



Pelvic discontinuity: a challenge to overcome

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- Pelvic discontinuity (PD) has been a considerable challenge for the hip revision arthroplasty surgeon. However, not all PDs are the same. Some occur during primary cup insertion, resembling a fresh periprosthetic fracture that separates the superior and inferior portions of the pelvis, while others are chronic as a result of gradual acetabular bone loss due to osteolysis and/or acetabular implant loosening.
- In the past, ORIF, various types of cages, bone grafts and bone cement were utilized with little success. Today, the biomechanics and biology of PD as well as new diagnostic tools and especially a variety of new implants and techniques are available to hip revision surgeons. Ultraporous cups and augments, cup-cage constructs and custom triflange components have revolutionized the treatment of PD when used in various combinations with ORIF and bone grafts. For chronic PD the cup-cage construct is the most popular method of reconstruction with good medium-term results.
- Dislocation continues to be the leading cause of failure in all situations, followed by infection. Ultimately, surgeons today have a big enough armamentarium to select the best treatment approach. Case individualization, personal experience and improvisation are the best assets to drive treatment decisions and strategies.

Keywords: arthroplasty; hip; outcomes; pelvic discontinuity; pelvic dissociation; revision; treatment

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It is projected that by 2030 the number of total hip arthroplasty (THA) revision procedures will have doubled in the USA.¹ Similar projections have been made in Australia, the UK and worldwide.^{2,3} Revision THA poses a major challenge for orthopaedists. Especially acetabular reconstruction and the management of acetabular bone loss can be demanding and challenging, even for the experienced revision arthroplasty surgeon. Perhaps of all the difficult scenarios that a surgeon can encounter, pelvic discontinuity (PD) is the most challenging.

Pelvic discontinuity or pelvis dissociation refers to the loss of structural continuity between the superior and inferior portions of the pelvis.⁴ Such disruption can occur either acutely during the impaction of an uncemented acetabular component or during the removal of the previous acetabular cup or in the setting of revision THR due to gradual acetabular bone loss.

Classification

According to the American Academy of Orthopaedic Surgeons (AAOS) classification as described by D'Antonio et al, pelvic discontinuities are considered type IV deficiencies.⁵ Berry et al further sub-classified the type IV AAOS bone loss in type IVa (PD + cavity bone loss), type IVb (PD + segmental bone loss) and type IVc (PD + previous irradiation of the pelvis with or without cavity or segmental bone loss).⁴

In other widely used classifications, such as that of Paprosky et al, PD can be seen in type IIC and IIIA defects but are more commonly associated with type IIIB defects.⁶ In Gross et al's classification, PD is described as a type V defect.⁷

Each classification system has demonstrated mixed validity and reliability in different studies.^{8,9} In the case of PD, regardless of the classification, there is general agreement that attempting to insert a standard hemispheric cap alone is prone to fail. In such cases variable degree complex reconstruction techniques have to be employed depending on the amount of associated bone loss.

PD can also be classified as stiff or flexible depending on the amount of movement at the PD site, and as acute PD (after an acetabular periprosthetic fracture) or chronic PD due to osteolysis and/or loosening. The latter resembles an acetabulum fracture nonunion in the presence of a loosened acetabular component.

Diagnosis and preoperative evaluation

As in any revision arthroplasty surgery, meticulous preoperative planning and evaluation is of paramount importance. Failure to recognize pre-existing problems such as

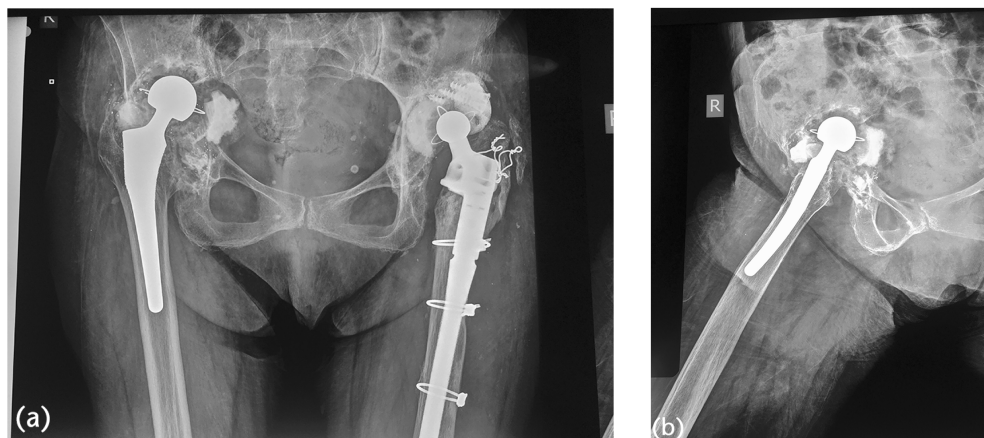


Fig. 1 (a) AP X-ray of a 76-year-old woman with DDH. She has a gross loosening and osteolysis of her R cemented cup. Loss of continuity is highly suspected. (b) Lateral X-ray of the same patient.

Notes. AP, anteroposterior; DDH, Developmental Dysplasia of the Hip; R, Right, GCB case.

infection, excessive bone loss, neurovascular dysfunction, malignancy, irradiation therapy, almost guarantees future complications and failures. Not recognizing the existence or the intraoperative iatrogenic creation of PD is perhaps the most common cause of surgery failure.

Preoperative evaluation starts with adequate radiographs including anteroposterior (AP) pelvis, AP view of the affected hip and lateral cross-table view of the hip. Additional examination with Judet views can be employed for more accurate diagnosis. Radiographic signs that indicate possible pelvic discontinuity include visible fracture line, obturator ring asymmetry and medial migration of the inferior hemipelvis (typically seen as a break in Kohler's line).⁴ However, it needs to be stressed that rarely are all three of these findings present or easily recognized in the setting of pelvic discontinuity (Fig. 1). Usually, the presence of previous implants or severe osteolysis renders the recognition of a fracture line difficult or even impossible. Additionally, signs such as the asymmetry of the obturator ring can be difficult to assess or can be misleading due to the possibility of bad pelvis positioning during X-ray examination. In the Judet views, presence of a fracture line throughout both columns is strongly indicative of pelvic discontinuity. Martin et al have demonstrated that combining the findings of an AP pelvis radiograph plus a lateral radiograph of the hip plus the Judet views allowed for identification of pelvic discontinuity in an extremely high percentage of patients.¹⁰

Other, less popular radiographic exams have been described to assist pelvic discontinuity diagnosis. Giori et al found that a lateral radiograph of the pelvis and/or high-angle oblique view (10–20° off a lateral view) of the pelvis can provide excellent visualization of the posterior column and aid in the diagnosis of pelvic discontinuity.¹¹

Wendt et al, working on cadaver pelvises, showed that the so called Lequesne view, or false profile view, can clearly show the posterior column and can more reliably reveal pelvic discontinuity.¹² The false profile view is a 65° oblique radiograph, where the pelvis is examined in a supine position on a 65° block and the radiograph is taken from a straight anterior position. This radiograph has been previously used to measure the severity of developmental dysplasia of the hip.

Computed tomographic (CT) scan of the acetabulum is also recommended for the diagnosis. It can diagnose a fracture line and help assess the degree of osteolysis and bone loss.¹³ On the other hand, the presence of previous prosthesis can limit its diagnostic value, due to the artifacts. Thick cuts, axial reconstruction parallel to the discontinuity fracture line, in combination with poor image due to artifacts can be misleading and lead to underestimation or even overestimation the presence of pelvic discontinuity.¹⁴

Metal artifact reduction (MAR) techniques and thin cuts can improve the diagnostic accuracy of CT scans.¹⁵ Three-dimensional (3D) CT reconstructions can also markedly improve detection and also facilitate the assessment of the degree and location of bone loss. Interestingly, Aprato et al¹⁴ showed that 3D modelling had higher specificity than traditional and 3D CT scans in identification of pelvic discontinuity. Three-dimensional modelling is not just a 3D reconstruction, but the development of a model based on bone structures and metal hardware segmentation. It also allows for better preoperative planning and tools and implant selection (Fig. 3).

Ultimately, the diagnosis of pelvic discontinuity should be done and confirmed intraoperatively, after the removal of the previous components. The pathognomonic finding

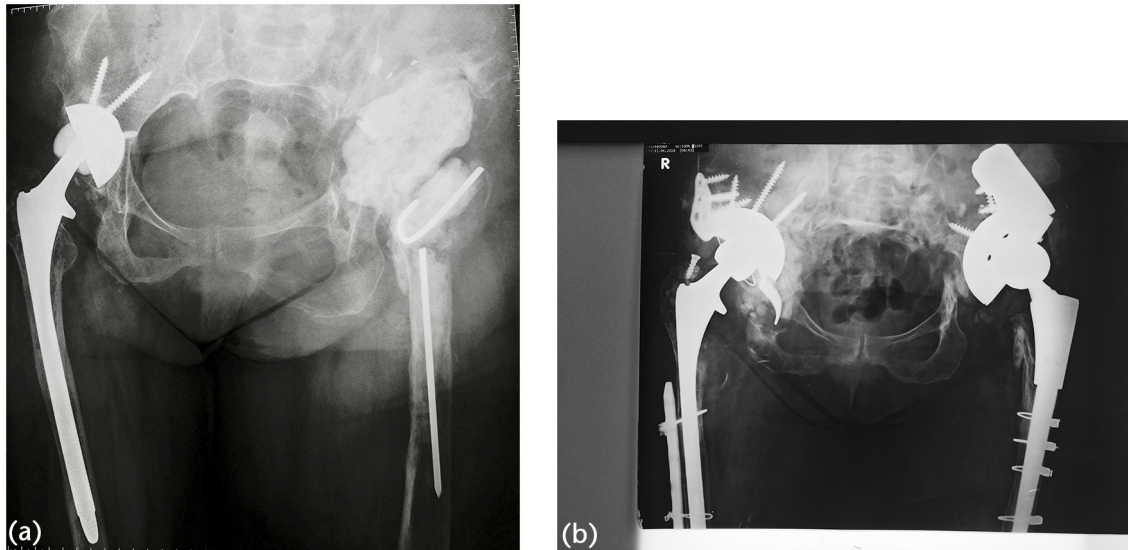


Fig. 2 (a) Left hip. PD and treatment of concurrent PJI with a spacer (broken). (b) Ultraporous tantalum cup supported by ultraporous tantalum wedge. PD is ununited but the cup-wedge construct is stable six years later.

Notes. PD, pelvic discontinuity; PJI, Periprosthetic Joint Infection, GCB case.

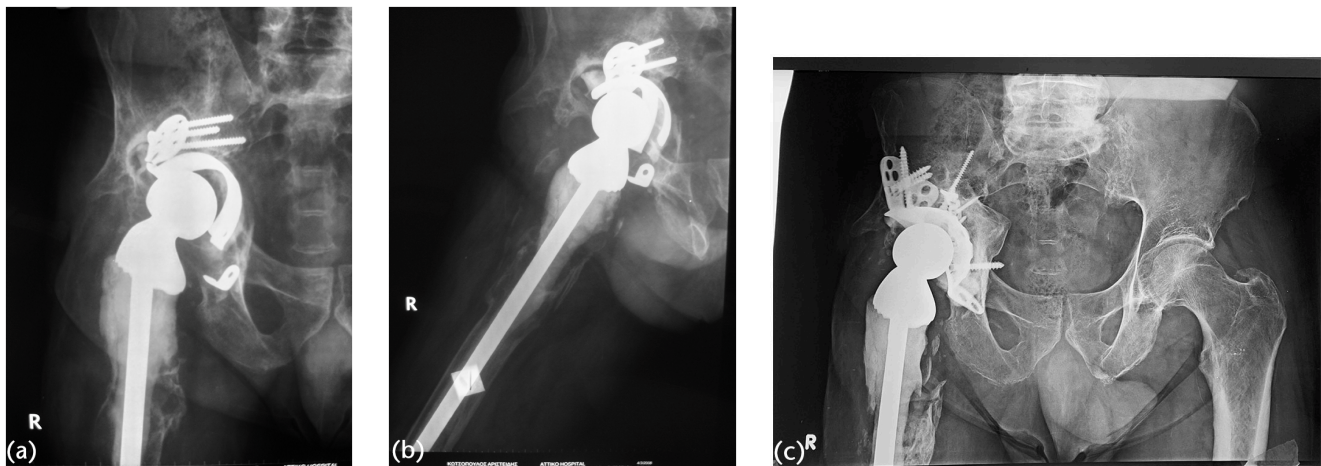


Fig. 3 (a) AP X-ray of pelvic discontinuity after revision for PJI. (b) Lateral X-ray of pelvic discontinuity after revision for PJI. (c) AP X-ray. After PJI was excluded, ORIF of the discontinuity, bone grafts and a full ischial cage, the PD united completely and the construct is stable 12 years post op.

Notes. AP, anteroposterior; PJI, Periprosthetic Joint Infection; ORIF, open reduction and internal fixation; PD, pelvic discontinuity, GCB case.

is an abnormal motion between the superior and inferior portions of the acetabulum. An instrument, such as a Cobb elevator or similar, can be used and gentle force can be applied on the inferior hemipelvis.^{4,16} Abnormal motion between the superior and inferior hemipelvis confirms the diagnosis. Inevitably, excessive osteolysis and/or presence of fibrous tissue may mask the presence of the fracture line. After meticulous removal of the previous prosthesis and careful debridement of the scar tissue and osteolytic lesions, then it is time to definitively classify

the bone defects and choose the appropriate reconstructive strategy.

Acute versus chronic pelvic discontinuity

Acute and chronic pelvic discontinuity are two different entities with differences in the biomechanical behaviour and the biological dynamic of healing and stability. Consequently, the treatment approach and the reconstruction techniques differ accordingly.¹⁷

Acute pelvic discontinuity usually occurs in the setting of acute trauma (i.e. falls) or is iatrogenic due to overreaming during the acetabular preparation, the uncemented acetabular shell impaction or during aggressive implant removal. Periprosthetic stress fracture, causing PD has been also described.¹⁸ Acute PD has the potential for healing and shows minimal gapping between the superior and inferior hemipelvis. Thus, bony apposition with compression is possible after acetabular cup removal.¹⁷

Chronic pelvic discontinuity usually occurs progressively due to bone resorption secondary to periprosthetic osteolysis and osteopenia with increasing age. Chronic discontinuity has a poor potential for healing. It may show large amounts of fibrous tissue between the hemipelves with the bone itself being sclerotic or non-vascularized. In fact it acts similar to an atrophic or fibrous nonunion.¹⁹

Detailed patient history and thorough preoperative imaging are mandatory to distinguish between chronic or acute pelvic discontinuity. However, as mentioned before, the final verdict should be made according to the intraoperative findings.

Management of the patient with pelvic discontinuity

As in any revision case, careful clinical examination and preoperative planning is of paramount importance. Apart from the imaging studies, patients' medical history and comorbidities should be registered. When possible, previous stickers of all implants should be obtained. Previous scars at the site of the operation should be registered. The integrity of the abductor mechanism should be examined. Any neurovascular impairment should be also examined and registered. Blood tests including serum erythrocytes sedimentation and C-reactive protein level should be routinely obtained before surgery. When infection is suspected, joint aspiration should be performed and the infection should be excluded according to the latest guidelines.²⁰

Before entering the operating room, the surgeon must be prepared for any unfavourable scenario. A variety of implant removal tools must be handy available, accommodating every possible scenario. The surgical approach must be chosen according to the surgeon's experience and the need for extensile acetabular approach and/or the need for femoral stem removal.

For pelvic discontinuity cases the posterolateral approach to the hip is the most popular approach. It allows for excellent exposure of the acetabulum, the posterior column and ilium. Additionally, a trochanteric osteotomy, or extended trochanteric osteotomy (ETO) can be used even if the choice is made intraoperatively.

In general, trochanteric osteotomies (including trochanteric slide, ETO, Wagner, or transfemoral osteotomy) are useful not only for the removal of the femoral stem but also to allow for a wider acetabular exposure without irreversibly compromising the abductor mechanism. Apart from the posterolateral approach, other authors have published good results using direct lateral with or without osteotomy approaches²¹ and more recently using the direct anterior approach.^{22,23} Lakstein et al^{24,25} have demonstrated that a modified sliding trochanteric osteotomy or modified ETO, with preservation of the posterior aspect of the greater trochanter and the attached external rotators and posterior hip capsule yielded excellent results in complex revision hip arthroplasty cases including PD.²⁵

Regardless of the approach that is used, the goals of PD reconstruction are: achieving a rigid fixation of the acetabular component to the pelvis and stabilizing the hemipelvis either by healing of that dissociation or by using the acetabular component as a bridge to stabilize the superior and inferior pelvis.

A number of techniques have been described to address pelvic discontinuity. Eventually, as Berry et al⁴ described, four are the guiding principles: firstly the problem itself has to be identified. Secondly the discontinuity scar tissue has to be removed and thirdly continuity between the superior and inferior hemipelvis has to be re-established, using if necessary, bone grafting. Finally a stable acetabular implant, preferably with the potential of bone ingrowth, has to be implanted.⁴

The main reconstruction strategies include: jumbo acetabular cups with or without porous metal augments, hemispheric acetabular components combined with open reduction and internal fixation (ORIF) with plates, cage reconstructions, cup-cage constructs, the distraction method, and finally custom triflange components.

Porous acetabular cups with or without porous metal augments

In cases with acute PD and good bone stock and quality, by firstly removing the previous cup and then fixing the discontinuity using ORIF, use of a highly porous metal acetabular component, such as porous tantalum cups, can be employed (Fig. 2a–b).

Tantalum porous structure resembles that of the cancellous bone and facilitates bone ingrowth, offering good primary and secondary stability.²⁶ Published studies on porous tantalum cups, used in revision THR surgery, have shown good short and medium-term results.^{27,28} Relatively newer highly porous implants, such as the trabecular titanium (TT) cups and augments have been also introduced with initially encouraging results.^{29,30}

In cases of PD, multiple screws at the superior (ilium) and inferior (ischium and pubis) hemipelvis assist with the stabilization of the construct. Bone graft, preferably autologous, is placed at the PD site. Thus, the cup itself acts as an internal fixator, as long as adequate viable host bone–implant contact is achieved (both superiorly and inferiorly) to promote biologic fixation. In cases where bone defect is also present, porous metal augments can be used to support the acetabular cup.

Sporer and Paprosky reported excellent results in 13 patients with PD treated with tantalum components. In eight of these patients a tantalum augment was used to fill bone defects. However, the mean follow-up time was only 2.6 years.¹⁶ Weeden and Schmidt assessed the effectiveness of tantalum porous metal implants in patients with type 3A and 3B deficiencies, according to the Paprosky classification.³¹ Ten of the 43 hips had pelvic discontinuity. In all PD cases a tantalum augment was used to fill bone defects. They reported 98% stability at minimum two years follow-up. Jenkins et al reported the minimum five years clinical and radiographic follow-up of 84 patients (85 hips) who underwent revision with a tantalum cup and augments.²⁷ Eleven hips had PD. The authors reported an overall 97% survivorship at minimum five years. However, they stressed that six of the 11 hips with preoperative pelvic discontinuity either failed or developed a radiolucency in zone 3 (according to DeLee and Charnley zones)³² and thus were considered at risk for future revision. In a recent large series, Martin et al³³ retrospectively reviewed 113 THA revisions, that presented PD. Ten patients (9%) were treated with a cup only. At five years only 80% of patients had a stable acetabular component. Additionally, only 50% of patients had radiographic present healing of the discontinuity. These mixed and sub-optimal results indicate that in case of PD usually an additional fixation strategy should be employed.

Hemispheric acetabular component and open reduction and internal fixation (ORIF) with plates

Posterior column plating with compression of the fracture and grafting, along with a hemispheric high porous acetabular component is a more reasonable option for acute pelvic discontinuity and in selected cases of chronic pelvic discontinuity with good bone stock and biology. In Martins et al's series,³³ 50 hips (44%) were treated with posterior column plate and an uncemented cup. Five-year revision-free survivorship of the implant was 80% and healing of the PD was evident in 74% of the patients. The authors concluded that other constructs such as using a supportive cage achieved better results than plating alone. In another series, Rogers et al used posterior column plating in patients with acute pelvic discontinuity.¹⁷

At a mean follow-up of 34 months, in all eight cases, hip reconstruction remained intact.

When possible, simple anterior column fractures can also be fixed in order to enhance stability. Double plating of the anterior and posterior column has been also suggested, offering more rigid fixation but with the cost of a most extensile approach and longer operating times.^{34,35} In a biomechanical study using an artificial pelvis Gilliland et al showed that plating of the posterior column in combination with an antegrade screw fixation of the anterior column created a more rigid construct, without the need for extensile approaches.³⁶

In any case, absolute stability is essential for acetabular implant bone ingrowth, therefore, apart from the fracture plating, multiple screws through the cup, superiorly at the ilium and inferiorly at the ischium and the pubis if possible, are mandatory.

The Kerboull plate offers an alternative ORIF to stabilize PD. It is a cross-plate that was firstly introduced in 1974 by Marcel Kerboull.³⁷ It is made of stainless steel and has a hemispheric cross-configuration. Its design allows for a hook on the distal side to be inserted and fixed to the teardrop and superior border of the obturator foramen, and a plate on the proximal side that can be fixed to the iliac bone with cortical screws. In the majority of published series this plate has been combined with grafts, acting as a protective device during the graft incorporation period. Kerboull et al³⁷ retrospectively looked at 60 hip revision cases performed with the Kerboull plate and allografts. Among these cases there were only 12 hips in 12 patients, with type IV acetabular defects according to AAOS classification. At mean follow-up time of 10 years there were only three failures, due to graft absorption. Other authors have also published favourable results, using this device. Wegrzyn et al³⁸ evaluated the results of THR revision in 85 patients (85 hips). There were seven type IV (AAOS) acetabular defects. A cemented dual mobility cap was used in all cases. At mean follow-up time of 7.5 years there was no failure. Similarly, Makita et al³⁹ investigated the results of revision THA in 65 hips (59 patients) with Paprosky type 3A or 3B acetabular bone defects. The mean follow-up duration was 11.2 years. Among them, there were seven cases with PD. In all patients the Kerboull plate and allografts were used. They reported 91% overall acetabular implant survivorship at 15.2 years. The main reason for revision in this series was aseptic loosening due to polyethylene wear. In earlier series authors have recognized that when acetabular defects involve the teardrop (for example for Paprosky III defects), then there is a high risk of proximal and medial migration of the device and high risk of failure.^{40–42} Overall, there is still scarcity of results specifically for pelvic discontinuity cases. Therefore, the Kerboull plate may not be routinely used in PD cases.

Cages and rings

Historically, reconstruction cages and rings have been the workhorse to deal with massive acetabular bone loss.⁴³ Especially in the cases of chronic PD, mainly ilioischial spanning cages^{4,44–46} but also non-ilioischial spanning cages and rings^{45,47,48} offered a treatment strategy for decades. In the majority of cases the reinforcement cage or ring protects the underlying structural of morselized allograft. A cemented liner is then cemented in the cage or ring in the proper orientation.

The Ganz reinforcement ring (Sulzer Medica, Winterthur, Switzerland) was designed to reinforce the anterior and posterior walls, the acetabular dome, and the acetabular fossa. It was originally designed to reconstruct dysplastic hips. The ring's hook is placed around the inferior pole of the acetabulum and multiple screws are allowed to the supra-acetabular part of the ilium, where adequate bone stock is available.⁴⁹ Similarly, the Graft Augmentation Prosthesis (GAP) II (Stryker Orthopaedics, Mahwah, NJ) is a reconstruction ring, made from grit-blasted titanium. It has an inferior hook and two superior plates to facilitate fixation to the ilium. It also allows for multiple screws to the acetabular dome, for extra stability.⁵⁰ However, results using these implants in cases of PD have been sub-optimal.^{48,50–52} In a recent review and meta-analysis, Malahias et al⁵³ have found that the survival rate of non-ilioischial spanning cages in patients with PD was 60.6% (20 of 33 cases). Specifically, the revision rate of the acetabular component only was 39.4% (13 of 33 cases). The most common modes of failure included aseptic loosening, and infection. Implant fatigue failures have been also reported.⁵²

Perhaps the most commonly used ilioischial spanning cage is the Burch-Schneider (BS) cage. It was first designed by Burch and later modified by Schneider during the 1970s.⁵⁴ It is a malleable construct consisting of a superior flange fixed with screws on the ilium and an inferior flange that is either slotted into the ischium or screwed on the ischium. Numerous screw holes allow for further fixation. (fig 3 a-c.) The implant was originally made of polished steel, but modern third-generation BS cages were introduced in 1998 and were made of a biocompatible rough-blasted TiAlNb alloy which allows for some bone ongrowth at the backside of the cage. Paprosky et al⁴⁵ presented the mean five-year follow-up of 16 THA revisions for PD. The BS cage was combined with posterior column plate and morselized or structural allograft. Seven out of the 16 cases were either revised or found to be loose. In another series, Goodman et al⁵⁵ presented the results of 10 cases of PD using an antiprotusio cage and allograft. They found 50% failure rate at mean follow-up time of 41 months. Better results were presented by Regis et al.⁴⁴ They treated 18 patients (18 hips) with PD with a BS cage

and bulk allograft. At mean follow-up time of 13.5 years, they revised only three cages (one for infection). The overall survival rate at 16.6 years with acetabular revision for any reason, radiographic loosening, or unhealing of the discontinuity as the end point was 72.2%. Other authors have presented mixed results.^{4,17,33} According to Malahias et al's⁵³ systematic review, with a mean follow-up time ranging from 35 to 162 months, the overall survival rate of ilioischial spanning cages in PD cases was 66.7%.

An interesting approach is the combination of antiprotusio cages with tantalum augments. Baecker et al⁵⁶ presented a series of 20 patients with Paprosky type IIIA or IIIB defects who underwent revision of the acetabular component with a tantalum augment, positioned at the weight-bearing acetabular dome and an antiprotusio cage and bone graft combination. Four of these patients had PD. At the latest follow-up (mean 2.8 years) only two of the 20 acetabular components had failed, mainly due to failure of the distal flange of the cage. It seems that the tantalum augments prevent superior migration of the cage, which is a common mode of failure. Nevertheless, larger series with longer follow-up time are needed to prove this concept.

Cup-cage

As discussed earlier, PD represents a complex problem for the revision arthroplasty surgeon, as in the unstable environment of a chronic pelvis dissociation, acetabular implant stability must be achieved along with a biologic promotion of the chronic fracture nonunion healing. The cup-cage concept (Fig. 4, Fig. 5) was first reported by Hanssen and Lewallen.⁵⁷ This technique has become popular in the treatment of chronic PD and also in the management of complex cases with massive bone loss.⁵⁸ Cup-cage constructs use an uncemented high porous metal component supplemented with a cage with flanges that engage both the ilium and the ischium. Structural and/or morselized allograft or high porous metal augments can be used to fill the remaining bone defects. Multiple screws are used superiorly and inferiorly to stabilize the construct. A liner is then cemented into the cage at the proper orientation. In theory, the cage protects the acetabular shell until bone ingrowth occurs, and also the allograft until it is incorporated.⁵⁹

Technical challenges when using this method are not rare. In the majority of cases the bone defects are large enough to accommodate a highly porous jumbo acetabular cup (a cup that measures at least 62 mm in women and 66 mm in men)⁶⁰ and a cage to accommodate a large enough polyethylene liner. However, in smaller hips, it is sometimes mandatory to also use smaller implants and cement small polyethylene liners that accept only 28 mm or even 22 mm heads. This can make the hip joint

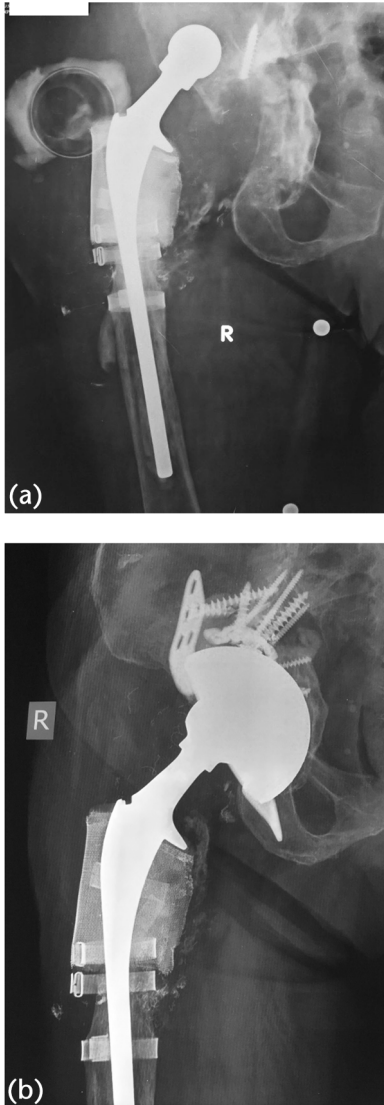


Fig. 4 (a) AP X-ray of a dislocated hip with a completely dislodged cemented cup. There is gross flexible PD. (b) A technique described by the senior author (GCB). Intra-acetabular ORIF and then cup cage-construct. PD is united and the contract is stable 10 years postoperatively.

Notes. AP, anteroposterior; PD, pelvic discontinuity, GCB case.

unstable and prone to dislocation. Another issue is that the acetabular shell has to be positioned more vertically and relatively retroverted in order to accommodate the cage.⁵⁹ The surgeon has to be careful to cement the liner at the correct orientation and also to avoid impingements. Moreover, securing the distal flange of the cage into the ischium is mandatory, in order to stabilize the discontinuity and add rotational stability to the cup cage construct. Often the ischium is inadequate to support the distal flange due to fracture or osteolysis. In such cases the distal flange cannot be securely embedded and the sciatic nerve can also be at risk.⁵⁵

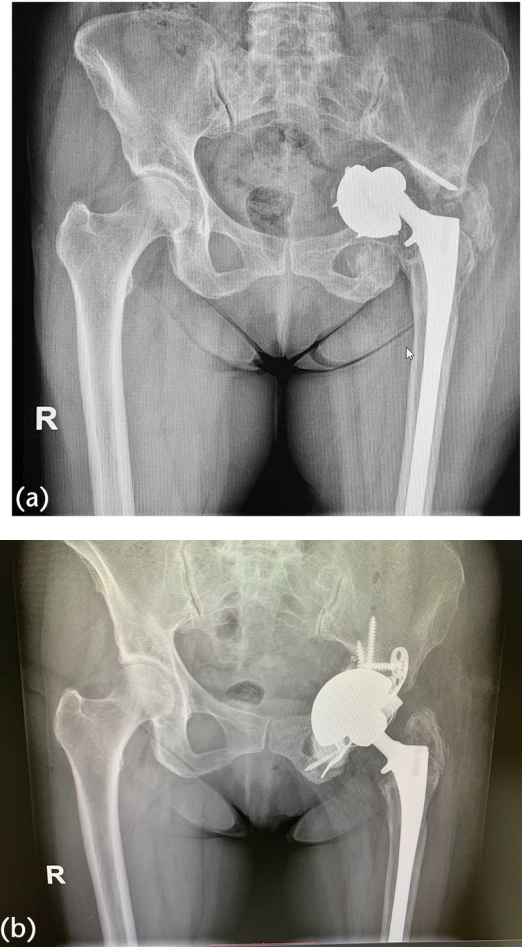


Fig. 5 (a) Gross pelvic discontinuity with intrapelvic cup protrusion. (b) A stable cup cage construct, GCB case.

Recently, Sculco et al⁶¹ presented the concept of the ‘half cup-cage reconstruction’ to address some of the aforementioned technical problems with the cage’s distal flange. By removing the distal flange from the ‘full cup-cage’ a ‘single-flanged cup-cage’ construct is created. Then multiple screws are placed through the remaining cage and through the cup distally. To analyse the outcomes of the half cup-cage construct the authors compared in a small preliminary study 27 revision THAs performed with this technique to 30 revision THAs with the full cup-cage construct. Twenty patients who were treated with full cup-cage and 14 who were treated with half cup-cage had Paprosky 3B defects and PD. They reported two sciatic nerve injuries with the full 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.

Overall, the cup-cage technique has been around for quite some time now to demonstrate not only early results but medium-term results as well. It is currently the most

popular method to address chronic PD.⁵³ Konan et al⁶² presented the 2–10 year follow-up (mean five years) of 24 patients treated with cup-cage construct for PD. They reported a 75% (18/24) success rate for the procedure, taking as failure aseptic loosening plus clinical and radiological failures of the constructs. Half of the failures were due to instability. Amenabar et al⁵⁸ reported the medium-term follow-up of 67 cup-cages in 64 patients. Forty-five hips had an acetabular defect in association with PD. Results showed that for these cases the revision rate for any cause was 9% (4/45 cases) at a mean follow-up time of 77 months. The main cause for revision was aseptic loosening. Martin et al³³ analysed data on 113 consecutive revision THRs performed for the treatment of unilateral PD: 27 hips (24%) received a cup-cage construct. The five-year revision-free survivorship of these patients was 100%. Dislocation occurred in 7% of patients. Overall, in Malahias et al's systematic review,⁵³ the survival rate of cup-cage constructs in PD cases was 91.9% (158 of 172 hips). Specifically, the revision rate for the acetabular component was 8.1%. The main reason for revision was dislocation (6.4% of cases), infection (6.4% of cases) and aseptic loosening (3.5% of cases). Similar results were presented in a more recent systematic review by Wang et al,⁶³ who reported the outcome of 232 patients who underwent revision THR, mainly presenting with AAOS type III and type IV defects. The mean follow-up period was 48.85 months (range, 1–140). They found a revision rate of 8% and an all-cause complication rate of 20%. The most commonly reported complication was dislocation, followed by aseptic loosening.

Acetabular distraction

Acetabular distraction was introduced in 2012 by Sporer et al.⁶⁴ According to the described technique, instead of compressing the discontinuity fracture line, acetabular distraction is used, thus further expanding the defect. In brief, after acetabulum exposure and verification of the discontinuity, careful debridement is performed to remove all interposed fibrous tissue and granulation tissue and to uncover viable host bone. Sequentially larger reamers are used until the anterior-superior and posterior-inferior margins of the acetabulum are engaged. Larger bone defects are filled with porous tantalum augments. The superior and inferior aspect of the hemipelvis are then distracted and a high porous tantalum acetabular component, 6–8 mm larger than the last reamer, is positioned. Due to the distraction, initial stability of the acetabular shell is achieved and then multiple screws are placed both superiorly and inferiorly to create a more stable construct. The liner is then cemented in the appropriate orientation.⁶⁴

At their initial publication Sporer et al⁶⁴ reported good medium-term results using this technique with one out of 20 (5%) patients revised for aseptic loosening. Four other patients presented cup migration but were found to be clinically asymptomatic and radiographically stable at four-year follow-up. In a more recent study, Sheth et al⁶⁵ presented the follow-up of the previous patients, with the addition of 12 more patients from two institutions. Overall, 32 patients were included with a mean follow-up of 62 months (range: 25 to 160). Results showed that one patient (3%) required acetabular revision for aseptic loosening (at 7.5 years). Two patients had evidence of radiographic loosening but were not revised, and three patients had migration of the acetabular component into a more stable configuration. Kaplan-Meier survivorship was 83.3% when using revision for aseptic loosening as an endpoint. The authors reported two cases of neurovascular injury. They speculated that over distraction may have transfer excessive stress to the adjacent neurovascular structures. They also emphasized that recognizing a flexible discontinuity is important, in order to avoid over-distraction. Currently there are no further studies to support these promising results.

Triflange custom-made implants

A custom triflange acetabular component is another option to address chronic discontinuities with excessive bone loss (Fig. 6). These implants are custom-made titanium components with three flanges (iliac, ischial and pubic). In order to facilitate osseointegration, porous coatings and hydroxyapatite are often applied to the flanges and backside acetabular portion of the implant. A CT scan with thin cuts of the patient's hip is obtained preoperatively, and a 3D model is created representing the hemipelvis with its bone defects. On the basis of this model a custom triflange component is created, allowing for stable fixation to the remaining solid host bone and also bringing the hip joint's centre of rotation back to its normal position. The surgeon has the opportunity to select the preferred location, inclination, and anteversion of the acetabular cup, as well as the positioning of flanges, location and direction of screws, and number of holes. Usually, multiple screws are positioned through all three flanges in order to achieve excellent stability, thus assisting the potential healing of the discontinuity.

At the moment there are series presenting very promising short to medium-term results. Taunton et al⁶⁶ retrospectively reviewed 57 patients with pelvic discontinuity treated with revision THA using a custom triflange acetabular component. At a mean follow-up time of 65 months (24–215 months) they reported three failures (5.3%) of the triflange acetabular components

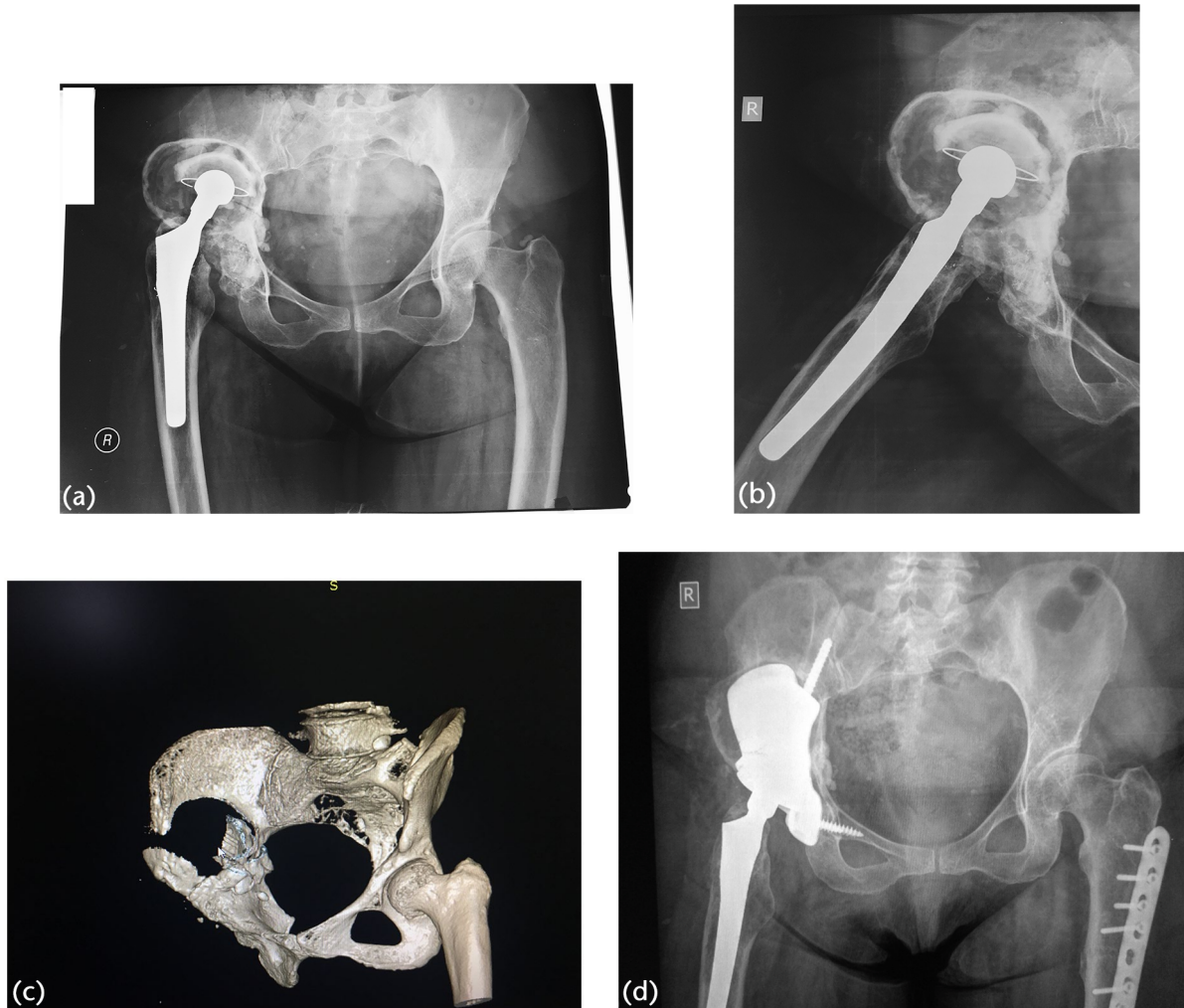


Fig. 6 (a) AP X-ray, a 62-year-old woman with extensive osteolysis after a THA with ultra-high cup placement for DDH. (b) Lateral preoperative X-ray. A fracture line is seen in the acetabulum. (c) 3D-CT showing the osteolysis and PD. (d) Bridging and filling the gap by a custom-made prosthesis with cemented dual mobility cup after 1.5 years follow-up. The patient has resumed light activities.

Notes. AP, anteroposterior; THA, total hip arthroplasty; DDH, Developmental Dysplasia of the Hip; 3D CT, three-dimensional computed tomography; PD, pelvic discontinuity, GCB case.

(two for infection). Forty-six of 57 (81%) triflange acetabular components were judged stable with a healed pelvic discontinuity. However, they also reported 21% dislocation rate. Matar et al⁶⁷ retrospectively reviewed 17 patients (17 hips) treated with custom triflange implants for Paprosky 3A/3B acetabular defects and PD. The mean follow-up was 3.6 years (2–7 years). Specifically, 15 hips (88%) had PD. Excellent results were achieved with 100% survivorship of the implants at the latest follow-up. In an earlier series, Christie et al⁶⁸ retrospectively reviewed 86 hips in 76 patients, treated with custom triflange implant for massive acetabular defect. Thirty-nine hips had PD. At a mean follow-up time of 53 months (24–107 months), no triflange cup was removed. However, there were six dislocations (7.8%)

that required reoperation. Malahias et al⁵³ reported in their systematic review, 95.8% (91 of 95 cases) overall survival rate of custom triflange acetabular components in patients with PD. They also confirmed that the main reasons for reoperation were dislocation (17.9%) followed by infection (6.3%).

Dealing with cases of massive bone defects

Fortunately, rarely, surgeons have to deal with such massive bone defects and PDs that none of the previously described implants can be applied to secure a stable hip prosthesis. In such cases salvage procedures and techniques have been presented, mostly in case series, giving solutions for both surgeons and patients.

Stemmed acetabular implants have been used for years, mainly in tumour resection surgeries. Multiple designs have been presented, including the so called ‘ice cream cone’ (Coned Hemi-Pelvis; Stanmore Implants, Elstree, UK),^{69,70} the McMinn cup (Link, Newsplint, Basingstoke, United Kingdom),⁷¹ the Ring prosthesis (Zimmer, Swindon, United Kingdom),^{72,73} the titanium pedestal cup,⁷⁴ the modular reconstructive cup (ModuRec system, Zimmer, Warsaw, IN),⁷⁵ the Integra cup with peg (Lépine, Genay, France)⁷⁶ etc. These prostheses rely on the good quality bone stock of the iliac isthmus, which is defined by the thick part of the ilium between the roof of the acetabulum and the sacroiliac joint.⁷⁶ Studies have shown that the iliac isthmus remains intact even in cases of extremely severe bone loss so, apart from in tumour cases, it has also been used for severe acetabular defects including PD. Indeed, Sakai et al⁷⁵ retrospectively reviewed the clinical and radiographic results of modular reconstructive cups and morselized allografts at a minimum 10-year follow-up (10–14 years), in 54 acetabular revisions. Among these cases there were four patients with PD. Results showed that using aseptic loosening as the endpoint, the survival rate was 89.3%. Earlier series revealed less optimistic results. Eisler et al⁷⁷ presented the results of 26 acetabular

reconstructions at five orthopaedic centres in Sweden. Twenty-four (92%) patients had severe bone defects. At median follow-up time of three years (1–3 years) 43.8% of cups have either been revised or presented definite loosening. Matharu et al⁶⁹ presented the results of the Stanmore ‘ice cream cone’ prosthesis in 28 acetabular reconstructions. Fifteen concerned oncology patients and 13 patients requiring complex arthroplasty. Ten of them presented PD. At mean follow-up of 12.5 months (2–33 months) there were no failures in patients with PD. In another series, Stihsen et al⁷⁸ investigated 35 patients (35 hips) who underwent revision THA using the Schoellner pedestal component (Zimmer, Freiburg, Germany) for severe acetabular defects. The mean follow-up time was 63 months (24 to 141 months). All patients had major acetabular defects and 13 had PD. The five-year survival for aseptic loosening was 94% in patients without PD but 56% in those with PD. Five patients (14%) had dislocation and there was one injury to an iliac vessel and one lesion of the femoral nerve. The authors advised caution in the use of this prosthesis in patients with PD.

These conflicting results indicate that it is still unclear whether these implants are appropriate to treat PDs. However, especially with the newer designs, results of these

Table 1. Selected series of PD reconstruction techniques, with a minimum mean five years (60 months) follow-up

Study, year	Nr of hips	Acetabular defect	Nr of PDs	Reconstruction type	Follow-up time	Acetabular implant survivorship (PD cases)	Main mode of failure
Jenkins et al, 2017 ²⁷	58	Paprosky type 2A: 4 type 3A: 28 type 2B: 3 type 3B: 22	11	Porous tantalum cup and augment	Minimum 5 years (Mean time N/A)	10/11 implants (90.0%) 5/11 implants radiographically at risk of failure	Aseptic loosening
Martin et al, 2017 ³³	113	AAOS type IVa: 2 type IVb: 108 type IVc: 3	113	Uncemented cup and posterior column ORIF (50 pts)	Mean 5.6 years (range, 3.2 to 8.9 years)	80%	Dislocation and infection
Kerboull et al, 2000 ³⁷	60	AAOS type III: 48 type IV: 12	12	Kerboull reinforcement acetabular device + Bulk allograft	Mean 10 years ± 3 years	11/12 implants (96.6%)	Aseptic loosening (graft resorption)
Hourscht et al, 2017 ⁴⁸	46	AAOS type III: 26 type IV: 15	15	Ganz reinforcement ring + with structural and morselized bone graft	Mean 74 months (24–161 months)	11/20 (55%)	Aseptic loosening
Regis et al, 2012 ⁴⁴	18	AAOS type IV: 18	18	Burch-Schneider cage + bulk allografts	13.5 years (10.5–16.6 years)	72.2%	Aseptic loosening
Amenabar et al, 2016 ⁵⁸	67	Gross type IV: 26 type V: 41	45	Cup-cage	74 months (24–135 months)	41/45 (91%)	Aseptic loosening
Sheth et al, 2018 ⁶⁵	32	Paprosky type IIC: 7 type IIIA: 5, type IIIB: 20	32	Acetabular distraction	mean 62 months (25 to 160 months)	31/32 (97%) 7 patients with radiographic risk of failure	Aseptic loosening
Taunton et al, 2012 ⁶⁶	57	AAOS type IV: 57	57	Custom triflange acetabular component	Mean 65 months (24–215 months)	54/57 (94.7%) stable component 12/57 (21%) developed instability	Instability infection

Notes. AAOS, American Academy of Orthopaedic Surgeons; N/A: not available; ORIF, open reduction and internal fixation; PD, pelvic discontinuity.

coned acetabular components are promising. All authors agree that implantation can be technically demanding, and initial success relies on the ability of the surgeon to correctly foot position and align the stem within the ilium.⁶⁹ Other complications that can be expected include infection, hip dislocation and aseptic loosening. Inevitably, larger series and longer follow-up time are needed to draw safer conclusions.

Another salvage option, when dealing with non-reconstructible PDs is placing a bipolar hemiarthroplasty in a high hip centre (hip transposition). This method has been described primarily by tumour surgeons but there are a few cases reported in the area of revision THR as well.⁷⁹ In brief, after the removal of the previous acetabular component, and if the PD and the bone defects are deemed non-repairable, a bipolar hemiarthroplasty head is positioned in a high hip centre, lateral to the ilium. A soft tissue cavity is created by the remnants of the capsule and the surrounding scar tissue. Post surgery the patient is allowed to ambulate with partial weight-bearing and gradually increase to full weight-bearing. Chalidis and Ries⁷⁹ presented two patients with PD (three hips) and reported fair results.

Finally, the so called Girdlestone procedure⁸⁰ might be the best option in cases where the bone stock is extremely poor and any attempt to reconstruct the hip joint is doomed to failure and also endangers the health and the life of the patient.

Dislocation seems to be the leading cause of failure in all situations, followed by infection. As dual mobility cups are gaining in popularity, there is hope that the problem of instability will be also reduced.⁸¹

Ultimately, surgeons today have a big enough armamentarium to select the best treatment approach (Table 1). Case individualization and personal experience are the best assets to drive treatment decisions and strategies.

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