At a mean follow-up of 11.4 years, 8% of the hips undergone re-revision, two for aseptic loosening and one for septic loosening. Later on, Gerber et al. [58] used the Ganz ring for AAOS Type II, III and IV acetabular defects. Fifty hips were analyzed and defects were filled with morselized allograft bone. Their results showed seven failures due to aseptic loosening and the survivorship at 10 years was 81%. Further 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 appropriate for AAOS Type IV defects or segmental defects affecting the medial wall. Likewise, a Japanese team [59] evaluated the outcomes of the Ganz ring associated with bone allograft in 30 revision THAs. They used their own acetabular defect classification, which makes it difficult to compare to other studies. Moreover, they introduced a

Fig. 9.2 The Ganz® ring. (Courtesy of Zimmer-Biomet)

special technique for massive bone defect, which consisted in screwing two or three cancellous screws ("strut screws") in the allograft prior to installation of the ring. The authors reported five aspetic loosenings but none of them required re-revision and the survival rate using loosening, as the end point was 80.2% at 10 years. As previously shown by Gerber et al. the Japanese team also highlighted the critical importance of a reliable primary stability of the ring as 75% of the hips with malpositioning of the ring (hook out of position) failed. Lately, Hourscht et al. [60] investigated the outcomes of the Ganz ring with structural allograft in revision THAs with AAOS Type III and IV acetabular defects. Additionally, the Types IV were 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 5-year survival rate using revision for any reason was 86% and 57% in Type III and IV, respectively. Therefore, the authors concluded the Ganz ring should not be used when there is a pelvic discontinuity.

Taken together, these data show that the Ganz ring is reliable for minor acetabular defects but should not be used for AAOS Type IV acetabular defects or segmental defects affecting the medial wall.

The Kerboull Acetabular Reinforcement Device and Its Evolution

In the early 1970s, at the authors' institution, pelvic discontinuities associated with acetabular bone loss were present in some cases of metal on metal total hip arthroplasty. To fix the fracture and implant a new socket in one stage, in 1974 Marcel

Table 9.1 Comparative data regarding the Kerboull device used in major acetabular defects

Studies (authors)	Year	AAOS defect type (number of hip)	Mean follow-up (years)	Device used in the study	Survival/end point[a]
Kim et al. [62]	2015	n = 40 III (37); II (3)	12.8	KT + bulk allograft + HA	94.9%/revision for loosening (type III)
Hori et al. [63]	2011	n = 32 IV (3); III (29)	7.5	KT + bulk or morselised allograft	92.3%/revision for loosening or rx loosening
Akiyama et al. [64]	2011	n = 40 III (23); II (17)	6.7	KT + bulk or morselised allograft	87%/revision for loosening or rx loosening
Okano et al. [65]	2010	n = 31 III (29); II (2)	6.3	KT + bulk or morselised allograft	NA
Kawanabe et al. [66]	2007	n = 42 IV (1); III (28) II (13)	8.7	KT + bulk or morselised allograft	53%/failure of acetabular implant (morsellised allograft) 82%/failure of acetabular implant (bulk allograft)
Tanaka et al. [61]	2003	n = 21 III (16); II (5)	5.3	KT + HA ± morselised allograft	NA
Kerboull et al. [67]	2000	n = 60 IV (12); III (48)	8	Kerboull cage (original) + bulk allograft	92.1%/loosening of the acetabular implant

[a]Survival at the mean follow-up of the series
NA non available, *KT* Kerboull-Type device, *HA* hydroxyapatite, *rx* radiographic

Kerboull conceived a special acetabular armature, hemispheric cross shaped, with four arms, an inferior hook, and a superior plate. First intended for this indication, this device was used later as a guide and reinforcement with bulky frozen femoral head allografts in almost all acetabular reconstructions. This device can also be employed in primary THAs when dealing with fragile bone or altered anatomy such as is frequently the case following an acetabular fracture or a pelvic osteotomy. Series of reconstruction using the original device have been mainly reported from France, whereas a modification to its design has been made by Chiaki Tanaka [61] to adapt to Japan with favorable results. It should be emphasized that most of the early failures are related to inadequate surgical technique. Comparative data regarding the Kerboull device used in major acetabular defects are seen in Table 9.1.

Mechanical Principles

The Kerboull acetabular reinforcement device (KARD) is a semi-rigid and open component allowing prevention from graft overloading during the initial osseointegration process that starts with osteoclastic resorption. Also, because of its

Fig. 9.3 The original Kerboull device. (Courtesy of Zimmer-Biomet)

specific design, when correctly positioned, one can expect to accurately reconstruct the acetabular defect and orient the acetabular component. To achieve this goal, it is of major importance to choose the adequate size of the KARD, and to not modify its shape, that would alter its mechanical properties.

The KARD Evolution

The original KARD (Fig. 9.3) consists of a four-branched hemispheric cross, made of 316 L stainless steel. Its shape results from the orthogonal crossing of two hemispheric plates. The vertical plate ends distally with a hook which must be inserted 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 anterior branch being shorter than the posterior determines a 10° anteversion of the opening plane of the device. A left and a right series of the device are available in six sizes in which sockets with an outer diameter of 37–54 mm can be cemented (Fig. 9.4). 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.

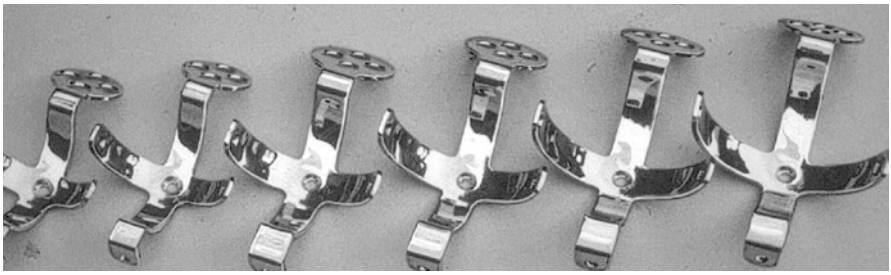

Fig. 9.4 The original KARD displayed in a series of six sizes

Fig. 9.5 The modified Kerboull device. (Courtesy of Medacta)

In some Paprosky III acetabular defects involving the tear drop requiring 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 including its the hook is of paramount importance for long-term survival. For this reason, we have recently modified the KARD (Kerboull Cage, Medacta International SA, Castel San Pietro, Switzerland). The general design and the number of sizes have not been modified, as can be seen in Fig. 9.5. However, based upon the results from Tanaka et al. [61] this new device is made of Grade 4 Titanium (ASTM F67) in order to increase the resistance to fatigue, whilst keeping the same rigidity by slightly increasing its thickness from 2 to 2.5 mm and remove the holes that were present on the branches and at their crossing. The finite element

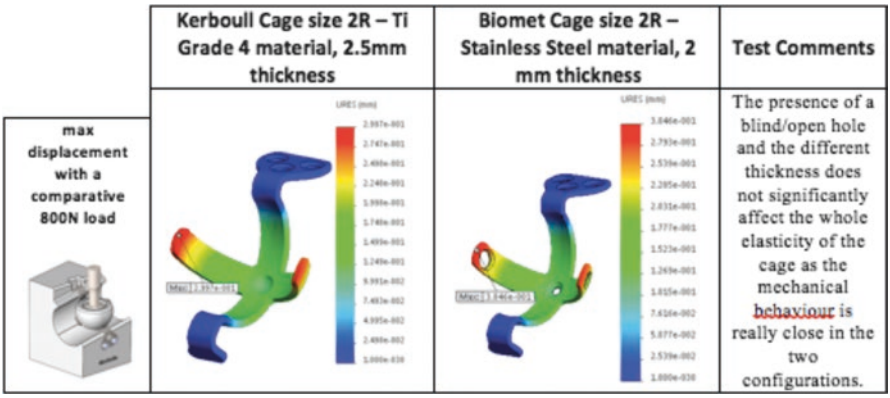

Fig. 9.6 Comparative fatigue resistance test between the new KARD (left) and the original KARD (right)

analysis indicated that taken together, these modifications did not modify the general rigidity of the device. We have also demonstrated in vitro that the fatigue resistance (Fig. 9.6) of the new design was greater than that of the original one. Indeed, the original version showed breakage at a maximal load of 800 N over 0.57 million cycles, whereas the new design did not exhibit failure at 1500 N up to eight million cycles (Table 9.2).

Also, the outer convex surface of the device has a sand-blasted finish in order to promote fixation to host bone where direct contact occurs.

Finally, the hook has been made larger in order to accommodate situations where the inferior margin is partially destroyed in order to increase its primary stability.

Surgical Technique

This section will not discuss the optimal approach to achieve the prerequisite goals but a wide exposure of the acetabular cavity is necessary to completely remove the loosened socket and the cement fragments when present. Of major importance is the complete excision of the fibrous membrane adherent to the socket and the granulation tissue filling in the defects. Also, remnant osteophytes and fibrous tissue present around the inferior margin should be completely excised in order to clearly visualize this region. The acetabular cavity is thereafter washed with pulsatile lavage. No reaming of the cavity is performed because of the fragility of the acetabular walls related to the bone stock loss.

The size of the device to choose should be anticipated on preoperative radiograph when the opposite hip is un-operated. Otherwise, intraoperatively it should

Table 9.2 Outcomes of fatigue resistance tests for the original KARD (Biomet) and the new KARD (Medacta)

Medacta Kerboull cage				Biomet CMK reinforcement cage			
Sample	Load(N)	TOT cycles	Result	Sample	Load(N)	TOT cycles	Result
1.1	3400	5140	Fracture	1.1 (step 1)	3400	574	Deformation
1.2 (step 1)	3400	3478	Fracture	1.2 (step 3)	800	1.58 milion	Fracture
1.3 (step 2)	2300	21,406	Fracture	1.3 (step 3)	800	0.52 milion	Fracture
1.4 (step 3) + locati	800	5 milion	No failure	1.4 (step 3)	800	0.57 milion	Fracture
	900	5.5 milion					
	1000	6 milion					
	1100	6.5 milion					
	1200	7 milion					
	1300	7.5 milion					
	1400	8 milion					
	1500	8 milion	Fracture				
1.5 (step 3) + locati	800	5 milion	No failure	1.5 (step 3)	800	0.63 milion	Fracture
	900	5.5 milion					
	1000	6 milion					
	1100	6.5 milion					
	1200	7 milion					
	1300	7.5 milion					
	1400	8 milion					
	1500	8 milion	Fracture				
1.6 (step 3) + locati	800	5 milion	No failure				
	900	5.5 milion					
	1000	6 milion					
	1100	6.5 milion					
	1200	7 milion					
	1300	7.3 milion	Fracture				

Courtesy of Medacta

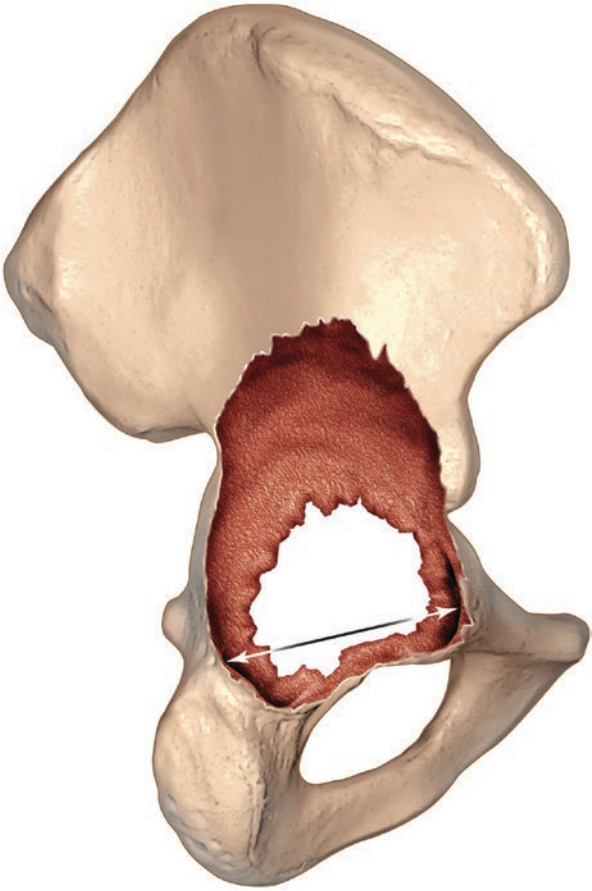

Fig. 9.7 Assessing the anatomic osseous size of the acetabulum

be based upon the anatomic osseous size of the acetabulum in the inferior part (Fig. 9.7).

The hook of the acetabular device must be placed under the teardrop in its posterior portion, near the ischium (Fig. 9.8). The acetabular device is then tilted 40–45° of abduction (Fig. 9.9). Once placed in its correction position, the device allows to assess 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 usually starts with acetabular roof restoration. This superior bone defect is reconstructed whenever possible, by one allograft block shaped from a fresh frozen femoral head allograft (Fig. 9.10). Then, the recon-

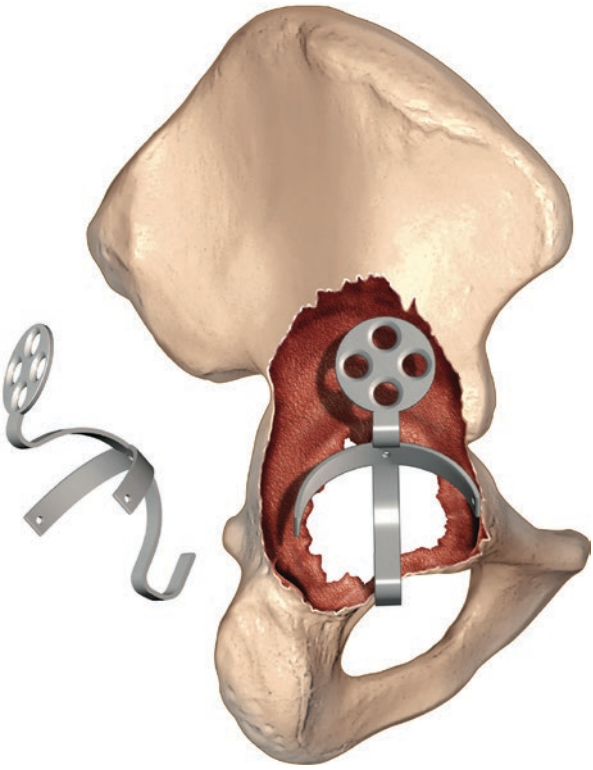

Fig. 9.8 The hook of the acetabular device must be placed under the teardrop in its posterior portion, near the ischium

struction of the medial wall is performed with an adequate slice cut from a femoral head. The plate then was fixed to the iliac host bone with 5-mm screws (Fig. 9.11). 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 fragments wedged in between the residual walls and the horizontal branches of the acetabular device (Fig. 9.12). Finally, the reconstruction is completed by morselized cancellous bone packed in the cavitary defects of the pubis and the ischium and in the gaps between the different allograft fragments to avoid any cement leak.

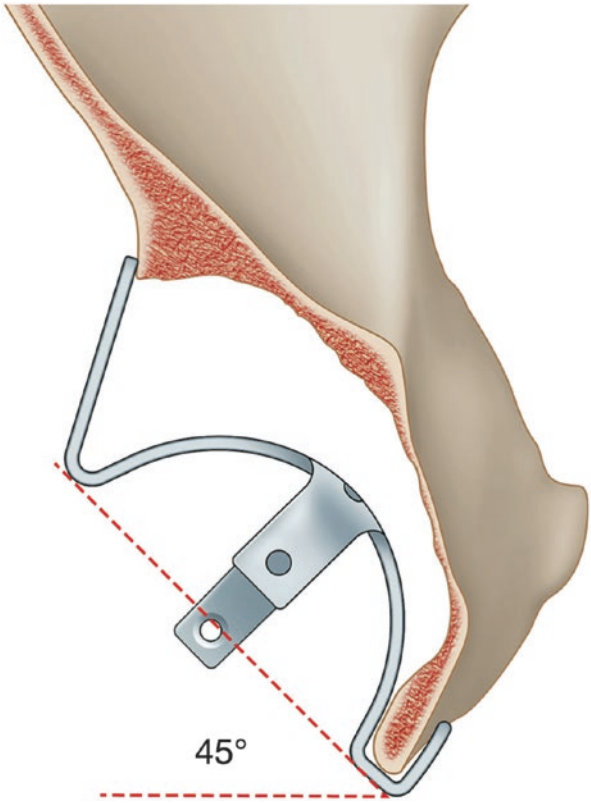

Fig. 9.9 The acetabular device is tilted 40–45° of abduction

The Gap Ring

Published data on the outcomes of the GAP ring (Graft Augmentation Prosthesis) are scarce. The design of this device is special as it combines an inferior hook to be placed under the teardrop and two superior plates for screw fixation to the pelvis (Fig. 9.13). The outside surface is made of grit blasted titanium with HA (hydroxyapatite) coating. Duffy et al. [68] investigated the GAP ring in revision THA. Within their series of 17 patients, they had 11 cases of severe acetabular bone loss graded AAOS type III. Six patients received bulk femoral heads. The average follow-up was 6.5 years, and at the latest follow-up, 7 of the 12 still alive patients were revised. Five cases were revised for fatigue failure of the GAP ring including four cases of breakage at the bone-plate junction. The authors concluded that "this device should not be used unless it is adequately supported by the host bone." In a similar study,

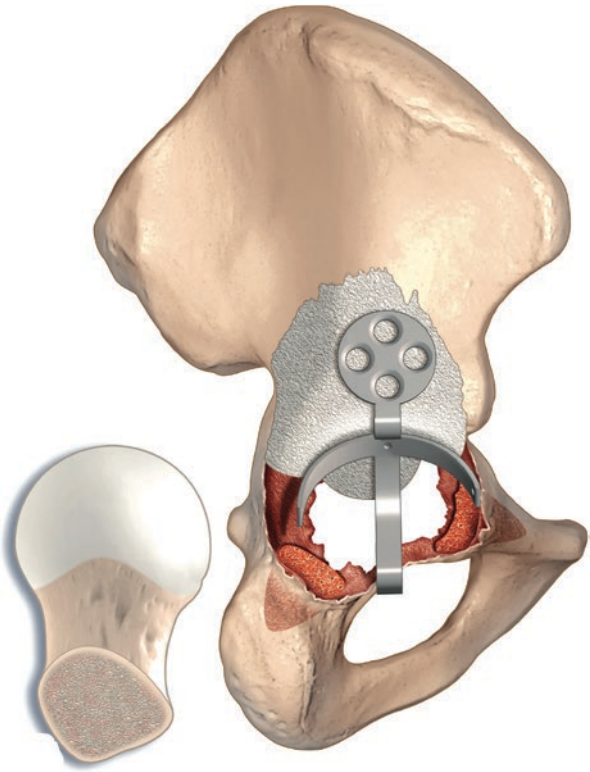

Fig. 9.10 This superior bone defect is reconstructed whenever possible, by one allograft block shaped from a fresh frozen femoral head allograft

Buttaro et al. [69] also found catastrophic early failure. In their work, they reviewed 24 cases of AAOS type III and IV acetabular defects treated with the GAP ring and bone allograft. At 34 months, the survival rate was 67%. Nine failures occurred at the last follow-up and they reported five fractures of the ring at the plate-cup junction. Eventually, the authors abandoned its use for the treatment of severe acetabular defects, especially AAOS type IV.

The Burch Schneider Cage and Its Evolution

The Burch Schneider cage is discussed in Chap. 9.

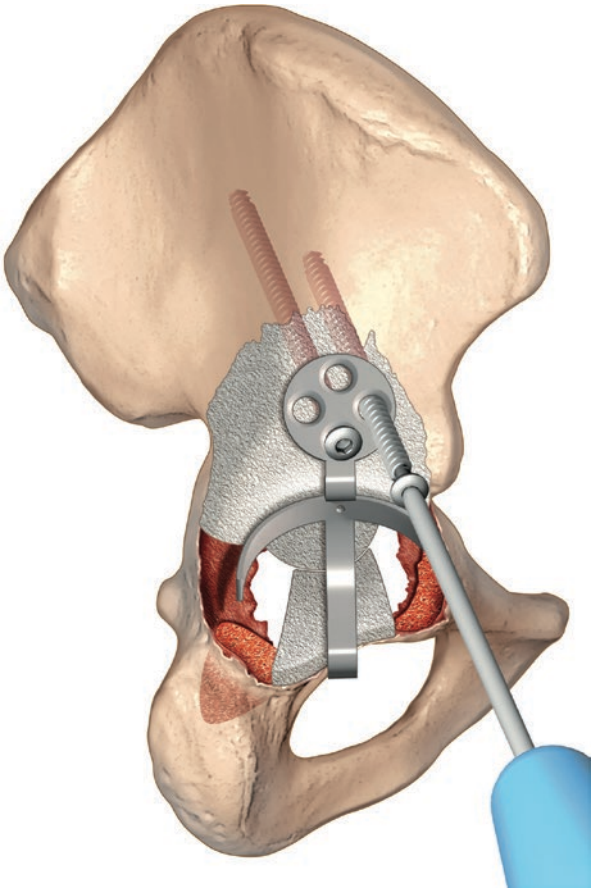

Fig. 9.11 The plate is fixed to the iliac host bone with 5-mm screws. At least two screws are used to obtain sufficient stability, always starting with the inferior screw

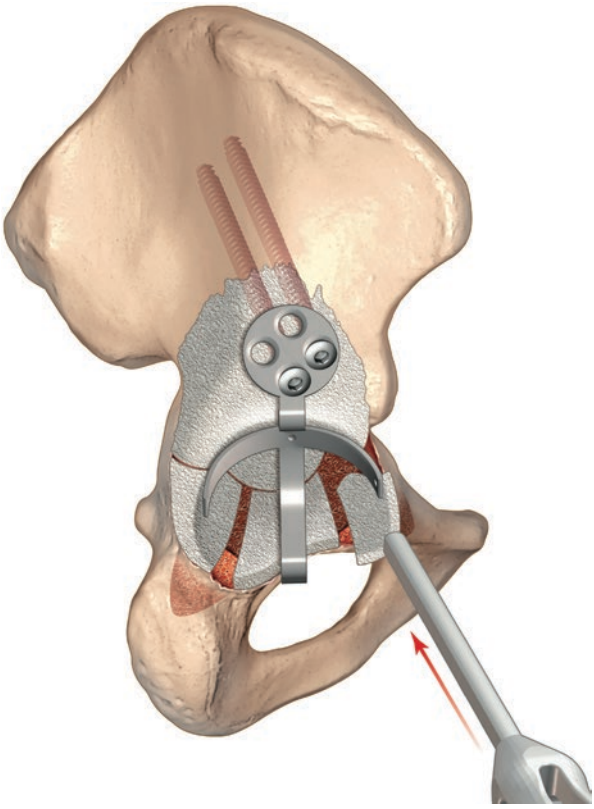

Fig. 9.12 Reconstruction of the anterior and posterior walls is performed using allograft fragments wedged in between the residual walls and the horizontal branches of the acetabular device

Fig. 9.13 The Gap II® ring. (Courtesy of Stryker)

Conclusion

Reconstruction of major acetabular defects is a surgical challenge. Nowadays, there are numerous acetabular reinforcement devices available on the market as well as various reconstruction techniques, with or without bone graft. The top priorities are to restore the anatomic center of rotation of the hip and ensure a long-term success of the reconstruction. Several solutions based upon the literature review and depending on the surgeon's own experience can be proposed to deal with these complex cases.

References

1. Kurtz SM, Ong KL, Schmier J, Zhao K, Mowat F, Lau E. Primary and revision arthroplasty surgery caseloads in the United States from 1990 to 2004. J Arthroplast. 2009;24(2):195–203.
2. Kurtz S, Mowat F, Ong K, Chan N, Lau E, Halpern M. Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002. J Bone Joint Surg Am. 2005;87(7):1487–97.

3. Kurtz SM, Ong KL, Lau E, Bozic KJ. Impact of the economic downturn on total joint replacement demand in the United States: updated projections to 2021. J Bone Joint Surg Am. 2014;96(8):624–30.
4. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89(4):780–5.
5. Inacio MCS, Graves SE, Pratt NL, Roughead EE, Nemes S. Increase in total joint arthroplasty projected from 2014 to 2046 in Australia: a conservative local model with international implications. Clin Orthop Relat Res. 2017;475(8):2130–7.
6. Patel A, Pavlou G, Mújica-Mota RE, Toms AD. The epidemiology of revision total knee and hip arthroplasty in England and Wales: a comparative analysis with projections for the United States. A study using the National Joint Registry dataset. Bone Joint J. 2015;97-B(8):1076–81.
7. Bozic KJ, Kurtz SM, Lau E, Ong K, Vail TP, Berry DJ. The epidemiology of revision total hip arthroplasty in the United States. J Bone Joint Surg Am. 2009;91(1):128–33.
8. Hanna SA, Somerville L, McCalden RW, Naudie DD, MacDonald SJ. Highly cross-linked polyethylene decreases the rate of revision of total hip arthroplasty compared with conventional polyethylene at 13 years' follow-up. Bone Joint J. 2016;98-B(1):28–32.
9. Shen C, Tang ZH, Hu JZ, Zou GY, Xiao RC, Yan DX. Does cross-linked polyethylene decrease the revision rate of total hip arthroplasty compared with conventional polyethylene? A meta-analysis. Orthop Traumatol Surg Res. 2014;100(7):745–50.
10. Bitsch RG, Loidolt T, Heisel C, Ball S, Schmalzried TP. Reduction of osteolysis with use of Marathon cross-linked polyethylene. A concise follow-up, at a minimum of five years, of a previous report. J Bone Joint Surg Am. 2008;90(7):1487–91.
11. Epinette J-A, Jolles-Haeberli BM. Comparative results from a National Joint Registry hip data set of a new cross-linked annealed polyethylene vs both conventional polyethylene and ceramic bearings. J Arthroplast. 2016;31(7):1483–91.
12. Delaunay C, Hamadouche M, Girard J, Duhamel A, So FG. What are the causes for failures of primary hip arthroplasties in France? Clin Orthop Relat Res. 2013;471(12):3863–9.
13. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res. 1976;121:20–32.
14. Chiang PP, Burke DW, Freiberg AA, Rubash HE. Osteolysis of the pelvis: evaluation and treatment. Clin Orthop Relat Res. 2003;417:164–74.
15. Engh CA, Glassman AH, Griffin WL, Mayer JG. Results of cementless revision for failed cemented total hip arthroplasty. Clin Orthop Relat Res. 1988;235:91–110.
16. Gustilo RB, Pasternak HS. Revision total hip arthroplasty with titanium ingrowth prosthesis and bone grafting for failed cemented femoral component loosening. Clin Orthop Relat Res. 1988;235:111–9.
17. D'Antonio JA, Capello WN, Borden LS, Bargar WL, Bierbaum BF, Boettcher WG, et al. Classification and management of acetabular abnormalities in total hip arthroplasty. Clin Orthop Relat Res. 1989;243:126–37.
18. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg. 2013;21(3):128–39.
19. Gross AE, Allan DG, Catre M, Garbuz DS, Stockley I. Bone grafts in hip replacement surgery. The pelvic side. Orthop Clin North Am. 1993;24(4):679–95.
20. Saleh KJ, Holtzman J, Gafni Asaleh L, Jaroszynski G, Wong P, Woodgate I, et al. Development, test reliability and validation of a classification for revision hip arthroplasty. J Orthop Res. 2001;19(1):50–6.
21. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplast. 1994;9(1):33–44.
22. Della Valle CJ, Berger RA, Rosenberg AG, Galante JO. Cementless acetabular reconstruction in revision total hip arthroplasty. Clin Orthop Relat Res. 2004;420:96–100.
23. Hallstrom BR, Golladay GJ, Vittetoe DA, Harris WH. Cementless acetabular revision with the Harris-Galante porous prosthesis. Results after a minimum of ten years of follow-up. J Bone Joint Surg Am. 2004;86-A(5):1007–11.

24. Park DK, Della Valle CJ, Quigley L, Moric M, Rosenberg AG, Galante JO. Revision of the acetabular component without cement. A concise follow-up, at twenty to twenty-four years, of a previous report. J Bone Joint Surg Am. 2009;91(2):350–5.
25. Templeton JE, Callaghan JJ, Goetz DD, Sullivan PM, Johnston RC. Revision of a cemented acetabular component to a cementless acetabular component. A ten to fourteen-year follow-up study. J Bone Joint Surg Am. 2001 2001/11//;83-A(11):1706–11.
26. Trumm BN, Callaghan JJ, Liu SS, Goetz DD, Johnston RC. Revision with cementless acetabular components: a concise follow-up, at a minimum of twenty years, of previous reports. J Bone Joint Surg Am. 2012;94(21):2001–4.
27. Boscainos PJ, Kellett CF, Maury AC, Backstein D, Gross AE. Management of periacetabular bone loss in revision hip arthroplasty. Clin Orthop Relat Res. 2007;465:159–65.
28. Garcia-Cimbrelo E. Porous-coated cementless acetabular cups in revision surgery: a 6- to 11-year follow-up study. J Arthroplast. 1999;14(4):397–406.
29. Goodman S, Saastamoinen H, Shasha N, Gross A. Complications of ilioischial reconstruction rings in revision total hip arthroplasty. J Arthroplast. 2004;19(4):436–46.
30. Morsi E, Garbuz D, Gross AE. Revision total hip arthroplasty with shelf bulk allografts. A long-term follow-up study. J Arthroplast. 1996;11(1):86–90.
31. Woodgate IG, Saleh KJ, Jaroszynski G, Agnidis Z, Woodgate MM, Gross AE. Minor column structural acetabular allografts in revision hip arthroplasty. Clin Orthop Relat Res. 2000;371:75–85.
32. Lee PTH, Raz G, Safir OA, Backstein DJ, Gross AE. Long-term results for minor column allografts in revision hip arthroplasty. Clin Orthop Relat Res. 2010;468(12):3295–303.
33. Harris WH. Allografting in total hip arthroplasty: in adults with severe acetabular deficiency including a surgical technique for bolting the graft to the ilium. Clin Orthop Relat Res. 1982;162:150–64.
34. Harris WH, Crothers O, Oh I. Total hip replacement and femoral-head bone-grafting for severe acetabular deficiency in adults. J Bone Joint Surg Am. 1977;59(6):752–9.
35. Sporer SM, O'Rourke M, Chong P, Paprosky WG. The use of structural distal femoral allografts for acetabular reconstruction. Surgical technique. J Bone Joint Surg Am. 2006;88(Suppl 1 Pt 1):92–9.
36. Jasty M, Harris WH. Salvage total hip reconstruction in patients with major acetabular bone deficiency using structural femoral head allografts. J Bone Joint Surg Br. 1990;72(1):63–7.
37. Pollock FH, Whiteside LA. The fate of massive allografts in total hip acetabular revision surgery. J Arthroplast. 1992;7(3):271–6.
38. Hooten JP, Engh CA, Engh CA. Failure of structural acetabular allografts in cementless revision hip arthroplasty. J Bone Joint Surg Br. 1994;76(3):419–22.
39. Kwong LM, Jasty M, Harris WH. High failure rate of bulk femoral head allografts in total hip acetabular reconstructions at 10 years. J Arthroplast. 1993;8(4):341–6.
40. Paprosky WG, Magnus RE. Principles of bone grafting in revision total hip arthroplasty. Acetabular technique. Clin Orthop Relat Res. 1994;298:147–55.
41. Garbuz D, Morsi E, Gross AE. Revision of the acetabular component of a total hip arthroplasty with a massive structural allograft. Study with a minimum five-year follow-up. J Bone Joint Surg Am. 1996;78(5):693–7.
42. Brown NM, Morrison J, Sporer SM, Paprosky WG. The use of structural distal femoral allograft for acetabular reconstruction of paprosky type IIIA defects at a mean 21 years of follow-up. J Arthroplast. 2016;31(3):680–3.
43. Sporer SM, O'Rourke M, Chong P, Paprosky WG. The use of structural distal femoral allografts for acetabular reconstruction. Average ten-year follow-up. J Bone Joint Surg Am. 2005;87(4):760–5.
44. Hanssen AD, Lewallen DG. Modular acetabular augments: composite void fillers. Orthopedics. 2005;28(9):971–2.

45. Kosashvili Y, Backstein D, Safir O, Lakstein D, Gross AE. Acetabular revision using an anti-protrusion (ilio-ischial) cage and trabecular metal acetabular component for severe acetabular bone loss associated with pelvic discontinuity. J Bone Joint Surg Br. 2009;91(7):870–6.
46. Abolghasemian M, Tangsaraporn S, Drexler M, Barbuto R, Backstein D, Safir O, et al. The challenge of pelvic discontinuity: cup-cage reconstruction does better than conventional cages in mid-term. Bone Joint J. 2014;96-B(2):195–200.
47. Amenabar T, Rahman WA, Hetaimish BM, Kuzyk PR, Safir OA, Gross AE. Promising mid-term results with a cup-cage construct for large acetabular defects and pelvic discontinuity. Clin Orthop Relat Res. 2016;474(2):408–14.
48. Sculco PK, Ledford CK, Hanssen AD, Abdel MP, Lewallen DG. The evolution of the cup-cage technique for major acetabular defects: full and half cup-cage reconstruction. J Bone Joint Surg Am. 2017;99(13):1104–10.
49. Haentjens P, Handelberg F, Casteleyn PP, Opdecam P. The Müller acetabular support ring. A preliminary review of indications and clinical results. Int Orthop. 1986;10(4):223–30.
50. Schatzker J, Glynn MK, Ritter D. A preliminary review of the Müller acetabular and Burch-Schneider antiprotrusio support rings. Arch Orthop Trauma Surg Arch Orthopadische Unfall-Chir. 1984;103(1):5–12.
51. Zehntner MK, Ganz R. Midterm results (5.5–10 years) of acetabular allograft reconstruction with the acetabular reinforcement ring during total hip revision. J Arthroplasty. 1994;9(5):469–79.
52. Korovessis P, Stamatakis M, Baikousis A, Katonis P, Petsinis G. Mueller roof reinforcement rings. Medium-term results. Clin Orthop Relat Res. 1999;362:125–37.
53. van der Linde M, Tonino A. Acetabular revision with impacted grafting and a reinforcement ring: 42 patients followed for a mean of 10 years. Acta Orthop Scand. 2001;72(3):221–7.
54. Schlegel UJ, Bitsch RG, Pritsch M, Clauss M, Mau H, Breusch SJ. Mueller reinforcement rings in acetabular revision: outcome in 164 hips followed for 2–17 years. Acta Orthop. 2006;77(2):234–41.
55. Massin P, Tanaka C, Huten D, Duparc J. Treatment of aseptic acetabular loosening by reconstruction combining bone graft and Müller ring. Actuarial analysis over 11 years. Rev Chir Orthop Reparatrice Appar Mot. 1998;84(1):51–60.
56. Gill TJ, Siebenrock K, Oberholzer R, Ganz R. Acetabular reconstruction in developmental dysplasia of the hip: results of the acetabular reinforcement ring with hook. J Arthroplast. 1999;14(2):131–7.
57. Siebenrock KA, Trochsler M, Sadri H, Ganz R. Hooked roof cup in revision of difficult loose hip prosthesis cups. Results after a minimum of 10 years. Orthopade. 2001;30(5):273–9.
58. Gerber A, Pisan M, Zurakowski D, Isler B. Ganz reinforcement ring for reconstruction of acetabular defects in revision total hip arthroplasty. J Bone Joint Surg Am. 2003;85-A(12):2358–64.
59. Uchiyama K, Takahira N, Fukushima K, Yamamoto T, Moriya M, Itoman M. Radiological evaluation of allograft reconstruction in acetabulum with Ganz reinforcement ring in revision total hip replacement. J Orthop Sci. 2010;15(6):764–71. https://doi.org/10.1007/s00776-010-1549-y.
60. Hourscht C, Abdelnasser MK, Ahmad SS, Kraler L, Keel MJ, Siebenrock KA, et al. Reconstruction of AAOS type III and IV acetabular defects with the Ganz reinforcement ring: high failure in pelvic discontinuity. Arch Orthop Trauma Surg. 2017;137(8):1139–48.
61. Tanaka C, Shikata J, Ikenaga M, Takahashi M. Acetabular reconstruction using a Kerboull-type acetabular reinforcement device and hydroxyapatite granules: a 3- to 8-year follow-up study. J Arthroplast. 2003;18(6):719–25.
62. Kim Y, Tanaka C, Kanoe H. Long-term outcome of acetabular reconstruction using a Kerboull-type acetabular reinforcement device with hydroxyapetite granule and structural autograft for AAOS type II and III acetabular defects. J Arthroplasty. 2015;30(10):1810–4. https://doi.org/10.1016/j.arth.2015.04.034.

63. Hori J, Yasunaga Y, Yamasaki T, Yoshida T, Oshima S, Yamasaki K, Matsuo T, Ochi M. Mid-term results of acetabular reconstruction using a Kerboull-type acetabular reinforcement device. Int Orthop. 2012;36(1):23–6. https://doi.org/10.1007/s00264-011-1248-0.
64. Akiyama H, Yamamoto K, Tsukanaka M, Kawanabe K, Otsuka H, So K, Goto K, Nakamura T. Revision total hip arthroplasty using a Kerboull-type acetabular reinforcement device with bone allograft: minimum 4.5-year follow-up results and mechanical analysis. J Bone Joint Surg Br. 2011;93(9):1194–200. https://doi.org/10.1302/0301-620x.93b9.26598.
65. Okano K, Miyata N, Enomoto H, Osaki M, Shindo H. Revision with impacted bone allografts and the Kerboull cross plate for massive bone defect of the acetabulum. J Arthroplasty. 2010;25(4):594–9. https://doi.org/10.1016/j.arth.2009.04.003.
66. Kawanabe K, Akiyama H, Onishi E, Nakamura T. Revision total hip replacement using the Kerboull acetabular reinforcement device with morsellised or bulk graft: results at a mean follow-up of 8.7 years. J Bone Joint Surg Br. 2007;89(1):26–31. https://doi.org/10.1302/0301-620x.89b1.18037.
67. Kerboull M, Hamadouche M, Kerboull L. The Kerboull acetabular reinforcement device in major acetabular reconstructions. Clin Orthop Relat Res. 2000;378:155–68.
68. Duffy GP, O'Connor MI, Brodersen MP. Fatigue failure of the GAP ring. J Arthroplast. 2007;22(5):711–4.
69. Buttaro MA, de la Rosa DM, Comba F, Piccaluga F. High failure rate with the GAP II ring and impacted allograft bone in severe acetabular defects. Clin Orthop Relat Res. 2012;470(11):3148–55.