

■ CHILDREN'S ORTHOPAEDICS

Remodelling of femoral head deformity after hip reconstructive surgery in patients with cerebral palsy

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Aims

Hip displacement, common in patients with cerebral palsy (CP), causes pain and hinders adequate care. Hip reconstructive surgery (HRS) is performed to treat hip displacement; however, only a few studies have quantitatively assessed femoral head sphericity after HRS. The aim of this study was to quantitatively assess improvement in hip sphericity after HRS in patients with CP.

Methods

We retrospectively analyzed hip radiographs of patients who had undergone HRS because of CP-associated hip displacement. The pre- and postoperative migration percentage (MP), femoral neck-shaft angle (NSA), and sphericity, as determined by the Mose hip ratio (MHR), age at surgery, Gross Motor Function Classification System level, surgical history including Dega pelvic osteotomy, and triradiate cartilage status were studied. Regression analyses using linear mixed model were performed to identify factors affecting hip sphericity improvement.

Results

A total of 108 patients were enrolled. The mean preoperative MP was 58.3% (SD 31.7%), which improved to 9.1% (SD 15.6%) at the last follow-up. NSA and MHR improved from 156.5° (SD 11.5°) and 82.3% (SD 8.6%) to 126.0° (SD 18.5°) and 89.1% (SD 9.0%), respectively. Factors affecting the postoperative MHR were preoperative MP ($p = 0.005$), immediate postoperative MP ($p = 0.032$), and history of Dega osteotomy ($p = 0.046$).

Conclusion

We found that hip sphericity improves with HRS. Preoperative MP, reduction quality, and acetabular coverage influence femoral head remodelling. We recommend that surgeons should consider intervention early before hip displacement progresses and that during HRS, definite reduction and coverage of the femoral head should be obtained.

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Introduction

Hip displacement is common in nonambulatory patients with cerebral palsy (CP) of Gross Motor Function Classification System (GMFCS) levels IV and V.¹⁻⁴ CP is a permanent disorder affecting movement and posture that causes activity limitations due to nonprogressive injury to the fetal or immature infant brain.⁵ Owing to the primary abnormalities of CP, such as spasticity and muscle imbalance, hip displacement progresses and is usually detected around the age of five to seven years old.^{1,2} If left untreated, hip displacement eventually causes pain, thereby hindering the

benefit of weight-bearing which is crucial for quality of life.^{6,7}

Traditionally, resection arthroplasty has been considered as an option for palliative treatment of a CP hip with femoral head destruction.⁸ However, there are no clear-cut indications for resection arthroplasty for a deformed femoral head.⁹

Previous studies have shown that reduction of displacement through hip reconstructive surgery (HRS), which includes femoral varus and derotational osteotomy (FVDO), with or without pelvic osteotomies, relieves both pain frequency and intensity.⁶ It has been found however that hip

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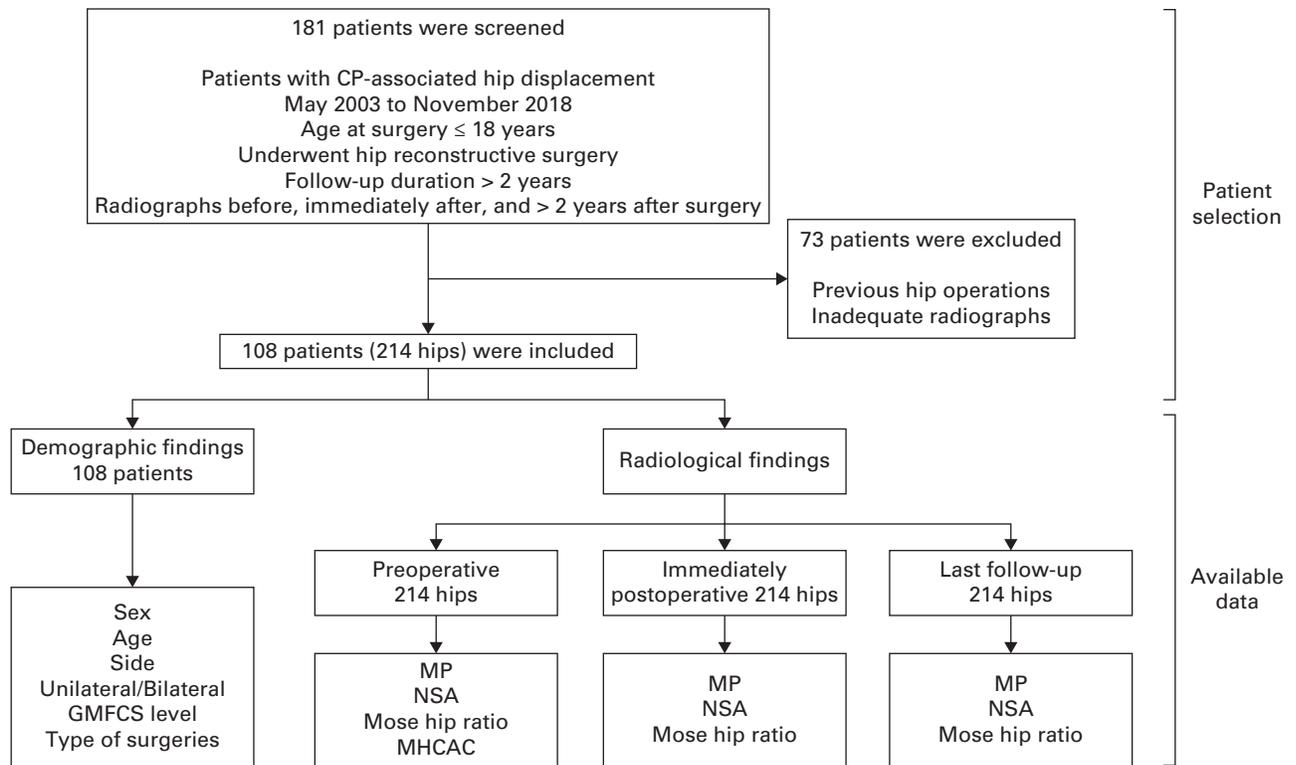


Fig. 1

Flowchart of patient inclusion and exclusion and available data for analysis. CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; MP, migration percentage; NSA, neck-shaft angle; MHCAC, Melbourne hip classification for adolescents with cerebral palsy.

joint congruity after HRS improves even if the initial presentation of a CP hip seems irreversible.¹⁰ Radiological changes in femoral head sphericity have also been studied previously, but quantitative evaluation of the improvements in sphericity of the femoral head after HRS have been rarely performed. In this retrospective study, we have quantitatively assessed the extent of improvement in hip congruency after HRS in patients with CP and identified the factors that are involved.

Methods

Patients and study design. This retrospective study was approved by the review board of our institution (Seoul National University Bundang Hospital), which is a tertiary referral centre for CP. The need for informed consent was waived.

Patients who had been treated between May 2003 and November 2018 were screened using the clinical data warehouse (eZCaretech, Seoul, South Korea). Inclusion criteria were: patients with CP who were less than 18 years old at initial visit; presented due to CP-associated hip displacement; who underwent HRS; had a minimum two years of follow-up; and underwent radiological evaluation before, immediately after, and at least two years after surgery. Exclusion criteria were patients with previous HRS and those with inadequate preoperative or postoperative radiographs. A flow diagram of the patient inclusion process is shown in Figure 1.

After screening, two authors (JJM, MSP) reviewed the patients’ medical records and radiographs. Patient age at surgery,

sex, GMFCS level, involvement (unilateral/bilateral), surgical history including Dega osteotomy,¹¹ and the date on which the radiographs were taken were included in the measurement data. To compare the changes in hip sphericity, only the sides of the hip that had undergone HRS were included. Anteroposterior (AP) hip radiographs were obtained with patients in the supine position, using the UT 2000 unit (Philips, Eindhoven, The Netherlands) with a source-to-image distance of approximately 100 cm, 60 kVp, and 10 mAs. All radiological images were digitally acquired with the use of a picture archiving and communication system (PACS) (INFINITT Healthcare, Seoul, South Korea), and measurements were subsequently carried out with the use of PACS software.

Surgery. HRS including FVDO was performed in nonambulatory patients with CP. In those patients with unilateral hip displacement, FVDO was conducted on the side of displacement along with prophylactic surgery on the contralateral side regardless of displacement.¹² Osteotomy sites were internally fixed with a paediatric locking compression plate (Synthes, Zuchwil, Switzerland) or a blade plate (Stryker, Selzach, Switzerland) depending on the surgeon’s preference. After intraoperative fluoroscopic examination, open reduction was carried out where there was insufficient reduction following a closed reduction. A modified Dega osteotomy was performed either bilaterally or on the side with the acetabular defect or if there was insufficient coverage, which was evaluated intraoperatively. The goals of surgery were to achieve a painless, stable hip and to prevent hip

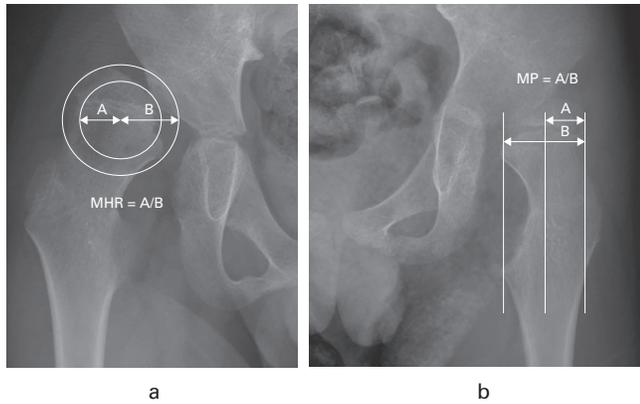


Fig. 2

Anteroposterior (AP) hip supine radiographs of an eight-year-old male patient. a) On the right hip, the Mose hip ratio (MHR) was defined as the percentage ratio between radii of two concentric circles (the inner A) and outer cortices (B) of femoral head). b) On the left hip, the migration percentage (MP) was calculated by dividing the width of the femoral head lateral to the Perkin's line (A) by the total width of the femoral head (B).

displacement relapse. The radiological goal was an immediate postoperative migration percentage (MP) of 0%.

Consensus building and measurement. Three authors, who are orthopaedic surgeons with two, 16, and 19 years of experience (JJM, KHS, MSP), and a statistician (S-SK), agreed on the indices to be measured on the radiographs. Previous studies were reviewed, and one of the authors pooled four indices relevant to the evaluation of sphericity and severity of hip displacement, and were as follows: Melbourne hip classification system,¹³ Mose hip ratio (MHR),¹⁴ MP,¹⁵ and femoral neck-shaft angle (NSA). The participating authors considered the reliability and validity of the radiological indices as the most important criteria when choosing which indices to include in this study. Each index was measured on preoperative AP hip radiographs before surgery as close to the date of operation as possible, immediately after surgery, and at the most recent follow-up.

The morphology of the femoral heads was evaluated using femoral head deformity grading, as described in the Melbourne hip classification system,¹³ with grade 1 representing a normal hip; grade 2, a hip with mild femoral head deformity; and grades 3 and 4, hips with more severe deformity.

In the modified Mose technique, the MHR is calculated to quantitatively evaluate the sphericity of the femoral head.^{14,16} Concentric circles were drawn at the centre of the femoral head with the larger circle outlining the outer cortex of the femoral head and the inner circle outlining the innermost cortex of the head. The ratio between the radii of the two circles was calculated as the sphericity of the femoral head (Figure 2).

MP was calculated by dividing the width of the femoral head lateral to the Perkin's line by the total width of the femoral head.¹⁵ NSA was defined as the angle between a line passing through the centre of the femoral shaft and another line connecting the femoral head centre and the midpoint of the femoral neck.

After consensus building, a reliability test was conducted before the primary measurements. Sample size estimation

Table I. Summary of patient data.

Parameters	Values
Patient information (n = 108)	
Sex, n (male/female)	76/32
GMFCS level, n	
I	0
II	1
III	8
IV	50
V	49
Mean age at surgery, yrs (SD)	9.4 (3.2)
Mean follow-up duration, yrs (SD)	5.2 (3.2)
Hip information (n = 214)	
Side, n (right/left)	108/106
MHCAC, n	
FH0	18
FH1	183
FH2	9
FH3	4
Dega pelvic osteotomy, n	135
Triradiate, n (open/closed)	196/18
Postoperative AVN, n	3
Radiological findings	
Mean migration percentage (SD)	
Preoperative	58.3 (31.7)
Last follow-up	9.1 (15.6)
Mean neck-shaft angle, ° (SD)	
Preoperative	156.5 (11.5)
Last follow-up	126.0 (18.5)
Mean mose hip ratio (SD)	
Preoperative	82.3 (8.6)
Last follow-up	89.1 (9.0)

AVN, avascular necrosis; GMFCS, Gross Motor Function Class System; MHCAC, morphological hipclassification for adolescents with cerebral palsy.

showed that a minimum of 36 hip (18 left and 18 right) radiographs should be assessed. Three authors (JJM, KHS, MSP) determined the interobserver reliability using intraclass correlation coefficients (ICCs), and independently measured the radiographs in a blinded fashion. Four weeks after the primary measurements, intraobserver reliability was assessed with one of the authors repeating the radiological measurements. Following the reliability testing, two authors (JJM, MSP) with two and 19 years of orthopaedic experience measured the indices on all radiographs.

Building a linear mixed model. The effects of age at surgery, GMFCS level, status of Dega osteotomy, ossification of the triradiate cartilage, preoperative MP, preoperative NSA, preoperative MHR, immediate postoperative MP, and NSA were investigated as the primary endpoints using the linear mixed model, wherein the dependent variable was MHR on the last day of follow-up. Among these factors, we assumed the follow-up duration and side as the random effects. A linear mixed model analysis was conducted to investigate the association between the MHR at the last follow-up and each related factor. The effect of age at operation, GMFCS level, preoperative MP, and preoperative NSA with side as the random effect was investigated as the secondary outcome to determine the trend of preoperative

Table II. Interobserver and intraobserver reliability of the radiological measurements.

Measurement	Interobserver reliability, ICC (95% CI)	Intraobserver reliability, ICC (95% CI)
Migration percentage	0.939 (0.892 to 0.967)	0.947 (0.897 to 0.973)
Neck-shaft angle	0.877 (0.793 to 0.931)	0.925 (0.853 to 0.961)
Mose hip ratio	0.858 (0.753 to 0.923)	0.828 (0.662 to 0.913)

CI, confidence interval; ICC, intraclass correlation coefficient.

Table III. Factors affecting preoperative Mose hip ratio.

Factor	Coding of variables	Estimate (95% CI)	p-value
Intercept	N/A	67.94 (51.01 to 84.87)	< 0.001
Age at initial surgery	Yrs	0.47 (0.11 to 0.83)	0.012
GMFCS level			
II/III	Base		
IV	(1/0)	-0.18 (-4.28 to 3.91)	0.930
V	(1/0)	-2.35 (-6.54 to 1.83)	0.268
Side (left/right)	(1/0)	-1.17 (-3.45 to 1.11)	0.313
Preop MP	%	-0.09 (-0.13 to -0.06)	< 0.001
Preop NSA	°	0.11 (0.01 to 0.21)	0.038

*The linear mixed model was used to estimate the factors affecting preoperative Mose hip ratio.

CI, confidence interval; GMFCS, Gross Motor Function Classification System; MP, migration percentage; NSA, neck-shaft angle; Preop, preoperative.

Table IV. Factors affecting Mose hip ratio on most recent follow-up radiographs.

Factor	Coding of variables	Estimate (95% CI)	p-value*
Intercept	N/A	68.75 (41.78 to 95.72)	< 0.001
Age at initial surgery	Yrs	0.16 (-0.32 to 0.64)	0.514
GMFCS level			
II/III	Base		
IV	(1/0)	-0.74 (-5.22 to 3.75)	0.747
V true	(1/0)	-1.83 (-6.41 to 2.75)	0.432
Side (left/right)	(1/0)	0.38 (-2.12 to 2.89)	0.764
Dega (yes/no)	(1/0)	3.59 (0.06 to 7.12)	0.046
Triradiate (closed/open)	(1/0)	-0.55 (-5.75 to 4.66)	0.836
Preop MP	%	-0.08 (-0.14 to -0.03)	0.005
Preop NSA	°	0.09 (-0.02 to 0.20)	0.119
Preop MHS	%	0.07 (-0.08 to 0.22)	0.364
IMPO MP	%	-0.21 (-0.39 to -0.02)	0.032
IMPO NSA	°	0.03 (-0.08 to 0.14)	0.618

*The linear mixed model was used to estimate the factors affecting Mose hip ratio on most recent follow-up radiographs.

CI, confidence interval; GMFCS, Gross Motor Function Classification System; IMPO, immediately postoperative; MHS, Mose hip scale; MP, migration percentage; NSA, neck shaft angle; Preop, preoperative.

MHR. Moreover, the models were accepted as valid for an estimation of the responses using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). A smaller AIC or BIC value is preferred in terms of model selection. The model used in this study had a low AIC/BIC score.

Statistical analysis. In this study, reliability was assessed based on the ICCs and a two-way mixed-effects model, assuming a single measurement and absolute agreement.^{17,18} Using an ICC target value of 0.8, Bonett approximation was employed

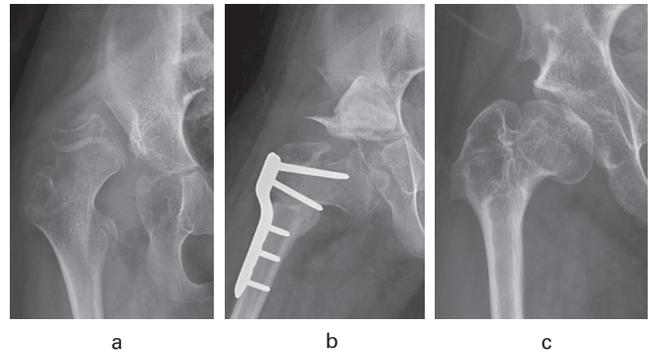


Fig. 3

Radiographs of an 11-year-old female patient with Gross Motor Function Classification System level V who underwent hip reconstructive surgery (HRS) because of bilateral cerebral palsy (CP) hip displacement. a) Preoperative radiograph of the right hip shows the migration percentage (MP) (100%) and Mose Hip Ratio (MHR) (64%), along with head destruction. b) Immediate postoperative radiograph after HRS consisting of bilateral open reduction, femoral varization and derotational osteotomy, Dega osteotomy, and soft tissue release. c) Radiograph at last follow-up (four years after HRS). Head deformity has improved to a MHR of 71% and MP of 13%. The patient is currently pain-free.

with 0.2 set as the width of 95% confidence intervals (CIs). The minimum sample size was calculated to be 36.¹⁹

Descriptive statistics were used to summarize patient demographics and radiological measurements. The Kolmogorov-Smirnov test was used to verify the normality of the distribution of continuous variables. Descriptive statistics used included the mean, SD, and frequency. A linear mixed model was used to assess the covariate effects and examine the factors that contributed significantly to the pre- and postoperative MHR.

All statistical analyses were performed using the SAS statistical package v. 9.4 (SAS Institute, Cary, North Carolina, USA) and R v. 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria) with the STATS package 2.3. All statistical tests were two-tailed, and CIs were considered to indicate significance when they did not include zero. A p-value < 0.05 was considered to reflect statistical significance.

Results

Overall, 108 patients were enrolled in the study, and 642 AP hip radiographs were evaluated. There were 50 and 49 patients who had GMFCS levels of IV and V, respectively. The mean age at surgery was 9.4 years (SD 3.2), and mean follow-up period was 5.2 years (SD 3.2). All 108 patients underwent FVDO with pelvic osteotomy. A total of 214 hips underwent 135 Dega osteotomies. Three patients at the last follow-up showed evidence of postoperative avascular necrosis (Table I).

The MP, NSA, and MHR showed good to excellent intraobserver and interobserver reliabilities (Table II). The mean preoperative MP was 58.3% (SD 31.7%), which improved to 9.1% (SD 15.6%) at the last follow-up. The NSA improved from 156.5° (SD 11.5°) to 126.0° (SD 18.5°). Sphericity, as described by the MHR, improved from 82.3% (SD 8.6%) to 89.1% (SD 9.0%).

In our linear mixed model (LMM), factors affecting preoperative sphericity were age, MP, and NSA at the time of preoperative assessment. When a patient was one year younger at the time of preoperative assessment, femoral head was more spherical by 0.47% ($p = 0.012$, linear mixed model). With a 1% increase in preoperative MP, sphericity decreased by 0.09% ($p < 0.001$, linear mixed model), and with a 1° increase in preoperative NSA, sphericity increased by 0.11% ($p = 0.038$, linear mixed model) (Table III).

In another analysis using LMM, factors affecting femoral head sphericity at last follow-up were preoperative MP ($p = 0.005$), immediate postoperative MP ($p = 0.032$), and performance of Dega osteotomy ($p = 0.046$). With a 1% increase in preoperative MP, sphericity deteriorated by 0.08% (95% confidence interval 0.03% to 0.14%) at the last follow-up. With 1% decrease in immediate postoperative MP ($p = 0.032$), the sphericity at last follow-up improved by 0.21% (Table IV).

Discussion

In our quantitative analyses of the changes in femoral head morphology after HRS, we have demonstrated that femoral head sphericity improves after HRS, and that factors affecting its improvement are preoperative and immediately postoperative MP and the performance of a Dega osteotomy (Figure 3).

Improvement in femoral head sphericity following HRS has been noted before. Braatz et al^{10,20} classified hip displacement into four categories: spherical congruity, spherical incongruity, aspheric congruity, and aspheric incongruity. After an average of 7.7 years, 45 hips which had been classified as aspheric incongruent, improved to 59 congruent hips with HRS and additional Dega pelvic osteotomy.^{10,20} Similarly, in our study, the MHR improved from a mean of 82.3% (SD 8.6%) to 89.1% (SD 9.0%) at the most recent follow-up after surgery, with a mean follow-up duration of 5.2 years (SD 3.2). Thus, the Cohen's d in our study would be 0.6, indicating a medium effect size,²¹ which is a statistically meaningful difference, although, its clinical implication, that is, the relationship between sphericity and functional outcome, needs further examination.

The Melbourne hip classification system has been introduced to describe femoral head sphericity according to its radiological morphology.¹³ However, this classification only conveys current hip status and is less useful when applied to analyze the extent of improvement in sphericity after HRS. To compensate for this shortcoming, the modified Mose technique has been used to quantitatively evaluate the sphericity of the femoral head.^{14,16} The original Mose method of calculating hip sphericity involved calculating the discrepancy in length between two concentric circles.¹⁴ In our study, as the size of the femoral head increases as patients reach skeletal maturity, we used the modified Mose technique and incorporated the ratio between the areas of the two concentric circles in our analysis of sphericity.^{14,16}

Preoperative MP has been considered to be an important factor in femoral head sphericity.^{3,7,10,22,23} In those patients with greater preoperative MP and longer duration of hip displacement, the femoral head asphericity worsens.^{1,3,7,22} The same result has been found in our study showing that, with a 1% increase in preoperative MP, the femoral head asphericity

progressed by 0.08%. We also found that immediate postoperative MP was a factor affecting head sphericity, showing that, with a 1% increase in MP immediately after surgery, sphericity deteriorated by 0.21%. Therefore, it would be reasonable to suggest that when HRS is performed, decreasing the postoperative MP as much as possible through maximum variation and including pelvic procedures for better acetabular coverage, such as Dega pelvic osteotomy, should be taken into account. Braatz et al²⁰ showed that a Dega pelvic osteotomy improved hip congruency, because the hip joint develops more physiologically and function improves after HRS. This finding also relates to our final results in which we show that the sphericity improved by 3.59 times in patients who underwent Dega pelvic osteotomy compared to patients who had not undergone an additional Dega osteotomy during HRS.

Despite the clinical implications of the present study, it is crucial to consider its limitations. These are that the study was retrospective. As such, a uniform protocol was not implemented in all patients who differed in age at their initial assessment, and duration of follow-up. However, a linear mixed model consisting of fixed and random effects was selected to adjust for the retrospective data that are an inherent limitation of this study design. Moreover, this study was based on the basic tenet that there is a strong correlation between radiological femoral head sphericity and clinical symptoms as has been shown in several studies.^{24–26} Secondly, our study contains the inherent limitation of assessing a 3D object through a 2D diagnostic tool. Even though MHR is a well-known and useful tool in assessing hip sphericity in Perthes' disease and developmental dysplasia of the hip, implementing MHR is novel in CP hip. Sphericity is already used in an important hip classification of CP.¹³ We have tried to utilize MHR as a surrogate for assessing femoral head deformities and incongruity commonly observed in CP. However, this has only been carried out in our study and further validation of MHR usage in CP will be needed in future studies. Lastly, our study lacks a control group. In this paper we have tried to demonstrate objectively the changes that occur to a deformed femoral head in patients with CP after HRS and, in doing so, raise awareness for imprudent femoral head resections when potential for remodelling still exists. The question remains as for how much of a femoral head deformity should be an indication for resection arthroplasty. This problem still lacks consensus and needs further study.

In conclusion, when treating CP patients with hip displacement, HRS is recommended before hip displacement progresses. When surgery is performed, decreasing the MP as much as possible through maximum variation and the addition of Dega pelvic osteotomies needs to be taken into consideration.



Take home message

- When hip reconstructive surgery is performed, deep-seated reduction of the femoral head with sufficient acetabular coverage should be achieved.
- Hip reconstructive surgery should be performed before the migration percentage progresses in order to achieve the best result in the remodelling of femoral head sphericity.

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K. M. Lee: Prepared the manuscript.

C. Y. Chung: Prepared the manuscript.

M. S. Park: Designed the study, Prepared the manuscript, Performed the measurements and the reliability testing.

J. J. Min and S-S. Kwon contributed equally to this work.

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