REVIEW ARTICLE

Cup-Cage Solution for Massive Acetabular Defects: A Systematic Review and Meta-Analysis

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Our systematic review compiled multiple studies and evaluated survivorship and clinical outcomes of cup-cage construct usage in the management of massive acetabular bone defects. This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Various combinations of "acetabular", "pelvis", "cup cage" and their corresponding synonyms were used to search relevant articles in the Cochrane, EMBASE, and PubMed databases. Basic information of the functional scores, implant revision rate, and complication rate were selected as outcomes for analysis. Finally, a total of 11 articles published between 1999 and 2019 were selected, which include 232 patients with an average age of 68.5 years (range, 30–90). The mean follow-up period was 48.85 months (range, 1–140). Our study shows that the cup-cage construct has a good clinical outcome with a low revision rate and a low complication rate. Improved clinical outcomes of cup-cage constructs were seen with a revision rate of 8% and an all-cause complication rate of 20%. The most commonly reported complication was dislocation, followed by aseptic loosening, infection, and nerve injuries. In summary, it is a promising method for managing large acetabular bone defects in total hip revision.

Key words: Acetabular defect; Bone defects; Cup-cage; Total hip revision

Introduction

Acetabular defects are a challenging condition for surgeons in revision total hip arthroplasty (THA). The American Academy of Orthopaedic Surgeons (AAOS) system[1], the Paprosky system[2], and the Gross system[3] are widely used to help define bone loss and provide detailed preoperative planning. In addition, AAOS types III and IV, Gross types IV and V or Paprosky types 3A and 3B are the most challenging bone defects, and multiple surgical strategies have been employed for restoring the bone stock and achieving stable fixation. Strategies have included noncemented hemispherical cups, impaction bone grafting, structural allografts, ilioischial cages, highly porous augments and cups, custom triflange acetabular components, and cup-cage constructs.

For acetabular defects with less than 50% contact between the host bone and revision implant, the noncemented hemispherical cup is regarded as the method of choice in the revision[4]. Furthermore, the impaction bone grafting technology was well-developed that can provide a successful fixation in the contained defects[5], and the structural allografts can achieve further mechanical support, but the rate of failure is unacceptably high due to the resorption of the graft.

For acetabular defects with more than 50% contact of the acetabulum, the ilioischial cages can protect the graft and offer excellent initial stability. However, loosening and

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fatigue fracture over time is inevitable due to the resorption of the graft and its nonbiological fixation[6–8]. Furthermore, highly porous metal cups with or without augmentation can provide bone ingrowth and solidly fixed constructs, but they cannot achieve initial stability when the acetabular defects are severe and the host bone contact is limited[9–11]. The custom-made triflange cup is another option for massive acetabular defects with favorable results at early and midterm follow-up. However, previous reports underline the disadvantages of a high dislocation rate and prolonged preparation time[12].

In 2005, cup-cage constructs were originally introduced as a viable option by Hansen and Lewallen[13]. The cup cage consists of a trabecular metal (TM) cup with screws and an antiprotrusio cage placed over the top. The cage provides support for bone ingrowth and stabilization of the TM cup over the short term[14], and the TM cup promotes biological integration with the cage in the long term. Therefore, cup-cage constructs could provide permanent fixation of the acetabulum and improve the hip rotation center.

Although several studies have reported encouraging clinical outcomes of cup-cage construct usage in the management of massive acetabular bone defects, most of them are small case series based on a single center. Therefore, our systematic review compiled multiple studies with the aim to: (i) evaluate the implant revision rate and complication rate of the cup-cage construct; (ii) compare the overall performance of the cup-cage construct over the short and medium terms; and (iii) find the evidence to support better functional scores with the use of cup-cage construct.

Material and Methods

Literature Search

The systematic review was conducted in accordance with the PRISMA guidelines. A comprehensive search was conducted with multiple sources of databases, including PubMed, Embase, and Cochrane Library. The MeSH terms "acetabular," "pelvis" and its corresponding synonyms were designated as keywords, and the terms "cup-cage" were combined in an "AND" form in the search strategy with no other restrictions (Appendix 1). In addition, we manually examined the corresponding reference lists for each retrieved article. The procedures mentioned above were conducted by two reviewers independently. Any disagreement was resolved by consensus.

Selection Criteria

All the retrieved studies had to fulfill the following inclusion criteria: (i) the study was conducted based on patients with AAOS types III and IV, Gross types IV and V, or Paprosky types 3A and 3B acetabular defects; (ii) the original study topic comprised postoperative outcomes of the cup-cage construct in the revision THA; (iii) the necessary information on functional scores, implant revision rates, and complications of patients was sufficiently provided; and (iv) the study was a randomized controlled trial, nonrandomized clinical trial, prospective or retrospective cohort study, case–control study, cross-sectional study, case report or a case series.

The exclusion criteria were as follows: (i) reviews, conference abstracts, letters to editors, expert opinions, and animal studies; (ii) studies based on the same database; (iii) sample size of less than five hips; (iv) mean follow-up of less than 12 months; and (v) studies involving oncologic disease.

Quality Assessment

The quality of the study was assessed using the Methodological Index for Non-Randomized Studies (MINORS) criteria, which is valid in accessing the quality of nonrandomized surgical studies[14]. Each item of the criteria was graded as well described, partly described, or poorly/not described. The assessment was made by two reviewers independently.

Data Extraction

The following characteristics were extracted from all studies: first author, country, publication year, study design, age and gender of patients, follow-up, sample size, classification of acetabular defects, clinical outcome score, revision rate, complication rate, and reoperation rate for any reason. Two independent researchers examined all identified studies and obtained relevant information.

Outcome Measures

The outcome data were reported as described previously[15]. An overall pooled rate were subclassified as short, and medium term depending on the mean follow-up time. Short term was defined as, 3 years, medium term was defined as 3 to 8 years. The exchange or removal of any part of the acetabular construct excluding the liner was defined as revision. The complications included dislocation, loosening, infection, nerve injuries, and other complications such as hematoma.

Statistical Analysis

The outcome data were evaluated overall and in the short and medium terms, and were analyzed by a Chi-Square Test, Continuity Correction Test, or Fisher's Exact Test. SPSS v25.0 (SPSS, Inc., Chicago, USA) and STATA (Stata Corp, TX, USA) was used to perform this work, and $P < 0.05$ was considered statistically significant.

Results

Literature Search Results

A total of 124 publications were obtained from the literature search in the databases. By excluding duplicates ($n = 25$) and scanning titles or abstracts ($n = 81$), 18 articles were prepared for full-text review. Finally, a total of 11 articles were selected for quality. Details of the literature search process are shown in Fig. 1.

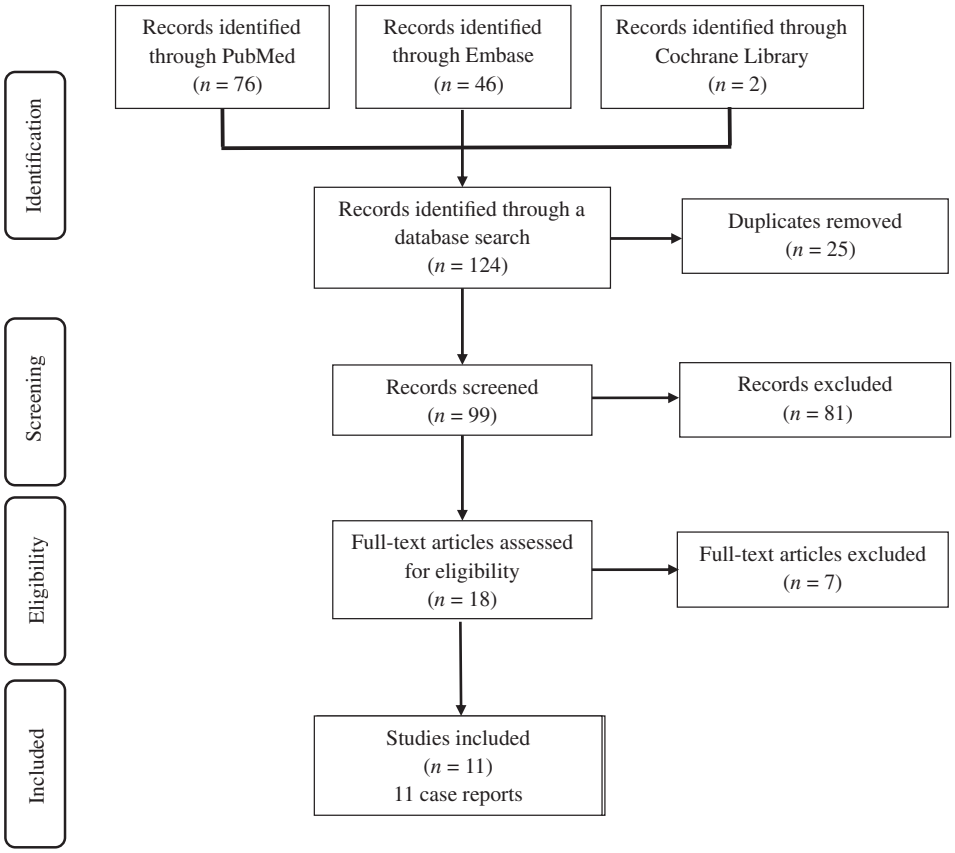

Fig. 1 Flow diagram of the systematic literature search

Study Characteristics

The remaining 11 studies are all case series published between 1999 and 2019[16–26]. Detailed baseline characteristics of these studies are presented in Table 1. The 11 included studies were participated in by 232 patients with an average age of 68.5 years (range, 30–90). The mean follow-up period was 48.85 months (range, 1–140).

Additionally, indications for revision surgery were not mentioned in four studies[18,24–26]. The most common reason for revision surgery was aseptic loosening (130 cases). The other indications included infection (18 cases) and periprosthetic bone fracture (two cases).

Two studies utilized intraoperative findings to evaluate bone loss[20,26], one study used preoperative radiographs[23], and both intraoperative findings and preoperative radiographs were combined in four studies[19,20,24,25]. The remaining four studies did not mention the evaluation of bone loss[17,18,21,22].

In four studies, the classification of the bone defect was based on the Paprosky classification[16,17,19,25]; in one study, it was based on the Gross classification[26]; and in one study, both the Paprosky and Gross classification systems were utilized[20]. The remaining five studies did not mention the classification of the bone defect[18,21–24].

Quality Assessment

The quality assessment is presented in Appendix 2, and the mean MINORS score of all the studies was 9.4 points (range, 9–10), indicating that their quality was limited. This is because they are all case series and are therefore prospectively designed or accessed blindly.

Implants Evaluation

A total of 12 cup-cage constructs were revised, and the revision rate was 8% (95% *CI*, 3% to 13%) and there was no significant difference between subgroups (P = 0.900). Aseptic loosening was the most common reason for revision. Of the 12 cup-cage constructs revised, eight were revised for aseptic loosening, three were revised for infection, and one was revised for aseptic loosening.

Functional Evaluation

Generally, the included studies all showed improved postoperative scores. The clinical outcome score of the cup-cage group was not found in one study[24], and the Harris hip score or Postel-Merle d'Aubigne (PMA) score were widely used in the remaining studies. Among the three studies, the Harris hip score (HHS) was recorded preoperatively and postoperatively, with improvements from 40.79 points (1–57) to 68.69

TABLE 1 Study characteristics

Author	Year	No. of hips	Gender (female/male)	Mean age (years)	Mean follow-up (years)	Classification (No. of hips)	Revision reason (No. of hips)
Suari	2019	22	8/14	72(40–89)	45(12–73)	Paprosky type 3A (8), type 3B (14)	Aseptic loosening (17) Infection (3) Fracture (2)
Arvinte	2019	6	5/1	76(73–81)	72(63–140)	Paprosky type 3B (7)	Aseptic loosening (6)
Hipfl	2018	35	7/27	70(42–85)	47(25–84)	Gross type IV (11),type V (25)	Aseptic loosening (29) Infection (6)
Alfaro	2010	5	3/2	66(61–78)	19(8–31)	Paprosky type 3B (5)	Aseptic loosening (5)
Kellett	2010	14	NR	62(45–82)	27(1–39)	Uncontained bone loss more than 50% in all 14 patients	NR
Konan	2017	24	17/7	72(37–90)	72(24–120)	Pelvic discontinuity in all 24 patients	NR
Martin	2017	27	NR	NR	46(25–87)	Pelvic discontinuity in all 27 patients	NR
Boscainos	2007	14	NR	NR	32(6–45)	No host bone contact with the cup in six patients, less than 40% host bone contact in seven patients	NR
Rogers	2012	42	NR	NR	35(24–45)	Pelvic discontinuity in all 42 patients	Septic or aseptic periprosthetic bone loss
Mu	2017	16	6/10	62(40–84)	18(6–36)	Paprosky type 3B (16)	Aseptic loosening (14) Infection (2)
Amenabar	2015	27	14/50	66(30–86)	74(24–135)	Gross type IV (26), type V (41)	Aseptic loosening (59) Infection (7)

NR, not reported.

points (18–90)[16,19,25]. The Postel-Merle d'Aubigne (PMA) score was also recorded in three studies, with improvements from 5.69 points (3–7) to 12.34 points (8–16)[17,19,26]. Varieties of patient-reported instruments, such as the short-form 12 score, short-form 36 score, Oxford Hip Score, and Western Ontario and McMaster Universities Arthritis Index, have also been used in the clinical outcome assessment[16,18,21,22] (Table 2).

Complications

The overall complication rate was 20% (95% *CI*, 13% to 27%) and there was no significant difference between subgroups (P = 0.652). The most common complications were dislocation (19 hips), followed by aseptic loosening (13 hips), infection (nine hips) and nerve palsy (seven hips). Others included hematoma (two hips), fracture (one hip), and deep vein thrombosis (1 hip).

Dislocation

Dislocation was the most common complication, the overall incidence of dislocation was 9% (95%*CI*, 5% to 13%), and there was no significant difference between subgroups (P = 0.212). The liners were revised to constrained dislocations in four of 19 (21.05%) dislocations[18,21,26] and were exchanged with a dual-mobility device in the other patient with recurrent dislocation[20]. In two patients, liners and heads were all exchanged[19]. Two patients received open reduction, and two patients were treated with closed reduction[26]. Finally, eight patients had no treatment information[23,24].

Aseptic Loosening

Aseptic loosening was the second most common complication. The overall prevalence of aseptic loosening was 9% (95%*CI*, 3% to 14%), and there was no significant difference between subgroups (P = 0.954). The criteria published by Massin[27] and the criteria of Gill with the modification added by Kosashvili *et al.*[28] were widely used to determine loosening of the acetabular component in most included studies[16,19,20,22,25,26]. Among patients who developed aseptic loosening, two patients had no reoperation[23,24], and three patients received revision for recurrent instability, but the cup-cage construct did not need to be revised[22]. The cup-cage constructs were revised in the remaining eight patients[24,26].

Nerve Injuries

The compromised nerve in all seven patients with nerve injuries was the sciatic nerve (4%, 95% *CI*: 1% to 7%), and there was no significant difference between subgroups (P = 0.707). Among these patients, one patient underwent removal of the flange and sciatic neurolysis and regained full function[20], two patients developed peroneal distribution and were treated with orthosis[26], and two patients had recovery of function without any reoperation[17,20]. The remaining two patients had no treatment information[23].

Infection

Infection after cup-cage placement accounted for 4% (95% *CI*, 1% to 7%), and there was no significant difference between subgroups (P = 0.157) (additional file 6). Among these, five patients underwent irrigation and debridement

TABLE 2 Outcome date

Author	No. of hips	Reoperation for any Reason	Revisions of the construct	Complications	Dislocation	Loosening	Infection	Nerve injuries	Others	Mean functional outcomes
Suari	22	3	0	3	2	0	1	0	0	HHS improved from 30 to 72; MAP score improved from 6.91 to 14.36;
Arvinte	6	0	0	0	0	0	0	0	0	HHS improved from 8 to 36. WOMAC score improved from 76 to 26.5; SF-12: PCS improved from 24.78 to 40.15; MCS improved from 35.5 to 46.64.
Hipfl	35	4	3	6	2	0	2	2	0	NR
Alfaro	5	0	0	1	0	0	0	1	0	MAP score improved from 4 to 8.8;
Kellett	14	1	0	2	1	0	0	0	Hematoma (1)	OHS improved from 45 to 28. WOMAC score improved from 64 to 33; SF-36 improved from 351 to 601.
Konan	24	4	1	4	0	3	1	0	Fracture (1)	OHS improved to 78.6; WOMAC score improved to 80.2; SF-36 improved from 351 to 601.
Martin	27	Unknown	0	7	2	1	1	1	DVT (1)	HHS improved to 66.
Boscainos	14	2	0	2	2	0	0	0	Hematoma (1)	OHS improved from 45 to 28. WOMAC score improved from 64 to 33; SF-36 improved from 352 to 601.
Rogers	42	Unknown	4	13	6	5	1	1	0	NR
Mu	16	0	0	1	1	0	0	0	0	HHS improved from 45.63 to 75.78.
Amenabar	27	10	4	13	3	4	3	2	0	MAP score improved from 6 to 13.

NR: Not reported; DVT: Deep vein thrombosis; HHS: Harris Hip Score; OHS: Oxford Hip Score; PMA: Postel-Merle d'Aubigne; WOMAC: Western Ontario and McMaster Universities Arthritis Index; SF-12: Short-Form 12, PCS: Physical Component Score, MCS: Mental Component Score; SF-36: Short-Form 36.

and did not require further surgery[19,24,26], one patient was successfully treated with a 2-stage revision[20], two patients were converted to excision arthroplasty due to poor general health[20,22], and one patient had no treatment information[23].

Discussion

Revision THA for acetabular defects is a difficult procedure for surgeons. AAOS types III and IV, Gross types IV and V, or Paprosky types 3A and 3B were the most challenging bone defects. In this systematic review, only short-term and medium-term reports are available, but their results are promising. The improved clinical outcomes of cup-cage constructs can be seen with a revision rate of 8% and an all-cause complication rate of 20%. The commonly reported complications include dislocation, aseptic loosening, infection, and nerve injuries. This suggests that the cup-cage construct is a promising way to manage complex acetabular bone loss.

Implant Revision

We reported a revision rate of 8% for massive acetabular defects treated with a cup-cage construct, which provides similar long-term success in comparison with other alternative treatments[12]. For instance, custom triflange acetabular components have a complication rate of 6.4%[12]. On the one hand, the initial stability of the cup-cage constructs in the massive acetabular defects is the same as that of the combined cage and posterior-column plate[28]. And reliable biologic ingrowth is observed in radiography, giving the entire construct long-term stability[28]. On the other hand, the improvement of the acetabular component rotation center after revision with cup-cage constructs also impacts the long-term survivorship of the femoral and acetabular components[30,31]. Therefore, the stability and restoration of the anatomy play a determining role for a good outcome in treating massive acetabular defects[18].

Functional scores

In recent years, recognition of patient perspectives on functioning and health has been increasing. Therefore, a wide variety of patient-reported instruments, such as the short-form 12 score, short-form 36 score, and Western Ontario and McMaster Universities Arthritis Index, have been used in outcome assessment in arthroplasty studies[32]. It was reported that patients who were treated by revising the cup-cage constructs had considerable improvements in at least one of the functional scores above with a relatively low level of complication, which indicates that treatment by this technique offers a substantial improvement in function and quality of life. The improvement in the hip rotation center can also explain the functional results[33] since it is of great importance for muscle function.

Complications

In our systematic review, we only included studies based on patients with AAOS types III and IV, Gross types IV and V, or Paprosky types 3A and 3B acetabular defects to reduce the heterogeneity across studies. The overall complication rate of the cup-cage constructs is still lower than that of other alternative treatment strategies. For instance, anti-protrusio cages have a complication rate of 34%[34], and custom triflange acetabular components have a complication rate of 29%[12].

Dislocation was the most widely reported complication and was recorded in eight studies[18–21,23–26]. Many patients with massive acetabular defects have the risk of instability due to repeated hip operations, leg length discrepancies, poor abductor function, soft-tissue contracture, and so on. There is a tendency for the surgeon to place the cup too vertical and relatively retroverted to accommodate the proper placement of the cage[35]. Measures should be made to increase the stability, including correct anteversion and inclination and larger femoral and acetabular components. However, it is not recommended to use the constrained liner. This might further result in aseptic loosening in the borderline conditions of acetabular component fixation[29]. However, replacement of the liner with a constrained or dual-mobility component may be appropriate after the cup has integrated with bone.

Aseptic loosening was the second most reported complication, and the rate was slightly higher than that of the other alternative treatment strategies[34]. The higher rates of aseptic loosening might be explained by the massive acetabular defects of the included patients. Ischial nerve injuries were also commonly reported complications, similar to those of reconstruction with a custom-made triflange[12]. This might be due to soft-tissue dissection and impaction of the flange around the ischium. A recent study by Sculco *et al.* first reported the evolution of the cup-cage technique[36]. They removed the ischial flange of the cage through the central hemispherical section to create a half cup cage to prevent iatrogenic pelvic dissociation and postoperative sciatic nerve injury[37]. However, nonprogressive acetabular radiolucencies were observed in 7% of the full cup-cage constructs and 6.22% of the half cup-cage constructs, which may impact long-term survivorship, particularly in the presence of pelvic discontinuity. Long-term surveillance is required to observe its durability.

Limitation

Admittedly, there are still several limitations contained herein. First, the included studies were all case series, and the absence of the clinical date limited further analysis. In addition, the smaller sample size may have resulted in biased results. Nevertheless, the differences in the severity of acetabular defects, postoperative care protocols, length of follow-up, and other confounding factors might lead to study heterogeneity. In addition, there was no uniform definition or measurement of outcomes, such as the definition of radiographic loosening and clinical outcome assessment measures. Finally, we did not attempt to identify unpublished literature on the cup-cage construct, and the potential publication bias

may lower the validity of the results. Therefore, the suggestions made in this systematic review should be interpreted with reservation. And prospective randomized clinical trials and long-term surveillance might be needed in the future to confirm the clinical utility of the technique.

Conclusions

Overall, our study shows that the cup-cage construct had good clinical outcomes with a low complication rate and a low revision rate. The cup-cage construct is considered an effective intervention for the treatment of acetabular defects, based on our analysis. When dealing with large acetabular bone defects for THA revision, careful preoperative planning and excellent surgical techniques are required from surgeons. Moreover, long-term follow-up is necessary to assess the durability and efficacy of the cup-cage construct in patients with complex acetabular bone loss.

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Appendix S1: SUPPORTING INFORMATION
Appendix S2: SUPPORTING INFORMATION

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