Arthroplasty Today 17 (2022) 101–106

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original Research

Total Hip Arthroplasty With Subtrochanteric Osteotomy for Developmental Hip Dysplasia: A Long-term Follow-up Study

Brian T. Palumbo, MD [a, b], Kevin Salomon, BS [c, b], Alex Sullivan, MD [a, b], Peter Simon, PhD [c, b], Steven Lyons, MD [a, b], Thomas L. Bernasek, MD [a, b, *]

[a] Florida Orthopaedic Institute, Temple Terrace, FL, USA
[b] University of South Florida, Tampa, FL, USA
[c] Foundation for Orthopaedic Research and Education, Tampa, FL, USA

ARTICLE INFO

Article history:
Received 6 June 2022
Accepted 8 July 2022
Available online xxx

Keywords:
Total hip arthroplasty
Subtrochanteric shortening derotational osteotomy
Developmental dysplasia of the hip
Long-term

ABSTRACT

Background: Total hip arthroplasty (THA) for developmental hip dysplasia (DDH) often requires a subtrochanteric shortening derotational osteotomy (SDO) to limit leg lengthening, mitigate risk of peripheral nerve palsy, and reduce excessive femoral anteversion. Few studies exist detailing long-term clinical outcomes and survivorship. The aim of this study is to analyze the long-term outcomes and survivorship of an SDO-THA cohort.

Methods: We retrospectively reviewed all patients who underwent cementless THA with femoral osteotomy due to Crowe I-IV DDH between 1991 and 2001. Primary outcome measures included revision surgery for any reason and functional outcome measures using modified Harris Hip scores. Secondary outcome measures included mode of implant failure and radiographic assessment for osteotomy union, polyethylene wear, osteolysis, and implant loosening.

Results: Our review resulted in 24 SDO-THA cases in 20 patients with a mean follow-up of 19 years (range, 8-27 years). Overall survivorship was 67%. All 8 failures were treated with acetabular revision at a mean time to revision of 11 years (range, 1-25 years). Of the failures, there were 5 cases due to polyethylene wear (62.5%), 2 cases due to acetabular loosening (25%), and 1 case due to recurrent instability (12.5%). The mean postoperative modified Harris Hip score was 76 (range, 52-91) with long-term improvement of 43 points maintained ($P < .001$).

Conclusions: THA with SDO can produce durable long-term outcomes for the patient with DDH. It is important to consider some common reasons for revision, namely polyethylene wear and osteolysis, acetabular loosening, and recurrent acetabular dislocations.

Introduction

Developmental dysplasia of the hip (DDH) is a common cause of secondary osteoarthritis and often presents with reduced acetabular diameter, a narrow proximal femur, and increased femoral anteversion [1]. These anatomic features can make total hip arthroplasty (THA) technically challenging and complex, including the need for femoral shortening derotational osteotomy (SDO) [2–6].

When required, subtrochanteric SDO is a reliable technique for DDH arthroplasty patients, which can restore the anatomic hip center of rotation; decompress sciatic and femoral nerve tension, thereby reducing the risk of palsy; minimize leg length discrepancy; and improve abductor muscle orientation and function, thereby minimizing instability and limp [4,7]. Several preoperative assessments can be utilized to determine the possible need for SDO including radiographic findings of DDH with subluxation, dislocation, marked coxa breva, and thigh soft-tissue contracture as determined by physical examination findings of a tight hamstring (popliteal angle less than 180° with the hip flexed to 90°) (Fig. 1) and tight quadriceps muscles. The SDO indication is traditionally confirmed based on intraoperative assessment of soft tissue and sciatic nerve tension upon attempted trial hip reduction. Femoral

* Corresponding author. Florida Orthopaedic Institute, 13020 Telecom Parkway N, Temple Terrace, FL 33637 USA. Tel.: +1 813 220 8338.
E-mail address: buckteeth@aol.com

https://doi.org/10.1016/j.artd.2022.07.004

Figure 1. (Left) Popliteal angle of a DDH patient showing physical examination findings of a tight hamstring (popliteal angle significantly less than 180° with the hip flexed to 90°). (Right) Popliteal angle of a volunteer showing physical examination findings of a fully extended (180°) knee with hip at 90°.

derotational osteotomy without shortening can also be performed to correct marked femoral anteversion and intraoperative osseous impingement. Several studies show good short- to intermediate-term outcomes for SDO-THA in DDH patients [2–5].

There are few studies that report on the long-term outcomes of the SDO-THA [8]. Therefore, there is a need to assess the durability of this procedure. This study retrospectively analyzes long-term implant survivorship and functional outcomes of the SDO-THA for DDH patients at 19-year follow-up. A radiographic analysis is also performed to assess osteotomy union, polyethylene wear, osteolysis, and implant loosening. We hypothesize good long-term implant survivorship and functional outcomes. Second, we hypothesize that polyethylene wear is the main mode of failure that leads to revision surgery.

Material and methods

Study population

Institutional review board approval was obtained prior to initiation of the study. Institutional surgical database has been screened for all subtrochanteric SDO-THA surgeries performed between 1991 and 2001. A total of 31 subtrochanteric SDO-THAs performed in 27 patients diagnosed with osteoarthritis secondary to DDH were identified. Patients who did not reach a minimum of 5-year follow-up were further excluded (2 deceased patients, 5 loss of follow-up). Therefore, 23 SDO-THA cases in 19 patients and 1 case (Crowe I) treated with derotational osteotomy without shortening were confirmed and included for analysis. All but 2 surgeries were performed by the senior author (T.L.B.), and the other 2 surgeries were done by 2 surgeons at the same institution. Demographic data, implant specification, and radiographic evaluation of the severity of DDH (Crowe classification) are summarized in Table 1. The surgical technique has been described in detail in a previous article written by the senior author (T.L.B.) published in 2007 [2].

Primary outcome measures included implant survivorship and improvement in preoperative and postoperative modified Harris Hip score (mHHS) for intermediate (5-15 years) and long (≥15 years) periods.

Secondary outcome measures included diagnosis for revision and radiographic analysis (osteotomy union, polyethylene wear, osteolysis, and implant loosening) performed by 2 independent observers and confirmed by the senior author. If osteolysis was

Table 1
Demographics table.

Demographics by crowe classification					
Variable	Total	Crowe I	Crowe II	Crowe III	Crowe IV
No. of hips	24	4	2	4	14
Age (mean ± STD)	40.8 ± 13.0	30.6 ± 5.1	36.6 ± 13.8	47.9 ± 7.9	45.8 ± 14.4
Postop years (mean ± STD)	18.6 ± 6.9	22.9 ± 1.0	22.8 ± 6.2	20.1 ± 8.3	16.4 ± 7.1
BMI (mean ± STD)	26.1 ± 4.2	22.8 ± 0.9	24.3[a]	28.6 ± 6.5	26.4 ± 4.3
Sex	22 F/2 M	2 F/2 M	2 F	4 F	14 F

BMI, body mass index; F, female; M, male; STD, standard deviation.
[a] Only BMI for 1 patient was available in this subcohort.

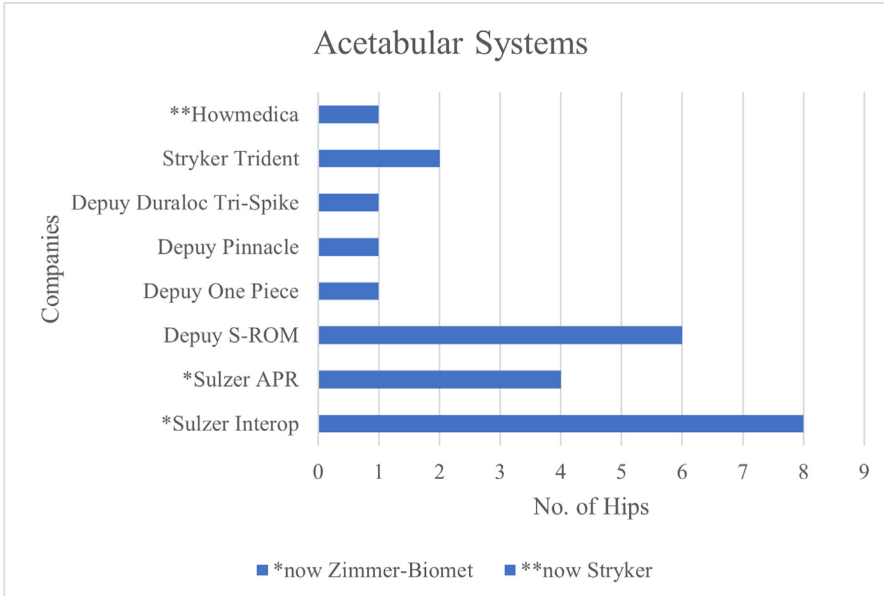

Figure 2. Acetabular systems graph.

found around the acetabular or femoral components, the zones and sizes were recorded according to the Gruen, Johnston, and Charnley zones [9]. Acetabular wear was measured and recorded as the asymmetric distance between the head of the prosthesis and the acetabular rim [9]. The heterotopic ossification grading was assigned according to the Brooker classification system [10].

Statistical analysis

Means and standard deviations were reported for continuous variables, and counts for categorical variables. SPSS (IBM, Armonk, NY) was used for statistical analysis. The survivorship analysis was done using the cumulative incidence method to estimate the survival of the femoral stems and acetabular cups with revision for any reason as the endpoint. A repeated analysis of variance test was used to compare the current long-term clinical outcomes to both preoperative and intermediate follow-up.

Results

Our final analysis included 24 SDO-THA cases in 20 patients with a mean follow-up time of 19 years (range, 8-27 years). This includes 18 women and 2 men with an average age of 44 years (range, 20-68 years) at the time of the index surgery. There were 15 left and 9 right SDO-THAs which included 4 staged bilateral THAs. The mean body mass index was 26 (range, 21-34) at index surgery.

All femoral reconstructions were performed using a modular, distally fluted and proximally porous-coated stem (DePuy, Warsaw, IN). Several different acetabular systems were used and are outlined in Figure 2. Metal heads were used in all cases. Conventional polyethylene was used in all cases. Acetabular cup diameters ranged from 40 to 55 mm. Size 22-mm femoral heads were used in 20 hips, and 28-mm femoral heads in 4. Superolateral acetabular bulk allografting was used in 5 cases. Postoperative treatment included home physical therapy with 20 lb. weight-bearing with

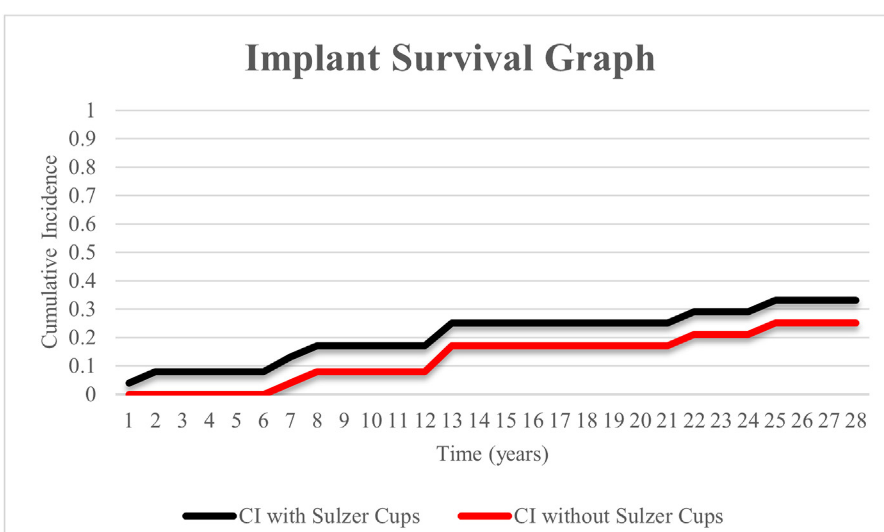

Figure 3. Cumulative incidence (CI) of implant revision over time.

Table 2
Revision table with demographics.

Gender	Diagnosis	Cup diameter (mm)	Femoral head size (mm)	Failure mode	Time to revision (y)
F	Crowe IV	49	22	AL	1
F	Crowe IV	49	28	AL	1.3
F	Crowe III	41	22	PWO	6.6
F	Crowe IV	45	22	RI	7.7
F	Crowe IV	40	22	PWO	12.3
F	Crowe IV	40	22	PWO	12.6
F	Crowe IV	42	22	PWO	21.2
F	Crowe I	47	22	PWO	24.5

AL, acetabular loosening (Sulzer cup recall); PWO, polyethylene wear and osteolysis; RI, recurrent instability.

walker or crutches for 6 weeks, then 50% with walker or crutches for an additional 6 weeks. Full weight-bearing and weaning to a cane were permitted upon radiographic evidence of osteotomy union.

Primary outcomes

Implant survivorship was 67% at the mean follow-up of 19 ± 7 years (Fig. 3). Eight hips (33%) required acetabular revision (Table 2). There were no femoral revisions. The mean time to revision was 11 ± 9 years (range, 1-25 years). The mean preoperative mHHS was 35.4 ± 12.9 (range, 0-58) and 76.4 ± 14.4 (range, 52-91) at the final follow-up. There was a significant improvement in mHHS from baseline to intermediate follow-up period (delta = 42.4, $P < .001$), as well as to long period (delta = 42.7, $P < .001$). There were no significant differences between 2 studied postoperative follow-up periods (delta = 0.4, $P = .911$) (Fig. 4).

Secondary outcomes

Radiographs were available for 23 of 24 cases (96%). We were unable to retrieve radiographs for 1 patient due to institutional record purge. All femoral osteotomies healed with a mean time to union of 6.5 ± 3 months (range, 1-15). This was measured by radiographic union of the osteotomy. The major cause for revision was polyethylene wear and osteolysis in 5 cases (62.5%), followed by acetabular loosening in 2 cases (25%), and recurrent instability in 1 case (12.5%). Both cases of acetabular loosening were due to recalled oil residue-contaminated Sulzer acetabular components (Sulzer Orthopedics, Austin, TX). All revision cases are shown in Tables 2 and 3. There were no cases of femoral loosening or subsidence, and all shells and stems were radiographically well fixed at the final follow-up. All femoral stems were shown to have good bony ingrowth of the proximal porous-coated sleeve. Asymptomatic Brooker grades 2 and 3 heterotopic ossification was observed in 4 hips.

Complications

There were 3 cases (12.5%) of postoperative instability after index surgery. One case of dislocation was treated with open reduction and femoral cabling of a nondisplaced femur fracture without component revision. It has been 18 years without a reoperation for this patient. Another patient dislocated at 2 weeks postoperatively and was successfully treated with closed reduction, and it has been 24 years without a revision. One patient suffered 1 dislocation at 3 years postoperatively then 3 more dislocations 5 years later which resulted in revision at 8 years after the index surgery. This patient with recurrent instability expired 13 years later without subsequent revision.

There were no observed femoral, sciatic, or obturator nerve palsies, and there were no postoperative infections. Two patients demonstrated a positive Trendelenburg sign at the final follow-up.

Discussion

The purpose of this study was to evaluate the long-term results of DDH patients that underwent THA with the femoral

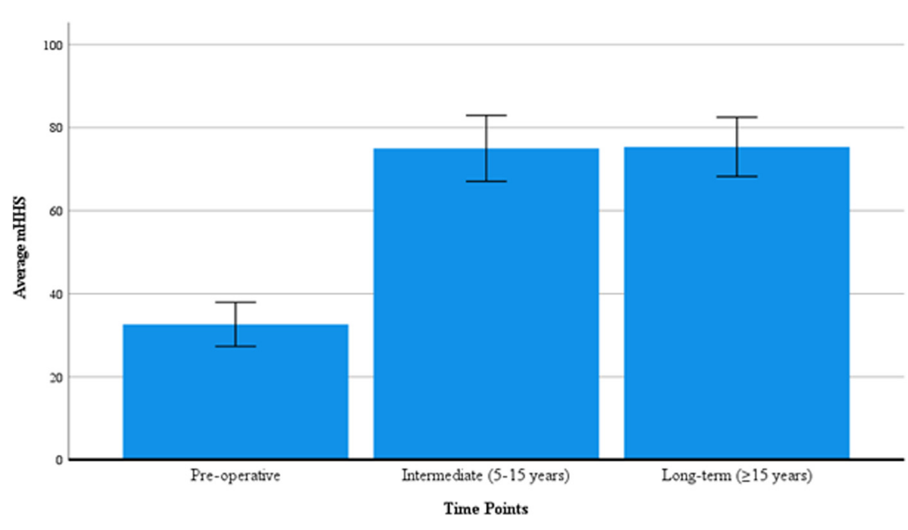

Figure 4. Comparison of mHHS for the 17 SDO-THA cases that completed preoperative, intermediate, and long-term follow-up.

Table 3
Revision table with revision component and modes of failure over time.

Variable	<6 y	6-10 y	11-15 y	16-20 y	21-25 y	>26 y
Revised component						
Socket	2	2	2	0	1	0
Liner exchange	0	0	0	0	1	0
Mode of failure						
Acetabular loosening[a]	2	0	0	0	0	0
Polyethylene wear	0	1	2	0	2	0
Recurrent instability	0	1	0	0	0	0

[a] Acetabular loosening from Sulzer cup recall.

subtrochanteric SDO technique. We observed good long-term functional outcomes with a mean mHHS of 76 at the final follow-up. This is equivalent to a traditional HHS of 85 after conversion. This compares similarly to other intermediate and long-term studies previously reported [11–13]. One retrospective review of 26 SDO-THAs for patients with Crowe IV DDH reported a mean HHS of 86 at 7 years postoperatively [3]. Another study of 56 SDO-THA cases reported HHS of 87 at 10 years [12]. These studies, along with our report, demonstrate good to excellent long-term functional outcomes can be achieved in this challenging patient population.

We observed a 67% survivorship at a mean follow-up of 19 years with all failures occurring on the acetabular side. There were no femoral failures or nerve palsies in our series confirming that this technique is a reliable method to successfully reconstruct the dysplastic femur while mitigating peripheral nerve injury during THA. Low rates of femoral failure using this technique have been similarly reported [8,14]. Vreim-Holm et al. reported 65 SDO-THA cases with a mean follow-up of 19 years and a 56% acetabular revision rate [8]. They reported only 2 femoral revisions, 1 case of subsidence, and 1 infection with the use of a nonmodular, grit-blasted hydroxyapatite-coated stem. Eskelinen et al. reported 68 DDH cases treated with a shortening femoral osteotomy and trochanter advancement during THA [14]. This technique differs from an SDO-THA in that the trochanter is detached and advanced distally to facilitate exposure and improve tension of the abductor. They reported an overall survivorship of 57% at a mean follow-up of 12.3 years. In contrast to our series, they reported a Trendelenburg sign and decreased abduction strength in 8% of cases. Furthermore, they reported a 7% femoral revision rate with 2 cases of loosening and 3 due to "malposition" with the use of a nonmodular stem. While both these studies reported relatively low femoral failure rates with nonmodular stems in osteotomy-THA cases, they were both higher than our series. Our experience is that a modular, proximal porous-coated, distally fluted stem provides superior axial and rotational stability to the diaphysis after osteotomy.

Acetabular failure through wear and osteolysis was the dominant reason for revision. This accounted for 63% of the failures in our series, which is comparable to similar studies for SDO-THA with conventional polyethylene [8,14–17]. Vreim-Holm et al. reported 35 acetabular revisions with 23 (66%) of these due to loosening and 8 (23%) due to polyethylene wear [8]. They used several acetabular implants with varying biologic ingrowth or ongrowth technologies and attributed their high rates of acetabular loosening to the use of a hydroxyapatite-coated shell. Acetabular failure was involved in 95% of the revisions in the 68 DDH cases reported by Eskelinen et al. [14]. In their series, aseptic acetabular loosening accounted for 40% of acetabular failures; however, a majority of these were attributed to the use of threaded sockets. They observed a 21% failure rate due to polyethylene wear at 12-year follow-up [14]. The relatively high incidence of polyethylene wear and osteolysis observed in our series as well as those cited are partly due to the relatively young age and presumably higher demand of this patient cohort. Additionally, most of the cases in our study and those cited were during an era prior to the advent of highly crosslinked polyethylene. Improved survivorship and wear characteristics of highly crosslinked polyethylene compared to conventional polyethylene have been well demonstrated [17–20]. Additionally, polyethylene sterilization in air was still being performed by implant manufacturers during the time of our study and of those cited [21–23]. Since then, evidence demonstrating reduced wear and osteolysis for polyethylene sterilized in a low-oxygen or inert gas packaging has been reported and accepted as the standard [24–26].

Excluding the 2 recalled Sulzer acetabular components, our overall survivorship was 75% at an average period of 19 years. This implant was recalled in December of 2000 for machining oil residue left on the implant porous surface which resulted in failure of osseous ingrowth after implantation. Although it is impossible to determine if these cases would have failed by other means, it is notable that our rates of acetabular loosening may have been zero if these shells were not used. This observation highlights the efficacy of contemporary, porous titanium shells that were used predominately in this cohort of deficient acetabula.

Hip instability was the most common complication in our series. Three cases (12.5%) dislocated postoperatively. Our data compare favorably to similar studies with reports of instability ranging from 3% to 15% [14,15]. This observation is reassuring given that the DDH patient cohort is at higher risk of instability. The generally small stature of DDH hips necessitates the use of micro shells and 22-mm or 28-mm heads. This results in a lower head-to-neck ratio and higher risk of intraprosthetic and extra-articular impingement and potential for dislocation [27]. Despite these factors, instability rates in our series were still low, which may be attributed to the rotational component of the SDO and its ability to optimize femoral version and avoid intraprosthetic and greater trochanter-to-pelvis impingement.

We observed no hip-related nerve palsies, which is consistent with similar studies [3,4,8,15,28]. However, Eskelinen et al. reported 5 nerve palsies in a cohort of 68 THA-DDH cases [14]. This included 3 peroneal nerve palsies, 1 femoral nerve palsy, and 1 superior gluteal nerve palsy. An important distinction is that they did not employ an SDO as we reported but rather a transverse femoral osteotomy and trochanter osteotomy with advancement. Alp et al. reported 5 nerve palsies in a cohort of 90 DDH THA cases [29]. In their cohort, 77 cases were performed without an SDO, and a transverse or step-cut osteotomy was performed in only 13 of these cases. Of the postoperative nerve palsies, 4 resolved, yet 1 patient did suffer unspecified permanent nerve function loss.

This study contains several limitations. First, the retrospective structure of the study lends itself to inherent limitations. The sample size is relatively small with only 24 SDO-THA cases. There were also 5 excluded cases (17%) due to loss of follow-up. However, SDO-THA procedures are not common, and large study populations with long follow-up are rare [8]. To our knowledge, there is only 1 other SDO-THA study with comparable follow-up length to ours [8]. Additionally, some may consider the inclusion of Crowe I and II cases a limitation. However, we specifically included all degrees of DDH to account for the importance of derotation of marked femoral anteversion in lesser degrees of DDH. Marked anteversion can be found to be independent of Crowe classification and may still warrant derotational osteotomy when the need for shortening is lacking [30].

Conclusions

In conclusion, THA with the SDO technique can produce good long-term functional outcomes with acceptable implant survivorship for the patient with DDH. It is an excellent technique to mitigate hip-related peripheral nerve palsies in this patient cohort. It is important to consider some common reasons for revision, namely polyethylene wear and osteolysis, acetabular loosening, and recurrent acetabular dislocations. The SDO technique should remain the gold standard THA in patients with DDH, marked leg-length discrepancy, and femoral anteversion.

Acknowledgments

The authors would like to acknowledge the Debartolo Center for Adult Reconstruction Research and Education for funding support for this research.

Conflicts of interest

Dr. Palumbo receives royalties from and is a paid consultant for DJO and Conformis and has stock or stock options in Acutos LLC. Dr. Lyons receives royalties from and is a paid consultant for Zimmer, has stock or stock options in Amedica and Zimmer, is in the editorial or governing board of Journal of Arthroplasty, and is a board member in Florida Orthopaedic Society. Dr. Bernasek receives royalties from DePuy Synthes, a Johnson & Johnson company; is in the speakers' bureau of or gave paid presentations for DePuy Synthes, a Johnson & Johnson company; is a paid consultant for DePuy Synthes, a Johnson & Johnson company, and Corin Orthopaedics; receives research support from DePuy Synthes, a Johnson & Johnson company, and Corin Orthopaedics; and is in the AAOS Board of Councilors and a board member in Florida Orthopaedic Society. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.07.004.

References

[1] Argenson J-NA, Flecher X, Parratte S, Aubaniac J-M. PRESIDENTIAL GUEST LECTURE: anatomy of the dysplastic hip and consequences for total hip arthroplasty. Clin Orthop Relat Res 2007;465:40–5.
[2] Bernasek TL, Haidukewych GJ, Gustke KA, Hill O, Levering M. Total hip arthroplasty requiring subtrochanteric osteotomy for developmental hip dysplasia: 5- to 14-year results. J Arthroplasty 2007;22(6 Suppl 2):145–50.
[3] Erdem Y, Bek D, Atbasi Z, Neyisci C, Yildiz C, Basbozkurt M. Total hip arthroplasty with rectangular stems and subtrochanteric transverse shortening osteotomy in Crowe type IV hips: a retrospective study. Arthroplast Today 2019;5:234–42.
[4] Hua WB, Yang SH, Xu WH, et al. Total hip arthroplasty with subtrochanteric femoral shortening osteotomy for high hip dislocation. Orthop Surg 2015;7:112–8.
[5] Karaismailoglu B, Karaismailoglu TN. Comparison of trochanteric slide and subtrochanteric shortening osteotomy in the treatment of severe hip dysplasia: mid-term clinical outcomes of cementless total hip arthroplasty. J Arthroplasty 2020;35:2529–36.
[6] Liu T, Wang S, Huang G, Wang W. Treatment of Crowe IV developmental dysplasia of the hip with cementless total hip arthroplasty and shortening subtrochanteric osteotomy. J Int Med Res 2019;47:3223–33.
[7] Krych AJ, Howard JL, Trousdale RT, Cabanela ME, Berry DJ. Total hip arthroplasty with shortening subtrochanteric osteotomy in Crowe type-IV developmental dysplasia: surgical technique. J Bone Joint Surg Am 2010;92(Suppl 1 Pt 2):176–87.
[8] Vreim Holm AG, Terjesen T, Reikerås O. Subtrochanteric shortening and uncemented arthroplasty in hips with high dislocation - a cohort study with 13-30 years follow-up. J Orthop 2019;16:80–5.
[9] Chan J, Khoriati A, Chiang C-H, Al-Hadithy N. Understanding, interpreting and reporting a total hip arthroplasty radiograph. Orthop Muscular Syst 2017;06. https://doi.org/10.4172/2161-0533.1000243.
[10] Hug KT, Alton TB, Gee AO. Classifications in brief: Brooker classification of heterotopic ossification after total hip arthroplasty. Clin Orthop Relat Res 2015;473:2154–7.
[11] Sun C, Zhang Y, Li LT, Ding H, Guo T, Zhao JN. Long-term outcomes of total hip arthroplasty with transverse subtrochanteric shortening osteotomy and modular stem in Crowe IV developmental dysplasia. J Arthroplasty 2021;36:630–5.
[12] Wang D, Li LL, Wang HY, Pei FX, Zhou ZK. Long-term results of cementless total hip arthroplasty with subtrochanteric shortening osteotomy in Crowe type IV developmental dysplasia. J Arthroplasty 2017;32:1211–9.
[13] Rasi AM, Kazemian G, Khak M, Zarei R. Shortening subtrochanteric osteotomy and cup placement at true acetabulum in total hip arthroplasty of Crowe III-IV developmental dysplasia: results of midterm follow-up. Eur J Orthop Surg Traumatol 2018;28:923–30.
[14] Eskelinen A, Helenius I, Remes V, Ylinen P, Tallroth K, Paavilainen T. Cementless total hip arthroplasty in patients with high congenital hip dislocation. J Bone Joint Surg Am 2006;88:80–91.
[15] Hasegawa Y, Iwase T, Kanoh T, Seki T, Matsuoka A. Total hip arthroplasty for Crowe type developmental dysplasia. J Arthroplasty 2012;27:1629–35.
[16] Tsukamoto M, Mori T, Ohnishi H, Uchida S, Sakai A. Highly cross-linked polyethylene reduces osteolysis incidence and wear-related reoperation rate in cementless total hip arthroplasty compared with conventional polyethylene at a mean 12-year follow-up. J Arthroplasty 2017;32:3771–6.
[17] Prock-Gibbs H, Pumilia CA, Meckmongkol T, Lovejoy J, Mumith A, Coathup M. Incidence of osteolysis and aseptic loosening following metal-on-highly cross-linked polyethylene hip arthroplasty: a systematic review of studies with up to 15-year follow-up. J Bone Joint Surg Am 2021;103:728–40.
[18] Shi J, Zhu W, Liang S, Li H, Li S. Cross-Linked versus conventional polyethylene for long-term clinical outcomes after total hip arthroplasty: a systematic review and meta-analysis. J Invest Surg 2021;34:307–17.
[19] Moon NH, Shin WC, Do MU, Kang SW, Lee SM, Suh KT. Wear and osteolysis outcomes for highly cross-linked polyethylene in primary total hip arthroplasty compared with conventional polyethylene: a 15- to 18-year single-centre follow-up study. Hip Int 2021;31:526–32.
[20] Kuzyk PR, Saccone M, Sprague S, Simunovic N, Bhandari M, Schemitsch EH. Cross-linked versus conventional polyethylene for total hip replacement: a meta-analysis of randomised controlled trials. J Bone Joint Surg Br 2011;93:593–600.
[21] Illgen 2nd RL, Bauer LM, Hotujec BT, Kolpin SE, Bakhtiar A, Forsythe TM. Highly crosslinked vs conventional polyethylene particles: relative in vivo inflammatory response. J Arthroplasty 2009;24:117–24.
[22] Ponzio DY, Weitzler L, deMeireles A, Esposito CI, Wright TM, Padgett DE. Antioxidant-stabilized highly crosslinked polyethylene in total knee arthroplasty: a retrieval analysis. Bone Joint J 2018;100-b:1330–5.
[23] Spece H, Schachtner JT, MacDonald DW, et al. Reasons for revision, oxidation, and damage mechanisms of retrieved vitamin E-stabilized highly crosslinked polyethylene in total knee arthroplasty. J Arthroplasty 2019;34:3088–93.
[24] Faris PM, Ritter MA, Pierce AL, Davis KE, Faris GW. Polyethylene sterilization and production affects wear in total hip arthroplasties. Clin Orthop Relat Res 2006;453:305–8.
[25] McKellop H, Shen FW, Lu B, Campbell P, Salovey R. Effect of sterilization method and other modifications on the wear resistance of acetabular cups made of ultra-high molecular weight polyethylene. A hip-simulator study. J Bone Joint Surg Am 2000;82:1708–25.
[26] García-Rey E, García-Cimbrelo E. Polyethylene in total hip arthroplasty: half a century in the limelight. J Orthop Trauma 2010;11:67–72.
[27] Burroughs BR, Hallstrom B, Golladay GJ, Hoeffel D, Harris WH. Range of motion and stability in total hip arthroplasty with 28-, 32-, 38-, and 44-mm femoral head sizes. J Arthroplasty 2005;20:11–9.
[28] Kawai T, Goto K, Kuroda Y, Matsuda S. Total hip arthroplasty combined with subtrochanteric transverse shortening osteotomy: factors associated with delayed union at the osteotomy site. J Am Acad Orthop Surg Glob Res Rev 2020;4:e2000056.
[29] Alp NB, Akdağ G, Erdoğan F. Long-term results of total hip arthroplasty in developmental dysplasia of hip patients. Jt Dis Relat Surg 2020;31:298–305.
[30] Greber EM, Pelt CE, Gililland JM, Anderson MB, Erickson JA, Peters CL. Challenges in total hip arthroplasty in the setting of developmental dysplasia of the hip. J Arthroplasty 2017;32:S38–44.