

# The Femoral Head-Shaft Angle Is Not a Predictor of Hip Displacement in Children Under 5 Years With Cerebral Palsy: A Population-based Study of Children at GMFCS Levels III-V

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**Background:** The aim of this study was to evaluate whether the femoral head-shaft angle (HSA) is a predictor of hip displacement in children with cerebral palsy (CP).

**Methods:** The patients were recruited from a population-based hip surveillance program. Inclusion criteria were age under 5 years, bilateral CP, Gross Motor Function Classification System (GMFCS) levels III-V, and migration percentage (MP) of both hips <40% at the primary radiograph. With these criteria, 101 children (61 boys) were included. GMFCS was level III in 26 patients, level IV in 23, and level V in 52. An anteroposterior radiograph of the pelvis was taken at diagnosis and at the last follow-up. Only the worst hip of each patient (the hip with the largest MP) was used for the analyses.

**Results:** The mean age at the primary radiograph was 2.4 years (range, 0.8 to 4.9 y). The mean primary HSA was 171.0 degrees (range, 152 to 190 degrees). The mean follow-up time was 4.3 years (range, 0.9 to 11.8 y). The mean MP at the primary radiograph was 17.5% (range, 0% to 39%) and at the last follow-up 41.9% (range, 0% to 100%). At that point, MP was <40% in 54 hips and  $\geq$ 40% in 47 hips. There was no significant difference in primary HSA between patients with final MP <40% and those with final MP  $\geq$ 40% (170.8 and 171.3 degrees, respectively;  $P=0.761$ ). At the last follow-up, the mean HSA was significantly larger in hips with final MP  $\geq$ 40% than in hips with final MP <40% (171.1 vs. 167.4 degrees;  $P=0.029$ ).

**Conclusions:** There was a markedly increased valgus position of the proximal femur in nonambulatory children with CP. However, the primary HSA in children below 5 years of age was not a predictor of later hip displacement, defined as MP  $\geq$ 40%.

**Clinical Relevance:** Measurement of HSA is not necessary in routine hip surveillance in children below 5 years.

**Level of Evidence:** Level I—investigating a diagnostic test.

**Key Words:** femoral head-shaft angle, hip displacement, migration percentage, cerebral palsy

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Nonambulatory children with cerebral palsy (CP) have an increased risk of hip subluxation and dislocation, which may cause pain and increasing problems with mobility and sitting.<sup>1,2</sup> Therefore, surveillance programs for early detection and management of hip displacement have been developed.<sup>3–5</sup> Hip displacement is measured by the migration percentage (MP) according to Reimers.<sup>6</sup> An MP above 40% is usually considered an indication for surgical correction in order to restore femoral head coverage.<sup>3,7,8</sup> Early preventive surgery may reduce the need for later reconstructive and salvage surgery.

For optimal surveillance of hip development, the children should be enrolled in the screening program as soon as the diagnosis of CP has been established, usually at an age of 1 to 2 years.<sup>4,8</sup> The primary radiograph should be taken at the time of diagnosis. As there is a pronounced trend to hip deterioration in nonambulatory children, reliable predictors for later subluxation to MP  $\geq$ 40% are important for follow-up policy and treatment. One known risk factor is reduced functional capacity, which is assessed by Gross Motor Functional Classification System (GMFCS).<sup>9</sup> The risk of hip migration increases with increasing GMFCS levels.<sup>5,8,10</sup>

It has been established that valgus position of the proximal femur is a common deformity in children with CP.<sup>11,12</sup> Coxa valga can be measured as the femoral neck-shaft angle (NSA) or the head-shaft angle (HSA). In children with CP, HSA is a more adequate parameter than NSA. One reason is that the femoral head is often in a valgus position in relation to the femoral neck and thus the NSA may underestimate the total valgus deformity of

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the proximal femur, whereas HSA measures the combined valgus deformity.<sup>12</sup> Another reason is that NSA is markedly dependent on the degrees of femoral anteversion and the rotation of the limb at radiography, whereas the HSA is less influenced by the rotation of the limb.<sup>11</sup>

Recently, the HSA has been suggested as a risk factor for hip displacement. A large HSA at the primary radiograph was found to be significantly associated with later hip displacement, defined as  $MP \geq 40\%$  in children at GMFCS levels III-V.<sup>13</sup> However, others reported no significant effect of the primary HSA on later hip displacement.<sup>14</sup> Van der List et al<sup>15</sup> found that HSA at patient age 2 years was predictive of later hip displacement, whereas HSA was not a predictor at patient age 4 years. Thus, this question needs further research. The aim of this retrospective population-based study was to evaluate whether the HSA at the time of diagnosis in children under 5 years of age is a predictor of later hip displacement.

## METHODS

### Design

This is a retrospective population-based study of children enrolled in the Norwegian surveillance program for children with CP (CPOP, Cerebral Palse Oppfølgings Program), living in 1 of the 10 counties of southeast Norway.<sup>8</sup> The study protocol was approved by the Regional Ethics Committee, REC South East (229054/2021 REK) and by our institutional review board.

### Patients

Inclusion criteria for the study were: children born during the 5-year period 2002-2006, age at diagnosis under 5 years, bilateral CP, GMFCS levels III-V, and MP of both hips  $< 40\%$  at the first (primary) radiograph. Of the 139 children at GMFCS levels III-V, 38 were excluded because of age 5 years or above ( $n = 17$ ) or primary  $MP \geq 40\%$  ( $n = 20$ ). All the remaining 101 children (61 boys and 40 girls) were included in the study. The mean age at the primary pelvic radiograph was

2.4 years (range, 0.8 to 4.9 y). GMFCS levels and type of CP were determined by physiotherapists and neuropaediatricians working at the child habilitation centers (1 in each county) and this information was obtained from the CPOP database. The GMFCS distribution was level III in 26 patients, level IV in 23, and level V in 52 patients. The type of CP was spastic bilateral in 73 patients (quadriplegia in 42 and diplegia in 31), dyskinesia in 26 patients, and uncertain type in 2.

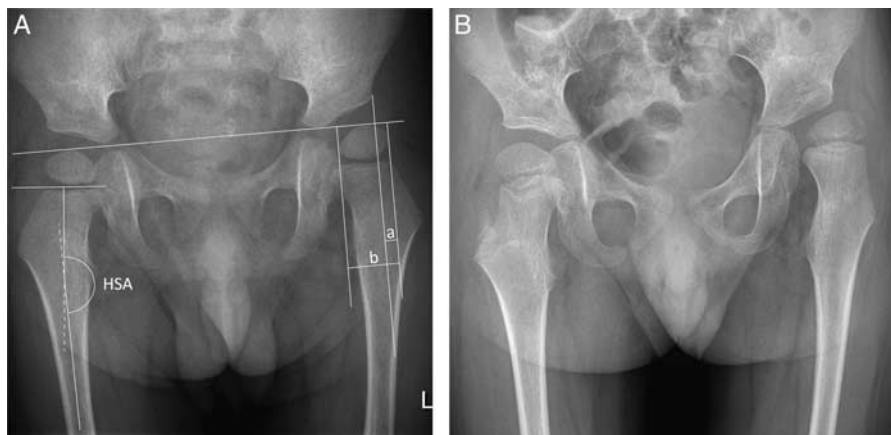
### Radiographic Measurements

An anteroposterior radiograph of the pelvis and hips was taken at the time of diagnosis. The child was in the supine position with legs parallel and knees facing anteriorly, and care was taken to avoid rotation of the pelvis and the legs. The valgus position of the femoral head relative to the femoral shaft (HSA) was measured in both hips on the first and last radiographs as described by Hermanson et al.<sup>13</sup> HSA expresses the valgus position of the proximal femur and is measured as the medial angle between a line perpendicular to the proximal femoral physis and a line through the middle of the femoral shaft (Fig. 1). The measurements were performed by 1 of the authors (T.T.), who has many years of experience in evaluating radiographs of children's hips. To assess intraobserver agreement of the initial HSA, the measurements were performed twice with 4 to 5 weeks interval. In addition, measurements of the HSA in every second patient ( $n = 50$ ) were performed by the second author (J.H.) for analysis of interobserver agreement.

The femoral head displacement was measured as the MP according to Reimers.<sup>6</sup> MP is the percentage of the femoral head lateral to the acetabulum (lateral to Perkins' line) (Fig. 1). The limit between contained hips and subluxation is  $MP 33\%$ .

### Follow-up Routines

According to the routines of our surveillance program, a pelvic radiograph should be taken once a year in



**FIGURE 1.** A, Primary radiograph of a boy aged 1.7 years, with spastic quadriplegia, at Gross Motor Function Classification System level V. The head-shaft angle (HSA) is the medial angle between a line perpendicular to the proximal femoral physis and a line through the middle of the femoral shaft, as indicated in the right hip. Measurement of the migration percentage (MP) is shown in the left hip ( $MP = a/b \times 100$ ). HSA is 175 degrees and MP is 27% in the worst (left) hip. B, Radiograph of the same patient at the age of 4.3 years. The left hip is subluxated with migration percentage 56% and head-shaft angle 173 degrees.

children at GMFCS levels III-V. Patients who had not undergone surgical treatment for hip displacement were followed until the last available radiograph in our radiographic archive. In patients who had been operated for hip displacement, the last preoperative radiograph was used for the last (final) HSA and MP. To avoid the statistical problem of bilaterality as the hips of the 2 sides hardly are independent of each other, only the worst hip of each patient (the hip with the largest MP at the last radiograph) was used for the analyses.

**Statistics**

SPSS (version 26; IBM, Armonk, NY) was used for the statistical analysis. Categorical variables were analyzed with the Pearson  $\chi^2$  test. Continuous variables were analyzed with Student *t* tests for independent samples and paired samples and 1-way analysis of variance with Scheffe post hoc test. Correlation between parameters was evaluated by Pearson correlation coefficient (*r*). Potential risk factors of clinically relevant hip displacement, defined as MP  $\geq$  40% at the last radiograph, were analyzed with univariable logistic regression. Differences were considered significant when the *P*-value was  $<$  0.05. Intra-observer and interobserver agreements were analyzed by calculating the limits of agreement (LOA), defined as mean  $\pm$  2 SD of the differences between the observers.<sup>16</sup>

**RESULTS**

The mean HSA at the initial radiograph (primary HSA) was 171.0 degrees (range, 152 to 190 degrees; SD = 7.3). There were no significant associations between primary HSA and GMFCS levels (Table 1). The mean follow-up time was 4.3 years (range, 0.9 to 11.8 y) and the mean age at the last radiograph was 6.7 years (range, 2.8 to 13.8 y). The mean MP at the initial radiograph was 17.5% (range, 0% to 39%) and at the last follow-up 41.9% (range, 0% to 100%). At that point, MP was  $<$  40% in 54 hips and  $\geq$  40% in 47 hips (47%).

Possible risk factors for hip displacement (MP  $\geq$  40% at the last radiograph) are shown in Table 2. GMFCS level V was a significant risk factor for hip displacement. There was

**TABLE 1.** Association Between HSA at the First and Last Radiographs and GMFCS Levels III-V

Time Point	GMFCS	N	HSA	Comparison	<i>P</i>
First radiograph	Primary HSA				
	Level III	26	170.2 (7.7)	GMFCS III vs. IV	0.825
	Level IV	23	171.4 (6.7)	GMFCS IV vs. V	1.000
Last radiograph	Last HSA				
	Level III	26	165.9 (6.8)	GMFCS III vs. IV	0.937
	Level IV	23	166.7 (7.6)	GMFCS IV vs. V	0.044
	Level V	52	171.9 (9.1)	GMFCS III vs. V	0.011

GMFCS indicates Gross Motor Function Classification System; Primary HSA, femoral head-shaft angle at the time of diagnosis, expressed as mean value (with SD in parentheses).

**TABLE 2.** Possible Risk Factors for Hip Displacement, Defined as MP  $\geq$  40% at the Last Radiographic Follow-up

Parameter	N	Last Radiograph		<i>P</i> *
		MP $<$ 40%	MP $\geq$ 40%	
Sex				
Boys	61	29	32	0.142
Girls	40	25	15	
GMFCS level				
III	26	20	6	0.003
IV	23	13	10	
V	52	21	31	
Age at primary radiograph (y), mean (SD)	101	2.6 (1.2)	2.2 (1.0)	0.109
Primary HSA (deg.), mean (SD)	101	170.8 (6.8)	171.3 (7.5)	0.761

\*Statistics is univariable logistic regression.

GMFCS indicates Gross Motor Function Classification System; HSA, head-shaft angle; MP, migration percentage.

no significant difference in primary HSA between patients with final MP  $<$  40% and those with final MP  $\geq$  40% (170.8 and 171.3 degrees, respectively; *P* = 0.761) (Figs. 1, 2); the mean difference was 0.4 degrees (95% confidence interval, -3.3 to 2.4). Sex and age were not significantly associated with hip displacement.

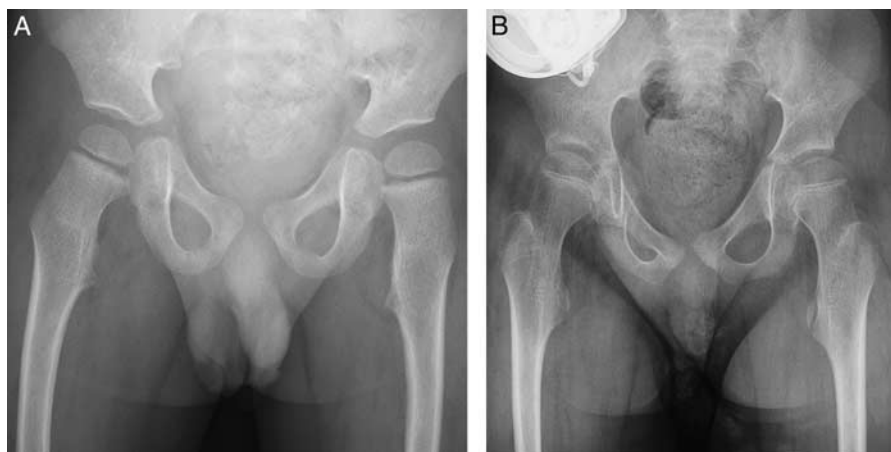
To evaluate the effect of age at the primary radiograph on the association between primary HSA and later hip displacement, the children were divided into 3 groups:  $<$  2, 2.0 to 2.9, and 3.0 to 4.9 years. The numbers of children in the 3 groups were 42, 25, and 33, respectively. There were no significant associations between primary HSA and later hip displacement in any of the age groups (Table 3). Neither were there any significant associations when all the children under 3 years (*n* = 68) or under 4 years (*n* = 90), were separately analyzed (*P* = 0.565 and 0.679, respectively).

At the last follow-up, the mean HSA was 169.1 degrees (range, 146 to 192 degrees) and the mean reduction in HSA was 0.3 degrees per year (range, -10.0 to 9.2 degrees per year; SD = 2.5), 0.9 degrees per year at GMFCS level III, and -0.3 degrees per year at GMFCS level V. The last (final) HSA was significantly larger in hips with final MP  $\geq$  40% than in hips with final MP  $<$  40% (171.1 and 167.4 degrees, respectively; *P* = 0.029) and significantly larger in patients at GMFCS level V compared with those at GMCS levels III and IV (Table 1).

The intraobserver agreement of HSA was good; the mean difference (measurement 1 - measurement 2  $\pm$  2 SD) was -0.3 degrees (SD 1.3), LOA was -2.9 to 2.3 degrees, and the correlation coefficient was 0.98 (*P*  $<$  0.001). There was also satisfactory interobserver agreement, with mean difference (measurement TT - measurement JH) of 0.2 degrees (SD 2.6), LOA -5.0 to 5.4 degrees, and correlation coefficient 0.95 (*P*  $<$  0.001).

**DISCUSSION**

GMFCS level V was significantly associated with hip displacement during follow-up, supporting previous



**FIGURE 2.** A, Primary radiograph of a boy aged 2.7 years, with spastic quadriplegia, at Gross Motor Function Classification System level V. Left hip: head-shaft angle 171 degrees; migration percentage 15%. B, Follow-up radiograph of the same patient at an age of 10.5 years (follow-up 7.8 y). Left hip: head-shaft angle 172 degrees; migration percentage 23%.

studies that severely reduced functional capacity is an important risk factor.<sup>4,8,17,18</sup> We found no significant association between HSA at the first radiograph, taken at the time of diagnosis, and later clinically relevant hip displacement, defined as MP  $\geq$  40%. This is in agreement with Chougule et al<sup>14</sup> who studied CP children with a mean age of 8.8 years and at least 5 years follow-up. They found no significant effect of primary HSA on MP at follow-up. Our findings are inconsistent with those of Hermanson et al,<sup>13</sup> who reported that the primary HSA was a predictor of later hip displacement. The discrepancy could be caused by differences in patient age at the first radiograph. All children in the present study were below 5 years of age, whereas children up to 9.7 years of age were included by Hermanson et al<sup>13</sup> and up to 18 years by Chougule et al.<sup>14</sup> Such high age is hardly relevant for the evaluation of a hip surveillance program, as its main intention is to discover displacement before deterioration to severe subluxation or complete dislocation occurs. In a population-based study on the natural history of hip displacement in CP, the mean age at subluxation was 3.6 years and at complete dislocation 4.4 years.<sup>8</sup> Three children had dislocation under 3 years of age, which corresponds with another systematic hip surveillance program, where 3 of 15 children with dislocation were under

3 years of age.<sup>5</sup> This indicates that the first pelvic radiograph should be taken at an age of 1 to 2 years.<sup>4,8</sup> Thus, the upper age limit in studies of predictors of later hip displacement, at least in nonambulatory children, should be about 5 years.

Van der List et al<sup>15</sup> reported that HSA at patient age 2 years was predictive of later hip displacement, whereas HSA was not a predictor at age 4 years. On the basis of these findings, we examined whether or not there was any difference in the predictive value of HSA according to different age groups under 5 years. We found, however, no difference according to age at the first radiograph. The primary HSA was not predictive of hip displacement with MP  $\geq$  40% in any of the age groups: under 2, 2.0 to 2.9, and 3.0 to 4.9 years.

The most important deformities of the proximal femur in children with CP are increased valgus and increased femoral anteversion.<sup>19</sup> The degree of coxa valga measured as NSA is quite dependent on the degrees of anteversion and rotation of the limb. The true NSA can only be measured when the hip is internally rotated as much as the degree of anteversion.<sup>19</sup> When the radiograph is taken with the knees facing anteriorly, as was done in the present study, the apparent NSA is larger than the true angle and the measurement error increases with the degree of anteversion. Foroohar et al<sup>11</sup> reported measurement errors of 15 degrees for a femoral rotation of 45 degrees, whereas the error was only 5 degrees or less when the HSA was used. Moreover, as the femoral epiphysis is often in a valgus position in relation to the femoral neck, the NSA may underestimate the total degree of coxa valga. Thus, HSA is the most adequate way of assessing the valgus deformity of the proximal femur.

The HSA is increased during the first years of life in both normally developing children and children with CP. The mean HSA at the age of 2 years was 168 degrees in normal hips (the contralateral side in children with unilateral developmental hip dysplasia) and 168 degrees in children with CP at GMFCS levels II-V,<sup>20</sup> which is in

**TABLE 3.** Association Between the Last MP (< 40% vs.  $\geq$  40%) and the Primary HSA, According to the 3 Age Groups at the First Radiograph

Age Groups (y)	N	Last MP (%)	Primary HSA (SD)	P
0.8-1.9	20	< 40	170.7 (6.0)	0.717
		$\geq$ 40	171.6 (8.6)	
2.0-2.9	12	< 40	172.9 (5.1)	0.187
		$\geq$ 40	169.7 (6.6)	
3.0-4.9	21	< 40	169.2 (7.5)	0.244
		$\geq$ 40	172.3 (6.7)	

Last MP indicates migration percentage at the last radiograph; Primary HSA, head-shaft angle at the first radiograph.

accordance with our mean HSA of 171 degrees at a mean age of 2.4 years in patients at GMFCS levels III-V. The HSA decreased by a mean of 2 degrees/y from 2 to 8 years in normal hips and by 0.9 degrees/y in children from 2 to 7 years with CP at GMFCS levels III, whereas there was no decrease in HSA over time at GMFCS levels IV-V.<sup>20</sup> This corresponds with the present results where a mean decrease of 0.9 degrees/y at GMFCS level III and -0.3 degrees at level V occurred, indicating no change of HSA with time in nonambulatory children from 2 to 6 years.

The mean patient age at the last follow-up was 6.7 years. At this age the mean HSA was larger in hips with final MP  $\geq 40\%$  than in hips with final MP  $< 40\%$ . This shows that there is an association between HSA and hip displacement at this age and confirms the findings of Foroohar et al<sup>11</sup> who reported that the mean HSA at age 7 to 8 years was 152 degrees in normal hips, 161 degrees in children with CP without subluxation, and 170 degrees in CP hips with subluxation. Thus, although HSA at a young age ( $< 5$  y) is not a predictor of later hip displacement, HSA at a higher age ( $> 5$  y) is associated with hip displacement and can then be useful for the choice of surgical treatment. A particularly large HSA indicates that varus femoral osteotomy, which will reduce the HSA, should be performed rather than soft tissue release alone in hips with slight or moderate subluxation.

There are a few limitations of this study. It was retrospective and the number of patients in each age subgroup was rather small. Although the HSA is easy to measure in hips with adequate radiographs and well-defined landmarks, it can be difficult and less reliable if too short part of the femoral shaft is shown on the radiograph. Moreover, the proximal femoral physis was not well demarcated in some patients, which also will reduce the reliability of the measurements. Nevertheless, the good intraobserver and interobserver agreement in our study confirmed the findings of previous studies that HSA measurements are sufficiently reliable in clinical use.<sup>11,14,21</sup> The strengths of the present study are that it is population-based and longitudinal and that follow-up could be performed in all the patients.

What are the clinical implications of this study? As HSA is not a predictor of hip displacement in children under 5 years of age, measurement of HSA is not necessary in routine hip surveillance at this age. In older children, HSA is associated with hip displacement and could be useful for the choice of surgical methods to prevent deterioration.

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