



Original research

Mid-term results of total hip replacement with subtrochanteric osteotomy, modular stem, and ceramic surface in Crowe IV hip dysplasia

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ABSTRACT

Background: Total hip arthroplasty (THA) in Crowe IV developmental dysplasia of the hip (DDH) presents many challenges for surgeons with regard to acetabular and femoral deformities. The purposes of this study are to (1) report the mid-term results of THA with subtrochanteric transverse osteotomy using S-ROM prosthesis and ceramic-on-ceramic (COC) surface for Crowe type IV DDH; and (2) compare the wear performance between COC and metal-on-polyethylene (MOP) bearing couple.

Methods: Eighty Crowe IV DDH patients (103 hips) treated with cementless THA were retrospectively reviewed. The S-ROM prosthesis was used in all the hips and subtrochanteric osteotomy was performed in 74 hips. COC and MOP bearing surfaces were compared through the evaluation.

Results: At mean follow-up of 65.6 months, the mean Harris hip score improved from 54.2 to 87.7 points; however, Trendelenberg sign positive was confirmed in 20.4% of the hips. Postoperative dislocation occurred in 6 cases and overall 4 hips were revised. With any component revision as endpoint, Kaplan-Meier survival curve showed that 8-year cumulative survival rate in the COC group was 97.2% and 9-year survival rate in the MOP group was 85.9%. The mean linear wear rate for COC and MOP surface was 0.006 and 0.175 mm/y, respectively.

Conclusions: Subtrochanteric osteotomy combined with the modular S-ROM prosthesis and COC surface in Crowe IV DDH has achieved satisfactory mid-term results. However, postoperative dislocation and limp remain major complications. Linear wear rate for MOP surface is high and the long-term prosthesis survival is affected. Ceramic or highly cross-linked polyethylene should be preferred.

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Introduction

Total hip arthroplasty (THA) in Crowe type IV developmental dysplasia of the hip (DDH) presents many challenges for surgeons with regard to acetabular and femoral deformities. The acetabulum is generally small, shallow, and accompanied by anterolateral and superior bone defects, which makes acetabular reconstruction anatomically difficult [1]. Femoral reduction may be difficult and

lead to a major risk of neurologic traction injury due to the long-term dislocation and soft tissue contracture. Subtrochanteric osteotomy is a safe way to perform the reduction and various osteotomy types have been described including transverse [2], oblique [3], V-shaped [4], and step-cut osteotomy [5]. The modular S-ROM prosthesis is favored because of the structure accommodated with DDH anatomical features and the ability to adjust femoral anteversion, femoral offset, and leg length [6]. Subtrochanteric transverse osteotomy combined with an S-ROM prosthesis simplifies the procedure, while providing sufficient rotational stability for the osteotomy site.

Bearing surface choices in DDH patients are controversial, and the longest follow-up data support the use of metal-on-polyethylene (MOP) surface [7]. However, ceramic and highly cross-linked polyethylene (HXLPE) are most used currently in DDH

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Table 1
Patient demographics in 3 groups.

Groups	A group (MOP)	B group (Forte COC)	C group (Delta COC)	Total	P value
Number of patients	11	45	25	80	
Number of hips	14	58	31	103	
Mean age	37.7	39.5	38.9		.913
Mean height (cm)	147.6	156.2	157.5		.032
Mean weight (kg)	46.3	54.8	54		.079
Mean BMI (kg/cm ²)	20.5	22.2	21.9		.383
Mean follow-up time	94.6	69.3	45.7		.000
Mean Harris score	45.1	53.1	57.2		.234

BMI, body mass index.

patients to reduce polyethylene particle-induced osteolysis due to relatively younger age and higher activity level.

Therefore, the purposes of this study are to (1) report the mid-term results of THA with subtrochanteric transverse osteotomy using S-ROM prosthesis and ceramic-on-ceramic (COC) surface for Crowe type IV DDH patients; and (2) compare the wear performance between COC and MOP bearing couple.

Material and methods

Patients

We retrospectively analyzed 94 Crowe type IV DDH patients (123 hips) treated with cementless THA in our hospital between June 2007 and December 2012. Fourteen patients (20 hips) were lost to follow-up. The S-ROM (DePuy, Warsaw, IN) prosthesis was used in all hips and subtrochanteric transverse osteotomy was performed in 74 hips. These hips were divided into 3 groups based on surface type: A group (MOP, 14 hips), B group (Forte COC, 58 hips), and C group (Delta COC group, 31 hips).

Surgical technique

All surgeries were performed by one senior surgeon through posterolateral approach. Acetabular component was placed at the anatomical position, and the hyperplastic capsule was removed. As we advocate the use of COC surface, the acetabulum should be reamed to at least 44 mm for the third-generation COC (Forte) and 43 mm for the current fourth-generation COC (Delta). We reamed the acetabulum in attempting to accommodate the ceramic interface while protecting its anterior wall. The S-ROM prosthesis was used in all hips, and Cone or Sleeve was chosen based on proximal femur form. After femoral preparation was finished, we inserted the trial component and tried reduction, if not successful, the distance between the acetabulum cup center and femoral head component center during trial reduction was noted and subtrochanteric transverse osteotomy was performed subsequently. Osteotomy length equaled the distance described previously minus 1.5 cm. In our study, subtrochanteric osteotomy was performed in 74 hips, with an average length of 3.5 cm (range 2–5.5).

A regular antibiotic and antithrombotic prophylaxis was administered postoperatively. Patients lied in the genuflex hip flexion dorsal position to reduce femoral nerve and sciatic nerve tension. Those who did not undergo osteotomy were allowed partial weight-bearing 3 days after surgery, and 3 weeks for subtrochanteric osteotomy cases.

Implants

Thirty-five hips used Cone, while 68 hips used Sleeve. Three types of acetabular cup (DePuy) were used: Duraloc Bantam cup for group A, Duraloc Option for group B, and Pinnacle for group C, and

femoral head was of metal (22 mm), Forte ceramic (28 mm), and Delta ceramic (28 mm), respectively.

Clinical evaluation

We used the Harris hip score (HHS) for clinical evaluation at the initial admission and every postprocedure follow-up. Limp at the final follow-up was classified into 4 degrees: none or slight limp (could only be detected by physician), moderate limp (could be observed by family or friends), and severe limp (gait changed obviously) [8]. Reasons for moderate or severe limp were determined by 2 authors. We checked the Trendelenberg sign, which was considered to be positive if the iliac crest was higher on the supported side than the contralateral side. A delayed positive sign was recorded if it was negative initially, after a while the pelvis gradually fell toward the unsupported side [9].

Radiographic evaluation

Standard anteroposterior and lateral radiographs of the hips were obtained before operation, after operation, and at each follow-up.

We measured the cup abduction angle, femoral offset, abductor lever arm, and leg lengthening through postoperative radiographs. Femoral offset was calculated as the perpendicular distance of the femoral head center to the long axis of the femoral prosthesis. Abductor lever arm was measured as the perpendicular distance from the femoral head center to a line tangential to the greater trochanter. Leg lengthening amount equaled the inferior displacement of the greater trochanter relative to a horizontal line joining the ischial tuberosity minus femoral shortening length.

Radiographic outcomes included osteotomy union, component stability, osteolysis, and heterotopic ossification. Criterion for osteotomy healing was the presence of continuous cortical callus across the osteotomy site on anteroposterior and lateral radiographs. Osteolysis was defined as radiolucent lines at the bone-prosthesis interface area using the Delee [10] and Gruen [11] methods. Stem fixation was graded as bony ingrowth, stable fibrous ingrowth, or loosening based on the Engh classification [12]. Acetabular component was considered as loose if migration was >4 mm or complete, and contiguous radiolucency ≥ 2 mm wide present in all 3 Delee zones. Heterotopic ossification was evaluated using Brooker classification [13].

Polyware software (Draftware Inc., Vevay, IN) was used to measure femoral head penetration into the liner on the latest follow-up radiographs. Linear wear rate of ceramic was calculated by penetration distance divided by follow-up time, while penetration from 1 year after surgery to the latest follow-up divided by corresponding time for the MOP group as the bedding-in phenomenon mostly finished within 1 year [14]. The differences of wear performance were compared.

Statistical analysis

SPSS 19.0. (IBM, Armonk, NY) was used for data analysis. Variance analysis was performed to compare baseline and HHS at the latest follow-up among the 3 groups. Application of rank-sum test was used to demonstrate the wear property differences between COC and MOP groups. The cumulative survivorship was estimated by Kaplan-Meier survival curve with revision for any reason as the endpoint. *P* value <.05 is considered statistically significant.

Results

Eighty patients (103 hips) were included in our series, consisting of 8 men (11 hips) and 72 women (92 hips). Twenty-five hips



Figure 1. A 39-year-old woman with bilateral Crowe type IV DDH underwent THA. (a) Preoperative anteroposterior (AP) radiograph. (b) AP pelvic view 3 days after THA; we used cage and cement cup on the right side because the anterior wall of true acetabulum was destroyed intraoperatively. (c) AP view 5 years after surgery; the components on the right side were stable, whereas recurrent dislocation occurred on the left side and a revision surgery was performed. (d) AP view 3 days after revision; ceramic-on-ceramic surface and 32-mm femoral head were used.

underwent previous surgery. The mean follow-up time was 65.6 months (range 39–108). The mean age at the time of THA was 39.1 years (range 20–62). The mean patient height was 156.1 cm (range 133–182), the mean weight was 54 kg (range 32–72), and the mean BMI was 22 kg/m² (range 15–32). Finally, the mean preoperative HHS score was 54.2 (range 23–87.7).

Patient demographics for the 3 groups are described in Table 1. There are significant differences in patient height and the duration of follow-up among the 3 groups ($P = .032$ and $.000$, respectively).

Clinical outcomes

The mean HHS at the final follow-up was 87.7 (range 50–98), which improved significantly compared with the preoperative score ($P = .000$). The HHS among the 3 groups did not differ statistically significantly ($P = .830$). Fifty-one patients (63.8%) were able to resume all daily activities, 20 patients (25%) could walk long

distances, and 4 patients (5%) were able to run, swim, and do other workouts.

A positive Trendelenberg sign was confirmed in 16 hips (15.5%) and 5 hips (4.9%) were considered as delayed positive. There was none or slight limp in 54 patients (67.5%), moderate in 16 patients (20%), and severe in 3 patients (3.8%). Moderate and severe limps were mainly caused by gluteus medius dysfunction and leg length discrepancy. In addition, 7 patients (8.8%) showed moderate limp because of obvious valgus knee deformity. Four patients were not satisfied with surgery and recovery including 3 patients who complained about knee pain during walking which resulted from valgus knee and 1 severe limp case due to short abductor lever arm.

Radiographic outcomes

Ninety-nine acetabular cups were placed in the anatomical position, while 4 hip replacements were performed with a high hip center. The mean femoral offset was 2.9 cm (range 1.7–3.7) and the



Figure 2. Radiographs of a 45-year-old female patient who underwent THA. (a) Preoperative AP view. (b) AP pelvic view 3 days after THA; ceramic-on-ceramic surface and Cone were used on both sides. (c) AP view 5 years after hip replacement; femoral stem on the right side showed progressive subsidence and aseptic loosening, caused by small Cone size. (d) AP view 3 days after revision; acetabular component was reserved and Cone was replaced by Sleeve.

mean lever arm of gluteal medius was 4.9 cm (range 2.7–6.2). The mean leg lengthening amount was 3.6 cm (range 1.0–5.9). Seventy-four hips underwent subtrochanteric osteotomy, and nonunion occurred in only 1 case (1.4%).

Eighty-two hips were available for radiographic evaluation and all the cups were stable but 2 cups were revised for recurrent dislocation and polyethylene wear. Seventy-five stems (91.5%) showed bone ingrowth fixation among which spot welds were observed in 33 hips (44%), 5 stems (6.1%) were classified as stable fibrous ingrowth and 2 stems (2.4%) were revised for loosening (1 aseptic loosening and 1 septic loosening).

Alignment of the 80 stable stems was neutral in 72 cases (90%) and varus in 8 hips (10%) (5 stems $<2^\circ$ and 1 stem $>5^\circ$). Osteolysis was not detected in the COC group and was evident in 5 hips (50%) of the MOP group: 3 cases in Gruen zone 1 and 1 case in both Gruen zone 1 and DeLee zone 2. Another hip was revised 8 years after THA resulting from severe osteolysis in Gruen zone 1, zone 2 and DeLee zone 2. Moreover, 3 polyethylene liners showed eccentric wear.

Heterotopic ossifications were found in 5 hips, including 4 cases of grade 1 and 1 case of grade 2.

Complications

A cage and cemented cup were required in 1 hip because the anterior and inner wall of the true acetabulum was destroyed during reaming (Fig. 1), and this hip has functioned well during 7 years since the procedure according to the follow-ups. There were 8 cases of intraoperative femoral fracture, 1 proximal fragment, and 7 distal fragment, all treated with cerclage wires or bands. Intraoperative femoral fracture was not detected in 2 patients (3 hips) until postoperative radiographs were obtained, therefore they had to undergo a secondary fixation surgery. Two weeks after the secondary surgery, 1 hip developed deep vein thrombosis and anticoagulation therapy was administered.

One hip developed femoral stem loosening and nonunion was diagnosed as infection, and revised 1.5 years after THA.

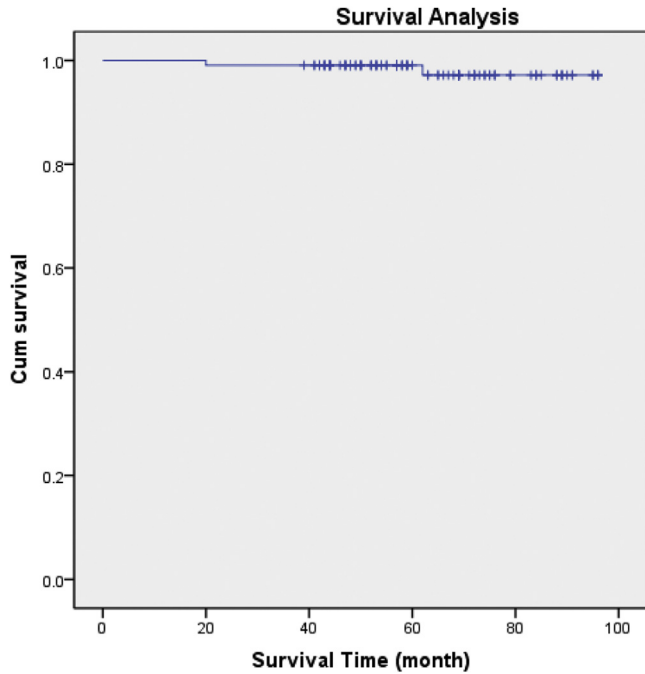


Figure 3. Kaplan-Meier cumulative survival rate of any component for ceramic-on-ceramic group, with revision for any reason as the endpoint.

Periprosthetic femoral fracture involving the osteotomy site occurred in 1 hip, and was treated with internal fixation using locking plate, cerclage bands, and allogeneic cortical bone plates. Four hips (3.9%) had symptoms of nerve palsy: 3 of them were transient and fully recovered within 2 months, another hip partially recovered at the final follow-up with remaining numbness and sensory deficit. The mean leg lengthening of these hips was 4.1 cm (range 2.3–5.8). Six hips (5.8%) experienced dislocations: 3 hips (21.4%) in the MOP group (22-mm head) and 3 hips (3.4%) in the COC group (28-mm head), including 1 recurrent dislocation treated

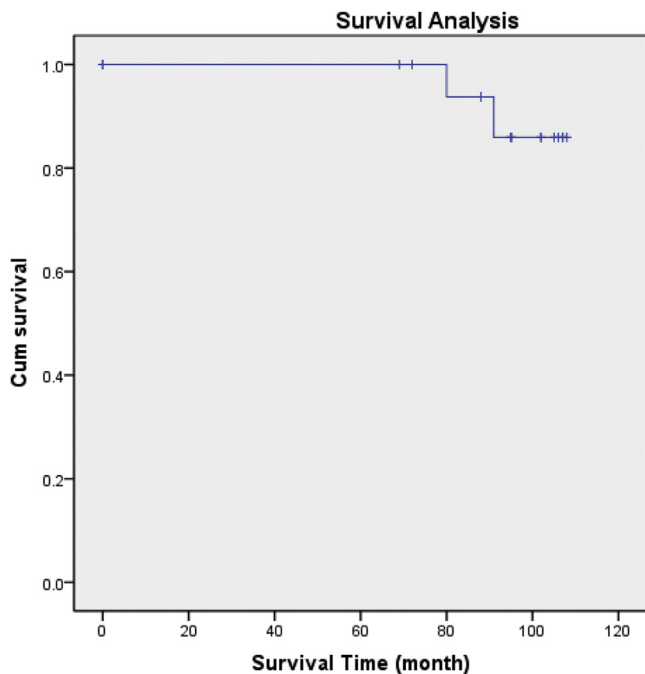


Figure 4. Kaplan-Meier cumulative survival rate of any component for metal-on-polyethylene group, with revision for any reason as the endpoint.

with revision at 7 years after THA. Five cases were managed with closed reduction and 1 with open reduction. The mean abduction angle of these cups was 46.9° (39.6°–52.1°).

Eleven hips (10.7%) reported mild and negligible squeaking and we did not find any ceramic fracture event until the final follow-up. Twenty-five hips (24.8%) developed valgus deformity of the knee, of them 14 were mild and did not impair function; 8 hips were evident and resulted in moderate limp; 3 hips were severe, affecting their daily activities and patient satisfaction. One severe case underwent corrective osteotomy and subsequent anterior cruciate ligament reconstruction; however, the symptom remained.

Revision and survival analysis

Overall, 4 hips underwent revision, of them 2 hips in the MOP group were revised because of polyethylene wear and recurrent dislocation (Fig. 1). There were 2 cases of stem loosening in the COC group as described before. One was considered as aseptic loosening, the other stem showed progressive subsidence caused by small Cone size (Fig. 2).

With any component revision as endpoint, the 8-year cumulative survival rate in the COC group was 97.2% (95% confidence interval 95.6–98.4) (Fig. 3), presented by Kaplan-Meier survival curve, and the 9-year survival rate in the MOP group was 85.9% (95% confidence interval 79.5–91.4) (Fig. 4).

Wear performance

The mean linear wear rate for the COC group and the MOP group was 0.006 and 0.175 mm/y, respectively. Rank-sum test demonstrated the significant difference ($P = .000$).

Discussion

THA in Crowe type IV DDH presents many challenges for surgeons with regard to acetabular and femoral deformities. Our purposes were to (1) report the mid-term results of THA combined with subtrochanteric transverse osteotomy using an S-ROM prosthesis and a ceramic surface; and (2) compare the wear performance between COC and MOP bearing surfaces.

The current consensus of acetabulum reconstruction recommends implantation of the cup in the true acetabulum in order to restore the lever arm of the gluteus medius and reduce hip joint reaction force. As we advocated using COC interface and the acetabulum must be reamed to at least 43 or 44 mm, acetabular reconstruction became more difficult and may lead to a major risk of failure due to small size and bone defects. There was 1 case in which a cage and cement cup were required for fixation as mentioned before. Therefore, grasping the balance between reaming and protecting the anterior wall was challenging and required experience and cautious maneuver. Another tip was reaming in the posterosuperior area of acetabulum because the bone in this area was relatively abundant and the anterior wall was usually thin. The acetabular cup anteversion can be large and the modular stem anteversion can be adjusted to obtain an optimal combined anteversion. However, attempting to address increased femoral anteversion needs a combination of osteotomy and modularity because addressing with a modular stem alone can result in impingement of the posterior trochanter on the ischium in external rotation position and such impingement may cause anterior dislocation [15].

Postoperative dislocation rate in Crowe type IV DDH mostly ranged from 1.5% to 10.7% in previous studies, and that rate even reached 15%–17.4% in a few studies (Table 2). In this study,

Table 2
Studies of cementless total hip arthroplasty with subtrochanteric osteotomy for Crowe type IV DDH.

Study	No. of hips	Mean age (y)	Mean follow-up (y)	Osteotomy design	Trendelenberg sign	Intraoperative fracture	Nerve palsy	Dislocation	Nonunion
Bao et al [16]	30	35.3	4.6 (2-11)	Lesser trochanter osteotomy	21 (70%)	3 (10%)	2 (6.7%)	0	0
Takao et al [17]	33	60	8 (5-11)	Step-cut	2 (6.1%)	8 (24.2%)	0	2 (6.1%)	0
Reikeras et al [18]	65	48	13 (8-18)	Oblique and step-cut	12 (18.5%)	0	2 (3.1%)	1 (1.5%)	2 (3.1%)
Kilicoglu et al [3]	20	43.4	6.8 (3.7-10)	Oblique	6 (30%)	3 (15%)	0	3 (15%)	0
Bernasek et al [15]	23	43	8 (5-14)	Transverse	N/A	N/A	0	4 (17.4%)	0
Park et al [2]	24	49	4.7 (2-7.6)	Transverse	N/A	3 (12.5%)	0	1 (4.2%)	3 (12.5%)
Ollivier et al [19]	28	48	10	Transverse and step-cut	N/A	5 (17.8%)	0	3 (10.7%)	2 (7.1%)
Sofu et al [20]	73	47	5.1 (3-7.7)	Transverse	N/A	N/A	0	1 (1.3%)	4 (5.5%)
Baz et al [21]	21	41	5 (3-8)	Transverse	7 (33.3%)	5 (23.8%)	1 (4.8%)	2 (9.5%)	0
Mu et al [22]	71	35.8	5.9 (3.3-8.2)	Transverse	N/A	20 (28.2%)	8 (11.3%)	2 (2.8%)	2 (2.8%)
This study	103	38.5	5.7 (3.3-9.3)	Transverse	21 (20.4%)	8 (7.9%)	3 (3%)	6 (5.9%)	1 (1.4%)

N/A, not applicable.

dislocation occurred in 6 hips (5.8%) until the final follow-up and there were a number of reasons accounting for the relatively high rate. First, most of the patients were female, and all surgeries were performed through the posterolateral approach. Second, as we all know femoral head size is associated with the dislocation rate, even though currently we are trying to use the fourth-generation ceramic head, and the femoral head size is no larger than 28 mm in most cases because of the small acetabulum. Third, due to long-term dislocation or previous surgery injury, abductor muscle recovery still needs a longer time after reconstruction of the lever arm in patients performed for THA. In our series, 20.4% of the hips showed a positive or delayed Trendelenberg sign and abductor dysfunction may lead to joint instability. Fourth, in early times we preferred extensively releasing the iliopsoas muscle, contracture, and scar tissue around the joint to facilitate reduction. Although extensive release could prevent impingement, it may also result in soft tissue relaxation and increase the risk of dislocation. Thus, we suggest that the acetabular component should be placed in the safe zone, and patients' individual soft tissue tension and impingement should be taken into account. In addition, using modular prosthesis for femoral anteversion adjustment and large head may contribute to joint stability [23].

Knee valgus deformity is not a rare complication for DDH patients; however, few studies have reported this previously. Strictly speaking, it does not belong to postoperative complications because it is caused by congenital development of patients. Guo et al [24] reviewed 206 lower limbs of patients with untreated DDH and found that 14.1% had valgus deformities, and the severity of valgus deformity was strongly associated with the lateral migration of femoral head but not with the superior migration. Therefore, for Crowe type IV DDH, dislocation height of hips with a false acetabulum is lower than those without a false acetabulum, but valgus deformity may be more serious. Symptoms of lower limb valgus deformity are covered by pain or claudication of the hip joint preoperatively. It emerges after THA, manifesting as an abnormal line of force and knee joint pain, sometimes surgical correction of force line is necessary in severe cases. Fortunately, severe cases are less common (3%) in which the function is impaired. Even so, we strongly suggest that DDH patients should be fully informed of this risk before THA, especially when lateral migration of the femoral head is large.

Postoperative residual limp is an important factor affecting patient satisfaction, mainly caused by gluteus medius dysfunction. The incidence of Trendelenberg sign ranges from 18% to 70%. The causes underlying these problems are listed below. First, hip abductors are shortened and weakened in dysplastic hips as a result of

long-term high dislocation and disuse atrophy. Second, many patients underwent pelvic or femoral osteotomy surgery previously, which could damage the abductor muscle. For instance, rotational acetabular osteotomy requires broad dissection of pelvis and detachment of muscles for adequate exposure and bone grafting. Detachment of the gluteus medius might result in weakness in the abduction strength [25]. Furthermore, extensive scar tissue was often formed after these surgeries and sometimes restricted reduction of the greater trochanter during THA, thus leading to reconstruction failure of the abductor lever arm.

Although HXLPE was not utilized in this cohort, we prefer the COC bearing surface for DDH patients. First, patients are generally young and more active, although wear particles produced by HXLPE are thought to be much fewer than that of traditional polyethylene; the long-term survival of prosthesis is expected. Second, there are still concerns about HXLPE regarding fatigue fracture risk and potential to increase biological activity of polyethylene particles [26]. Third, sometimes for type III and type IV DDH, the high hip center technique might increase the joint reaction force, thus accelerating polyethylene wear. Fourth, debris particles produced by fretting may also accelerate liner polyethylene wear if a modular stem is used [27]. Fifth, squeaking of ceramic was not rare, but it was infrequent and the function was not impaired in our series, and we did not observe any ceramic fracture event. Last but not the least, patients were much more worried about wear than doctors; a considerable number of patients in the COC group were afraid of activity and exercise even though we had informed them of the negligible wear of ceramic material.

This study has several limitations. First, it is retrospective and lacked control group. In addition, most of our patients were from other provinces and 15% of them were lost to follow-up, which may increase the bias of findings. Furthermore, there were a small number of cases in the MOP group, and the mean follow-up time between the 3 groups was significantly different, which might be another source of bias.

Conclusions

Subtrochanteric osteotomy combined with the modular S-ROM prosthesis and COC surface in Crowe type IV DDH has achieved satisfactory mid-term results, and 8-year survival rate of prosthesis is 97.2%. However, postoperative dislocation and limp remain major issues. Linear wear rate for MOP surface is high and the long-term survival is affected with a 9-year survival rate of 85.9%. Ceramic or HXLPE should be preferred, and which one is the better choice needs further investigation.

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