Review Article

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Total Hip Arthroplasty in Protrusio Acetabuli: A Systematic Review

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Protrusio acetabuli, or abnormal protrusion of the femoral head into the acetabulum, requires performance of a total hip arthroplasty (THA) for which various reconstruction techniques and outcomes have been described. The aim of this systematic review is to provide a comprehensive analysis of the current evidence, evaluate treatment efficacy, compare surgical techniques, and identify topics for future research along with improving evidence-based decision-making, improving patient outcomes in the management of this condition. A thorough systematic review of the PubMed, Embase, Cochrane Library databases, and Scopus library was conducted, and articles describing techniques of THA for treatment of protrusion acetabuli were extracted. The initial search generated 751 results. After exclusion, 18 articles were included. Of these, eight were prospective studies and 10 were retrospective. Surgery was performed on 783 hips with a mean age of 60 years; 80% of females who mostly had inflammatory arthritis were followed up for 8.86 years (range, 2-15.4 years). Good outcomes have been achieved with THA using uncemented cups with bone graft; however, no conclusion could be drawn with regard to the femoral side. It can be concluded that the concept of restoration of the anatomical hip center of rotation is paramount for good outcome and better survival of the implant is important when using uncemented cups with a bone graft. In addition, screw augmentation for fixation is not recommended unless absolutely necessary. The most common complications were aseptic loosening and heterotopic ossification. While the former required revision, conservative management was administered for the latter.

Keywords: Total hip arthroplasty, Protrusio acetabuli, Systematic review

INTRODUCTION

Protrusio acetabuli (PA), or acetabular protrusion, is a complex condition that poses unique challenges in the context of total hip arthroplasty (THA). It refers to the abnormal protrusion of the acetabulum into the pelvic cavity, which is associated with a variety of symptoms and functional limitations. It is defined as a medial projection of the acetabular line beyond the ilioischial line (Kohler's line) by 6 mm in females and 3 mm in male patients. The etiology of primary or idiopathic PA is unknown, whereas development of secondary PA can occur as a result of various underlying conditions, including rheumatoid arthritis, osteoarthritis, developmental dysplasia of the hip or genetic predisposition, Paget's disease, or inflammatory hip diseases. THA can be considered as a viable treatment option in cases where use of conservative measures has not resulted in alleviation of pain and restoration of joint function[1-3].

Comprehensive preoperative evaluation and thorough surgical planning is required for successful management of PA with THA. Treatment with THA should be administered in cases of painful and progres-

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sive PA. Due to concerns regarding poor bone quality or cortical bone defects, the stability of the socket is an important consideration after arthroplasty. In addition, successful clinical and radiological results may not always be achieved after conventional THA for treatment of PA[1]. The objectives of performing THA for treatment of PA include restoration of abductor function and hip mechanics as well as restoration of the anatomical relationship between the femoral head and the acetabulum[2]. Potential concerns include surgical exposure, implant selection, lack of bone stock, deficient medial support to the cup, and medialization of the joint center[3].

Various techniques for management of PA have been described in the literature. Commonly used techniques include the use of morselized impacted autografts or allografts with a cemented or uncemented cup for acetabular reconstruction, metal cages, reinforcement rings, and solid grafts for acetabular reconstruction[4-7]. The aim of this systematic review is to provide a comprehensive analysis of the current evidence, evaluate treatment efficacy, compare surgical techniques, and identify topics for future research. Through synthesis of the available data, such a review can be helpful in the management of this particular condition by contributing to evidence-based decision-making, informing clinical practice guidelines, and ultimately improving patient outcomes.

MATERIALS AND METHODS

This study (Systematic Review) does not involve direct participation of patients, but assimilating data from studies conducted by other authors who have obtained permission from their respective boards. Thus, ethical approval is not required for conduct of a systematic review, which was confirmed after subjecting the information to the Medical Research Council (MRC) Health Research authority. Informed consent was not required for this study.

A comprehensive search of the literature was conducted for the systematic review following the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The search of online databases included PubMed (http://www.ncbi.nlm.nih.gov/pubmed), Embase (http://www.elsevier.com/online-tools/embase), Scopus, and the Cochrane Library database (http://www.cochrane.org) for all studies published until 17th June 2023. Search terms used were 'Protrusio acetabuli' OR 'Acetabular protrusion' AND 'total hip replacement' OR 'total hip arthroplasty'. The search was restricted to articles on human subjects in the English language. A hand search of references for the included full text articles was also performed for identification of any other relevant studies (Fig. 1).

The abstracts were identified first using the above-mentioned search methods and an assessment for eligibility was performed based on strict criteria mentioned below. The shortlisted abstracts were then followed up for full texts and another assessment for eligibility was performed. Another search of the reference list for the finalized articles was performed for identification of additional relevant studies.

1. Eligibility Criteria

The review included all original studies that included adult patients with a diagnosis of PA due to any cause undergoing THA, who underwent primary THA, with a minimum follow up period of one year and articles on the study of functional or radiological outcomes and survival after the THA procedure. Only papers in the English language were included. The exclusion criteria included (1) articles with incomplete data, (2) case reports, reviews, biomechanical studies, expert opinions, letters to editors or editorials, and (3) non-English language, (4) case series that included less than 10 patients, (5) Studies that included patients with an etiology, who did not have acetabular protrusion, were also excluded. All cases that were available for follow-up after accounting for losses during follow up were included in the review.

2. Data Extraction

The systematic review was conducted by two authors (S.A. and K.G.) who each performed an independent analysis of the data. Any controversy was resolved by mutual agreement and consultation with the senior author (R.B.K.). Data from full text articles was extracted into Microsoft Excel 2019 (Microsoft). Information on the demographic details of patients including author name, year of publication, sample size, follow-up period, outcomes (scores if present), prosthesis and surgical approach used, technique of protrusio management, complications, and survival of the prosthesis was extracted. In the case of an eligible study with incomplete data/information or not accessible by internet, the authors were contacted by

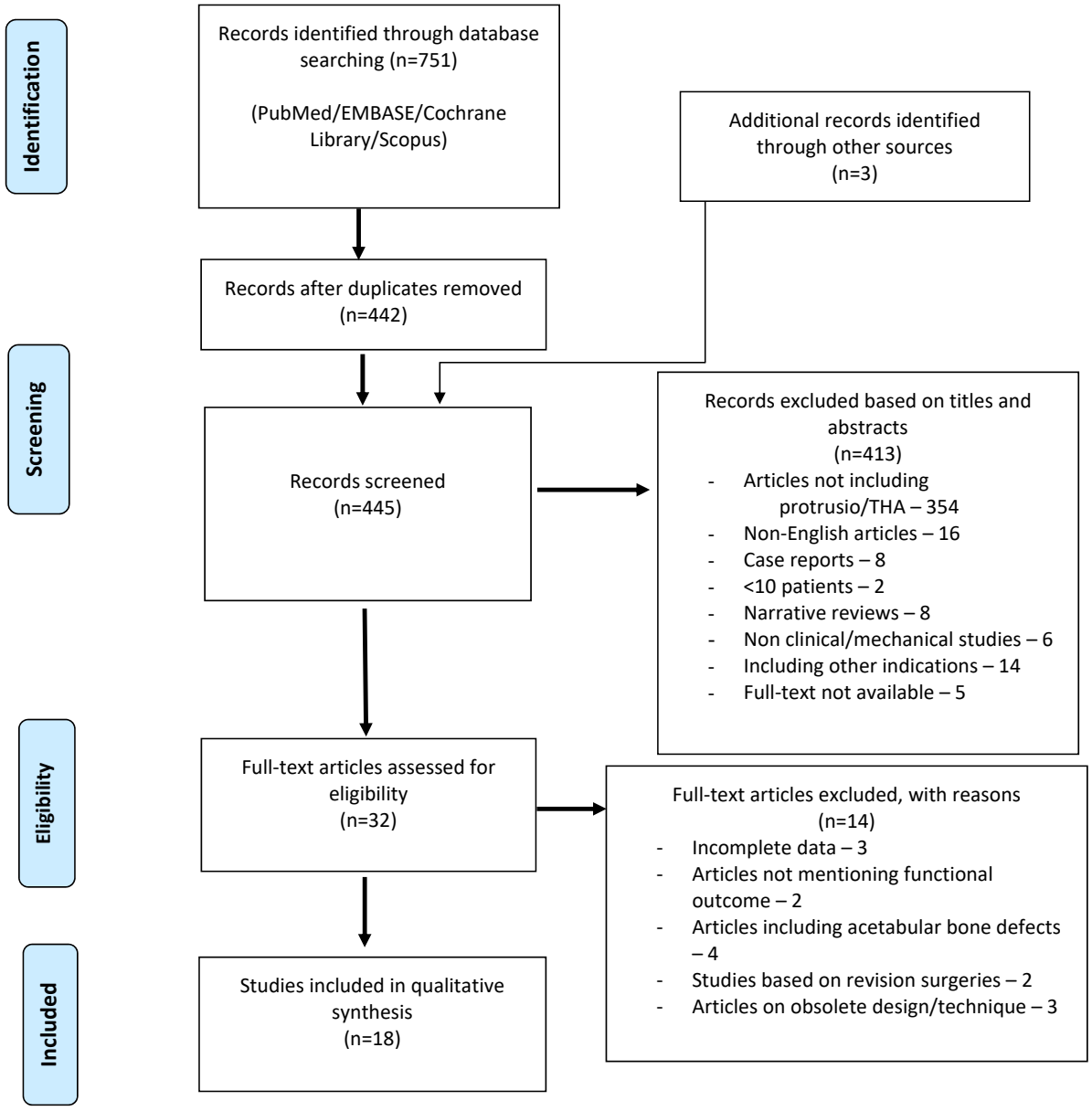

Fig. 1. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) chart. THA: total hip arthroplasty.

email using the correspondence address provided requesting the required information. In cases where the author had not responded by the data extraction stage or when data were considered irrelevant to our study, the study was excluded. The continuous variables were extracted and expressed as mean±standard deviation.

3. Quality Assessment of Included Studies

The quality of the studies included in the review was assessed by two separate reviewers (T.G. and P.J.). The Newcastle–Ottawa scale was used for assessment of the methodological quality of each study (Table 1)[2,3,8-23]. Assessment was performed for each included study by each reviewer and any disagreements were resolved by a third reviewer (B.S.R.).

RESULTS

1. Selection of Studies and Demographic Data

After an extensive search and performance of quality assessment prior to extraction of data in order to avoid selection bias, 751 studies were identified in the search. Titles and abstracts of all articles were evaluated for potential inclusion in the review. After assessing the studies against inclusion criteria, 18 studies were finally included in this review[2,3,8-23]. A flow chart

Table 1. Quality Assessment of Studies according to New Castle–Ottawa Score

Cohort studies	Representativeness of cohort	Ascertainment of exposure	Ascertainment of outcome (functional)	Adjustment for confounder	Follow-up mentioned
Zhen et al.[3] (2018)	Yes	Yes	Yes	Yes	Yes
Baghdadi et al.[8] (2015)	Yes	Yes	Yes	Yes	Yes
Dutka et al.[10] (2011)	Yes	Yes	Yes	Yes	Yes
Mullaji and Marawar[20] (2007)	Yes	Yes	Yes	Yes	Yes
Krushell et al.[15] (2008)	Yes	Yes	Yes	Yes	Yes
Baghdadi et al.[2] (2013)	Yes	Yes	Yes	Yes	Yes
Hansen and Ries[12] (2006)	Yes	Yes	Yes	Yes	Yes
Rosenberg et al.[21] (2000)	Yes	Yes	No	Yes	Yes
Matsuno et al.[18] (2000)	Yes	Yes	Yes	Yes	Yes
Gates et al.[11] (1989)	Yes	Yes	No	Yes	Yes
Kondo et al.[14] (2002)	Yes	Yes	Yes	Yes	Yes
Liu et al.[17] (2023)	Yes	Yes	Yes	Yes	Yes
Zuh et al.[23] (2015)	Yes	Yes	Yes	Yes	Yes
Yun et al.[22] (2021)	Yes	Yes	Yes	Yes	Yes
Mibe et al.[19] (2005)	Yes	Yes	Yes	Yes	Yes
Lee et al.[16] (2022)	Yes	Yes	Yes	Yes	Yes
Figueras Coll et al.[9] (2008)	Yes	Yes	Yes	Yes	Yes
Johnsson et al.[13] (1984)	Yes	Yes	No	Yes	Yes

of the literature search using the PRISMA format is shown in Fig. 1. Among the included studies, eight studies were prospective (Level II) and 10 studies were retrospective (Level III) in nature. A list of the study demographics is provided in Table 2. Surgery was performed on 783 hips, in 665 patients with a mean age of 60 years (range, 45.8-71.1 years). The patient population included 80% females. The mean follow-up period was 8.86 years (range, 2-15.4 years). The most common etiology was inflammatory arthritis, predominantly rheumatoid arthritis. Other types of inflammatory arthritis included psoriatic, systemic lupus erythematosus, and ankylosing spondylitis. Other common etiologies included idiopathic, degenerative osteoarthritis, and post traumatic, in that order (Table 2).

2. Technique of Acetabular Reconstruction

Restoring the native hip center of rotation (COR) is at the core of THA in treatment of protrusion acetabuli. While the Ranawat triangle method[24] was used by Baghdadi et al.[2] for estimation of the COR, Zuh et al.[23] used the method developed by Pierchon et al.[25]. Yun et al.[22] performed the procedure using a direct anterior approach and intra-operative fluoroscopy was used for placement of the implant and restoration of the COR. Other studies have used Kohler's line, teardrop, or inter-teardrop line as a reference for measuring COR distance. An uncemented cup was used in the majority of hips (n=436). Of these, a porous coated cup was used in 160 hips. Details on the various components used are shown in Table 2. An uncemented cup was used along with bone grafting for acetabular reconstruction in most studies. Six studies evaluated use of a cemented acetabular cup supported by a bone graft[9,11,13,14,19,21]. Both reconstruction techniques were used in two studies and the outcomes were compared[2,10]. Wherever deemed necessary, based on the lack of acetabular support, screws or acetabular support rings were used to aid stability. According to the pooled data, augmentation of the cup with screw fixation was performed in 148 uncemented hips[3,8,12,17,20]. An acetabular support ring was used in three studies in 37 hips; the details are provided in Table 2[14,18,19]. Lee et al.[16] reported on use of acetabular reinforcement components in two out of 26 hips in which press fit could not be achieved due to >50% rim defect. The type of stem used has been mentioned in eight studies. There were 113 uncemented stems (34.1%) and 218 cemented stems (65.9%). No consensus nor rationale has been identified among the various studies with regard to the type of stem that should be used. Femoral

Table 2. Study Characteristics and Demographic Details

Study	Country	Inclusion/exclusion criteria	Etiology	Total hips	Study design	Mean age (yr)	Sex (F:M)	Extension of protrucio from Kohler's line/ Sotelo-Garza classification	Intervention	Approach	Implant	Follow-up
Zhen et al.[3] (2018)	China	Protrusio in RA	RA	20 hips (18 patients)	Prospective cohort	45.8±8.3	12:6	12.7 mm	Uncemented with bone grafting	Posterolateral approach	Porous tantalum cups, 16 hips; titanium porous coated cups, 4; 4th generation ceramic-ceramic implantations, 8; polyethylene-lined ceramic implantations, 12	4.5±1.7 yr
Baghdadi et al.[8] (2015)	USA	THA done in protrusio	OA, 48 hips; RA, 15; sequele of septic arthritis, 2	65 hips (53 patients)	Retrospective cohort	66	53:12	7±4 mm	Uncemented 58 hips, impacted with morselized bone graft; 26 hips, supplementary screw fixation	Anterolateral, 34 procedures; posterior, 28; transtrochanteric, 3	Harris-Galante (HG)-I, 6 hips; Harris-Galante (HG)-II, 13; Omnifit, 17; Reflection™, 7; Porous-Coated Anatomic (PCA), 4; Press-Fit Condylar (PFC), 2; Elliptical, 1; Bi-Articular, 1; Trilogy®, 11; Hedrocel®, 3	15.4 yr
Dutka et al.[19] (2011)	Poland	1. THA done in patients with protrusion acetabuli with any etiology 2. Minimum 4-year follow-up 3. Full medical records available	RA, 122 hips; Otto's disease, 6; psoriatic arthritis, 3; SLE, 2; acetabular fracture, 1; radiation damage, 1	135 hips (127 patients)	Retrospective cohort	55.2	119:8	Grade 1, 48; grade 2, 36; grade 3, 21	128 hips, cemented; 7 hips, uncemented Autogenous grafts, 97 hips; mixed grafts, 38	NA	NA	12.7 yr
Mullaji et al.[20] (2007)	India	1. Primary THAs in significant protrusio acetabuli 2. Minimum follow-up of 2 years	RA, 14 patients; ankylosing spondylitis, 5; Idiopathic, 4	30 hips (23 patients)	Prospective cohort	46	17:6	Grade 1, 8; grade 2, 10; grade 3, 12	Uncemented THR with morselized BG	Anterolateral approach	Duraloc porous-coated cups, 17 cases; Bicontact cups, 13 One screw used to augment, 15 cases; 2 screws used, 12; no screw used, 3 A porous-coated stem used 21 cases: Bicontact, 13; Summit, 8 Cemented Charnley stems used, 9 cases	4.2 yr
Krushell et al.[15] (2008)	England	Primary THA of any cause with acetabular protrusio	Inflammatory arthritis in 22 cases and OA in 7 cases	29 hips (27 patients)	Retrospective cohort	66	20:7	Mean, 4.1 mm protrucio medial to Kohler's line	Uncemented, Autologous BG in all cases Additional synthetic grafts, 3 cases	Posterolateral approach	Beaded dual-geometry acetabular shell design with multilayer titanium MicroStructured porous ingrowth surface	4 yr
Baghdadi et al.[2] (2013)	USA	All patients with protrusio acetabuli who had undergone primary THR with a minimum follow-up of 2 years	Idiopathic, 117 hips; underlying inflammatory component, 38; genetic - 2, post infectious - 2, post radiation - 1, metabolic - 2	162 hips (127 patients)	Retrospective cohort	66±13	112:15	7±5 mm	Cemented, 55 hips (14/55 cemented hips, bone grafting) Uncemented, 107 hips (83/107 uncemented hips, bone grafting done)		First-generation designs: Charnley, Aufranc Turner, Elliptical, Ti-Bac Cups Second-generation designs: Harris-Galante (HG)-I, Harris-Galante (HG)-II, Omnifit, Reflection, Porous-Coated Anatomic, PressFit Condylar Third-generation designs: Pinnacle, Trilogy, Hedrocel, Trident, Trabecular Metal Modular, Tritanium Hemispherical Cluster	10±6 yr

Table 2. Continued

Study	Country	Inclusion/exclusion criteria	Etiology	Total hips	Study design	Mean age (yr)	Sex (F:M)	Extension of protrucio from Kohler's line/ Sotelo-Garza classification	Intervention	Approach	Implant	Follow-up
Hansen and Ries[12] (2006)	USA	1. Revision surgeries 2. Large medial defect with at least 50% radiographic projected acetabular bone loss 3. Minimum 2-year follow-up	OA in 9 patients, RA in 3, posttraumatic arthritis in 2, avascular necrosis in 1, PVNS in 1, and DDH in 1	19 hips (17 patients)	Prospective cohort	66	13:9	10.5 mm	Uncemented porous coated acetabular cup and morselized allograft	Posterior approach+ extended trochanteric osteotomy if necessary	Cementless hemispherical component with a widened peripheral rim	2.8 yr
Rosenberg et al.[21] (2000)	Netherlands	1. Patients diagnosed as RA with protrusio hip who under goes THA 2. Patients with minimum 8-year follow-up	RA	20 hips (16 patients)	Prospective cohort	53	13:3	NA	Cemented cups with Morselized allograft	Posterolateral approach	32 mm polyethylene Mueller or Allopro cup	11.7 yr
Matsuno et al.[18] (2000)	Japan	Patients diagnosed to have RA with protrusio hip	RA	15 hips (13 patients)	Prospective cohort	61.9	9:4	NA	Uncemented with iliac crest and morsellised femoral head graft	Aposterior approach	MC cup supporter	53.6 mo
Gates et al.[11] (1989)	USA	Painful progressive protrusio acetabuli	RA, hemiarthroplasty, THA, OA	48 hips (40 patients)	Prospective cohort	57.8	29:11	8.6 mm	Cemented THA with medial acetabular reinforcement with BG Autologous BG, 39 hips; Allograft, 9	NA	NA	12.3 yr
Kondo et al.[14] (2002)	Japan	RA with protrusion acetabuli treated with THA Minimum 9-year follow-up	RA	25 hips (19 patients)	Prospective cohort	56.7	16:3	Grade 1, 8; grade 2, 13; grade 3, 4	Cemented with autologous graft	NA	NA	129.6 mo
Liu et al.[17] (2023)	China	1. RA 2. Moderate and severe in patients with acetabular protrusions in which the bottom of the acetabulum exceeded Kohler's line in the pelvic AP radiography	RA	56 hips (45 patients)	Prospective cohort	55.64±5.38	28:17	10.97±3.08 mm	Uncemented THA with impacted bone grafting	Posterolateral approach	Biological total hip prostheses: A porous tantalum cup, 42 hips; sintered, three-dimensional, asymmetric, titanium, and porous-coated cups, 14; weight-bearing interfaces, 24; fourth-generation ceramic-on-ceramic implantations, and ceramic-on-highly cross-linked polyethylene, 32	5.20±1.20 yr

Table 2. Continued

Study	Country	Inclusion/exclusion criteria	Etiology	Total hips	Study design	Mean age (yr)	Sex (F:M)	Extension of protrucio from Kohler's line/Sotelo-Garza classification	Intervention	Approach	Implant	Follow-up
Zuh et al.[23] (2015)	Romania	THA in protrusio	Protrusion of unknown aetiology, 16 hips; RA, 6; protrusion secondary to tuberculous arthritis, 3; post-traumatic protrusion, 2; hip arthritis with thin medial acetabular wall, 12	39 hips (32 patients)	Retrospective study	58.3±8.9	15:17	I, 15 hips; II, 9; III, 3; thin medial wall, 12	Medial acetabular wall – augmented by impaction bone grafting Uncemented cup – all cases	Direct lateral approach		4.5 yr
Yun et al.[22] (2021)	USA	THA in protrusio	5 patients, RA; 18 patients, idiopathic PA	23 THAs in 21 patients	Retrospective study	68±9	19:2	Mild, 7 patients; moderate, 13; severe, 3	Morcellized femoral head autograft using Bone Mill, cementless acetabular cups	Direct anterior approach		5.3 yr
Mibe et al.[19] (2005)	Japan	Protrusio in RA	RA	19 hips of 15 patients	Retrospective	60.2 (48-75)	All F	12 hips, grade 1; 3 hips, grade 2; 1 hip, grade 3 Medial-proximal type, 3 hips	THA using a support ring All cups- cemented	Not mentioned	4 hips, TACT cup supporter; 1 hip, Kerboull plate; 6 hips, a Ganz ring; 5 hips, Müller ring	38 mo
Lee et al.[16] (2022)	Korea	THA in protrusio	RA, 14 hips; post-traumatic arthritis, 7; ankylosing spondylitis, 4; previous infection, 1	26 cementless THAs of 22 patients	Retrospective study	59.9	17:5	Mild, 5 hips; moderate, 19; severe, 2	Uncemented THA, reinforcement acetabular components in 2 hips	Kocher-Langenbeck approach	PLASMACUP SC, 9 hips; Bencox cup, 7; Pinnacle cup, 5; G7 cup, 1; ABT cup, 1; Delta TT cup, 1 SPH reinforcement cups, 2 hips with defective rim of the acetabulum	5.1 yr
Figueras Coll et al.[9] (2008)	Spain	THA in protrusio	Severe arthrosis (50% of cases), protrusio due to hemiarthroplasties (15%), and rheumathoid arthritis (15%) Aseptic loosening of the acetabular cup in THA, and some other causes- less common diagnoses	25 hips (25 patients)	Retrospective study	71.1	16:9	Paproski's classification – 20 type IIa cases, 4 type IIb and 1 type IIc	Cemented acetabular cup, autogenous morcellized bone-graft and acetabular wiremesh	Anterolateral	Charnley stem and cemented cup (7 right and 18 left hips)	8.6 yr
Johnsson et al.[13] (1984)	Sweden	Protrusio in RA	RA	27 hips (25 patients)	Retrospective study	56 (29-76)	21:4	Joint destruction according to Larsen and Larsen et al. 12 hips, grade IV; 15 hips, grade V Mean acetabular protrusion, 6 mm	Spongious bone chips from the trochanter and/or the femoral head, and iliac crest, 10 cases – thin titanium net A high density polyethylene (HDPE) protrusion cup – last 5 cases	26 hips, postero-lateral; 1 hip, anterior approach without trochanteric osteotomy	Lubinus (25) and McKee-Arden (2) types	2 yr

Values are presented as mean±standard deviation or mean (range).
F: female, M: male, RA: rheumatoid arthritis, THA: total hip arthroplasty, OA: osteoarthritis, SLE: systemic lupus erythematosus, NA: not available, THR: total hip replacement, BG: bone graft, PVNS: pigmented villonodular synovitis, DDH: developmental dysplasia of hip, AP: anteroposterior, PA: protrusio acetabuli.

anatomy and bone quality can be considered when deciding on the type of stem and fixation. Another major problem in these patients is that dislocating the head is difficult due to its incarceration within the acetabulum. Four studies have mentioned performing an in-situ neck cut[8,17,22,23]. However, in severe cases where the neck is not visible, removal of the lateral part of the edge of the femoral head and neck can be performed using a drill or narrow bone knife. Resection of the neck can then be performed while the head can be removed in pieces if needed[3,17]. Lee et al.[16] reported on removal of a thick part of the neck after two osteotomies to facilitate dislocation.

A morselized autograft from the femoral head, iliac crest, and trochanter was used in almost all studies to fill the medial wall defect and for restoration of the hip COR. A femoral head graft was considered adequate for this purpose. Kondo et al.[14] described the use of a sliced bone graft from the femoral neck along with a morselized graft. An allogenic graft can also be used when needed[8,10-12,23]. Krushell et al.[15] and Mibe et al.[19] mixed synthetic bone graft in eight patients. Eleven studies reported on the method of graft impaction, including reverse reaming (n=122), impaction with a small trial head (n=96) or impactor (n=55). A wire mesh was used in 52 hips, all cemented, in two studies[9,21]. Baghdadi et al.[2] reported that only 72 patients out of the pool of patients underwent surgery without bone graft (41, cemented; 31, uncemented). Thirteen studies mentioned the approach used in performance of the surgery (Table 2). The most commonly used approach was posterolateral (n=177), followed by anterolateral (n=85) and posterior (n=62).

3. Outcomes

Extension of protrusio medial to Kohler's line, which has a mean of 7.99 mm (range, 4.1-12.7 mm), was described in seven studies. Protrusio was classified according to Sotelo-Garza classification in seven studies. There were 103 grade I hips, 103 grade II hips, and 46 grade III hips. Other classification systems including American Academy of Orthopaedic Surgeons (AAOS) Committee on the Hip, Paprosky, and Larsen & Larsen classification were also used. The Harris hip score (HHS) was used in nine studies for evaluation of preop and postop hip function. The mean preoperative HHS was 47.5 (range, 32.3-55.3), which improved to 82.3 (range, 71.7-92.5) postoperatively[2,3,8,9,12,15,17,20,23]. The Japanese Orthopedic Association score (JOA), which improved from 21.7 (range, 19.6-25.2) to 50.7 (range, 35.2-70.4), was used in three studies[14,18,19]. Grading the clinical outcome was based on scoring in three studies[10,15,20]. The results were as follows: 36.6% (n=71) excellent, 46.9% (n=91) good, 11.3% (n=22) fair, and 5.2% (n=10) poor. Only Dutka et al.[10] graded the radiological outcome as excellent in 47 hips (34.8%), good in 60 hips (44.5%), fair in 18 hips (13.3%), and poor in 10 hips (7.4%). Three studies reported graft incorporation in all cases[17,18,21] while Krushell et al.[15] reported graft incorporation in 97% of cases. Mean time for graft union ranging from 3-6 months was reported in three studies[3,11,20].

4. Revisions and Complications

Among the studies, 48 revisions were reported. The mean time to revision surgery was 6.75 years (range, 0.27-8.8 years). The most common cause of revision surgery was aseptic loosening (n=38), followed by polyethylene wear/failure (n=4), and recurrent dislocations (n=4). The details regarding various revisions and other complications are shown in Table 3. Other common complications included heterotopic ossification (n=21), deep vein thrombosis (n=10), and nerve palsies (n=3). Four studies evaluated the survival rate of THAs in treatment of protrusion. Baghdadi et al.[8] reported a survival rate free from acetabular revision of 85.4%. In their previous study, a higher 15-year survival rate was reported for uncemented cups as compared to cemented cups (89% vs. 85%)[2]. Rosenberg et al.[21] reported a survival rate of 90% at 12-year follow-up, while Mibe et al.[19] reported a survival rate of 72% when using both revisions and deaths as the end point.

DISCUSSION

PA can pose certain problems for patients requiring a THA. The most common indication of THA for protrusion was inflammatory arthritis, particularly rheumatoid arthritis. In such cases performance of THA can be challenging due to medialization of the acetabulum and the femoral head. However, all of the studies included in this review reported consistently good outcomes. The aim of this first-of-its-kind review is to determine the best method for achieving good outcomes with THA in treatment of protrusion. Literature includes evaluation of both cemented and uncemented options for THA. While achievement of better outcomes with uncemented cups with bone graft as compared to cemented

Table 3. Evaluation and Follow-up

Study	Outcome measure	Preop	Postop	Revisions	Complications	Radiological evaluation	Conclusion/remarks	Follow-up mentioned?
Zhen et al.[3] (2018)	HHS	55.3±9.5	92.5±12.7	Nil	Nil	Distance from center of femoral head to Kohler's line increased from 19.87±3.9 mm to 21.5±3.5 mm after the operation.	For patients with PA secondary to RA cementless, trabecular, metal modular cup allowing peripheral press fitting and restoration of bone stock by impacted bone graft - satisfactory short-term results	Yes
Baghdadi et al.[8] (2015)	HHS	55	82	Revision, 15 hips; aseptic loosening, 12; polyethylene liner failure, 2; recurrent instability, 1	Aseptic loosening, liner wear, recurrent instability	5 unrevised acetabular components and 3 unrevised femoral components - non-progressive radiolucency	Satisfactory results for a median follow-up of 15 years for uncemented acetabular component in THR with PA	Yes
Dutka et al.[19] (2011)	HHS	NA	Mean, 86.6; cemented, 84.2; uncemented, 92.6	Revision in 10 hips Both component loosening, 6; acetabular component loosening, 4	10 hips, loosening; HO Brooker II in 15 cases, DVT in 6, and wear of the acetabular component in 4	The radiographic outcomes: excellent in 47 hips (34.8%), good in 60 (44.5%), fair in 18 (13.3%), and poor in 10 (7.4%)	At 12-year follow-up, better outcomes seen with patients operated with autogenous bone grafting than mixed bone grafting. No significant difference in type of prosthesis, aetiology and severity of PA in final outcome.	Yes
Mullaji et al.[20] (2007)	HHS	52	85	Nil	1 postoperative hematoma 1 secondary suturing owing to necrosis of the superficial edges of the wound	All bone grafts united by the 6th month. Several small radiolucencies seen around the screw in 3 cases.	Uncemented porous coated hemispheric cups with peripheral press fit fixation and restoration of bone stock with impacted autologous bone grafting appears to give satisfactory medium-term results.	Yes
Krushell et al.[15] (2008)	HHS Hip centre to Kohler's line distance	41 24 mm	84.6 30.9 mm	1 case - secondary osteolysis due to polyethylene wear after 8 years	1 peroneal nerve palsy and 1 case of recurrent dislocation. 1 case of late reoperation for polyethylene wear and secondary osteolysis.	At follow-up, mean protrusion medial to Kohler's line was 1.0 mm, mean vertical distance 12.5 mm, mean horizontal distance 30.9 mm.	Excellent results obtained in 29 hips both clinically	Yes
Baghdadi et al.[2] (2013)	HHS	51±12	77±18	11 revised - 9 asepic loosening, 1 linear wear and liner exchange, 1 instability	9 - asepic loosening 1 - linear wear and liner exchange 1 - instability	Femoral offset decreased by 4±9 mm Hip COR improved by 11±6 mm	10-year survival rate is 95% (95% CI). 15-year survival rate is 89% (95% CI) in uncemented. 10-year survival rate is 92% (95% CI). 15-year survival rate is 85% (95% CI) in cemented.	Yes
Hansen and Ries[12] (2006)	HHS	32.3	71.7	Revision - 1 due to recurrent dislocation	5 - dislocation, 1 - developed a transient lateral femoral cutaneous neuropraxia, 1 - perioperative cardiac event	Mean protrusio position of the acetabular prostheses medial to Kohler's line was 10.5 mm.	Uncontained medial acetabular defects can be successfully augmented with morselized bone graft , oversized rim fit acetabular component if good quality peripheral bone exists and integrity of acetabular rim is maintained.	Yes
Rosenberg et al.[21] (2000)	Long-term survival rate for primary THA	NA	NA	2 revisions due to aseptic loosening	Aseptic loosening - 2	In all cases, radiographs - the impacted morsellized bone grafts had become incorporated with the surrounding bone.	Long-term survival rate for primary THA in RA patients having protrusio acetabuli and acetabular reconstruction with impacted morselized bone graft is 90% (95% CI) at an average 12-year follow-up.	Yes
Matsuno et al.[18] (2000)	JOA score	20.6	70.4	Nil	One patient - transient sciatic nerve palsy	The COR of the hips was improved to within 4 mm of normal.	All grafts appeared to heal radiologically with no radiolucent line between graft and acetabulum.	Yes
Gates et al.[11] (1989)	Central edge angle Protrusion medial to Kohler's line	80.3° +8.6 mm	57.7° –10.5 mm	5 revisions -progressive protrusion	Loosening, 8; trochanteric non-union, 2	Postoperatively-average distance of migration of the femoral head medial to Kohler's line 10.5 mm, vertical migration average 5.3 mm.	Vertical migration and horizontal distance, two measurements utilizing a x-y coordinate system based on the tear drop-most useful radiographic measurements for determining the presence of PA and in following postoperative progression	Yes
Kondo et al.[14] (2002)	JOA score	19.6	35.2	Nil	6 acetabular component loosening	Acetabular component loosening	The rate of loosening of THA without bone grafting was higher than that of THA with bone grafting.	Yes

Table 3. Continued

Study	Outcome measure	Preop	Postop	Revisions	Complications	Radiological evaluation	Conclusion/remarks	Follow-up mentioned?
Liu et al.[17] (2023)	1. Range of flexion motion of the hip joint 2. Range of abduction motion 3. HHS	39.48°±8.36° 10.86°±4.34° 37.84±4.74	103.07°±7.64° 36.75°±3.99° 89.55±4.05	Nil	Reduction of the hip joint was extremely difficult in three patients (4 hips)	The horizontal distance of the hip rotation center increased from preoperative 10.40±2.50 mm to postoperative 24.03±1.77 mm, and the vertical distance increased from preoperative 72.36±3.10 mm to postoperative 92.48±5.31 mm.	Uncemented THA combined with impacted grafting granule bone of the autogenous femoral head and biological acetabular cup-reconstruct the acetabulum, restore the COR of hip joint, and achieve good medium-term outcomes in the treatment of moderate to severe PA secondary to RA.	Yes
Zuh et al.[23] (2015)	HHS	42.3±3.9	85.2±3.0	Nil	HO, 6 cases	Hip COR was restored close to the ideal values on the vertical axis, while on the horizontal axis the COR obtained was lateral to the ideal point.	Impaction bone grafting for acetabuloplasty, associated with the implantation of an un-cemented cup, yields good midterm clinical and radiological results in patients with PA or primary hip arthrosis with a thinned medial acetabular wall.	Yes
Yun et al.[22] (2021)	Hip disability and osteo-arthritis outcome score	Not done	91±10.4	1 revision - stem subsidence	1 case - Meckel's diverticulum required 20 days of inpatient care for small bowel obstruction and acute pyelonephritis	Preoperative AK distance (mm): 8±4.5; range, 1-16 Postoperative AK distance (mm): 0±2.2; range, -4 to 3	Anterior approach may decrease the significant risks of dislocation by avoiding posterior dis-section.	Yes
Mibe et al.[19] (2005)	JOA score	25.2±8.6	55.6±8.7	2 revisions owing to loosening of the Ganz ring	Loosening of the Ganz ring - 2 patients	The mean depth of the protrusio acetabuli was 3.6 mm before operation, and 3.1 mm just after the operation.	With THA for protrusio acetabuli in RA - no loosening, and bone stock maintained by a bone graft using a support ring. It suppresses progression of the PA in the short-term.	Yes
Lee et al.[16] (2022)	Modified HHS	NA	Restored group: 83.6±12.1, Medialized group: 83.8±10.4	One patient - periprosthetic femoral fracture	No other complications	The mean abduction and anteversion angles (in degrees) of the acetabular component were 37.4 and 23.7 in the medialized group and 43.8 and 24.9 in the restored group, respectively.	Implant stability and favorable results were obtained by press-fitted cups, irrespective of hip center restoration. THA in PA patients-promising clinical and radiological results.	Yes
Figueras Coll et al.[9] (2008)	HHS	42.3	90.6	Nil	4 DVT, 3 posterior hip dislo-cations, 3 wound infection	One had radiolucent lines >2 mm - zone 2, which did not progress.	Bone-grafting and acetabular wiremesh - effective and simple method to arrest the progresion of PA	Yes
Johnsson et al.[13] (1984)	NA	NA	NA	One hip revised - deep infection Recurrent dislocations occurred in one - re-operation planned	Recurrent dislocations, 1 hip; deep infection, 1	Progressive radiolucent zone of 4-5 mm at the bone-cement interface - 2 hips Calcar resorption of 4-10 mm - 2 hips with 10 mm distal migration of the femoral component in the latter case	THA with the use of autogenous spongious bone graft reinforcement to the medial acetabular wall-successful surgical procedure in patients with RA and PA	Yes

Values are presented as mean±standard deviation.

Preop: preoperative, Postop: postoperative, HHS: Harris hip score, Nil: nothing, PA: protrusio acetabuli, RA: rheumatoid arthritis, THR: total hip replacement, NA: not available, HO: heterotopic ossification, DVT: deep vein thrombosis, COR: centre of rotation, CI: confidence interval, THA: total hip arthroplasty, JOA: Japanese Orthopaedic Association, AK distance: medial acetabular border to kohler line distance.

has been confirmed, few studies evaluating the type of femoral stem that should be used have been reported, thus no conclusion can be drawn in that regard.

Opinion regarding the concept of restoration of the anatomical hip COR for achievement of a good outcome and better survival of the implant has been consistent. The Ranawat triangle method is the best-known method for estimation of anatomic hip COR[24]. When using this method, an isosceles right-angled triangle is drawn with base and perpendicular length equal to 20% of pelvic height projected from a point 5 mm lateral to the teardrop. The anatomic hip centre falls at the centre of the hypotenuse that is drawn. More recent studies have described different formulas for determining COR and maintain that their accuracy is greater than that of previous methods. Fujii et al.[26], who formulated two new methods, the Modified Ranawat method and the pelvic height ratio method, reported that these methods are more accurate than the Ranawat triangle method. Pierchon et al.[25] developed a method for calculating the hip centre using the teardrops and sacro-iliac joint. However, the COR migrates superomedially and requires inferiorization and lateralization. Baghdadi et al. detected a 24% risk of aseptic loosening with every 1 mm shift of the COR from the native COR. However, no difference was observed with a shift of COR on the vertical axis[2]. Lee et al.[16] reported that implant stability and good outcomes were achieved with a press fit of cups and was not related to the restoration of the COR.

Filling the acetabular cavity secondary to lateralization of the cup with morselized bone graft is the best option. Ranawat and Zahn[27] presented the first guidelines for bone grafting in patients with protrusion. Grafting is not recommended in cases of protrusion <5 mm with a strong medial wall; grafting is required for protrusion >5 mm with a thin medial wall; use of additional fixation devices is required in the case of a grossly deficient medial wall. Autogenous morcellised femoral head graft was used in most studies for restoration of the COR. Additional grafts from the iliac crest or trochanter can be used in cases where the femoral head is inadequate. Although allogenic graft and synthetic graft substitutes have also been used, Dutka et al.[10] reported that a relatively poorer outcome was observed with use of a mixed graft as compared to an autogenous graft in 12-year follow-up. Histological studies have demonstrated complete graft incorporation after eight months followed by remodeling to the point that conversion of the graft into normal trabecular bone can be observed at 15 months post-surgery[28]. All studies included in the review reported that good incorporation of the bone graft was observed in almost all patients, which was achieved within approximately 3-6 months followed by consolidation and trabeculation of the graft. Kondo et al.[14] reported a higher rate of loosening in hips that underwent surgery without a bone graft and placed emphasis on the importance of bone grafting. The majority of authors preferred to fill the medial acetabular cavity with bone graft and only 72 THAs were performed without bone grafting. Further progression of protrusion post THA can also be prevented with bone grafting. In the series reported by Baghdadi et al.[2] poorer clinical scores were observed in hips that underwent surgery without bone grafting.

Commercially available bone mills, reamers, or rongeurs can be used in preparation of bone graft. Mullaji and Marawar[20] reported that use of commercial bone mills can result in production of a graft size that is too small for use; however, Yun et al.[22], who exclusively used a commercial mill, reported that there were no poor outcomes in terms of ingrowth or consolidation. A review by Mirza and Sadiq[29] maintained that larger bone chips of 8 mm are the ideal size to provide stability for acetabular bone grafting. Some authors used only morselized bone graft while others used smaller pieces of bone impacted into the acetabulum while the gaps were filled with morselized graft. Kondo et al.[14] reported on use of femoral neck slices when filling the bone defect. Good results were achieved with use of various methods of impaction, from the use of smaller trial heads to specialized impactors for reversal of reaming. Figueras Coll et al.[9] reported on use of a titanium mesh in 25 patients while Rosenberg et al.[21] used a vitallium mesh over the impacted bone graft to contain it in 27 patients. They reported that bone grafting with mesh is an effective and simple method for arresting progression of protrusion[9,21].

Historically, cemented cups have been used routinely with good results[11,13,14,21]. However, in more recent studies the dynamics have shifted towards the use of uncemented cups based on achieving a peripheral rim fit. Proper acetabular preparation for use of a cementless cup is required in order to avoid overreaming the medial wall and consequent medialization of the cup. Smaller reamers or curettes can be used with care in preparation of the acetabular floor in order to create

only a bleeding bed, not to enlarge the cavity. Reaming must be anatomical, with the goal of obtaining an equatorial press-fit fixation while avoiding the process described as "reaming-related medialization", in order to avoid compromise of the acetabular offset[30]. Previous studies have reported on several techniques for achieving an adequate press-fit when using cementless cups, from a 2-mm underreaming to 1-mm line-to-line reaming[23,31]. Most authors have reported avoiding the use of additional screws for fixation until and unless considered necessary. A screw augmentation was used in only 148 out of 436 uncemented cups. Acetabular support rings were also used in two studies. Matsuno et al.[18] reported on use of a Harris Galante porous coated cup with an MC ring supporter. The COR was restored within 4 mm of normal[18]. A study by Mibe et al.[19] evaluated use of two cemented rings, the TACT Cup supporter and the Kerboul plate, and two uncemented rings, the Ganz ring and the Müller ring, with all cemented cups. They reported a survival rate of 72% when using both failure and death as end points. Better maintenance of acetabular thickness was achieved with use of uncemented rings as compared to cemented support rings[19].

The studies included in this review do not provide adequate evaluation of the choice of femoral stem. Cementless stems were used primarily. The choice of femoral stem, which is based on the patient's bone quality, should be individualized. The majority of patients with protrusio are females in the age group 65-70 years, many of whom are on chronic steroid therapy. These findings suggest the use of cemented stems in the majority of patients[30]. Dorr classification based on the cortical thickness of the proximal femur can provide guidance in the selection of a stem. According to a review by Bengoa et al.[30], a low femoral neck osteotomy to avoid limb lengthening and use of femoral stems with collodiaphyseal angle in varus are recommended (<125°). Lateralization and posteriorization of the initial box osteotome are required in order to avoid placing a stem in varus, which is highly likely with the overhand of the greater trochanter. However, none of the studies included in the review have offered any rationale regarding the types of femoral stem or the type of fixation that should be used.

Baghdadi et al.[2] performed surgery on 162 hips (107 uncemented vs. 55 cemented) and compared survival rates; the 10-year survival rate was 95% and the 15-year survival rate was 89% in the uncemented group and 92% and 85%, respectively, in the cemented group. In another study, they reported acetabular cup revision free survival of 94.3% at 10 years and 85.4% at 15 years for all uncemented cups[8]. Rosenberg et al.[21] reported a survival rate of 90% at 12-year follow-up with use of cemented acetabular cups in rheumatoid patients with protrusion. The most common complications were aseptic loosening (n=55) and heterotopic ossification (n=21). While the former required revision, conservative management was administered for the latter. Other common complications included recurrent dislocations, polyethylene wear, and deep vein thrombosis. The incidence of infection and wound complications was relatively low. However, awareness of such complications is required, particularly in cases of inflammatory arthritis where the patient is on immunomodulatory and biological drugs[30].

Our review has limitations. First, the review includes a mix of study types, many of which were retrospective, with no control groups for comparison of the outcome of THA in treatment of PA with that of THA for other indications. Identification of prospective comparative studies would be ideal. Second, in most studies the sample size was less than 50. However, due to the paucity of literature, we needed to utilize all available studies. Third, larger studies on this topic, such as studies utilizing registry data, are currently missing and interest will perhaps increase in the near future.

However, the large number of studies included in the review for analysis is a major strength of our study. To the best of our knowledge, this is the first systematic review reported in recent years that provides details on the various aspects of THA in the cohort of patients with PA. Performance of THA in this subset of patients is technically more difficult compared with other indications for a primary THA, as is the difference in outcome and complications. Therefore, this article would be helpful in assessing the outlook for such patients as it integrates all of the current evidence regarding the outcome of THA in patients with acetabular protrusio.

CONCLUSION

Performance of THA in patients with PA presents a greater challenge as compared to other routine indications. However, the results of the surgery are promising

and, if done properly, survivorship may be comparable with that of THA for other indications. This review supports the use of an uncemented cup with a morselized autograft for filling the medial acetabular defect. Restoration of the anatomic hip centre of rotation and achieving a good press fit is extremely important. Screws or rings can be used to augment the fixation when considered necessary. Selection of the femoral stem should be decided on an individual basis according to anatomy and bone quality. However, there is a lack of good quality case-control studies comparing outcomes in patients undergoing THA for treatment of PA and other indications. Such studies are needed in order to attain a higher quality of evidence on this topic.

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Conflict of Interest

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