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REVIEW

Reconstruction of failed acetabular component in the presence of severe acetabular bone loss: a systematic review

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Abstract
Acetabular revision especially in the presence of severe bone loss is challenging. There is a paucity of literature critiquing contemporary techniques of revision acetabular reconstruction and their outcomes. The purpose of this study was to systematically review the literature and to report clinical outcomes and survival of contemporary acetabular revision arthroplasty techniques (tantalum metal shells, uncemented revision jumbo shells, reinforced cages and rings, oblong shells and custom-made triflange constructs). Full-text papers and those with an abstract in English published from January 2001 to January 2016 were identified through international databases. A total of 50 papers of level IV scientific evidence, comprising 2811 hips in total, fulfilled the inclusion criteria and were included. Overall, patients had improved outcomes irrespective of the technique of reconstruction as documented by postoperative hip scores. Our pooled analysis suggests that oblong cups components had a lower failure rate compared with other different materials considered in this review. Custom-made triflange cups had one of highest failure rates. However, this may reflect the complexity of revisions and severity of bone loss. The most common postoperative complication reported in all groups was dislocation. This review confirms successful acetabular reconstructions using diverse techniques depending on the type of bone loss and highlights key features and outcomes of different techniques. In particular, oblong cups and tantalum shells have successful survivorship.

Keywords Acetabular revision surgery · Paprosky classification · Hip revision surgery · Acetabular defects · Pelvic discontinuity

Introduction

Total hip arthroplasty (THA) is considered one of the most successful procedures in orthopaedic surgery with regard to relieving pain and improving function in patients with end-stage degenerative hip joint disease.

Kurtz et al. [1] reported that the number of THA per year will exceed 50,000 by the year 2020 in the USA alone, and concurrently the number of arthroplasties performed per annum worldwide is expected to double within the next two decades [2].

As the number of THA increases every year, the number of revision cases is likely to rise as well.

The main reasons for acetabular revisions are aseptic loosening, instability due to a malposition of the component or abductor mechanism failure, infection, failure of fixation and fracture [3, 4].

Acetabular revision surgery can be challenging due to the loss of acetabular bone stock and the poor conditions of soft tissues [3, 4].

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Severe acetabular bone loss and pelvic discontinuity pose a technical challenge for revision surgery, and these affect the mechanical stability and interfere with the osteointegration of the acetabular component. Several reconstruction methods are available for acetabular revision surgery including trabecular metal components, reinforcement devices as cages and rings, oblong shells, cone shells (stemmed shells), uncemented jumbo revision shells and custom-made triflange shells [5]. The choice to select a particular technique is often based on the available bone stock, available implants, surgical expertise and preference. No single technique of acetabular reconstruction has shown superior results, and this may be due to several factors such as paucity of published clinical results, inconsistent reporting of outcomes and practical difficulties with long-term follow-up [5].

The aim of this systematic review and pooled analysis was to (1) consolidate the techniques for reconstruction of failed acetabular components and (2) where feasible, compare the clinical, radiological and functional outcomes of different reconstruction techniques.

Materials and methods

Search strategy

A comprehensive literature search was performed using the search engines Medline (OvidSP), PubMed Database (US National Library of Medicine, National Institutes of Health), Embase, Web of Science, Cochrane and Google Scholar. These databases were searched for articles published between January 2001 and August 2016. The citations within the identified article were searched to confirm the inclusion of all papers.

Eligibility criteria

The studies selected were original articles fulfilling the following 6 criteria:

(1) One of the following techniques for acetabular revision arthroplasty in non-neoplastic conditions was used: (i) tantalum metal systems, (ii) reinforced devices such as cages and rings, (iii) oblong cups, (iv) custom-made triflange cups, (v) cone cups, (vi) uncemented jumbo revision cup. (2) The indications for surgery were failed acetabular shells associated with severe bone defects corresponding to Paprosky III and IV grades or AAOS 3 and 4 grades. (3) Postoperative complications were reported. (4) Full-text articles were available. (5) Articles were written in English. (6) The studies' designs were randomized controlled trial, prospective cohort study, retrospective cohort study or case control study. All studies that did not meet these criteria were excluded.

Identification of eligible studies

Identified studies were screened, based on title and/or abstract, independently by two reviewers. Disagreements were solved by consensus. All final decisions, in the case of uncertainty, were resolved by mutual agreement between the two reviewers.

Data extraction

Two independent reviewers performed data extraction from each included publication.

Extracted data from the included studies were as follows: study type, year of publication, number of included subjects, gender, mean patient age at time of revision surgery, bone defect's classification, technique of revision, mean duration of follow-up, radiographic follow-up, mortality rate, identification of any complications intraoperatively and postoperatively, revision rate and implant survival, functional validated outcome scores and quality of life assessments.

Risk-of-bias assessment

Observational studies were heterogeneous with regard to study population, methodological quality, duration of follow-up and measurement of outcomes, we therefore followed standard practice and refrained from statistically pooling the data and performed a 'best-evidence' synthesis based on the studies of van Tulder et al. [6] and of Malmivaara et al. [7].

Each study was assessed using a checklist (Table 1). A maximum score of ten points could be obtained. The quality score calculated was not used as an exclusion criterion. According to the total quality score, articles were considered of high methodological quality if a total score of six points or higher had been rewarded. The materials extracted by two reviewers were compared to each other; any conflicting data re-checked from the original papers and corrected after discussion.

Outcome measures

The primary outcome measure was failure of the acetabular component defined as the need for a revision, or a reoperation as in the case of liner exchange. The modes of failure were classified into two types, mechanical failure (aseptic loosening, component fracture, periprosthetic fractures, abductor mechanism failures/dislocation) or non-mechanical failure (i.e. septic joint infections requiring washout, hematoma requiring incision and drainage with irrigation), following classifications described by Korim et al. [8].

Table 1 List of criteria used for methodological quality assessment

Criteria for the assessment of the study quality	
Question	Response
1. Is there a clearly stated aim?	Did they have a 'study question' or 'main aim' or 'objective'? The question addressed should be precise and relevant in light of available literature. To be scored *adequate* the aim of the study should be coherent with the 'Introduction' of the paper
2. Is the inclusion of patients described in sufficient detail so that you could compare it to the patient population you treat or to the materials of other studies on the same subject?	Did the authors report the inclusion and exclusion criteria?
3. Prospective collection of data. Data were collected according to a protocol established before the beginning of the study	Did they say 'prospective,' 'retrospective' or 'follow-up'? The study is NOT PROSPECTIVE when: chart review, database review, clinical guideline, practical summaries
4. Is the intervention described in sufficient detail so that you could provide the same treatment for your own patients?	Did they report the surgical technique description?
5. Are the primary outcome measures reported?	Did they report outcome measures to evaluate patients after the operation?
6. Unbiased assessment of the study outcome and determinants	To be judged as *adequate* the following 2 aspects had to be positive: Outcome and determinants had to be measured independently Both for cases and controls the outcome and determinants had to be assessed in the same way
7. Were the determinant measures used accurate (valid and reliable)?	For studies where the determinant measures are shown to be valid and reliable, the question should be answered *adequate*. For studies, which refer to other work that demonstrates the determinant measures are accurate, the question should be answered as *adequate*
8. Are the complications peri-operatively and postoperatively reported?	Did they report the complications and the following treatment in details?
9. Are there any losses to follow-up?	Did they report the losses to follow-up?
10. Is the statistical analyses adequate?	Was an adequate statistical analyses performed?

Secondary outcome measures were: validated hip scores to assess improvements in pain and function, and incidence of radiographic loosening defined as radiographic lucency on follow-up radiographs.

Results

Identification and selection of the literature

From the initial 2571 relevant articles identified, 2521 publications were excluded based on title and abstract, because they did not meet the inclusion criteria. Consequently, a total of 50 studies of level IV scientific evidence were included. A flowchart of the literature search is presented in Fig. 1.

No randomized controlled trials (RCTs) were available. However, this was expected given the nature of the study.

Acetabular shells with stems ('ice-cream cones') were excluded from the study at this stage because of the few papers available; none met the inclusion criteria.

Seven papers were included in the custom-made triflange cup group, 7 publications in the uncemented jumbo revision cup group, 5 papers in the oblong cup group, 14 publications

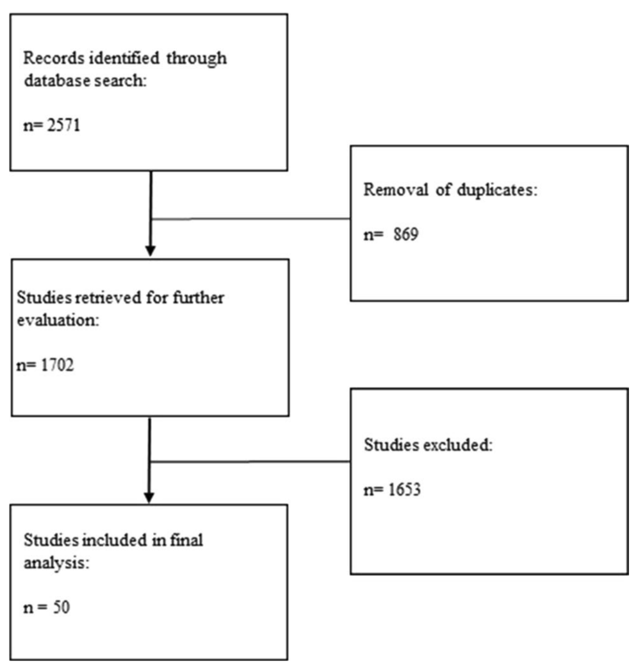

Fig. 1 Sequence of the literature search

in the reinforced devices such as cages and rings, and 17 publications in the Trabecular Metal shell group.

Risk-of-bias assessment

According to the predefined criteria, the majority of the studies included in this review had a total score higher than six points and were considered to have a low risk of bias. Nine studies had a score of less than six points and therefore were considered to have a higher risk of bias.

The mean quality score in the custom-made triflange cup group was 6.5 [range from 5 to 8], 7.1 [range from 6 to 9] in the uncemented jumbo revision cup group, 5.6 [range from 5 to 7] in the oblong cup group, 6.8 [range from 5 to 9] in the in the group of reinforced devices as cages and rings, and 6.4 [range from 5 to 9] in the group with Trabecular Metal cups (Table 2).

Custom-made triflange cup group

The demographics of the patients in the custom-made triflange group [9–15] were mean ages ranging from 55.8 to 69 years; percentage of male patients ranged from 11.7 to 50%. Body mass index (BMI) was only recorded in 2 studies (28 kg/m^2 [10] and 27 kg/m^2 [12]). All studies were carried out in the USA [9, 10, 12–15] except for 1 study from Belgium [11]. All studies were carried out between 2001 and 2015. These studies included a total of 233 patients (238 hips). Of these 3 were classified as Paprosky 3A and 64 Paprosky 3B, 42 AAOS type 3 and 139 AAOS type 4.

Mean age at the time of the surgery of 62.5 years and patients were followed up for a mean of 57.9 months (range 28.5–123). Outcomes of this group are summarized in Table 3.

There were 38 re-operations for any reason (failure rate of 15.9%). The most common cause for reoperation was due to chronic instability or liner exchange with a rate 10.9% (26/238). The most common complication followed this procedure was dislocation at 15.5% (37/238).

There were 37 patients with custom-made triflage cups whose hips subsequently dislocated. This complication was more common when a constrained liner was not used [10, 12]. One single surgeon series of six patients reported no dislocations at a minimum of 10-month follow-up when an anterolateral approach was used [11]. However, most commonly this implant was placed through a posterior [10, 12–14] or posterolateral approach [15]. In 5 of the revisions for dislocation, the femoral component was not revised [10]. Other potential factor attributed to dislocation was trochanteric escape. One multicentre trial [12] with a post-revision dislocation rate of 21% reported preoperative trochanteric escape as a potential contributing factor and also that the custom-made triflange construct requires a significant amount of soft tissue dissection putting the superior gluteal nerve at risk and destroys the soft tissue protective mechanism. To reduce this risk, the authors recommended the use of constrained sockets and postoperative bracing in the context of preoperative trochanteric escape [12]. When patients required reoperation for recurrent dislocation, a constrained liner was commonly used [10, 15]; however, constrained liners do not always prevent dislocation [10] and one case of revision for dislocation was due to failure of the locking ring in the constrained liner which subsequently required exchange [10].

A total of 12 cases were reported for probable radiological loosening, but these were not revised. In one study [10], two minor pull-offs from ischium of the acetabular component were seen, but they were noted to stabilized at the lasted follow-up.

In another study [12], the migration of at least a part of the triflange acetabular component was observed in eight patients, and in five of those that migrated, pelvic discontinuity apparently healed.

One study reported two cases [15], where the components demonstrated radiological loosening and migration with screw disengagement from the ischium. However, patients were not symptomatic enough and refused additional surgical interventions in the light of comorbidities.

The studies reporting functional outcomes noted mean improvement in Harris Hip Score from 38.6 preoperatively to 70.4 postoperatively.

Uncemented jumbo revision cup group

The demographics of the patients of these studies [16–22] were 33.3–58.8% male patients. Mean age was 60.6 (ranged from 52.1 to 66 years). Mean BMI when recorded was 28.6 (ranged from 27 to 30). The studies were carried out worldwide and were published between 2003 and 2015. These studies included a total of 499 patients (518 hips). Of them 86 were classified as Paprosky 3A and 29 Paprosky 3B, 114 AAOS type 3 and 2 AAOS type 3.

Patients were followed up for a mean of 117.4 months (range 65.0–240.0).

There were 63 re-operations for any reason (failure rate of 12.1%). Outcomes of this group are summarized in Table 4. The most common cause for reoperation was due to chronic instability or liner exchange with a rate 7.1% (37/518). The most common complication followed this procedure was dislocation [8.3% (43/518)].

The study [18] with the highest reported incidence (10%) of instability evaluated their aetiology of dislocation. The concurrent use of a femoral head size of < 32 mm was depicted as being a contributing factor. In this prospective review of 120 patients undergoing revision with jumbo acetabular implants, Lachiewicz et al. [18] performed a

Table 2 Quality assessment scores

Study	Criteria										Total
	1	2	3	4	5	6	7	8	9	10	
	Aim	Inclusion/ exclusion	Prospective	Surgical technique	Primary outcome	Assessment	Valid measures	Compli-cations	Losses to follow-up	Statistical analysis	
Berasi [9]	1	0	0	1	1	0	1	1	1	0	6
Wind [10]	1	0	0	1	1	0	1	1	1	0	6
Colen [11]	1	0	0	1	1	0	1	1	1	0	6
Taunton [12]	1	1	0	1	1	1	1	1	1	0	8
DeBoer [13]	1	1	0	1	1	1	1	1	1	0	8
Denis [14]	1	0	0	1	1	0	1	1	0	0	5
Christie [15]	1	1	0	1	1	0	1	1	1	0	7
von Roth [16]	1	1	0	1	1	0	1	1	1	1	8
Gustke [17]	1	1	0	1	1	1	1	1	0	1	8
Lachiewicz [18]	1	1	0	1	1	1	1	1	1	1	9
Bilgen [19]	1	0	0	1	1	0	1	1	1	0	6
Fan [20]	1	0	0	1	1	0	1	1	1	0	6
Wedemeyer [21]	1	0	0	1	1	0	1	1	0	1	6
Patel [22]	1	0	0	1	1	0	1	1	1	1	7
Šťastný [23]	1	0	0	1	1	0	1	1	0	0	5
García-Rey [24]	1	0	0	1	1	1	1	1	0	1	7
Desai [25]	1	0	0	1	1	1	1	1	0	0	6
Köster [26]	1	0	0	1	1	0	1	1	0	0	5
Civinini [27]	1	0	0	1	1	0	1	1	0	0	5
Kmieć [28]	1	0	0	1	1	1	1	1	0	0	6
Mao [29]	1	1	0	1	1	1	1	1	1	1	9
Amenabar [30]	1	0	0	1	1	0	1	1	1	1	7
Regis [31]	1	0	0	1	1	0	1	1	0	1	6
Philippe [32]	1	0	0	0	1	0	1	1	0	1	5
Lamo-Espinosa [33]	1	0	0	1	1	0	1	1	1	0	6
Jones [34]	1	0	0	1	1	0	1	1	1	1	7
Schneider [35]	1	0	0	1	1	0	1	1	0	1	6
Akiyama [36]	1	0	0	1	1	0	1	1	1	1	7
Hori [37]	1	0	0	1	1	0	1	1	1	1	7
Coscujuela-Mañá [38]	1	0	0	1	1	0	1	1	0	1	7
Regis [39]	1	1	0	1	1	1	1	1	1	1	9
Schlegel [40]	1	0	0	0	1	0	1	1	0	1	5
Kosashvili [41]	1	1	0	1	1	1	1	1	1	1	9
Lachiewicz [42]	1	0	0	1	1	1	1	1	1	1	8
Abolghasemian [43]	1	0	0	1	1	0	1	1	0	1	6
Borland [44]	1	0	0	1	1	0	1	1	0	0	5
Davies [45]	1	0	0	1	1	0	1	1	1	1	8
Del Gaizo [46]	1	1	0	1	1	0	1	1	1	1	8
Elganzoury [47]	1	1	0	1	1	1	1	1	1	1	9
Fernández-Fairen [48]	1	0	0	1	1	0	1	1	0	1	6
Flecher [49]	1	0	0	1	1	0	1	1	0	0	5
Grappiolo [50]	1	0	0	1	1	0	1	1	0	1	6
Kim [51]	1	0	0	1	1	0	1	1	1	1	7
Lakstein [52]	1	0	0	1	1	0	1	1	0	1	6
Moličnik [53]	1	0	0	1	1	0	1	1	0	1	6
Simon [54]	1	0	0	0	1	0	1	1	0	1	5
Unger [55]	1	0	0	1	1	0	1	1	0	1	6
Van Kleunen [56]	1	0	0	1	1	0	1	1	0	1	6
Weeden [57]	1	0	0	1	1	0	1	1	0	1	6
Whitehouse [58]	1	0	0	1	1	0	1	1	0	1	6

Table 2 (continued)

Each item scored one point if it met the methodological criteria listed in Table 1. If not, or the item was not reported, a score of zero was assigned

multi-variant analysis on causes of dislocation in his series. Fisher's exact test for the suspected contributing factors was $p > 0.05$ with no association shown between age, sex, BMI, approach, Paprosky type, component type or isolated acetabular revision and dislocation [18].

There were 9/518 (1.7%) acetabular components demonstrating probable radiological loosening that were not revised at the last follow-up. Von Roth et al. [16] reported one case of radiological lucency > 1 mm in zones 1, 2 and 3, at early follow-up. However, the patient complained of only slight pain and was able to walk six blocks and the acetabular component was followed up for 20 years.

Bilgen et al. [19] found that there was 6.2 ± 7.8 mm of mean migration on plain radiographs and migration distance did not differ according to rim contact achieved intraoperatively ($p = 0.054$); moreover, there was no correlation between migration and amount of graft used ($p > 0.05$) and there was a significant correlation between migration and follow-up time ($p < 0.01$).

The studies reporting functional outcomes noted mean improvement in Harris Hip Score from 54 preoperatively to 78.5 postoperatively.

Oblong cup group

The demographics of the patients of these studies [23–27] were mean age of 65.1 (ranged from 50 to 71 years). Percentage of male patients was 32.2–45.2%. Mean BMI was only recorded in 1 study [22.7 kg/m^2 (20)]. These studies, published between 2007 and 2014, included a total of 196 patients (203 hips). Of them 44 were classified as Paprosky 3A and 8 Paprosky 3B.

The patients had a mean age at the time of the surgery of 65.1 (range from 50 to 71.6) and were followed up for a mean of 90.9 months (range 84.0–108.0).

Table 5 summarizes the outcomes in this group. There were 12 re-operations for any reason (failure rate of 5.9%). The most common cause for revision was acetabular aseptic loosening with a rate 3.9% (8/203), while the most common complication followed this procedure was dislocation at 2.4% (5/203).

Of the small number of patients in this group who dislocated, one required further revision surgery and a constrained liner was used.

12/203 (5.9%) acetabular components were noted to be probably loose on plain radiographs. Interestingly, 10 of these were reported by a single study; García-Rey et al. [24] found that in the majority of the cases, they were hips with previous bone defects 3A and 3B, the other radiological parameters like acetabular abduction angle and vertical distance from teardrop were not related to radiological cup loosening [24].

The studies reporting functional outcomes noted mean improvement in Harris Hip Score from 40.7 preoperatively to 82.3 postoperatively.

Reinforced devices as cages and rings group

The demographics of the patients of these studies [28–41] were 2.7–36.6% male patients. The patients had a mean age at the time of the surgery of 66.4 (ranged from 60.9 to 71.4 years). These studies included a total of 807 patients (831 hips); 156 were classified as Paprosky 3A and 178 Paprosky 3B, 228 AAOS as type 3 and 43 AAOS as type 4 (in one study [35] there were 62 cases classified as Sofcot Stage 3 and 26 as Stage 4).

Patients were followed up for a mean of 87.5 months (range 41.6–175.2).

Outcomes of this group are summarized in Table 6. There were 92 re-operations for any reason giving a failure rate of 11.0%. The most common cause for revision was acetabular aseptic loosening with a rate 3.7% (30/831), while the most common complication followed this procedure was dislocation at 7.2% (60/831).

Of those hips with dislocated reinforced devices, the majority ($n = 40$) were managed with closed or open reduction of the dislocated hip [28, 29, 31, 32, 37–39, 41]. Ten patients went on to have further revision surgery including 'in cage' revision with exchange of polyethelene liner [37], revision to constrained liner [41] and exchange of liner [38].

Factors which may have contributed to dislocation in this group are multiple previous operations included infection in 2 cases [33], previous infection in one [39], loosening of the prosthesis with lucency seen at the superior flange in one patient [39]. Lack of bone stock as one might expect is also reported as a contributing factor to dislocation [35, 39]. Schneider et al. [35] reported a lower-than-average dislocation rate for their cohort of 96 patients (10.4%). In the 6 patients who had early dislocations (at less than 3 months), the greater trochanter was missing at the time of revision surgery or a trochanteric defect was recorded. They found no association with the cup size and the incidence of dislocation [35].

Radiological loosening without further revisions was noted in 29/831 (3.5%) cases.

Table 3 Summary of outcomes in the custom-made triflange cup group

Author	Number of cases (hips)	AAOS/Paprosky classification	Mean follow-up (months)	Mechanical failure				Non-mechanical failure		Radiological loosening not revised
				Mean Harris Hip scores (pre and post)	Revisions for acetabulum problems (instability, liner exchange)	Revision for acetabular aseptic loosening	Dislocation	Revision for deep infection	Hematoma drainage/wound infection for washout	
Berasi [9]	23 (24)	24 Pap 3B	57 (28–108)	42–65	0	0	0	2	0	0
Wind [10]	19 (19)	3 Pap 3A 16 Pap 3B	31 (16–59)	38–63	2	1	5	1	0/2	2
Colen [11]	6 (6)	3 AAOS 3 and 3 AAOS 4	28.5 (10–58)	NR-61.1	0	0	0	0	0	0
Taunton [12]	57 (57)	57 AAOS 4	65 (24–215)	NR-74.8	12	1	12	2	2/0	8
DeBoer [13]	28 (30)	30 AAOS 4	123 (89–157)	41–80	6	0	6	0	0	0
Denis [14]	24(24)	24 Pap 3B	48 (24–78)	39–79	0	1	2	0	0	2
Christie [15]	76 (78)	39 AAOS 3 39 AAOS 4	53 (24–107)	33.3–82.1	6	0	12	0	0	0

Table 4 Summary of outcomes of uncemented jumbo cup group

Author	Number of cases (hips)	AAOS/ Paprosky classification	Mean follow-up (months)	Mean Harris Hip scores (pre and post)	Mechanical failure			Non-mechanical failure		Radiological loosening not revised
					Revisions for acetabulum problems (also liner exchange)	Revision for acetabular aseptic loosening	Dislocation	Revision for deep infection	hematoma drainage/wound infection for washout	
von Roth [16]	89 (89)	25 Pap IIIa 4 Pap IIIb	240 (168–324)	56–71	9	5	11	1	0	1
Gustke [17]	189 (199)	109 AAOS III 2 AAOS IV	120 (24–228)	44–72	9	3	11	1	0	2
Lachiewicz [18]	101 (108)	40 Pap IIIa 17 Pap IIIb	97.2 (24–240)	NR	13	4	12	4	0	1
Bilgen [19]	15 (15)	10 Pap IIIa 2 Pap IIIb	97.5 (58–130)	NR-88.3	0	1	0	1	0	5
Fan [20]	46 (47)	5 Pap IIIa 6 Pap IIIb	65 (48–84)	NR	3	0	5	1	0	0
Wedemeyer [21]	17 (17)	5 AAOS III	82 (33–149)	62–83	0	1	1	1	1/0	0
Patel [22]	42 (43)	6 Pap IIIa	120 (72–168)	NR	3	2	3	0	0	0

Table 5 Summary of the outcomes of the oblong cup group

Author	Number of cases (hips)	AAOS/Paprosky classification	Mean follow-up (months)	Mean Harris Hip scores (pre and post)	Mechanical failure			Non-mechanical failure		Radiological loosening not revised
					Revisions for acetabulum problems (also liner exchange)	Revision for acetabular aseptic loosening	Dislocation	Revision for deep infection	hematoma drainage/wound infection for washout	
Šťastný [23]	31 (31)	8 Pap 3A 1 Pap 3B	84 (63.6–111.6)	39.8–85.3	0	0	0	0	0	1
García-Rey [24]	45 (46)	15 Pap 3A 2 Pap 3B	86.4 (48–132)	NR	1	3	2	0	0	10
Desai [25]	14 (15)	3 Pap 3A	90 (60–120)	39–84	0	1	0	0	0	0
Köster [26]	53 (56)	9 Pap 3A 5 Pap 3B	108 (96–144)	50–81	0	3	0	1	0	1
Civinini [27]	53 (55)	9 Pap 3A	86.4 (60–121.2)	34–79	1	1	3	1	0	0

The cases of migration were observed mainly in De Lee and Charnley zones 1 and 2 [33, 35, 40] or in the ischial flange [30]. Possible causes of migration were severe resorption of the original graft [39] and breakage of the fixation screws [39, 40]. The studies reporting functional outcomes noted mean improvement in Harris Hip Score from 35.8 preoperatively to 74.7 postoperatively.

Trabecular metal augments group

The demographics of the patients of these studies [42–58] were 30–72.7% male patients. These studies included a total of 1006 patients (1021 hips). 291 were classified as Paprosky 3A, 98 3B and 9 as pelvic discontinuity, 14 as AAOS type 3 and 2 AAOS type 3, 53 as type 2 of Saleh Classification.

The patients had a mean age at the time of the surgery of 64.1 (range from 50 to 69.5) and were who were followed up for a mean of 48.9 months (range 20.9–175.2).

Patients' outcomes are summarized in Table 7. There were 75 re-operations for any reason giving a failure rate of 7.3%. The most common cause for revision was chronic instability or liner changing with a rate 2.5% (26/1021), while the most common complication followed this procedure was dislocation at 4.9% (50/1021).

Early dislocations (at less than 8 weeks postoperatively) were recorded in 5 patients, 4 of which required further revision surgery. Of all patients that dislocated and went on to have further open surgery, at least 9 included isolated liner exchange procedure [42, 46, 52, 56], and all of these cases were revised to constrained liners. Six had revision of the acetabular cup and liner [42, 50, 55] with 2 requiring repositioning of the cup and trochanteric advancement [55]. One patient required a revised strut with allograft of the femur to allow for re-attachment of the adductor mechanism. Lachiewicz et al. [42] report a dislocation rate of 13% (5 out of 39 hips) revised with tantalum components. In their practice, they chose to use the largest femoral head possible with the aim of avoiding constrained liners unless there is deficiency in the abductors, osteolysis of the greater trochanter or a non-compliant patient.

Radiological evidence of complete migration of the acetabular components was seen in only 4/1021 (0.4%) cases; none of them were revised.

The studies reporting functional outcomes noted mean improvement in Harris Hip Score from 45.1 preoperatively to 83 postoperatively.

Discussion

Our review and pooled analysis summarize the clinical, radiological and functional outcome of complex acetabular revisions with deficient bone stock.

Table 6 Summary of the outcomes of the reinforced devices as cages and rings group

Author	Number of cases (hips)	AAOS/ Paprosky classification	Mean follow-up (months)	Mean Harris Hip scores (pre and post)	Mechanical failure			Non-mechanical failure		Radiological loosening not revised
					Revisions for acetabulum problems including liner exchange)	Revision for acetabular aseptic loosening	Dislocation	Revision for deep infection	Hematoma drainage/wound infection for washout	
Kmieć [28]	69 (69)	27 Pap 3A 17 Pap 3B	86.4 (36–228)	30.5–73.8	3	4	2	1	0	0
Amenabar [30]	64 (67)	26 Pap 3A 41 Pap 3B	74 (24–135)	NR	3	4	4	1	3/0	4
Mao [29]	22 (23)	3 Pap 3A 20 Pap 3B	81.6	39.6–80.9	2	0	2	0	0	0
Regis [31]	65 (65)	27 Pap 3A 38 Pap 3B	175.2 (120–226.8)	33.1–75.6	1	5	6	3	0	4
Lamo-Espinosa [33]	16 (16)	9 Pap 3A 4 Pap 3B	60.6 (25–120)	NR	0	0	2	0	0	4
Philippe [32]	95 (95)	84 AAOS 3 6 AAOS 4	96 (60–156)	35.3–71.1	5	2	8	3	0	3
Jones [34]	30 (30)	21 Pap 3A 9 Pap 3B	85 (64–118)	NR	1	0	1	1	1/0	0
Hori [37]	29 (30)	29 AAOS 3 3 AAOS 4	90 (25.2–164.4)	NR	0	2	5	2	0	2
Schneider [35]	96 (96)	Sofcot 62 Stage 3 26 Stage 4	41.6 (1–101)	NR	5	1	10	2	1/1	4
Akiyama [36]	36 (40)	23 AAOS 3	80.4 (54–111.6)	NR	1	0	1	2	0	1
Coscujuela-Mañá [38]	96 (96)	25 Pap 3A 11 Pap 3B	97.2 (60–156)	NR	2	1	11	2	0/4	0
Kosashvili [41]	24 (26)	26 AAOS 4	44.6 (24–68)	46.6–76.6	2	3	2	0	0/1	0
Regis [39]	56 (56)	18 Pap 3A 38 Pap 3B	140.4 (120–172.8)	30–75	0	2	6	2	0	5
Schlegel [40]	109 (122)	92 AAOS 3 8 AAOS 4	72 (24–204)	NR-70	0	6	0	7	0	2

Table 7 Summary of the outcomes of the trabecular metal augments group

Author	Number of cases (hips)	AAOS/Paprosky classification	Mean follow-up (months)	Mean Harris Hip scores (pre and post)	Mechanical failure			Non-mechanical failure		Radiological loosening not revised
					Revisions for acetabulum problems (also liner exchange)	Revision for acetabular aseptic loosening	Dislocation	Revision for deep infection	hematoma drainage/wound infection for washout	
Whitehouse [58]	56 (56)	28 Pap 3A 11 Pap 3B	110 (88–128)	NR	2	3	2	1	0	1
Grappiolo [50]	54 (55)	42 Pap 3A 13 Pap 3B	53.7 (36–91)	40–90.5	1	3	1	0	0	0
Elganzoury [47]	18 (18)	10 Pap 3A 2 Pap 3B	18 (12–24	40–80	0	0	0	0	0	0
Moličnik [53]	25 (25)	6 Pap 3A 3 Pap 3B 1 Pap 4	20.9 (12–42)	40–79	1	0	1	0	1/0	0
Abolghasemian [43]	34 (34)	14 AAOS 3 2 AAOS 4	64.5 (27–107)	NR	0	3	0	1	0/1	0
Borland [44]	24 (24)	15 Pap 3A 9 Pap 3B	60 (36–84)	NR	0	0	0	0	0	2
Del Gaizo [46]	36 (37)	37 Pap 3A	60 (26–106)	33–81.5	3	1	4	0	0/3	1
Davies [45]	46 (46)	21 Pap 3A 11 Pap 3B 4 pelvic discontinuity	50 (28–76)	NR-78.2	0	0	2	1	0	0
Lachiewicz [42]	37 (39)	26 Pap 3 (no distinctions)	39.6 (24–84)	48–86	4	1	6	0	0/2	0
Fernández-Fairen [48]	263 (263)	40 Pap 3A 9 Pap 3B	73.6 (60–84)	43.6–80.4	0	0	8	2	0	0
Flecher [49]	71 (72)	23 Pap 3A 8 Pap 3B 4 pelvic disc	48 (24–72)	NR	3	0	3	1	0	0
Lakstein [52]	53 (53)	53 Type II Saleh classification	45 (24–71)	NR	0	2	4	0	0	0
Van Kleunen [56]	90 (97)	19 Pap 3A 16 Pap 3B	45 (24–79)	55–76	5	0	7	8	4/0	0
Simon [54]	51 (53)	4 Pap 3A 1 Pap 3B	28.3 (12–48)	NR	1	1	1	0	1/0	0
Kim [51]	46 (46)	6 Pap 3A 4 Pap 3B	40 (24–51)	NR	2	0	2	0	0	0
Weeden [57]	42 (43)	33 Pap 3A 10 Pap 3B	33.6 (24–48)	32–84	0	0	2	1	0	0
Unger [55]	60 (60)	7 Pap 3A 1 Pap 3B	42 (14–68)	74.8–94.4	5	2	7	0	0	0

Irrespective of the type of reconstruction shell/device, instability remains the main reason for revision after reconstruction. High complications rate was noted with the use of custom triflange constructs.

Our review identified several weaknesses in the included studies, many of which are common to other systematic reviews.

Because of the wide heterogeneity of the study demographics, inclusion criteria and outcome measures, meta-analysis couldn't be performed. Instead we assessed the methodological qualities of all studies with modified questions using quality assessment tools [6, 7]. It is also possible that the methodology of some of the studies that we analysed were weak, with several factors not accounted for such as loss to follow-up, short follow-up, deaths and selection bias.

The evidence presented here must be reviewed in the light of the quality of available studies. All the studies were retrospective with level IV of evidence, and prospective studies are lacking. In the majority of studies, several quality criteria were not fully described so there was a high risk of bias caused by confounding variables.

One other drawback of our study was the different in the length of the follow-up period between the different groups of implant, where the majority of the studies did not exceed 10-year follow-up.

Within the limitations discussed above, some conclusions can be drawn from our analysis.

The custom-made triflange cup group had the highest complication rate in terms of re-operation; however, they were used in the setting of pelvic discontinuity and severe bone loss, where Girdlestone pseudo-arthrodesis is the only other surgical option [10]. The main advantage of this technique is the ability to be customized and individualized for each patient the best fit based on the information from preoperative CT scan and nowadays also with physical three-dimensional reconstruction using rapid prototyping technology [9]. In particular, the physical object model gives the advantage to the surgeons to intuitively simulate the surgery and the component flanges are designed to provide the best fit against the bone and the bone's defect [9]. Their use also involves more extensive soft tissue dissection with possible local neuro-muscular damage as it has been proposed by Christie et al. [15] in their analysis.

Uncemented jumbo cup group had a follow-up of almost 10 years and had proven to be a good option due to the relative simplicity of the procedure where the main advantage is the reduction in the need of bone graft because the defects are filled by the cup itself providing maximal surface contact [16, 18].

The oblong cups had the lowest re-operation rate in general and the lowest rate of dislocation following the revision surgery. This may reflect the ability of these shells to restore the hip centre and sufficient bone implant contact for osseointegration [24]. However, the main limitation in this group is the small number of patients included in these studies.

Reinforced devices as cages and rings group has been designed in situation when the graft supports more than 50% of the acetabular component, and a reconstruction system from ilium to ischium should protect the graft and provide structural stability [31]. Comparison of results and outcomes is difficult due to the different type of devices and techniques used; however, the advantages of using a structural graft restore the bone stock and the pelvic anatomy [31].

Our review shows that the Trabecular Metal shells group had a very good survivorship and functional outcomes. These results may be due to the fact that TM has believed to have an increased biocompatibility and the ability of these shells to osseointegrate with the acetabular bone bed providing a better fixation [50].

A common finding in all the groups included was that dislocation was the most common complication after acetabular reconstruction. The highest rate was seen in the custom-made triflange cup group.

All the implants showed an improvement in functional hip scores. The Harris Hip Score was the most common score used to assess function preoperatively and postoperatively.

In this context, revision shells using the Trabecular Metal had the best outcomes; however, they also had short follow-up.

TM cups show promising results, and the literature supports and suggests their use in these selected patients with severe acetabular bone loss [58].

With the aseptic loosening the common complication of long term, TM acetabular components have demonstrated their superiority in enhancing bone ingrowth and fixation over the porous-coated implants [43].

Radiological evidence of possible shell loosening was seen in several studies and with various reconstruction techniques. However, this did not always translate to clinical failure or revision for symptomatic hips.

In conclusion, this review summarizes clinical, radiological and functional outcomes of some of the common acetabular revision techniques. Future studies reporting outcomes of revision acetabular shells should focus on prospective long-term outcomes with consistent reporting of clinical, radiological and patient reported outcomes to enhance our knowledge of this challenging surgical reconstruction.

Compliance with ethical standards

Conflict of interest A. Volpin, S. Konan, C. Biz, R. J. Tansey declare that they have no conflict of interest. F. S. Haddad reports grants from Stryker and grants from Smith and Nephew, outside the submitted work.

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