The Impact of Spinal Fusion on Hip Displacement in Cerebral Palsy

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Abstract

Background and study aims The aims of this study were to determine the risk of progressive hip subluxation in children with CP after spinal fusion for scoliosis and how frequent the hips follow-up should be scheduled.

Patients and methods Pelvis radiography [migration index (MI) and pelvic obliquity (PO)] of Gross Motor Function Classification System (GMFCS) levels IV and V children with CP who received spinal fusion and pelvic fixation were reviewed retrospectively. This population was categorized into three groups based on the MI at spinal fusion: G1 = 0–29%; G2 = 30–59%; and G3 = 60–100%.

Results Fifty children (age 7.5–15.0 years) and categorized into 3 groups (G1 = 19, G2 = 23, G3 = 8; 100 hips in total). Preoperative and last follow-up MI were $22 \pm 7\%$ and $30 \pm 20\%$ (G1), $41 \pm 9\%$ and $43 \pm 22\%$ (G2), $92 \pm 15\%$ and $97 \pm 10\%$ (G3). The MIs at spinal fusion between groups were statistically different ($p < 0.001$). In G1, the mean MI progression was 5% and 25% at 12 months and 62 months, respectively. In G2, the mean MI progression was 9% and 25% at 12 months and 32 months, respectively. The progression more than 10% occurred within 2 years in G1 and within 1 year in G2. There was no difference between groups based on preoperative degree of PO ($p = 0.653$) and correction rate in PO ($p = 0.421$).

Conclusions In GMFCS IV and V children with the highest risk for progression occurred with increasing preoperative MI, especially over 50%. Hips should be monitored continuously after spinal fusion until hip stability is documented.

Keywords Spinal fusion · Hip displacement · Migration index · Pelvic obliquity

Introduction

Progressive hip displacement and scoliosis are associated with increased severity of neurological involvement in children with cerebral palsy (CP) best defined by Gross Motor Function Classification System (GMFCS) [1]. The GMFCS levels IV and V are the most severe groups with the most common major orthopedic problems being hip displacement and spinal deformity. These deformities constitute management challenges for both orthopedic surgeons and patients' caretakers [2–5]. In the presence of these deformities, pain,

pressure ulcers, pulmonary difficulties, gastrointestinal difficulties, and postural or seating problems impact quality of life and are the most common indications for surgical treatments [6–8]. Scoliosis is diagnosed after 8 years of age in most children with CP [3] and commonly coexists with hip displacement and pelvic obliquity (PO) [8, 9]. Pelvic obliquity may improve coverage of the hip on the low side but progressive subluxation may occur on the high side [9]. Pelvic fixation is usually indicated in the treatment of scoliosis due to a progressive PO causing a difficult seating posture [10]. Conversely, a fixed-level pelvis may not compensate asymmetric hip posture and instability, and correction of PO could theoretically worsen an existing hip instability or lead to a new hip instability [11]. The GMFCS and overall disease severity is also affecting the hip apart from pelvic obliquity and the effect of spinal fusion with pelvic fixation is only one of the factors which should be acknowledged. A migration percentage of 30–60% (which is the gold standard test for demonstrating hip displacement in children with CP by measuring the displacement using the method of Reimers) may continue to progress over time [12, 13]. Over

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the last several years, there has been increased attention on hip surveillance as a way to identify hip status before severe displacement and degeneration occurs. Clear protocols have been developed based on the good population data showing the strong association of GMFCS level and age on risk for progressive hip displacement in children with CP. However, information on the risk of progressive hip subluxation after spinal fusion in children with CP is available in limited publications. The aims of this study were to determine the risk of progressive hip subluxation in children with CP after spinal fusion for scoliosis and to determine how frequent the hips follow-up should be scheduled.

Materials and methods

This is an institutional review board-approved (Nemours Office of Human Subjects Protection, 948962-1, 29 Aug 2016) retrospective case series. It is indicated that all reported research involving “Human beings” conducted in accordance with the principles set forth in the Helsinki Declaration 2008.

Inclusion criteria were: (1) children with CP; (2) GMFCS levels IV and V; (3) underwent spinal fusion with pelvic fixation between the ages of 7.5 and 15.0 years from 2004 to 2014. Follow-up period of the hips after spinal fusion was selected as the period from spinal fusion to post-spinal fusion hip surgery due to hip displacement or a minimum 18-month follow-up for patients who did not have further hip surgery after the spinal fusion. Exclusion criteria were: (1) any type of scoliosis without CP; (2) GMFCS levels I–III; (3) spinal fusion without pelvic fixation; (4) clinical or radiographic data was unavailable; and (5) age at the spinal fusion above 15 years.

Patients were categorized into three groups based on the MI of the worst hip at the time of spinal fusion: Group 1 (G1) included patients with 0 to 29% MI, Group 2 (G2) included patients with 30–59% MI, and Group 3 (G3) included patients with more than 60% MI. The other categorization based on MI of each hip at the time of spinal fusion was also done using the same classification system.

Radiological assessment

Minimum 5-year experienced surgeon in pediatric orthopedics performed the measurements in this study. Radiographic review included MI [13], acetabular angle prior to spinal fusion from supine anteroposterior bilateral hip radiographs (Fig. 1a), magnitude and direction of PO, and curve magnitude for scoliosis from posteroanterior sitting spine radiographs. Pelvic obliquity was measured as the angle between a line drawn perpendicular from the middle of T1–S1 and the iliac crest line (Fig. 1b) [10, 14]. All

parameters were determined from preoperative and postoperative spine surgery. Correction rate of PO and curve angle was calculated with the following formula:

$$\% \text{ correction} = (\text{preoperative angle} - \text{postoperative angle}) / \text{preoperative angle} \times 100.$$

Subluxation was defined as the lateral and superior displacement of the femoral head, and dislocation was defined as the lack of relationship between the acetabulum and femoral head.

Statistical analysis

Kolmogorov–Smirnov test and Shapiro–Wilk test were used to assess the normality of numeric variables. The numeric variables that were normally distributed and descriptive statistics were presented as means [standard deviation (SD)]. Analysis of variance (ANOVA) was used for independent variables to compare the independent parameters between the three groups. A *p* value below 0.05 was considered statistically significant. SPSS software, version 22 (IBM Corp., Armonk, NY), was used for all statistical analysis.

Results

There were 50 patients (male, *n* = 22; female, *n* = 28; in total 100 hips) between the ages of 7.5 and 15 years and underwent spinal fusion at the same facility who met the inclusion criteria. There were 12 patients who had history of intrathecal baclofen pump. No patients underwent any previous hip procedure (bony or soft tissues releases) prior to spinal fusion.

When the patients were categorized based on the MI of the worst hip at the time of spinal fusion, Group 1 included 19 (type 2 curve: 18 and type 1 curve: 1) patients with a mean age of 12 ± 2 (range 8–15) years and with 54 ± 30 (6–129) months of follow-up. Three of 19 patients had hip surgery after spinal fusion in G1 (Figs. 2, 3). Group 2 included 23 patients (type 2 curve: 19 and type 1 curve: 4) with a mean age of 12 ± 1.7 (range 8–15) years with 45 ± 32 (range 4–98) months of follow-up. Ten of 23 patients had hip surgery after spinal fusion. Group 3 included eight patients (type 2 curve: 6 and type 1 curve: 2) with a mean age of 12 ± 2 (range 8–12) years and with 50 ± 39 (range 3–129) months of follow-up. Four of eight patients had hip surgery after spinal fusion. The mean MIs in the preoperative and last follow-up for patients in G1, G2 and G3 are shown in Table 1. The MIs at spinal fusion between groups were statistically different (*p* < 0.001). The distribution of

Fig. 1 **a** The method of measurement of pelvic obliquity (the angle between a line drawn perpendicular from the middle of T1–S1 and the iliac crest line: narrow angle between the red dot lines) and mag-

nitude of scoliosis (between yellow lines) and **b** migration index ($x/y \times 100$) and acetabular angle (narrow angle between yellow lines)

the patients based on the worst hip before and after spinal fusion is shown in Table 2. Hip displacement did not improve in patients with MI over 60%. Hip reconstruction was performed in 50% of the patients with a MI over 30%. Hip reconstruction was performed with femoral varisation/derotation osteotomy or acetabular osteotomy or both based on the severity of hip displacement.

There were no significant differences between the three groups based on preoperative PO ($p=0.653$) and correction rate in PO ($p=0.421$) and correction in curve magnitude ($p=0.639$) and preoperative acetabular Sharp's angle ($p=0.094$) (Table 1). There was no difference in the immediate postoperative spinal fusion hip radiograph compared with the preoperative MI.

When the hips were categorized individually based on MI at the time of spinal fusion, there were 56 hips in G1, and at final follow-up, 45 hips (80%) were still G1; nine

hips (16%) were G2; and two hips (4%) were G3. There were 34 hips in G2, of which 10 (29%) improved to G1, 17 (50%) remained G2, and seven (21%) progressed to G3. There were 10 hips in G3 and all stayed in G3 (Table 3). To determine the rate of progression in hips, there were nine of 56 hips in G1 that progressed more than 10% MI for a mean progression of 25% MI (range 11–47%) over 62 (range 22–129) months (5% in 12 months); only two hips progressed more than 1% per month over the follow-up period. In G2, seven of 34 hips progressed more than 10% MI for a mean 24% (range 15–54%) over a mean follow-up of 32 (range 6–75) months (9% in 12 months). The progression more than 10% occurred within 2 years in G1 and occurred within 1 year in G2. There were 90 hips in G1 and G2 combined, and at the last radiographic follow-up, 26% (23/90) of the hips still had an open triradiate cartilage indicating that they were not skeletally mature.

Fig. 2 A 9-year-old case with scoliosis **a** preoperative spine radiograph **b** hip radiograph (right and left MI: 27%, pelvic obliquity: 6°) before scoliosis surgery **c** immediate postoperative X-ray demonstrat-

ing right MI: 27% left MI: 32% and pelvic obliquity: 2°, **d** second-year follow-up, **e** third-year follow-up (right MI: 19% left: 38%) **f** postoperative radiographs of hip reconstruction

Fig. 3 A 14.5-year-old case with type 2 curve with down hip displacement **a** preoperative spine radiograph **b** hip radiograph (right and left MI: 25) before scoliosis surgery **c** immediate postoperative X-ray demonstrating hip displacement after correction of pelvic obliquity

(right MI: 57 left MI: 25), **d** first-year follow-up (right MI: 73), **e** second-year follow-up (right MI: 81) **f** postoperative radiographs of hip reconstruction

Discussion

Asymmetric muscle function due to weakness, poor motor control, and spasticity are the etiologies for scoliosis, PO, and hip displacement in children with severe CP [15]. Neuromuscular scoliosis extends into the sacrum with an incidence of PO of 98%; scoliosis and hip displacement develop at least in 40% of children with CP, GMFCS levels

IV and V [8, 9]. The treatment protocol in our clinic is to closely monitor and correct hip subluxation in childhood at the time it occurs, and as a consequence, we only rarely see cases that present with scoliosis and hip subluxation concurrently. However, we also have a large referral base of patients who only come to our clinic when they have hip dysplasia and scoliosis. Our protocol for these patients is to correct the scoliosis first and then correct the hip pathology as is clinically indicated [16]. This has allowed us to

Table 1 Intergroup comparison of migration index, pelvic obliquity correction rate in pelvic obliquity, correction rate in curve magnitude, and acetabular angle [values are mean (SD)]

	Migration index at spinal fusion (min–max) (%)	Migration index at last follow-up (min–max) (%)	Pelvic obliquity (min–max) (degree)	Correction rate in pelvic obliquity (min–max) (%)	Correction rate in curve magnitude (min–max) (%)	Acetabular angle (min–max) (degree)
Group 1 (<i>n</i> = 19)	27 ± 7 (0–29)	30 ± 20 (0–72)	21 ± 9 (0–36)	89 ± 17 (33–107)	73 ± 17 (41–99)	46 ± 5 (36–53)
Group 2 (<i>n</i> = 23)	41 ± 9 (30–57)	45 ± 32 (4–98)	23 ± 13 (0–48)	95 ± 16 (67–121)	76 ± 19 (13–100)	46 ± 12 (19–58)
Group 3 (<i>n</i> = 8)	92 ± 15 (61–100)	97 ± 10 (72–100)	25 ± 12 (0–41)	94 ± 12 (74–113)	80 ± 7 (71–94)	53 ± 9 (40–66)
<i>p</i> value	< 0.001	< 0.001	0.653	0.421	0.639	0.094

p values were determined with analysis of variance

Table 2 Distribution of the patients categorized based on the worst hip before and after spinal fusion

Pre-spinal fusion	(n)	Post-spinal fusion at final visit (n)		
		Group 1	Group 2	Group 3
Group 1	19	12 (63%)	5 (26%)	2 (11%)
Group 2	23	8 (35%)	9 (39%)	6 (26%)
Group 3	8	0 (0%)	0 (0%)	8 (100%)

Table 3 Distribution of the hips before and after spinal fusion

Pre-spinal fusion	(n)	Post-spinal fusion at final visit (n)		
		Group 1	Group 2	Group 3
Group 1	56	45 (80%)	9 (16%)	2 (4%)
Group 2	34	10 (29%)	17 (50%)	7 (21%)
Group 3	10	0	0	10 (100%)

form three groups based on hip MI. To our knowledge, this is the first study focusing on whether or not severity of MI at the time of spinal fusion is a risk factor for future progressive hip subluxation. This information is important to formulate recommendations for monitoring hip radiographs after spinal fusion.

There was an increasing risk of progressive hip subluxation associated with the increased pre-spinal fusion MI. As the MI increased from G1 to G2, the risk for progression to G3 increased from 4 to 21%. There were hips and patients in G1 and G2 whose MI also improved, but there were no clear identifying characteristics that we could find for these groups. Although G2 encompassed 30–60% MI, and in G2 29% of the hips improved to G1, there were seven hips in G2 with 50% or greater MI and none of these hips improved without surgical reconstruction. No G3 hip improved either; therefore, we would likely consider an MI of 50% as having a very high risk of progression and a very low possibility of improvement following spinal fusion. Because of this risk, the need for hip reconstruction was an expected result in the follow-up for hips with an MI over 50% or 60%. This result demonstrates the impact of a hip monitoring and early

intervention program in which by maintaining hips under 50% prior to adolescent spinal fusion, there should be a reduced need for hip surgery after spinal fusion. Our findings are similar to a previous report which found that 25% of hips with a migration percentage of 30–60% continued to progress over time [12]. Migration index is of limited value in cases of direct anteroposterior migration [17, 18]; therefore, MI at the date of spinal fusion mainly predicts the lateral hip displacement during follow-up. Based on our assessment of Sharp's angle, acetabular structure has no predictable value related to hip displacement following spinal fusion. Also, the immediate postoperative spinal fusion hip radiograph is not predictive of future hip pathology.

There has been concern that the correction of PO may lead to new onset hip displacement immediately after surgery, or worsening of hip pathology due to contraction of muscles or muscle imbalance around the hip and hip instability causing progression of hip displacement. Crawford et al. found that in patients with hip pathology, those with greater correction of PO (more leveled pelvis) more often required hip surgery [11]. In our study in which almost all of the PO was corrected, there was no significant effect from the degree of correction of PO on the risk of hip displacement. Previous studies investigating hip dislocation and PO reported that 64–67% of dislocation occurred on the high side of PO [8, 11]. Lett's hypothesis of hip subluxation on the high side of the PO was later unsupported in multiple other studies, which found no significant correlation between the direction of the scoliosis, PO, windswept deformity, and hip subluxation [15, 19–21]. Based on our current findings, we believe all PO should be corrected, and this correction will not impact the future of the hips in a predictable manner. Because the risk of progressive hip subluxation after spinal fusion in children with CP GMFCS levels IV and V continues in both surgically treated and untreated hips, monitoring with periodic radiographs of the hips should be done. It is not possible to make recommendations for monitoring beyond 8 years of age, except those with significant subluxation (over 50%), which have potential to progress to dislocations throughout adolescence [22]. It is recommended to

take radiographs every 2–4 years until skeletal maturity for GMFCS levels III–V individuals [23] and those hips with untreated subluxation [13]. Some authors advocated that annually follow-up for hips with MI over 30% above the age of 8-year-old kids with CP [23]. Based on our data, only two hips progressed more than 1% per month; therefore, a follow-up hip radiograph every 2 years in G1 hips and every year in G2 hips until at least skeletal maturity should identify subluxation before severe displacement and degeneration has occurred.

Limitations

This study had several limitations. It was a retrospective study that focused on radiological examinations, which were not obtained on a strict schedule. Some patients who needed hip surgery in a short period after spinal fusion, had short follow-up periods. But some cases who had longer follow-up, did not have hip surgery. Information about range of motion (which may not be reliable in GMFCS level IV and V children) and contractures of the hips, which might affect the hip displacement before and after spinal fusion, was not available. Prior to spinal fusion, there were some subluxated and dislocated hips that were potential candidates for hip reconstruction but they did not proceed to reconstruction after the spinal fusion because the decision to perform the hip reconstruction, especially in hips with complete dislocation and degeneration, was made based on clinical symptoms rather than on the radiographic appearance.

Conclusion

In patients with CP GMFCS levels IV and V, there was a significant risk of progressive hip subluxation following spinal fusion. The highest risk for progression occurred with increasing preoperative MI, especially in those with greater than 50% subluxation. Hips should be monitored continuously after spinal fusion until hip stability is documented. A follow-up hip radiograph every 2 years in G1 hips and every year in G2 hips until at least skeletal maturity should identify subluxation before severe displacement and degeneration has occurred.

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Compliance with Ethical Standards

Conflict of interest None declared.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study, informed consent is not required.

References

1. Palisano, R. J., Rosenbaum, P., Bartlett, D., & Livingston, M. H. (2008). Content validity of the expanded and revised gross motor function classification system. *Developmental Medicine and Child Neurology*, 50(10), 744–750.
2. Scrutton, D., Baird, G., & Smeeton, N. (2001). Hip dysplasia in bilateral cerebral palsy: Incidence and natural history in children aged 18 months to 5 years. *Developmental Medicine and Child Neurology*, 43, 586–600.
3. Persson-Bunke, M., Måns, P.-B., Gunnar, H., Henrik, L.-P., Ma, P. W., & Lena, W. (2012). Scoliosis in a total population of children with cerebral palsy. *Spine*, 37, E708–E713.
4. Shukla, P. Y., Mann, S., Braun, S. V., & Gholve, P. A. (2013). Unilateral hip reconstruction in children with cerebral palsy: Predictors for failure. *Journal of Pediatric Orthopedics*, 33, 175–181.
5. Wynter, M., Gibson, N., Willoughby, K. L., Love, S., Kentish, M., Thomason, P., et al. (2015). Australian hip surveillance guidelines for children with cerebral palsy: 5-year review. *Developmental Medicine and Child Neurology*, 57, 808–820.
6. McCarthy, J. J., D'Andrea, L. P., Betz, R. R., & Clements, D. H. (2006). Scoliosis in the child with cerebral palsy. *Journal of the American Academy of Orthopaedic Surgeons*, 14, 367–375.
7. Chan, G., & Freeman, M. (2014). Assessment and treatment of children with cerebral palsy. *Orthopedic Clinics of North America*, 45, 313–325.
8. Senaran, H., Shah, S. A., Glutting, J. J., Dabney, K. W., & Miller, F. (2006). The associated effects of untreated unilateral hip dislocation in cerebral palsy scoliosis. *Journal of Pediatric Orthopedics*, 26, 769–772.
9. Patel, J., & Shapiro, F. (2015). Simultaneous progression patterns of scoliosis, pelvic obliquity, and hip subluxation/dislocation in non-ambulatory neuromuscular patients: An approach to deformity documentation. *Journal of Children's Orthopaedics*, 9, 345–356.
10. Dayer, R., Ouellet, J. A., & Saran, N. (2012). Pelvic fixation for neuromuscular scoliosis deformity correction. *Current Reviews in Musculoskeletal Medicine*, 5, 91–101.
11. Crawford, L., Herrera-Soto, J., Ruder, J. A., Phillips, J., & Knapp, R. (2017). The fate of the neuromuscular hip after spinal fusion. *Journal of Pediatric Orthopedics*, 37, 403–408.
12. Miller, F., & Bagg, M. R. (1995). Age and migration percentage as risk factors for progression in spastic hip disease. *Developmental Medicine and Child Neurology*, 37, 449–455.
13. Reimers, J. (1980). The stability of the hip in children. A radiological study of the results of muscle surgery in cerebral palsy. *Acta Orthopaedica Scandinavica Supplement*, 184, 1–100.
14. Maloney, W. J., Rinsky, L. A., & Gamble, J. G. (1990). Simultaneous correction of pelvic obliquity, frontal plane, and sagittal plane deformities in neuromuscular scoliosis using a unit rod with segmental sublaminar wires. *Journal of Pediatric Orthopedics*, 10, 742–749.
15. Porter, D., Michael, S., & Kirkwood, C. (2007). Patterns of postural deformity in non-ambulant people with cerebral palsy: What is the relationship between the direction of scoliosis, direction of pelvic obliquity, direction of windswept hip deformity and side of hip dislocation? *Clin Rehabil*, 21, 1087–1096.

16. Helenius, I. J., Viehweger, E., & Castelein, R. M. (2020). Cerebral palsy with dislocated hip and scoliosis: What to deal with first? *Journal of Children's Orthopaedics*, 14(1), 24–29.
17. Brunner, R., & Robb, J. E. (1996). Inaccuracy of the migration percentage and center-edge angle in predicting femoral head displacement in cerebral palsy. *Journal of Pediatric Orthopaedics. Part B*, 5, 239–241.
18. Rutz, E., Willoughby, K., & Cain, T. (2011). 2D versus 3D imaging of hip displacement in children with cerebral palsy. *Developmental Medicine and Child Neurology*, 53, 1072–1073.
19. Letts, M., Shapiro, L., Mulder, K., & Klassen, O. (1984). The windblown hip syndrome in total body cerebral palsy. *Journal of Pediatric Orthopaedics*, 4, 55–62.
20. Abel, M. F., Blanco, J. S., Pavlovich, L., & Damiano, D. L. (1999). Asymmetric hip deformity and subluxation in cerebral palsy: An analysis of surgical treatment. *Journal of Pediatric Orthopaedics*, 19, 479–485.
21. Lonstein, J. E., & Beck, K. (1986). Hip dislocation and subluxation in cerebral palsy. *Journal of Pediatric Orthopaedics*, 6, 521–526.
22. Elkamil, A. I., Andersen, G. L., Häggglund, G., & Lamvik, T. (2011). Prevalence of hip dislocation among children with cerebral palsy in regions with and without a surveillance programme: A cross sectional study in Sweden. *BMC Musculoskeletal Disorders*. <https://doi.org/10.1186/1471-2474-12-284>.
23. Pruszczyński, B., Sees, J., & Miller, F. (2016). Risk factors for hip displacement in children with cerebral palsy. *Journal of Pediatric Orthopaedics*, 36(8), 829–833.

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