High Hip Center Technique in Total Hip Arthroplasty for Crowe Type II-III Developmental Dysplasia: Results of Midterm Follow-up

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Abstract

**Background:** High hip center technique is still controversial about the survivorship of prothesis and postoperative complications. We aimed to show the utility of high hip center technique used in patients with Crowe II-III developmental dysplasia of the hip at the midterm follow-up and evaluated the clinical and radiographic results between different heights of hip center.

**Methods:** We retrospectively evaluated 69 patients (85 hips) with Crowe II-III dysplasia who underwent a high hip center cementless total hip arthroplasty at a mean follow up of 8.9 years (range, 6.0-14.1 years). The patients were divided into two groups according to the height of hip center, respectively group A (≥22mm and <28mm) and group B (≥28mm). Radiographic, functional and survivorship outcomes were evaluated.

**Results:** The mean location of the hip center from the inter-teardrop was 25.1mm vertically and 30.0mm horizontally in the group A, and 33.1mm vertically and 31.4mm horizontally in the group B. There were no statistically significant differences between two groups in postoperative femoral offset, abductor lever arm, leg length discrepancy and cup inclination. At the final follow up, the mean WOMAC and Harris hip score were significantly improved in both groups. Of the 85 hips, 7 hips (8.2%) showed a positive Trendelenburg sign. Additionally, 6 patients (8.7%) presented with a limp. No significant differences were shown regarding the Harris hip score, WOMAC score, Trendelenburg sign and limp between two groups. The Kaplan-Meier implants survivorship rates at the final follow-up for all-causes revisions in the group A and group B were similar (96.7% [95% confidence interval, 90.5%-100%] and 96.2% [95% confidence interval, 89.0%-100%], respectively).

**Conclusions:** The high hip center technique is a valuable alternative to achieve excellent midterm results for Crowe II-III developmental dysplasia of the hip. Further, we reported good results and could not demonstrate any significant differences in outcomes or survivorship between the groups with differing degrees of HHC in our study, however the relatively small sample size must be considered and larger comparative studies are required to confirm the value of high hip center technique.

**Background**

Total hip arthroplasty (THA) in developmental dysplasia of the hip (DDH) presents technical
challenges due to complex acetabular and femoral deformities which can be classified by the Crowe classification[1, 2]. The issue of acetabular reconstruction should be a priority especially for Crowe type II-III DDH which always encompasses segmental or complete absence of a superolateral rim. Previously, most studies concurred that the true acetabulum was the optimal location for the cup[3]. To achieve anatomical placement of the cup, augmentation by structural bone graft to supplement bone insufficiency was commonly required[4]. Nevertheless, high failure rates of bone graft have been revealed in the literature[5].

High hip center (HHC) has been discussed as a potential alternative option. The advantages of HHC include better bone stock with greater bone-implant contact and simplification of the operation. However, other studies have shown superolateral placement could result in accelerated polyethylene (PE) wear, decreased abductor moment arm and component loosening[6]. In contrast, more recent clinical studies have demonstrated promising results of this technique. Kaneuji et al.[7] reported no cup loosening in thirty hips (29 patients) using HHC technique for a mean of 15.2 years after surgery. Nawabi et al.[8] showed no difference in survivorship, wear rates and hip scores between the HHC group and the control group. Even so, high placement of the cup is still controversial.

When considering HHC THA, Schutzer and Harris[9] defined 28mm above the inter-teardrop line as HHC, which was at least two times higher than the normal level. In 2013, Fukui et al.[10] defined 22mm above the inter-teardrop line as high rotation center for Japanese. Therefore, different authors have suggested different definitions for HHC, but there is no research comparing different heights of HHC.

The aim of this study was to assess the utility of HHC technique used in patients with Crowe II-III DDH at midterm follow-up. Specifically, we aimed to evaluate the clinical and radiographic outcomes between different heights of HHC.

Methods

Patients

After obtaining institutional review board approval, we performed a retrospective analysis of a case series. From our departmental database, we identified 76 patients diagnosed with Crowe II-III
dysplasia with the acetabular cup placed at the high hip center, of which the threshold was defined as 22mm above the inter-teardrop line[10]. All operations were performed between December 2003 and November 2013 by one senior orthopedic surgeon. A standard x-ray should include the entire pelvis and the proximal femur. Cases with non-standard x-rays (3 hips) and those with histories of neuromuscular disease or trauma were excluded. One patient died of unrelated cause to the procedure at 8 years after surgery and 4 patients were lost to follow-up. Two patients refused to participate for questionnaires and clinical examination. Therefore, 69 patients (85 hips) were ultimately available for this study.

In this study, 54 patients were female (78.3%) and 15 patients were male (21.7%). Forty-two right hips (49.4%) and 43 left hips (50.6%) were surgically treated. The mean age of the patients at the time of THA was 46.4 years (range, 18–69 years). The mean body mass index was 24.1 kg/m² (range, 15.2-35.5 kg/m²). The mean follow-up time was 8.9 years (range, 6.0–14.1 years). According to the Crowe classification, 49 hips were categorized as type II and 36 hips were categorized as type III. Eleven patients had a history of previous surgeries: open reduction in 1 case, femoral derotational osteotomy in 2 cases, pelvic osteotomy in 3 cases and hip shelf procedure in 5 cases.

The patients were divided into two groups according to the height of hip center. In group A which consisted of 39 hips, the hip center was located at a vertical distance of ≥22 mm and 28mm from the inter-teardrop line, when the hip center of group B which consisted of 46 hips was ≥ 28mm (Table.1).

**Surgical technique**

All operations were performed using a modified Kocher-Langenbeck posterolateral approach. The adjustment of cup orientation and intentional medial placement were adopted, aiming to achieve a bone-cup surface contact not inferior to 70%. Partial uncoverage of the superolateral rim was deemed acceptable when good stability was achieved. No superior acetabular grafts or spongioplasty were used in all operations. In some case, a larger size stem was used to elevate the position of the stem in the femoral canal with different head/neck lengths, aiming to restore the proper tension of the gluteus medius and correct limb-length discrepancy. The detailed information of acetabular and femoral components and types of bearing were shown in Table 2.
All patients received antithrombotic prophylaxis using low-molecular-weight heparin postoperatively. We advised the patient to load the surgically treated leg using two crutches for 6 weeks.

**Radiographic Evaluation**

Radiological assessment based on anteroposterior (AP) radiograph of the pelvis was undertaken postoperatively for all patients at three and six months, at one year, then biennially thereafter and at last follow up. Osteolysis was defined as circular or oval areas of distinct bone loss. The location of radiolucent lines with a width of over 1 mm at the component-bone interface was described according to DeLee and Charnley[11]. The cup was considered loosened in presence of a change of more than 3mm of migration or at least 4° in the angle of abduction[12]. The position of the cup was defined as the vertical and horizontal distances of the center of rotation in relation to the acetabular teardrop. Medialization was measured by contrast with the contralateral hip in unilateral HHC. In bilateral HHC, the Ranawat triangle was drawn to define the correct anatomic hip center to calculate the medialization[13]. The cup inclination was defined as the abduction angle, formed by the inter-teardrop line and the connecting line to the edges of the rim of the cup. The measurements of leg length discrepancy, femoral offset (FO) and abductor lever arm (ALA) were described in Figure 1.

**Clinical Assessment**

We clinically evaluated each patient with the Harris Hip Score (HHS), WOMAC score, Trendelenburg sign and limp. To improve interpretability, the scores for WOMAC were transformed, so that a score of 100 indicated the best state of health and a score of 0 indicated the worst state[14]. Trendelenburg sign was regarded as an assessment of the abduction strength. A negative Trendelenburg sign was defined as that when the examiner asked patients to lift one leg off the ground with the hip flexed, the pelvis on the non-weight-bearing side could be elevated high and the patients could maintain this position for at least 5 seconds. The limp was defined as unable to keep the pelvis stable when performing a 10-meter fast walking test.

**Statistical Assessment**

The Shapiro-Wilk test and Q-Q plots were used to assess distributions of the measured variables. Except that the cup size was expressed as median and interquartile range, other continuous variables
such as demographics, radiographic measurements and clinical scores were expressed as mean and range. The categorical variables were assessed by chi-squared test. Differences in mean parameter values between groups were assessed by Student’s t test. The end point for survival was defined as revision for any reason. Kaplan-Meier analysis was performed to determine the probability of survivorship in both groups. The equality of the survival distributions between two groups was compared by Log-rank test. Significance was set at p<0.05. All analyses were performed using SPSS Version 24.0 software.

Result

Radiographic Results

The results of the radiographical evaluations are shown in Table 3. These outcomes indicated that horizontal distance, FO, ALA, leg length discrepancy and cup inclination in group B were maintained as well as they were in group A. Scatter diagram demonstrates the distribution of hip center relative to the anatomic center (Fig.2). Lateralization over 10mm in group B (11 hips) is significantly more than that (1 hip) in group A(p=0.012). At the final follow-up, slight osteolysis was observed in 2 hips in DeLee and Charnley zone 1. These 2 hips were all from group A. No loosening or progressive radiolucency adjacent to the acetabular and femoral component was observed (Fig.3).

Clinical results

The Harris hip score and WOMAC score at the time of follow-up were significantly improved in both group A (p<0.001) and group B (p<0.001). Table 4 showed no statistically significant differences between the groups regarding the Harris hip score, WOMAC score, Trendelenburg sign and limp. Additionally, limps in patients with unilateral and bilateral HHC were similar (p=0.912), respectively 7.5% and 12.5%. Of the 85 hips, 2 hips (2.4%) required revision during the follow-up period. One hip of group A was revised by reason of dislocation at 8.3 years after surgery. The other one hip of group B, which utilized a metal on conventional polyethylene bearing at the primary THA, was diagnosed with osteolysis and underwent a revision at 8.1 years after surgery. With revision for any reason as the end point, the Kaplan-Meier survival rates at last follow-up were similar (p=0.805) in both groups, respectively 96.7% (95%CI, 90.5%-100%) in group A and 96.2% (95%CI, 89.0%-100%) in group B.
Discussion
The reconstruction of the acetabulum in patients with Crowe II-III DDH is a demanding procedure for orthopedic surgeons. Most surgeons found it technically difficult to achieve acceptable cup coverage at the anatomical acetabulum on account of superolateral bone deficiency[15]. Therefore, femoral head structural autograft was usually utilized at the superolateral rim to provide additional support[16]. However, other authors have proposed the instability of cemented acetabular component with bulk bone grafts[17]. Though some excellent results were reported in cementless THA with autograft[18, 19], this procedure still could be correlated with longer duration of surgery and increased blood loss.

Because the posterosuperior bone above the native acetabulum is almost intact, the acetabular cup can be placed at high hip center to optimize host bone-implant contact[20]. In this study, we aimed to assess the utility of HHC technique used in patients with Crowe II-III DDH and evaluated the clinical and radiographic results between different heights of hip center. Early results have shown superior placement and especially lateralization of the cemented acetabular cup resulted in high rate of loosening[6]. In addition, in the cementless THA, aseptic loosening also occurred in long-term follow-up. Watts et al.[21] reviewed 88 primary cementless THA at a mean follow-up of 10 years and found a higher incidence of aseptic loosening and cup revision with superolateral placement of the cup, which was described as more than 10mm superior and 10mm lateral to the approximate femoral head center. To avoid this situation, the acetabular component was placed medially adjacent to medial wall during operation in our study. Medialization not only prevented an increase joint reaction force, but biomechanically relieved the burden of abductor muscle which was mostly dysfunctional preoperatively due to chronically shortened condition and subsequent atrophy. In our study, the mean horizontal distance of the center of rotation which was 30.0mm in group A and 31.4mm in group B was comparable to the results described by Flecher et al. [22] (horizontal distance was 30.4mm when vertical distance was 23.4mm), Fukui et al.[10] (horizontal distance was 28.9mm when vertical distance was 28mm) and Galea et al.[23] (horizontal
distance was 31.6mm when vertical distance was 30.9mm). However, referring to the anatomical center, only 73 (85.9%) acetabular cups attained the objective of medialization or lateralization less than 10mm. Lateral cup placement more than 10mm in group B significantly exceeded that of group A. One possible explanation may be the higher frequency of Crowe III hips in the group B, resulting in more cups placed in a higher position. Due to the funnel-shaped geometry of the bony pelvis, it is more difficult for medialization when the center of rotation was elevated increasingly higher. Nevertheless, it should be stated that no complications such as loosening and liner wear occurred in our hips with excessive lateralization. In contrast to other studies which utilized metal on polyethylene bearing surfaces, we used a ceramic on ceramic (COC) interface in 91.8% of cases, as we hypothesized that the favorable wear characteristics of COC bearing surfaces may counteract the excessive joint reaction forces related to lateralization.

Some authors indicated that there is a negative correlation of abductor strength with a high rotation center of the hip. Through a radiological and biomechanical study, Abolghasemian et al.[24] suggested that elevated hip center resulted in a decrease in the muscle length and a corresponding decrease in the preload, leading to the weakness of abductor strength. But in a recent study, Traina et al.[25] demonstrated that restoration of optimal femoral offset and abductor lever arm produced satisfactory results even for a center of hip rotation of >30 mm. We also reported low rates of limp and Trendelenburg sign in our HHC patients, although muscle strength was not quantitatively assessed. Though the height of hip center in group B significantly exceeded that in group A, the clinical and radiographic outcomes were similar after restoration of leg length, FO and ALA, and no significant difference was shown in two groups. In spite of the slack of gluteus medius due to elevated hip center, a larger size stem and appropriate head/neck lengths could be applied as a compensation and could also contribute to correcting leg length discrepancy, avoiding limp of lower limbs. Further, preserving the continuity of abductors meant a favorable event regarding the restoration of normal gait. In our series, only 8.2% of all hips presented with a positive Trendelenburg sign and 8.7% of patients presented with a limp. The result of Trendelenburg sign was superior to the cases described by Chen et al.[20] (14.2%) and Fukui et al.[10] (13%). Furthermore, a recent gait analysis study by
Karaismailoglu et al.[26] claimed that the bilateral HHC technique could provide similar gait characteristics as anatomical reconstruction. Although there was no detailed research on this issue, the rates of limp in unilateral and bilateral HHC were similar ($p=0.912$) and low in our cohort, respectively 7.5% and 12.5%.

In our series, the survival rates of implants at the final follow-up were high, respectively: 96.7% (95%CI, 90.5%-100%) in group A and 96.2% (95%CI, 89.0%-100%) in group B. Comparison of our survivorships with other studies showed that the HHC technique was a reliable alternative method for Crowe II-III DDH[7, 8]. Meanwhile, higher hip center did not significantly reduce the survivorship of implants at medium term even if it was above 28mm.

This study has some limitations. First, our conclusion is based on a relatively small sample size. Thus, the findings of no difference between the groups may be due to a lack of power. In addition, the validation of HHC technique needs a longer follow-up. Second, this is a retrospective study. However, our patients were identified from a consecutive series with DDH, which may reduce the possibility of selection bias. Third, there is a lack of comparison between HHC technique and other methods. Fourth, the measures of gait used in this study were somewhat crude compared to other studies which undertook formal gait analysis. Furthermore, gluteus medius strength was not quantified because it was measured using a crude clinical test (Trendelenburg sign) instead of dynamometer machine. Thus, our results could only indicate that there appears to be enough strength in the abductors to avoid a Trendelenburg sign in the majority of cases. However, we believe that we have demonstrated good medium term results with a HHC technique which lends credibility to this technique and may serve as a benchmark for further research to assess longer-term outcomes and to compare this technique with anatomic hip center techniques.

Conclusion
We believed that HHC technique could be valuable alternative in THA for Crowe II-III DDH. We reported good results and could not demonstrate any significant differences in outcomes or survivorship between the groups with differing degrees of HHC in our study, however the relatively small sample size must also be considered and larger comparative studies are required to confirm the
implications of HHC THA definitively.

**Abbreviations**

HHC: High hip center; DDH: Developmental dysplasia of the hip; THA: Total hip arthroplasty; PE: polyethylene; BMI: body mass index; AP: anteroposterior; FO: femoral offset; ALA: abductor level arm; HHS: Harris hip score; WOMAC: Western Ontario and McMaster Universities.

**Declarations**

**Ethics approval and consent to participate**

The Ethics Committee of our hospital, General Hospital of Chinese People’s Liberation Army, approved the study protocol. A certificate of approval has been provided. The requirement of informed consent was exempted due to the retrospective nature of the study.

**Consent for publication**

Not applicable.

**Availability of date and materials**

The data will be made available from the authors upon reasonable request.

**Competing interests**

The authors declare that they have no competing interests.

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**Authors’ contributions**

JMS: Designing the study, Analyzing the data, Writing the manuscript; YGZ: Designing the study, Editing the manuscript; JYS, HYM and YQD: Collecting the data, Analyzing the data, Reviewing the manuscript; TJL: Reviewing the literature. All authors have read and approved the final version of this manuscript.

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References

1. Crowe Jf, Mani Vj, Ranawat CS: **Total hip replacement in congenital dislocation and dysplasia of the hip.** *J Bone Joint Surg Am* 1979, **61**(1):15-23.

2. 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**(9S):S38-S44.

3. Russotti GM, Harris WH: **Proximal placement of the acetabular component in total hip arthroplasty. A long-term follow-up study.** *J Bone Joint Surg Am* 1991, **73**(4):587-592.

4. Hintermann B, Morscher EW: **Total hip replacement with solid autologous femoral head graft for hip dysplasia.** *Arch Orthop Trauma Surg* 1995, **114**(3):137-144.

5. Shinar AA, Harris WH: **Bulk structural autogenous grafts and allografts for reconstruction of the acetabulum in total hip arthroplasty. Sixteen-year-average follow-up.** *The Journal of bone and joint surgery American volume* 1997, **79**(2):159-168.

6. Doehring TC, Rubash HE, Shelley FJ, Schwendeman LJ, Donaldson TK, Navalgund YA: **Effect of superior and superolateral relocations of the hip center on hip joint forces. An experimental and analytical analysis.** *J Arthroplasty* 1996, **11**(6):693-703.

7. Kaneuji A, Sugimori T, Ichiseki T, Yamada K, Fukui K, Matsumoto T: **Minimum ten-year results of a porous acetabular component for Crowe I to III hip dysplasia using an elevated hip center.** *J Arthroplasty* 2009, **24**(2):187-194.
8. Nawabi DH, Meftah M, Nam D, Ranawat AS, Ranawat CS: Durable fixation achieved with medialized, high hip center cementless THAs for Crowe II and III dysplasia. Clin Orthop Relat Res 2014, 472(2):630-636.

9. Schutzer SF, Harris WH: High placement of porous-coated acetabular components in complex total hip arthroplasty. The Journal of arthroplasty 1994, 9(4):359-367.

10. Fukui K, Kaneuji A, Sugimori T, Ichiseki T, Matsumoto T: How far above the true anatomic position can the acetabular cup be placed in total hip arthroplasty? Hip Int 2013, 23(2):129-134.

11. DeLee JG, Charnley J: Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res 1976(121):20-32.

12. Maloney WJ, Galante JO, Anderson M, Goldberg V, Harris WH, Jacobs J, Kraay M, Lachiewicz P, Rubash HE, Schutzer S et al: Fixation, polyethylene wear, and pelvic osteolysis in primary total hip replacement. Clin Orthop Relat Res 1999(369):157-164.

13. Ranawat CS, Dorr LD, Inglis AE: Total hip arthroplasty in protrusio acetabuli of rheumatoid arthritis. J Bone Joint Surg Am 1980, 62(7):1059.

14. Singh J, Sloan J, Johanson N: Challenges with health-related quality of life assessment in arthroplasty patients: problems and solutions. J Am Acad Orthop Surg 2010, 18(2):72-82.

15. Olory B, Havet E, Gabrion A, Vernois J, Mertl P: Comparative in vitro assessment of the primary stability of cementless press-fit acetabular cups. Acta Orthop Belg 2004, 70(1):31-37.

16. de Jong PT, Haerkamp D, van der Vis HM, Marti RK: Total hip replacement with a superolateral bone graft for osteoarthritis secondary to dysplasia: a long-
term follow-up. *J Bone Joint Surg Br* 2006, 88(2):173-178.

17. Delimar D, Aljinovic A, Bicanic G: **Failure of bulk bone grafts after total hip arthroplasty for hip dysplasia.** *Arch Orthop Trauma Surg* 2014, 134(8):1167-1173.

18. Saito S, Ishii T, Mori S, Hosaka K, Nemoto N, Tokuhashi Y: **Long-term results of bulk femoral head autograft in cementless THA for developmental hip dysplasia.** *Orthopedics* 2011, 34(2):88.

19. Abdel MP, Stryker LS, Trousdale RT, Berry DJ, Cabanela ME: **Uncemented acetabular components with femoral head autograft for acetabular reconstruction in developmental dysplasia of the hip: a concise follow-up report at a mean of twenty years.** *The Journal of bone and joint surgery American volume* 2014, 96(22):1878-1882.

20. Chen M, Luo ZL, Wu KR, Zhang XQ, Ling XD, Shang XF: **Cementless Total Hip Arthroplasty With a High Hip Center for Hartofilakidis Type B Developmental Dysplasia of the Hip: Results of Midterm Follow-Up.** *J Arthroplasty* 2016, 31(5):1027-1034.

21. Watts CD, Martin JR, Fehring KA, Griffin WL: **Inferomedial Hip Center Decreases Failure Rates in Cementless Total Hip Arthroplasty for Crowe II and III Hip Dysplasia.** *J Arthroplasty* 2018, 33(7):2177-2181.

22. Flecher X, Parratte S, Brassart N, Aubaniac JM, Argenson JN: **Evaluation of the hip center in total hip arthroplasty for old developmental dysplasia.** *J Arthroplasty* 2008, 23(8):1189-1196.

23. Galea VP, Laaksonen I, Donahue GS, Fukui K, Kaneuji A, Malchau H, Bragdon C: **Developmental Dysplasia Treated With Cementless Total Hip Arthroplasty Utilizing High Hip Center Reconstruction: A Minimum 13-Year Follow-up Study.** *J Arthroplasty* 2018, 33(9):2899-2905.
24. Abolghasemian M, Samiezadeh S, Jafari D, Bougherara H, Gross AE, Ghazavi MT: Displacement of the hip center of rotation after arthroplasty of Crowe III and IV dysplasia: a radiological and biomechanical study. *J Arthroplasty* 2013, 28(6):1031-1035.

25. Traina F, De Fine M, Biondi F, Tassinar E, Galvani A, Toni A: The influence of the centre of rotation on implant survival using a modular stem hip prosthesis. *International orthopaedics* 2009, 33(6):1513-1518.

26. Karaismailoglu B, Kaynak G, Can A, Ozsahin MK, Erdogan F: Bilateral High Hip Center Provides Gait Parameters Similar to Anatomical Reconstruction: A Gait Analysis Study in Hip Replacement Patients With Bilateral Developmental Dysplasia. *J Arthroplasty* 2019, 34(12):3099-3105.

### Tables

#### Table 1. Demographics of the Patients.

| Demographic                      | Group A  | Group B  | p value |
|----------------------------------|----------|----------|---------|
| Number of hips (patients)        | 39 (31)  | 46 (38)  |         |
| Mean (range) age (y) at surgery  | 46.5 (18-66) | 46.4 (20-69) | 0.959*  |
| Gender (female/male)             | 25/6     | 29/9     | 0.665†  |
| Mean (range) height (cm)         | 161.1 (142-180) | 161.8 (141-186) | 0.723*  |
| Mean (range) BMI (kg/m²)         | 23.7 (18.7-29.1) | 24.5 (15.2-35.5) | 0.333*  |
| Crowe II /III (hips)             | 32/7     | 17/29    | <0.001  |
| Mean (range) follow up (y)       | 9.5 (6.6-13.3) | 8.4 (6.0-14.1) | 0.007*  |
| Mean (range) blood loss (ml)     | 403.8 (100-1000) | 440.8 (150-2000) | 0.544*  |
| Mean (range) duration of surgery (h) | 1.9 (1.2-2.8) | 2.1 (1.2-4.5) | 0.173*  |

* independent-samples t test; †Chi-squared test; BMI, body mass index.

#### Table 2. Specific designs of acetabular and femoral components and types of bearing used in all
|                              | Group A                  | Group B                  |
|------------------------------|--------------------------|--------------------------|
| Median cup size (mm) (IQR)   | 50 (50, 52)              | 50 (48, 52)              |

**Acetabular component**

| Component                     | Group A                  | Group B                  |
|-------------------------------|--------------------------|--------------------------|
| Betacup (Link, Hamburg, Germany) | 20 (51.3%)              | 24 (52.2%)              |
| Duraloc (DePuy, Warsaw, IN, USA) | 11 (28.2%)              | 9 (19.5%)               |
| Pinnacle (DePuy, Warsaw, IN, USA) | 7 (17.9%)               | 13 (28.3%)              |
| Trident (Stryker, Mahwah, NJ, USA) | 1 (2.6%)                | -                       |

| **Femoral stem** |
|------------------|
| Corail (DePuy, Warsaw, IN, USA) | 32 (82.0%) | 31 (67.4%) |
| S-ROM (DePuy, Warsaw, IN, USA) | 5 (12.8%) | 12 (26.1%) |
| Ribbed (Link, Hamburg, Germany) | 1 (2.6%) | 2 (4.3%) |
| LCU (Link, Hamburg, Germany) | - | 1 (2.2%) |
| Accolade (Stryker, Mahwah, NJ, USA) | 1 (2.6%) | - |

**Bearing type**

| Type | Group A | Group B |
|------|---------|---------|
| COC  | 36 (92.3%) | 42 (91.3%) |
| COP  | 2 (5.1%) | 2 (4.35%) |
| MOP  | 1 (2.6%) | 2 (4.35%) |

IQR, interquartile range; COC, ceramic on ceramic; COP, ceramic on polyethylene; MOP, metal on polyethylene.

Table 3. Postoperative radiographic evaluation.
## Table 4. Clinical evaluation.

| Parameters                        | Group A             | Group B             | p value |
|-----------------------------------|---------------------|---------------------|---------|
| Preoperative HHS*                 | 53.5 (35.5-65.0)    | 51.1 (33.0-68.0)    | 0.199†  |
| HHS at last follow-up*            | 94.0 (78.9-99.7)    | 92.8 (76.5-99.1)    | 0.187†  |
| Preoperative WOMAC*               | 55.5 (44.8-67.7)    | 53.9 (40.6-70.8)    | 0.340†  |
| WOMAC at last follow-up*          | 92.4 (61.5-100)     | 91.6 (58.3-100)     | 0.640†  |
| Positive Trendelenburg sign       | 4 (10.3%)           | 3 (6.5%)            | 0.819‡  |
| Patients with limp                | 4 (12.9%)           | 2 (5.3%)            | 0.526‡  |

* Values given as mean (range); † independent-samples t test; ‡ Chi-squared test.
Figure 1

a) Diagram for radiographic measurement of unilateral HHC; b) Ranawat triangle was drawn to define the anatomic hip center of bilateral HHC. The star represents teardrop and the dot represent the apex of the lesser trochanter. V: vertical distance; H: horizontal distance; L: leg length; FO: femoral offset; ALA: abductor lever arm; Leg length discrepancy = |L1-L2|; \( \Delta H = H2-H1 \) (unilateral HHC) or H0-H1 (bilateral HHC), positive indicates medialization and negative indicates lateralization.
Scatter-gram of medialization or lateralization in both groups. Lateralization over 10mm in group B (11 hips) is significantly more than that (1 hip) in group A (p=0.012). No revision and limp were observed in lateral placement (≥ 10mm). Between unilateral (53 hips) and bilateral (32 hips) HHC, there is no significant difference of lateralization≥10mm (p=0.756).
Figure 3

Preoperative (a) anterior-posterior X-ray highlighted a bilateral DDH (right hip as Crowe II and left hip as Crowe III) in a 47-year-old female patient (Crowe index: 0.13 in right hip and 0.16 in left hip). The postoperative anteroposterior radiographic evaluation after 8.8 years (b) showed no osteolysis and radiolucent line. The height of rotation center was 29.7mm in right hip and 38.5mm in left hip.
The Kaplan-Meier survival curve with revision for any reason as the end point for group A and group B was shown. CI, confidence interval.