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Low Reinfection Rates But a High Rate of Complications in THA for Infection Sequelae in Childhood: A Systematic Review

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Abstract

Background Childhood hip infections can result in serious sequelae during adulthood, including persistent pain, functional limitations, and premature THA. When THA is performed in patients who had hip joint infections during childhood, surgeons surmise these arthroplasties are at an increased risk of complications and incomplete recovery. However, the degree to which this is true is not well characterized and has varied across a large number of small, retrospective studies.

Questions/purposes (1) What proportion of THAs performed in patients who had pediatric septic arthritis result in periprosthetic joint infection? (2) What are the Harris hip scores associated with these reconstructions? (3) What proportion of these patients develop complications after THA? (4) What proportion of patients undergo revision after these THAs?

Methods For this systematic review, we searched the MEDLINE (PubMed), Scopus, and CINAHL (EbscoHost) electronic databases. We evaluated studies published in English between 1980 and 2020 that had a minimum of 10 patients (with a minimum of 2 years of follow-up) in whom sequelae of septic arthritis of the hip were treated with single-stage THA. We also evaluated studies reporting clinical outcomes by means of the Harris hip score, along with a radiographic assessment of the prosthesis. Updates of previous studies using the same database, case reports, surgical technique reports, systematic reviews, and expert opinions were excluded. No restrictions were applied regarding study design and loss to follow-up. A total of 430 studies were identified through the initial search, and 11 studies were included after applying the inclusion and exclusion criteria. All but two studies, which included a historical control group, were retrospective case series. A total of 691 patients with a mean age of 45 years were involved. A total of 599 patients underwent cementless THAs, 84 patients underwent hybrid THA (cemented stems), and the remaining eight patients received a cemented THA. A total of 287 additional procedures were performed on the acetabulum, including autografting, allografting, and medial wall osteotomies; in three hips, tantalum augments were used. Three hundred thirty-five additional procedures were performed on the femora, including 223 shortening osteotomies and 112 greater trochanter osteotomies. The mean follow-up duration ranged from 5.5 to 15.2 years (minimum follow-up range 2-13 years). To assess the quality of the studies, we used the Methodological Index for Non-randomized Studies and the Assessment of Quality in Lower-limb Arthroplasty, for which a higher score represents a better study quality. The mean Methodological Index for Non-randomized Studies score for case series was 9 of 16 (range 6-12), and 19 and 18 of 24 for the two comparative studies. The mean reporting quality of the Assessment of Quality in Lower Limb Arthroplasty score was 6 of 8 (range 3-8).

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Ethical review board approval for this study was waived by the IRCCS Istituto Ortopedico Galeazzi, Milan, Italy.

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Results Because of loss to follow-up, which was not consistently reported in the source studies, we caution the reader that the estimates provided here likely underestimate the risks of adverse events and overestimate the mean hip scores. The pooled proportion of patients in whom infections developed was 1% (seven of 691 THAs). Considering only studies published in the past 10 years, the proportion was 0.7% (two of 276 THAs). The Harris hip score increased from a mean of 52 ± 6 points before THA to a mean of 88 ± 2 points after THA. The pooled proportion of complications, including sciatic nerve palsy, femoral nerve palsy, intraoperative periprosthetic fracture, deep venous thrombosis, and dislocation, was 11% (76 complications among 691 THAs). The pooled proportion of patients who underwent revision was 8% (53 revisions of any components for any reason among 691 THAs) at a mean follow-up interval of 9.1 ± 3 years.

Conclusion In THAs for sequelae of childhood septic arthritis, reinfections were uncommon, whereas generally, infection rates were slightly higher than those reported for conventional primary THAs. However, the duration of follow-up might have been insufficient to identify all patients in whom infections later developed, and the available data were not adequate to precisely detect the minimum quiescent period to avoid reinfections. Moreover, the studies in this systematic review were retrospective, and selection bias, transfer bias, and assessment bias likely influenced our findings. The general effect of these biases is to cause an underestimation of the harms of the intervention. Complications, especially intraoperative fracture and nerve palsy, were common in patients with the most-severe infections. Further data on this topic are needed, ideally from multicenter or registry studies with even longer follow-up durations.

Level of Evidence Level IV, therapeutic study.

Introduction

The hip is the most common site of septic arthritis in children and can result in a broad spectrum of residual deformities, including coxa vara, persistent hip ankylosis, slipped capital femoral epiphysis, osteonecrosis of the femoral head, high dislocation of the hip, and severe soft tissue contracture [48]. Hip sepsis also can result in anatomic abnormalities and joint stiffness in adulthood that can be worsened by femoral or acetabular osteotomy and femoral lengthening, which is sometimes performed during childhood [45]. When surgery is indicated, THA is the treatment of choice to alleviate pain and restore joint function in these patients. A long waiting period (more than 10 years) has sometimes been recommended to avoid the risk of recurrent infection [16-18]. However, THA can be technically challenging because of soft tissue contractures that alter the location of the profunda femoris artery and femoral bundle [20], fixed deformities, deficient bone stock, dysplasia of the acetabulum and proximal femur, and leg length discrepancy. Small cups and additional procedures such as bone grafting may be performed to address shallow dysplastic acetabula [46]. Femoral preparation may be difficult because of hypoplasia, a narrow femoral canal, and femoral bowing, as well as possible metaphyseal-diaphyseal mismatches and deformities [43, 45]. Moreover, subtrochanteric shortening osteotomy is often indicated in patients with high hip dislocation along with massive soft tissue releases to allow joint reduction, lower the risk of neurovascular injury, and correct possible rotational deformities [47].

Although periprosthetic joint infection (PJI) is uncommon in primary THA (estimates vary from 0.4% to 2.2% of these procedures [28]), many surgeons surmise that THAs performed for the sequelae of childhood septic arthritis may be associated with an increased risk of PJI. Similarly, surgical complexity arising from difficulty achieving durable fixation in anatomically altered sockets and medullary canals, the use of supplementary procedures (such as femoral shortening osteotomies) that carry risk, potential detrimental effects of material wear over time, and a relatively young population affected by this condition may put these patients at an increased risk of revision. However, the degree to which this is true is not well characterized and has varied across a large number of small, retrospective studies [3, 6, 8, 14, 16, 18, 20, 22, 26, 27, 29, 36, 37, 43-46, 48]. Thus, a systematic review may provide useful information for surgeons treating these patients and indicate the knowledge gaps to be filled in the future.

We therefore performed a systematic review in which we asked: (1) What proportion of THAs performed in patients who had pediatric septic arthritis result in PJI? (2) What are the Harris hip scores associated with these reconstructions? (3) What proportion of these patients develop complications after THA? (4) What proportion of patients undergo revision after these THAs?

Patients and Methods

Eligibility Criteria

Studies were reviewed if they reported the results of patients undergoing THA for arthritis, dislocation, or joint deformity because of previous septic arthritis of the hip during childhood. Inclusion criteria were THA for infection sequelae, clinical outcomes reported with clinical scores, and reported radiographic assessment of the prosthesis. Exclusion criteria were case reports, surgical technique reports, systematic reviews, and expert opinions;

studies with fewer than 10 participants; studies with a minimum follow-up duration of less than 24 months; studies reporting single-stage or two-stage THA for acute or subacute septic arthritis; and updates of previous studies using the same database. No restrictions were applied regarding study design (randomized controlled trial, prospective comparative studies, case-control studies, retrospective comparative studies, and case series) or the proportion of patients available for follow-up, and we did not set a limit for the maximum loss to follow-up.

Search Strategy

We systematically searched the MEDLINE (PubMed), Scopus, and CINAHL (EbscoHost) electronic databases. Only studies published in English between January 1, 1980 and the last search (April 30, 2020) were considered. The search string was "septic arthritis AND (total hip replacement OR total hip arthroplasty OR THA OR THR)." Two authors (RD and GR) worked independently and were blinded to each other's decisions on studies selected for inclusion. Disagreement between individual judgments was resolved by a third author (GB). Lastly, the reference lists of the articles were manually searched for potential articles to be included. All decisions were recorded for integration into an attrition flowchart (Fig. 1).

Data Collection, Items, and Synthesis

The following data were extracted: first author, study design, and level of evidence (according to the tool provided by *Clinical Orthopaedics and Related Research*®: https://journals.lww.com/clinorthop/documents/authortools/Levels%20of%20Evidence.pdf), number of patients, gender

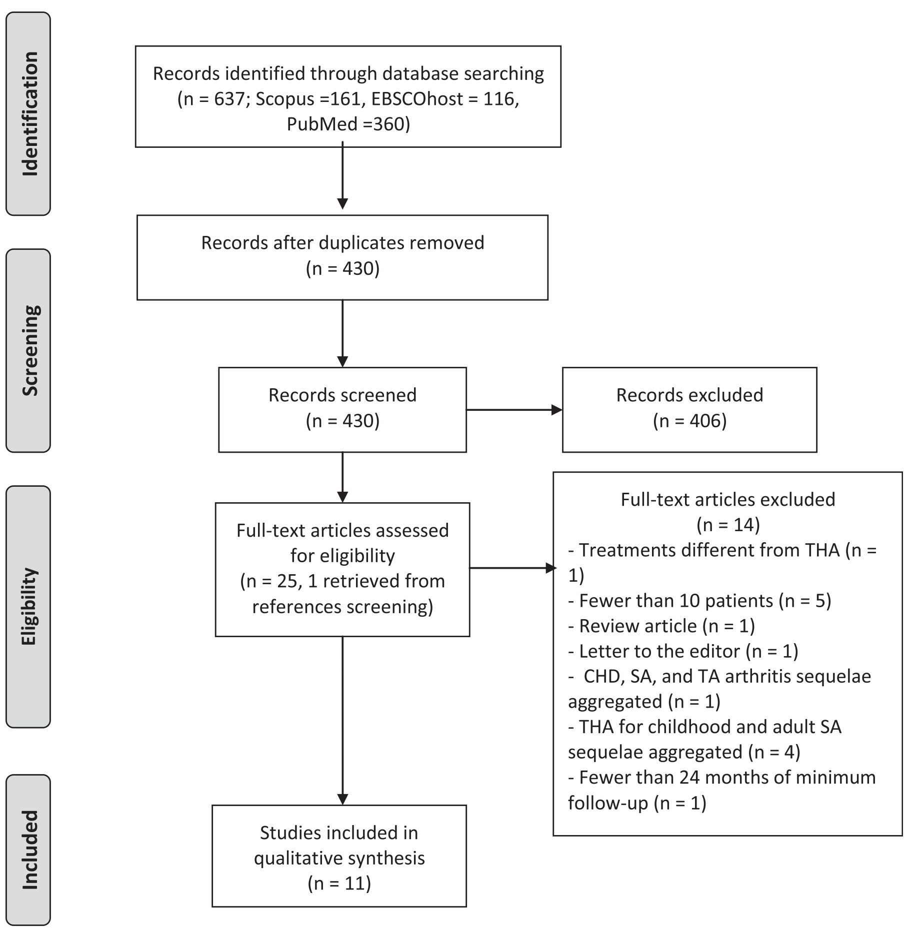

Fig. 1. This flowchart shows the search strategy and number of identified studies on THA for septic arthritis sequelae in children, following the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines. CHD = congenital hip dysplasia; TA = tuberculous arthritis; SA = septic arthritis.

distribution, age, quiescent period, follow-up duration, classification of the disease according to dislocation, preoperative leg length discrepancy, number of cemented and uncemented cups, number of cemented and uncemented stems, and implant brand. Early complications were defined as sciatic and/or femoral nerve palsy, intraoperative periprosthetic fracture, deep venous thrombosis, or dislocation. Clinical outcomes and preoperative and postoperative Harris hip scores were noted, along with postoperative leg length discrepancy, infection, aseptic loosening, reoperation, heterotopic ossification, antibiotic prophylaxis, and preoperative and intraoperative examinations to detect infection. Data were entered in a Microsoft Excel, version 16, spreadsheet (Microsoft Corporation, Redmond, WA, USA). Two authors (GR and GB) extracted the data independently. Disagreement was solved by a third author (RD), who double-checked the final data. Missing data in the spreadsheet were termed not applicable.

A meta-analysis was not performed because all but two of the studies were retrospective case series. For this reason, descriptive statistics were used. The outcomes are expressed as means and proportions.

Quality Assessment

Two authors (GR and GB) independently assessed the quality of the studies. In case of discordance, we consulted with a third author (FPJ) to reach a consensus. We independently graded the reporting quality and methodologic quality of the studies for the final analysis according to the Assessment of Quality in Lower-limb Arthroplasty criteria [38]. The Assessment of Quality in Lower-limb Arthroplasty consists of an eight-question quality-reporting item (score of 1 to 8) and a six-question methodologic-quality item on hip and knee arthroplasty. We also applied the Methodological Index for Non-randomized Studies [39] scoring system for non-randomized studies, wherein the global ideal score is 16 for noncomparative studies and 24 for comparative studies.

Search Results, Article Summary, and Quality Appraisal

Of the 430 studies retrieved and examined for title and abstracts, 11 were selected for review [16, 18, 20, 26, 27, 29, 36, 43, 45, 46, 48] (Fig. 1). All but two studies were retrospective case series (Level of Evidence: IV) (Table 1). Both [18, 36] were retrospective comparative studies (Level of Evidence: III); one involved adult patients undergoing THA for childhood hip infection in which uncemented or cemented components were implanted [18] and the other reported on THA with subtrochanteric shortening osteotomy for high hip dislocation caused by childhood septic arthritis or developmental dysplasia of the hip (DDH) [36] (Table 2). For one of the studies [18], data were extracted separately for the group of cementless implants and the group of cemented or hybrid prostheses, even though all patients were considered for the computing of this systematic review. We limited our study to one hip per patient, although two of the studies [16, 18] included patients who underwent bilateral THA.

All articles reported additional procedures on the acetabular side (for example, femoral head autografting and allografting, as well as medial wall osteotomy) or on the femoral side (for example, subtrochanteric shortening osteotomy, greater trochanter osteotomy, or distal femoral osteotomies) (Table 2).

A total of 691 patients with a mean age of 45 years were involved. Five hundred ninety-nine patients underwent cementless THAs, 84 patients underwent hybrid THA (cemented stem), and the remaining eight patients received a cemented THA. A total of 287 additional procedures were performed on the acetabula, grouped as autografting (23 patients), allografting (166 patients), and medial wall osteotomies (90 patients); in three hips, tantalum augments were used. Moreover, one study [29] reported autografts on the acetabula without specifying how many, whereas another study [46] reported eight structural grafts without specifying whether they were autografts or allografts. A total of 335 additional procedures were performed on the femora, including 223 shortening osteotomies and 112 greater trochanter osteotomies. In 243 hips, a modular stem was used (S-ROM, DePuy, Warsaw, IN, USA). No cases of high hip center were reported across the studies. The mean follow-up duration ranged from 5.5 to 15.2 years (minimum follow-up range 2-13 years).

Based on the Assessment of Quality in Lower-limb Arthroplasty criteria, the mean reporting quality score was 6 (range 3-8) (Table 3). The mean Methodological Index for Non-randomized Studies score was 9 (range 6-12) for noncomparative studies and 19 [36] and 18 [18] for the two comparative studies.

Ethical Approval

Because this was a meta-analysis, institutional review board approval was not required. This study followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement [31]. The protocol was registered with the International Prospective Register of Systematic Reviews (an international database of systematic reviews in health and social care; registration number CRD42020175578).

Table 1. Overall study characteristics

Author	Year of publication	Level of evidence	Years of index procedures (range)	Number of patients	M/F	Mean age in years	Mean quiescent period in years	Mean follow-up in years
Park et al. [36]	2020	III	1996-2013	25	5/20	41.2		12.3
Luo et al. [29]	2019	IV	2008-2015	101	51/50	52.3	24	6.1
Yang et al. [45]	2019	IV	2008-2012	49	23/26	44.3	37.4	8.7
Wang et al. [43]	2019	IV	2001-2011	56	23/33	47	33.4	10.7
Zeng et al. [48]	2019	IV	2008-2012	45	23/22	45.9	34.2	6.4
Kim et al. [20]	2009	IV	1990-2000	62	22/40	47.5	37.8	15.2
Yoo et al. [46]	2009	IV	1993-2000	38	13/25	44		8.3
Lian et al. [26]	2007	IV	1993-2000	52	15/37	44.5	36.8	7.8
Lim and Park [27]	2005	IV	1994-2000	58	26/32	49.3	35.2	6.3
Kim et al. (cementless group) [18]	2003	III	1996-2003	116		42.7	31.9	10.8
Kim et al. (cemented hybrid group) [18]	2003	III	1996-2003	45		41.9	34.9	9.8
Kim [16]	1991	IV		44	18/26	36.4	19.9	5.45

Results

Because of loss to follow-up, which was not consistently reported in the source studies, we caution the reader that the estimates provided here likely underestimate the risks of adverse events and overestimate the mean hip scores.

Infection After THA

The pooled proportion of patients in whom infections developed was 1% (seven of 691 THAs). No infections were reported in five studies [16, 26, 29, 36, 45] (Table 4). In the remaining six studies [18, 20, 27, 43, 46, 48], seven infections were reported: reactivation of a previous infection in three infections, infection because of microorganisms that were different from the original ones in two, and no information about the etiology in the remaining two. Hence, reactivation of the previous infection developed in 0.4% (three of 691 patients). The pooled proportion of patients in whom infections developed was 0.7% (two of 276 THAs) in studies published in the past 10 years [29, 36, 43, 45, 48].

Harris Hip Scores

All studies reported clinical outcomes based on the Harris hip score (Table 5), which increased from a mean of 52 ± 6 points preoperatively to a mean of 88 ± 2 points postoperatively. The mean clinical outcome scores were good (Harris hip score 80-89), with four studies reporting excellent outcomes (mean Harris hip score ≥ 90).

Complications

The pooled proportion of complications was 11% (76 complications in 691 THAs) and included sciatic and femoral nerve palsy, intraoperative periprosthetic fracture, deep venous thrombosis, and dislocation (Table 4). Most of the nerve palsies (75%; 21 of 28) were transient and resolved over time. In more detail, 23 sciatic nerve palsies, 19 of which were transient, were reported, whereas three of five patients with femoral nerve palsies had a permanent deficit. In two patients from a single study [16], sciatic nerve palsy was associated with femoral nerve palsy, and the damage to both nerves was permanent. Thirty-six intraoperative periprosthetic femoral fractures were reported. The pooled proportion of patients who had dislocation was 2% (15 of 691 THAs).

Frequency of Revision

The pooled proportion of isolated cup revision was 2% (12 of 691 THAs), and the pooled proportion of patients

Table 2. Classifications of deformities, type of fixation, prosthesis brands, and additional procedures on the acetabular and femoral sides

Author	n of patients	Classification, % (n)	Cemented cup, % (n)	Uncemented cup, % (n)	Cemented stem, % (n)	Uncemented stem, % (n)	Cup brand	Stem brand	Additional procedures/ devices on the acetabulum, % (n)	Osteotomy on the femur, % (n)
Park et al. [36]	25	Choi IV 100 (25)	0 (0)	100 (25)	0 (0)	100 (25)	Pinnacle DePuy®, Trilogy Zimmer®, Duraloc Depuy®	S-ROM DePuy®, Wagner Cone Zimmer®		STO 100 (25), tenotomies
Luo et al. [29]	101		0 (0)	100 (101)	0 (0)	100 (101)	Pinnacle DePuy®	S-ROM DePuy®, Taper DePuy®	FHSAU	STO 6 (6)
Yang et al. [45]	49	Crowe IV 100 (49)	0 (0)	100(49)	0 (0)	100 (49)	Pinnacle DePuy®	S-ROM DePuy®	FHSAU 16 (8)	STO 100 (49)
Wang et al. [43]	56	Crowe III-IV 45-55 (25-31)	0 (0)	100(56)	0 (0)	100 (56)	Pinnacle DePuy®	S-ROM DePuy®	FHSAL 64 (36), tantalum augment 5 (3)	STO 61 (34)
Zeng et al. [48]	45	Crowe III-IV 58-42 (26-19)	0 (0)	100(45)	0 (0)	100 (45)	Pinnacle DePuy®	S-ROM DePuy®, Corail DePuy®, Summit DePuy®	FHSAU 16 (7)	STO 36 (16)
Kim et al. [20]	62	Crowe IV 100 (62)	0 (0)	100(62)	0 (0)	100 (62)	Duraloc 1200 Series DePuy®	AML DePuy®	FHSAL 65 (40)	STO 100 (62)
Yoo et al. [46]	38		0 (0)	100(38)					MWO 100 (38), STGR 21 (8)	DDSO 32 (12)
Lian et al. [26]	52	Hartofilakidis I-II-III 31-21-48 (16-11-25)	0 (0)	100(52)	90(47)	10 (5)	Harris-Galante II Zimmer®, Trylogy Zimmer®, Omnifit Stryker®	CDH DePuy®, PFC DePuy®, Versys Zimmer®, ANA Zimmer®, Harris-Galante Zimmer®, Omnifit Stryker®	MWO 100 (52), FHSAU 12 (6)	SO 21 (11), DO 10 (5), GTA 4 (2)
Lim and Park [27]	58	Crowe I-II-III-IV 41-35-14-10 (24-20-8-6)	0 (0)	100(58)	0 (0)	100 (58)		S-ROM DePuy®	FHSAU 3 (2)	GT 10 (6), SO 5 (3)
Kim et al. (cementless group) [18]	116	Radiologic classification II-III	0 (0)	100(116)	0 (0)	100 (116)		PCA Howmedica®, AML DePuy®, Bantam DePuy®, Profile DePuy®, IPS DePuy®, Omnifit Stryker®	AL 27 (31)	GT 52 (60)

Table 2. continued

Author	n of patients	Classification, % (n)	Cemented cup, % (n)	Uncemented cup, % (n)	Cemented stem, % (n)	Uncemented stem, % (n)	Cup brand	Stem brand	Additional procedures/ devices on the acetabulum, % (n)	Osteotomy on the femur, % (n)
Kim et al. (cemented hybrid group) [18]	45	Radiologic classification I-II-III	18 (8)	82 (37)	100 (45)	(0)		Müller CDH Thackray®, Elite CDH DePuy®, Elite DePuy®	AL 71 (32)	GT 98 (44)
Kim [16]	44		0 (0)	100(44)	0 (0)	100(44)	PCA Howmedica®, AML Depuy®, Harris-Galante Zimmer®, BIAS Zimmer®, anatomic medullary locking components	Muller DePuy®	AL 61 (27)	

STO = subtrochanteric transverse osteotomy; FHSAU = femoral-head structural autograft; FHSAL = femoral-head structural allograft; MWO = medial wall osteotomy; STGR = structural graft; DDSO = distal derotational and shortening osteotomy; SO = subtrochanteric osteotomy; DO = distal osteotomy; GTA = greater trochanter advancement; GT = greater trochanter; AL = allograft.

undergoing isolated stem revision was 2% (11 of 691 THAs). One study reported 26 revisions of both components in 161 patients [18], and four studies [20, 43, 46, 48] each reported one revision of both components. Another study provided no information about revision [16], whereas the remaining studies did not describe revision of both components; most reported a few revisions of only one component (Table 6). More broadly, the pooled proportion of patients undergoing revision of any component for any reason was 8% (53 revisions of 691 THAs). The main reason for revision was aseptic loosening; 92% (45 of 49) of aseptic revisions were performed for loosening or osteolysis (eight cup revisions, 11 stem revisions, and 26 revisions of both components). Most of these reconstructions were complex because they were performed on hips classified as Crowe Type III, Crowe Type IV, or Choi Type IV, or because they had medial wall osteotomies. Radiologic evidence of aseptic loosening was seen in 10 cups and 47 stems, although not all of these patients underwent revision. In the study reporting the highest number of aseptic loosening cases [18], the authors attributed the revisions to the use of small femoral stems in the cemented group and undersized stems in the cementless group.

Discussion

Septic arthritis of the hip in childhood is rare in developed countries, but it can have devastating consequences, even when treated promptly and appropriately. This sometimes results in THA in patients who are very young. In such situations, THA may pose considerable challenges because of soft tissue contractures and deficient bone stock, with deformities that in some cases resemble those of patients with high hip dislocation because of dysplasia. Previous treatments and the presence of metal hardware sometimes further complicate the surgical procedure [7]. These procedures are believed to be at high risk for revision, premature loosening, and incomplete recovery. However, the magnitude of risk is poorly characterized because what we believe we know about risk in this setting comes from a large number of small, retrospective studies [3, 6, 8, 14, 16, 18, 20, 22, 26, 27, 29, 36, 37, 43–46, 48]. Thus, we performed a systematic review to better characterize this risk and to summarize Harris hip scores before and after surgery. We found that infections were surprisingly uncommon, but serious complications occurred frequently. Among those whose reconstructions were not revised, Harris hip scores generally improved. However, because of the types of bias that beset the source studies—particularly selection bias and transfer bias (follow-up that was insufficiently long or incomplete)—results may be poorer than they seem here.

Table 3. Assessment of Quality in Lower-limb Arthroplasty methodologic quality items [38]

Item	Park et al. [36]	Luo et al. [29]	Yang et al. [45]	Wang et al. [43]	Zeng et al. [48]	Kim et al. [20]	Yoo et al. [46]	Lian et al. [26]	Lim and Park [27]	Kim et al. [18]	Kim [16]
Is there a clear primary research question or hypothesis?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
How were the cohorts constructed?											
a. Consecutively	x			x							
b. Nonconsecutively											
c. Unknown		x	x		x	x	x	x	x	x	x
How adequate was the follow-up?											
a. Fully completed follow-up									x	x	
b. 5% or less lost to follow-up or follow-up quotient is 1 or less					x						
c. More than 5% lost to follow-up or follow-up quotient is more than 1	x	x	x	x		x		x			
d. Unknown							x				x
How was the follow-up performed?											
a. Predefined; for example, yearly	x	x	x	x	x	x		x		x	
b. When patients had complaints or chart review (of non-predefined follow-up)											
c. Unknown							x		x		x
How many arthroplasties are at risk at the follow-up of interest?											
a. 20 or more	x	x	x	x	x	x	x	x	x	x	x
b. Less than 20											
c. Unknown											
Has a worst-case analysis or competing risk analysis for competing endpoints [14] been performed?	No	No	No	No	No	No	No	No	No	No	No

Table 4. Complications and preoperative and postoperative LLDs

Author	n of patients	Infections, % (n)	Complications, n	Sciatic nerve palsy, % (n)	Femoral nerve palsy, % (n)	Intraoperative periprosthetic fracture, % (n)	Deep vein thrombosis, % (n)	Dislocations, % (n)	Mean LLD preoperatively in cm	Mean LLD postoperatively in cm
Park et al. [36]	25	0 (0)	11	0 (0)	4(1)	32 (8)	0 (0)	8 (2)	6.3	3.9
Luo et al. [29]	101	0 (0)	14	3 (3) (t)	0 (0)	7 (7)	0 (0)	4 (4)	3.4	1.1
Yang et al. [45]	49	0 (0)	4	4 (2) (t)	0 (0)	2 (1)	0 (0)	2 (1)	3.96	0.72
Wang et al. [43]	56	2 (1)	12	9 (5) (t)	0 (0)	9 (5)	0 (0)	4 (2)	4.5	1.2
Zeng et al. [48]	45	2 (1)	7	7 (3) (t)	0 (0)	4 (2)	0 (0)	4 (2)	3.89	0.64
Kim et al. [20]	62	2 (1)	9	3 (2) (t)	0 (0)	5 (3)	0 (0)	5 (3)	4.5	2.6
Yoo et al. [46]	38	3 (1)								
Lian et al. [26]	52	0 (0)	4	2 (1)	4 (2) (t)	0 (0)	0 (0)	2 (1)	3.4	1.2
Lim and Park [27]	58	2 (1)	4	2 (1) (t)	0 (0)	3 (2)	2 (1)	0 (0)		
Kim et al. (cementless group) [18]	116	0 (0)	1	1 (1) (t)	0 (0)	0 (0)	0 (0)	0 (0)		
Kim et al. (cemented hybrid group) [18]	45	4 (2)	1	2 (1) (t)	0 (0)	0 (0)	0 (0)	0 (0)		
Kim [16]	44	0 (0)	9	7 (3)	5 (2, associated with sciatic nerve palsy)	14 (6)	0 (0)	0 (0)	1.6	0.9

LLD = leg length discrepancy; t = transient.

Table 5. Harris hip scores and heterotopic ossifications

Author	n of patients	Mean Harris hip score preoperatively	Mean Harris hip score postoperatively	Hips with heterotopic ossification, % (n)
Park et al. [36]	25	48.7	85.1	24 (6)
Luo et al. [29]	101	48.5	90	5 (5)
Yang et al. [45]	49	45.0	84,8	6 (3)
Wang et al. [43]	56	44.2	87.5	11 (6)
Zeng et al. [48]	45	48,1	87.6	9 (4)
Kim et al. [20]	62	55	89	
Yoo et al. [46]	38	57	91	
Lian et al. [26]	52	62	91.6	
Lim and Park [27]	58	49.5	89.2	5 (3)
Kim et al. (cementless group) [18]	116	50	89	9 (10)
Kim et al. (cemented hybrid group) [18]	45	50	85	13 (6)
Kim [16]	44	57.6	90.4	2 (1)

Limitations

The present study has several limitations. First, most of the studies were retrospective case series (only two had a control group), and the reporting quality and methodologic quality varied considerably. These problems almost certainly caused selection bias, assessment bias, and transfer bias (insufficiently long or incomplete follow-up). Regarding selection bias, indications for THA other than a quiescent period longer than 10 years were inconsistently reported across the studies, and contraindications other than active infection were generally missing. Assessment bias may have affected the number of revisions that were performed because the surgeon who performed the index procedure may have been the one deciding whether it was revised. In addition, the follow-up might

Table 6. Reoperations, revisions, and loosening

Author	n of patients	Reoperations, % (n)	Total revisions, % (n)	Isolated cup revision, % (n)	Isolated stem revision, % (n)	Aseptic loosening of the cup, % (n)	Aseptic loosening of the stem, % (n)
Park et al. [36]	25	44 (11)	0 (0)	8 (2)	12 (3)	8 (2)	12 (3)
Luo et al. [29]	101	5 (5)	0 (0)	1 (1)	1 (1)	1 (1)	1 (1)
Yang et al. [45]	49	2 (1)	0 (0)	0 (0)	2 (1)	0 (0)	2 (1)
Wang et al. [43]	56	4 (2)	2 (1)	0 (0)	2 (1)	0 (0)	2 (1)
Zeng et al. [48]	45	4 (2)	4 (1)	0 (0)	4 (1)	0 (0)	4 (1)
Kim et al. [20]	62	10 (6; excluding 1 for skin necrosis)	2 (1)	5 (3)	3 (2)	3 (2)	3 (2)
Yoo et al. [46]	38	16 (6)	3 (1)	5 (2)	3 (1)	0 (0)	3 (1)
Lian et al. [26]	52	12 (6)	0 (0)	2 (1)	2 (1)	2 (1)	2 (1)
Lim and Park [27]	58	7 (4)	0 (0)	5 (3)	0 (0)	5 (3)	5 (0)
Kim et al. (cementless group) [18]	116	18 (21)	15 (18)	0 (0)	0 (0)		21 (24)
Kim et al. (cemented hybrid group) [18]	45	22 (10)	18 (8)	0 (0)	0 (0)		18 (8)
Kim [16]	44	2 (1)				2 (1)	9 (4)

have not been long enough to detect potential harms. Similarly, we did not set a limit of loss to follow-up as an inclusion criterion, so that transfer bias must be considered. Lastly, crude percentages were used as a survivorship estimator instead of a Kaplan-Meier or a competing-risk analysis, which would have considered missing data and allowed us to obtain good 95% CIs. In light of these biases, we again warn the reader that the findings of this study may overestimate the benefits and minimize the apparent harms. Therefore, our results might represent a best-case scenario, and we caution the reader that infections, complications, and revisions could be more common, and outcomes poorer, than estimated by the studies we evaluated.

In addition, it is likely that there was patient or procedure overlap; some of the studies shared authorship and several study centers were involved more than once. To identify studies with simple updates, we collected additional information (such as dates of procedures, prosthesis brand, and type of fixation) before including these studies. Because most studies were performed in high-volume centers, these results may be difficult for lower-volume surgeons or centers to replicate. Fourth, there was heterogeneity in the severity of hip deformity, ranging from normally centered hips to high hip dislocations, resulting in a variety of procedures on the acetabular and femoral side, as well as the use of several types of cups and stems. For those reasons, two clinically relevant questions could not be answered in this review because of a lack of evidence: whether the type of technique (additional procedures of the acetabulum and femur) and whether the type of implants used influence the proportion of complications and outcomes. Additionally, there was heterogeneity in the type of organisms causing the original infections and in the antibiotic regimen used (Table 7). Moreover, only one of the included studies reported the outcomes in three patients with a history of tuberculous arthritis [27]. Because there was insufficient evidence on this topic, our results speak only to bacterial septic arthritis rather than mycobacterial infections. Lastly, the evidence was insufficient to support specific recommendations about the superiority of one antibiotic regimen over another.

Infection After THA

The pooled proportion of patients in whom infection developed after THA was 1%, varying across the studies, and 0.7% in those published in the past 10 years (two of 276 THAs). In three of seven patients, the infections were reported as reinfections. Concerns have recently been raised about the high risk of PJI after total joint arthroplasty in patients with a history of treated septic arthritis, especially those who were treated with TKA [40]. Considering this risk in patients with a history of childhood septic arthritis, in light of our findings, we suggest including a joint aspiration and synovial fluid culture in patients with an elevated erythrocyte sedimentation rate and C-reactive protein level, or clinical or radiologic doubt of persistence. Although this might be insufficient to rule out infections completely, it may increase the chances of detecting clinically silent infections. Moreover, we suggest performing intraoperative tissue and bone specimen culturing for these patients, paying particular attention to dubious tissues and carefully examining images to detect suspect bone areas to sample intraoperatively. In many of the studies [18, 20, 26, 29, 43, 45, 48], a frozen section was used routinely or when suspicious-looking tissue was seen.

The percentage of infections was similar to, or slightly higher than, those reported for primary hip arthroplasty in large studies (ranging from 0.4%-1.6%) [10, 23, 24, 35]. We noted that the proportion of patients with infections was higher than the low rate in patients undergoing THA for DDH [1, 4, 11, 15, 25, 30, 32–34, 41, 42, 49]. Previous infection is one of several factors that can contribute to the infection risk in these patients. The type of microorganism could be another factor. Most of the studies in this review reported an infection quiescent period of more than 10 years as a criterion for THA, based on a report by Kim [16]. However, the most appropriate interval between the infection and THA has yet to be established. Two studies [36, 46] did not report these details on antibiotic prophylaxis, whereas norvancomycin was used in two [45, 48] of the other studies, and cephalosporins in the remaining studies. The duration of prophylaxis is an open question, because in some studies an antibiotic was administered for 48 hours postoperatively [16, 18, 20, 29, 45, 48], for 24 hours in another [43], and an extended regimen was used in two [26, 27]. It is unclear whether these patients may benefit from extended antibiotic prophylaxis, as has been suggested for other at-risk patients [13].

Harris Hip Scores

Clinical outcomes were rated from good to excellent in most patients at the most recent follow-up interval. The mean preoperative Harris hip score was below 50 points for many patients, which shows the great potential for recovery for these patients. However, this may also represent an optimistic view, in light of the limitations of the data sources we mentioned. Patient expectations must be contextualized, especially in those with severe infection. In the only Level III study comparing patients with high hip dislocation because of DDH with those with infection because of a childhood hip infection, the mean postoperative Harris hip score was 85.1 in those with infection and 91.3 in those with DDH; furthermore, patients with previous infections had more-severe limping and less muscle

Table 7. Bacteria causing childhood hip infections, work-ups to detect infections, and antibiotic regimens

Authors	Infective agents (n of infections)	Preoperative work-up	Intraoperative work-up	Antibiotic regimen
Park et al. [36]			Swab and tissue cultures	
Luo et al. [29]	*Staphylococcus aureus* (80), *Streptococcus* (9), unknown (12)	Suction 8 weeks before surgery, blood cell count, ESR, CRP	Swab and tissue cultures, frozen section of suspicious tissues	Cefuroxime intravenous 4.5 g/day for 2 days
Yang et al. [45]		Blood cell count, ESR, CRP	Synovial fluid and tissue cultures, frozen section	Norvancomycin 0.4 g intravenous, intraoperatively and twice daily for 2 days
Wang et al. [43]	*Staphylococcus aureus* (50), *Streptococcus* (2), *Pseudomonas aeruginosa* (1), *Escherichia coli* (2), *Hemophilus influenzae bacillus* (1)	Blood cell count, ESR, CRP, technetium-99, and gallium bone scans, local symptoms of the infection, and CT and MRI if septic arthritis suspected	Synovial fluid and tissue cultures, frozen section if radiolucent line	Cefuroxime 1500 mg intravenous every 8 hours for 1 day
Zeng et al. [48]		Blood cell count, ESR, CRP	Synovial fluid and tissue cultures, frozen section	Norvancomycin 0.4 g intravenous intraoperatively and twice daily for 2 days
Kim et al. [20]	*Staphylococcus aureus* (53), *Pneumococcus* (3), *Hemophilus influenzae* (3), Salmonella (1), *Meningococcus* (1), *Escherichia coli* (1)	Suction 8 weeks before surgery, blood cell count, ESR, CRP	Synovial fluid, smear and tissue cultures, frozen section of suspicious tissues, bone biopsy in case of radiolucent lines	Cefazolin intravenous 4 g/day for 2 days
Yoo et al. [46]				
Lian et al. [26]		Blood cell count, ESR, CRP, technetium-99 and gallium bone scans	Swab and tissue cultures, frozen section of suspicious tissues	4 g cephalosporin daily for 5 g, then orally for 1 week
Lim and Park [27]	Pyogenic infections (58)	Aspiration in case of suspicious infections, blood cell count, ESR, CRP	Swab and tissue cultures	Cephalosporin intravenous for 3 days, then orally for 1 week
Kim et al. [18]	*Staphylococcus aureus* (145), *Streptococcus* (8), unknown (17)	Suction 8 weeks before surgery, blood cell count, ESR, CRP	Synovial fluid, smear and tissue cultures, frozen section of suspicious tissues, bone biopsy in case of radiolucent lines	Cephalosporin intravenous 4 g/day for 2 days
Kim [16]		Suction before surgery, blood examinations	Synovial fluid, smear and tissue cultures	Cephalosporin intravenous 6 g/day for 2 days

ESR = erythrocyte sedimentation rate; CRP = C-reactive protein.

strength, despite having less limb lengthening, and the hip took more time to achieve union of the osteotomy site [36].

Complications

The most frequent complication was an intraoperative femoral fracture (5%; 36 of 691 THAs) [16, 20, 27, 29, 36, 43, 45, 48], followed by sciatic nerve palsy (3%; 23 of 691 THAs) [16, 18, 20, 26, 27, 29, 43, 45, 48]. These data highlight the need for accurate reaming and a correct implant choice, which should always be part of the procedure, while considering the characteristics of the femur and increased risk of fracture because of poor bone quality and previous infection and operations. Careful surgical planning is important when treating these patients, especially those with more scar tissue and a severe leg length discrepancy, in order to balance correction of the leg length discrepancy with the risk of nerve palsy and tailor soft tissue release and shortening osteotomy to the individual patient. From a practical point of view, considering the findings here, the moment when patients are the most at risk of a femoral fracture appears to be during the insertion of a definitive stem. The use of one or more prophylactic cerclage wire before stem insertion may be an option in patients with weakened bone or areas of stress risers. Moreover, we recommend surgeons be attentive to signs of intraoperative fracture [42], such as sudden subsidence during broaching and rotational instability of the stem at the final insertion. Patients with nerve palsies seem to be at a higher risk than those affected by DDH [36], presumably because of the higher number of procedures received during childhood and because of the fibrosis and soft tissue retraction caused by previous infection, which may alter the location of nerves. Thus, we suggest that surgeons consider a shortening osteotomy for patients whose reconstruction would result in lengthening greater than 3 cm, which has been offered as a possible threshold in earlier studies on patients undergoing THA for DDH [36, 41]. Clearly, other factors that influence the choice of osteotomy are soft tissue tension and the goal of restoring an anatomic center of rotation.

Frequency of Revision

The pooled proportion of patients undergoing revision of any component for any reason was 8% (53 revisions of 691 THAs) at a mean follow-up duration of 9 years. These data seem comparable to those of arthroplasty performed for DDH at a similar follow-up interval [1, 4, 11, 15, 25, 30, 32–34, 41, 42, 49]. The main reason for revision was aseptic loosening. Low survival rates at 15 and 20 years after protheses implantation before 30 years of age may explain the reluctance of surgeons to propose this procedure after infection, although recent progress in cementless implants and bearings has considerably reduced the number of cases of loosening compared with the past [12]. Indeed, contemporary THA has shown improved survivorship over time in patients 30 years or younger [2]. However, a higher risk of reoperation has been reported in younger people, who have a higher life expectancy and activity level than older people do [9]. The same authors reported young age at the time of primary THA, high number of previous surgeries, and occurrence of at least one dislocation as risk factors for revision, with hard-on-soft bearings being at higher risk of revision than hard-on-hard bearings [9]. The first two risk factors are often present in patients undergoing THA after childhood hip infection. Nonetheless, these data might have been influenced by revisions related to increased wear of conventional polyethylene, because newer highly-crosslinked polyethylene has recently shown good long-term results in combination with ceramic heads when used in young and active patients [19]. Correct cup positioning, promoting concentric load, and avoiding impingement counteract bearing-related drawbacks. Nevertheless, periprosthetic osteolysis did not seem to play a major role in the included studies, except for some older ones [18, 26, 27, 46]. Aseptic loosening in cementless THAs may have been caused by failure of initial osteointegration (especially on the femoral side) or by subsidence of undersized stems [20, 43, 45, 48]. With regard to modularity, which provides more flexibility in terms of leg length correction, version, and offset [45], the results of one design of modular sleeve prosthesis were reported across the studies. In this context, modularity may offer advantages in the management of complex infection. However, disadvantages related to modularity, including risks of fretting, corrosion, and fatigue fractures of modular components, may negatively affect implant survivorship and are worth considering when choosing these designs [5, 21]. The most suitable stem designs, along with the most cost-effective cup coatings for these patients, might be the focus of future comparative studies.

Conclusion

This systematic review of THAs performed for the sequelae of hip infection in childhood found that the proportion of reinfections is low, but perhaps slightly higher than that observed among THAs performed for other indications [10, 23, 24, 35]. The risk of reinfection may persist after long quiescent periods. In addition, serious complications, especially intraoperative fracture and nerve palsy, are common. Although the pooled proportion of revisions seemed low here, it is likely an underestimate of the actual risk of revision because of the effects of selection and transfer bias in the source studies. Because of the retrospective designs of the included studies, we are concerned that our estimates about the magnitude of risk and harm might represent a best-case scenario. To increase the chance of detecting silent infections, we suggest careful preoperative work-up to exclude persistent infection, including synovial fluid cultures when indicated and use of additional intraoperative diagnostic tools such as frozen sections, leukocyte esterase count, synovial fluid cell count, and percentage of polymorphonuclear neutrophils. Intraoperative tissue samples may provide the best chance of tailoring appropriate postoperative antibiotic therapy in patients with persistent or recurrent infection [20, 43, 48]. In anatomically altered femora, undersized stems may increase the risk of aseptic loosening and should be avoided. One or more preventive cerclage cables before insertion of the definitive stem may help avoid intraoperative fractures. Considering the increased risk of nerve palsy in this population, the surgeon may judiciously decide to lower the threshold for performing a shortening osteotomy. Because of the low frequency of these procedures, even in high-volume hospitals, multicenter efforts, along with registry studies, could be helpful. Future studies should focus on antibiotic regimens that will most effectively reduce the risk of infection, the most suitable components to restore the proper kinematics of the hip in order to enhance long-term fixation, and techniques that reduce the risk of intraoperative fractures and subsequent loosening.

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