Risk Factors for Avascular Necrosis in Children With Cerebral Palsy Following Varus Derotation Osteotomy

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Objectives: Varus derotation osteotomy (VDRO) is a well-established surgery for displaced hips in children with cerebral palsy (CP). However, avascular necrosis (AVN) remains a significant postoperative complication that can result in negative outcomes. Previous studies report various AVN rates after VDRO, and the true incidence and associated risk factors remain poorly characterized. This study aimed to determine the incidence of AVN after VDRO in a large cohort and to identify patient-specific and surgical risk factors for developing AVN.

Methods: The study included 316 children with CP who underwent VDRO (593 osteotomies, 501 bilateral) for hip subluxation or dislocation [196 male; mean age 8.3 y, SD: 3.2, range: 2.4 to 17.7; 2 Gross Motor Function Classification System (GMFCS) level I, 34 level II, 38 level III, 115 level IV, 127 level V] at a tertiary referral center. Potential determinants of AVN were analyzed using Fisher exact test and univariate and multivariate logistic regressions.

Results: Ten of 593 hips (1.7%) developed AVN. The entire cohort's mean preoperative Reimers MP was 51.1, SD: 28.0, range: 0 to 100, and was 77.6 (SD: 27.3, range 32.2 to 100) in the hips in which AVN developed and 50.6 (SD: 27.9, range 0 to 100) in those in which it did not. In univariate analysis, Reimers MP ($P = 0.02$), bilateral surgery ($P < 0.01$), and pelvic osteotomy (PO) ($P < 0.01$) were significant risk factors for developing AVN. In multivariate analysis, the sole significant risk factors was PO ($P < 0.01$). Lastly, the Rutz and MCPHCS data reveal similar rates of AVN across these femoral hip classification systems, regardless of the change in Rutz ($P = 0.13$) or MCPHCS ($P = 0.58$).

Conclusions: This is the largest analysis of AVN in children with CP who underwent VDRO. PO was a significant risk factor for developing AVN after VDRO. Although the overall incidence is low, the increased odds of AVN in patients undergoing POs is a factor surgeons should consider when undertaking surgery for children with CP and displaced hips. The association with PO may explain why several factors were significant solely in univariate analysis. For example, children functioning at GMFCS level V underwent ~3.5 times the rate of POs than their higher-functioning peers (29.0% vs. 8.2%, $P < 0.01$). Finally, the Rutz and MCPHCS classifications suggest that AVN may not significantly impact postoperative hip sphericity. In combination with the low incidence of AVN, these findings indicate that rather than focusing solely on AVN risk, sphericity preservation may be more critical for optimal health outcomes in children with CP.

Key Words: pediatrics, cerebral palsy, neuromuscular, orthopaedics, surgery

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Cerebral palsy (CP) is a well-described neurological disorder occurring from a lack of oxygen to the developing fetal or infant brain that affects movement/motor function and posture.[1] In children with CP, hip displacement is a common and potentially debilitating complication, with an overall incidence of ~35%.[1] Hip displacement has a strong correlation with Gross Motor Function Classification System (GMFCS) level.[2] Soo et al[1] previously demonstrated the incidence of hip displacement in children with CP to range from 0% for children functioning as GMFCS level I to 90% for children functioning as GMFCS level V.

Surgeons often use varus derotation osteotomy (VDRO) to help correct hip displacement in children with CP. At the time of VDRO, surgeons may also release soft tissue(s) like the adductors and psoas, and in severe cases, may also perform open hip reductions and/or pelvic osteotomies (POs).[3] Notably, VDROs are not without risks, and one of the most concerning complications is thought to be avascular necrosis (AVN) of the femoral head. The reported incidence of AVN after VDRO in children with CP varies widely in the literature, ranging from 0% to 69%.[4,5] The rates are likely extremely variable because (1) few studies have investigated AVN as the primary outcome of VDRO, and (2) there is poor inter-rater reliability in measuring AVN.

Evaluating the hips of children with CP for AVN is very difficult and riddled with disagreement. To start, there is no AVN classification schema specific to children with CP. The most common criteria to evaluate AVN of the femoral head in children are the Bucholz and Ogden classification[6] and the Kalamchi and MacEwen classification[7] systems. However, these classification schemes were designed to

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evaluate developmental dysplasia of the hip. Moreover, medical professionals have been shown to report 67% disagreement on hip evaluations when using the Bucholz and Ogden Classification.[8]

Given the potential for significant long-term consequences of AVN, including pain, limited range of motion, and premature osteoarthritis, the purpose of this study served to identify the incidence of and risk factors for developing AVN after VDRO in the largest cohort studied to date. We hypothesize that hips with higher Reimers migration percentages (MPs) and POs are the 2 key factors that increase the risk of AVN after VDRO in children with cerebral palsy, presumably due to an increased risk of temporary disruption of femoral head perfusion in these circumstances.

METHODS

Study Design

Upon obtaining Institutional Review Board approval, we executed a single-center, retrospective study at a large, urban, tertiary referral center. We studied children with CP who underwent VDRO between January 2004 and January 2022. Children with CP were included if they were younger than 18 years at the time of their index procedure. Fifteen patients (18 hips) were excluded from analyses because they had <1 year of total follow-up and did not develop AVN, and 21 patients (35 hips) were excluded because their GMFCS criteria were unavailable or unclassified. Lastly, 1 hip from a bilateral operation was excluded because it displayed AVN in advance of the index procedure. Thereby, we report an odd number of hips with bilateral osteotomies ($n=501$).

Either a trained, highly experienced physiotherapist or each patient's corresponding orthopaedic surgeon determined GMFCS levels, based on the criteria described by Palisano et al.[2]

Radiographs preoperatively, postoperatively, and at final follow-up were assessed to determine hip displacement (using Reimers MP), Melbourne Cerebral Palsy Hip Classification System (MCPHCS) grade at skeletal maturity,[9] Rutz femoral head classification[10,11] and AVN.[5–7,12–15] Three independent reviewers—1 orthopaedic surgeon and 2 clinical researchers—measured Reimers MPs. Their inter-rater agreement was analyzed, and they report an average coefficient of variation of 5.3% and an intraclass correlation coefficient (ICC) of 0.992. Regarding AVN, the same orthopaedic surgeon and one of the clinical researchers mentioned above were the 2 evaluators; their inter-rater reliability was calculated to be 92%. Because of poor inter-rater reliability in previous studies evaluating AVN severity,[8,14,16] the reviewers treated AVN as a binary variable: patients were classified as either having or not having developed AVN of their femoral head(s) after hip reconstruction surgery (Fig. 1). The reviewers relied upon the criteria put forth by Bucholz and Ogden[6] but did not classify the severity of AVN because AVN in hips of children with CP defies traditional categorical classifications and does not perfectly correlate.

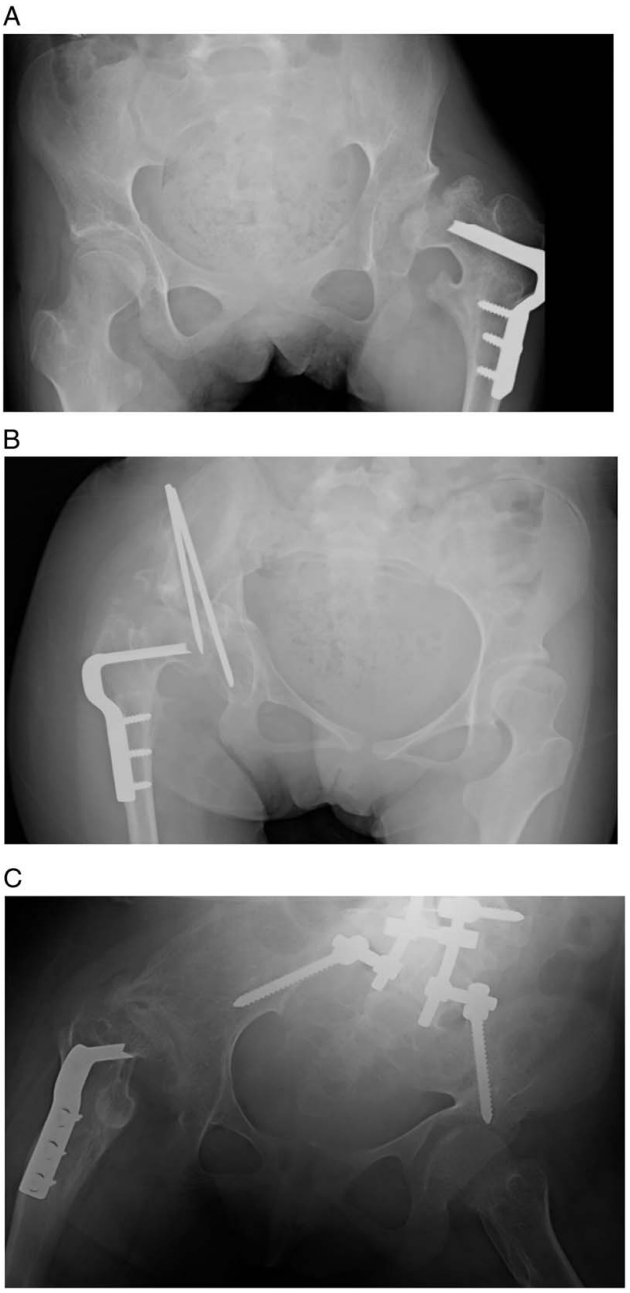

FIGURE 1. Avascular Necrosis Radiographs. Three radiographs from hips that developed avascular necrosis in this cohort are shown. In (A), the left femoral head depicts severe flattening postoperatively. B and C, highlight right femoral heads that flattened and progressed asymmetrically postoperatively.

Examples of AVN in the hips of children with CP in this cohort can be found in Figure 1. Lastly, this same orthopaedic surgeon was the sole authority in determining the MCPHCS and Rutz femoral head classifications.

Patients' social determinants of health were quantified with the Child Opportunity Index (COI) 3.0. The COI 3.0 composite index uses census tract data aggregated to reflect ZIP codes to generate scores.[17] These scores depict

one's neighborhood conditions and resources necessary for a child to develop in a healthy manner in the United States. The COI 3.0 offers national scores on a continuous scale from 1 (lowest opportunity) to 100 (highest opportunity). In addition, the COI is further categorized into national, state, and city levels, which can also be divided into quintiles (very low, low, moderate, high, and very high). All analyses in this study were conducted on the national level, and patient demographics can be found in Table 1.

Surgical Technique

The technique for VDRO has been previously described.[18] For this cohort in general, hip adductors were lengthened unless wide abduction was demonstrated at the time of surgery. The extent of femoral shortening was tailored to each patient's GMFCS level. For nonambulatory patients (GMFCS level IV and V), femurs were routinely shortened 2.0 to 2.5 cm to minimize soft tissue strain on the hip adductors and hamstrings. Among children functioning at GMFCS level III, comparable shortening was used for bilateral hip subluxation, whereas unilateral cases underwent minimal shortening of 0 to 1.0 cm. Femoral shortening was avoided for children functioning at GMFCS level I or II if they displayed a mainly rotational deformity with minimal subluxation.

The target neck-shaft angle was also stratified by GMFCS level to optimize gait and preserve hip function. Surgically, we aimed for a final neck-shaft angle of 100 to 110 degrees for patients functioning at GMFCS level IV and V and at least 115 to 120 degrees for patients functioning at GMFCS levels I to III.

The surgical technique used for this cohort incorporated blade-plate fixation with routine medialization from the implant. The degree of medialization corresponded with both the blade-plate offset and the magnitude of varus created. Minimal varus corrections generally received only millimeter-scale medialization, whereas larger patients undergoing substantial varus correction typically received 1.0 to 1.5 cm of medialization.

Intraoperative hip arthrogram helped to guide surgical decision-making concerning reduction quality, stability, and acetabular morphology. Open reduction was done through an anterior approach. The intra-articular and extra-articular impediments to reduction were addressed, including excision of the ligamentum teres. Capsular repair was typically executed with 6 nonabsorbable size 1 sutures with the superolateral capsule brought inferomedially and then the inferolateral capsule being brought superomedially with the hips typically in about 30 degrees of flexion, 30 degrees of abduction, and mild internal rotation.

POs were most typically reshaping osteotomies to enhance posterior and/or lateral coverage. Although blade plates were routinely used for the VDROs throughout the study period, no fixation was used for reshaping osteotomies. In rare cases of severely deficient acetabuli, an augmentative osteotomy such as a Chiari, was performed. POs were indicated in the presence of significant acetabular dysplasia and/or insufficient femoral head coverage after VDRO and capsulorrhaphy (when warranted). Assessment was based on both the ossified and unossified portions of the acetabulum, which was often best elucidated with intraoperative arthrogram.

TABLE 1. Demographic and Clinical Characteristics of Study Population

By patient: N = 316	
Sex, n [%]	
Female	120 [38.0]
Male	196 [62.0]
Race, n [%]	
Asian	8 [3.5]
Black	14 [6.1]
Hispanic	118 [51.5]
White	76 [33.2]
Other	13 [5.7]
87 unavailable	
BMI percentile (mean, SD, range)	48.6, 37.2, 0-99.9
Child Opportunity Index (mean, SD, range)	41.0, 32.0, 2-100
By hip: N = 593	
Age (mean, SD, range)	8.3, 3.2, 2.4-17.7
GMFCS, n [%]	
I	3 [0.5]
II	53 [8.9]
III	70 [11.8]
IV	229 [38.6]
V	238 [40.1]
Duration of follow-up (mean, SD, range)	5.5 y, 3.3, 1.0-14.9
Surgical side, n [%]	
Left	44 [7.4]
Right	48 [8.1]
Bilateral	501 [84.5]
Preoperative reimers migration percentage (mean, SD, range)	51.1, 28.0, 0-100
Pelvic osteotomy, n [%]	
No	495 [83.5]
Yes	98 [16.5]
Open reduction, n [%]	
No	488 [82.3]
Yes	105 [17.7]

Baseline characteristics of the study cohort presented at both patient and hip levels.

Statistical Analysis

All statistical analyses were performed in Stata (version 14.2; StataCorp, College Station, Texas). Results with an $\alpha \leq 0.05$ were considered statistically significant. Hips classified as MCPHCS IV, V, or VI were grouped into a singular MCPHCS IV-VI category because the sample sizes in these groups (87, 5, and 12, respectively) were rare in comparison to the number of hips determined to be either MCPHCS I, II, or III. Surgeon volume was assessed by comparing the VDROs performed by the highest volume surgeon (n = 409) to all other surgeons (n = 184). Initially, univariate logistic regressions were executed to evaluate risk factors for developing AVN (Table 2). We used a cluster-based variance estimator clustered on the participant to account for multiple hips per patient. Then, all variables reported in Table 2 were assessed with multivariate analysis (Table 3). In addition,

TABLE 2. Univariate Analysis of Risk Factors for Avascular Necrosis After Varus Derotation Osteotomy.

Variable	Odds ratio [95% CI]	*P*
Sex	0.62 [0.18, 2.14]	0.45
Age	1.06 [0.86, 1.30]	0.60
Child Opportunity Index	1.01 [1.00, 1.02]	0.20
BMI percentile	0.99 [0.97, 1.01]	0.47
Follow-up length	1.00 [1.00, 1.00]	0.92
GMFCS level V	3.66 [0.91, 13.83]	0.07
Preoperative reimers MP	1.04 [1.01, 1.07]	**0.02**
Surgery side (left/right)	0.43 [0.12, 1.67]	0.22
Bilateral surgery	0.18 [0.05, 0.62]	**< 0.01**
Hardware size	1.11 [0.31, 3.98]	0.88
Surgeon volume	0.29 [0.08, 1.05]	0.06
Immobilization type	1.39 [0.29, 7.70]	0.69
Open reduction	3.18 [0.88, 11.45]	0.08
Pelvic osteotomy	12.61 [3.21, 49.57]	**< 0.01**

Bold text denotes statistical significance at $P \leq 0.05$.

Univariate logistic regression analysis examining potential risk factors for developing avascular necrosis. Results include odds ratios with 95% CIs and *P*-values.

differences in preoperative Reimers MP between groups were calculated with 2-sample *t* tests. Lastly, MCPHCS and Rutz femoral head classification systems were analyzed with Fisher exact tests to determine differences in AVN and sphericity distributions (Table 4).

RESULTS

Demographics

In total, 316 children (593 hips, 196 males; 8 Asian, 14 Black, 118 Hispanic, 76 White, 13 Other, 87 with unavailable race data) were included in this study (Table 1). The mean BMI percentile was 48.6 (SD: 37.2; range: 0 to 99.9). The mean age at the time of VDRO was 8.3 years (SD: 3.2; range: 2.4 to 17.7 y) with an average follow-up duration of 5.5 years (SD: 3.3; 1.0 to 14.9 y).

TABLE 3. Multivariate Analysis of Risk Factors for Avascular Necrosis After Varus Derotation Osteotomy.

Variable	Odds ratio [95% CI]	*P*
Sex	0.53 [0.14, 1.95]	0.34
Age	1.16 [0.86, 1.56]	0.34
Child Opportunity Index	1.01 [0.99, 1.02]	0.50
BMI percentile	0.99 [0.96, 1.01]	0.37
Follow-up length	1.00 [1.00, 1.00]	0.45
GMFCS level V	1.67 [0.28, 9.82]	0.57
Preoperative reimers MP	1.03 [1.00, 1.06]	0.06
Surgery side (left/right)	0.49 [0.12, 2.00]	0.32
Bilateral surgery	0.22 [0.05, 1.10]	0.07
Hardware size	1.35 [0.34, 5.31]	0.67
Surgeon volume	0.85 [0.16, 4.57]	0.85
Immobilization type	1.11 [0.22, 5.58]	0.90
Open reduction	1.17 [0.28, 4.89]	0.83
Pelvic osteotomy	12.49 [2.79, 56.00]	**< 0.01**

Bold text denotes statistical significance at $P \leq 0.05$.

Multivariate logistic regression analysis examining all variables from univariate analysis as potential predictors of avascular necrosis. Results include adjusted odds ratios with 95% CIs and *P*-values.

TABLE 4. Relationship Between Avascular Necrosis and Hip Classifications.

Change in Rutz classification system (n = 593)					
	Rutz worsened	**Rutz improved**	**Rutz did not change**	**Rutz unavailable**	***P***
AVN, n (%)					
No	49 (94.2)	216 (98.6)	204 (99.0)	114 (97.4)	0.13
Yes	3 (5.8)	3 (1.4)	2 (1.0)	2 (1.7)	
MCPHCS (n = 453)					
	I	II	III	IV-VI	
AVN, n (%)					
No	117 (99.2)	99 (7.1)	127 (98.4)	101 (97.1)	0.58
Yes	1 (0.8)	3 (2.9)	2 (1.6)	3 (2.9)	

Distribution of avascular necrosis across Rutz femoral head classification changes and Melbourne Cerebral Palsy Hip Classification System (MCPHCS) grades. *P*-values calculated using Fisher exact test. MCPHCS grades IV to VI were combined due to small sample sizes in higher grades.

Surgical Details

Five hundred one of 593 osteotomies were performed bilaterally (Table 1). In regard to the 92 unilateral osteotomies, 44 were on the left and 48 on the right. Preoperatively, the average Reimers MP was 51.1 (SD: 28.0; range 0 to 100). During surgery, 98 hips (16.5%) received POs and 105 hips (17.7%) received open reductions. The size of the blade plates used was as follows: 250 infant (42.2%), 142 toddler (23.9%), 126 child (21.2%), 56 adolescent (9.4%), 15 adult (2.5%), and 4 unavailable sizes (0.7%). Lastly, the highest volume surgeon performed 409 of the 593 (69.0%) osteotomies.

Avascular Necrosis and Accompanying Risk Factors

AVN developed in 10 of the 593 hips [1.7%, 95% CI (0.09%, 3.11%)] in this cohort. Among these 10 cases, the average age at surgery was 8.9 years (SD: 3.8, range: 4.3 to 14.9 y; 1 GMFCS level III, 2 GMFCS level IV, 7 GMFCS level V). Moreover, AVN was first detected on postoperative films at an average of 1.9 years (SD: 1.7; range: 0.50 to 6.4 y). The average Reimers MP for these hips was 77.6 (SD: 27.3, range 32.2 to 100), whereas hips that did not develop AVN measured an average Reimers MP of 50.6 (SD: 27.9, range 0 to 100) ($P < 0.01$). Seven of the 10 (70.0%) hips with AVN had undergone a PO during surgery.

In univariate analysis, AVN was not related to sex, age, COI, BMI percentile, follow-up length, GMFCS level, surgery side (left/right), surgeon volume, hardware size, type of immobilization, or open reduction (Table 2). The statistically significant risk factors included preoperative Reimers MP [OR: 1.04, 95% CI (1.01, 1.07), $P = 0.02$], bilateral surgery [OR: 0.18, 95% CI (0.05, 0.62), $P < 0.01$] and POs [OR: 12.61, 95% CI (3.21, 45.57), $P < 0.01$]. Notably, GMFCS level V ($P = 0.07$), and surgeon volume ($P = 0.06$) were very close to significance. These factors would have become significant if n = 1 more GMFCS level V hip operated on by the highest volume surgeon developed AVN. AVN and pelvic osteotomy rates stratified by GMFCS level, bilateral surgery, and surgeon

TABLE 5. Relationship Between Pelvic Osteotomy, Avascular Necrosis, and Key Clinical Variables.

GMFCS level			
Pelvic osteotomy	**GMFCS levels I-IV, n [%]**	**GMFCS level V, n [%]**	***P***
No	326 [91.8]	169 [71.0]	**< 0.01**
Yes	29 [8.2]	69 [29.0]	
AVN	GMFCS levels I-IV, n [%]	GMFCS level V, n [%]	*P*
No	352 [99.2]	231 [97.1]	0.10
Yes	3 [0.8]	7 [2.9]	
Total	355	238	593
Bilateral surgery			
Pelvic osteotomy	Unilateral, n [%]	Bilateral, n [%]	*P*
No	67 [72.8]	428 [85.4]	**< 0.01**
Yes	25 [27.2]	73 [14.6]	
AVN	Unilateral, n [%]	Bilateral, n [%]	*P*
No	87 [94.6]	496 [99.0]	**0.01**
Yes	5 [5.4]	5 [1.0]	
Total	92	501	593
Surgeon volume			
Pelvic osteotomy	All other surgeons, n [%]	Highest volume surgeon, n [%]	*P*
No	116 [63.0]	379 [92.7]	**< 0.01**
Yes	68 [37.0]	30 [7.3]	
AVN	All other surgeons, n [%]	Highest volume surgeon, n [%]	*P*
No	178 [96.7]	405 [99.0]	0.08
Yes	6 [3.3]	4 [1.0]	
Total	184	409	593

Bold text denotes statistical significance at $P \leq 0.05$.

Analysis of pelvic osteotomy and avascular necrosis rates stratified by GMFCS level, bilateral surgery status, and surgeon volume. Results presented as frequencies and percentages with *P*-values calculated using Fisher exact test..

volume are reported in Table 5. Concerning GMFCS level V, specifically, pelvic osteotomies were significantly more common in this cohort than in GMFCS levels I to IV (29.0% vs. 8.2%, $P < 0.01$).

Multivariate analysis, on the other hand, identified only one of the factors described in univariate analysis to be significantly associated with AVN: PO [OR: 12.49, 95% CI (2.79, 56.00), $P < 0.01$] (Table 3). Preoperative Reimers MP ($P = 0.06$) and bilateral surgery ($P = 0.07$) were very close to being statistically significant risk factors in multivariate analysis.

Rutz and Melbourne Cerebral Palsy Hip Classification Systems

Analysis of femoral head morphology using both the Rutz classification system[10] and the MCPHCS[9] revealed no significant correlations between femoral head sphericity and AVN occurrence. In the Rutz classification analysis, AVN rates remained consistently low and statistically similar across all categories: 5.8% in cases where Rutz worsened, 1.4% where it improved, 1.0% where no change occurred, and 2.6% in cases where Rutz data were unavailable ($P = 0.13$) (Table 4). Similarly, when examining the MCPHCS data, AVN rates showed no significant variation across severity levels, with rates ranging from 0.8% in Level I to 3.8% in Levels IV to VI ($P = 0.58$).

DISCUSSION

In this large cohort study examining AVN after VDRO in children with CP, we found that PO and preoperative Reimers MP were the only significant risk factors in multivariate analysis. The relationship between PO and AVN provides important context for understanding why several factors—GMFCS level V, unilateral surgery, and surgeon volume—were significant in univariate but not multivariate analysis.

Our data demonstrate that PO rates varied substantially across these 3 endpoints. Children functioning at GMFCS level V underwent POs at ~3.5 times the rate of their higher-functioning peers (29.0% vs. 8.2%, $P < 0.01$). Similarly, unilateral surgeries had nearly twice the rate of POs compared with bilateral procedures (27.2% vs. 14.6%, $P < 0.01$). The highest volume surgeon, who predominantly operated on children functioning at GMFCS levels I to IV [71.4% (292/409) of osteotomies versus 34.2% (63/184) for all other surgeons], performed POs at only one-fifth the rate of other surgeons (7.3% vs. 37.0%, $P < 0.01$). These differences in PO rates likely explain why these 3 variables lost significance in multivariate analysis; their apparent relationship with AVN was primarily driven by their association with PO.

The analysis of femoral head morphology using both the Rutz classification system and the MCPHCS revealed an important clinical finding: AVN occurrence did not significantly correspond to changes in femoral head sphericity. The Rutz data showed similar AVN rates regardless of whether femoral head shape improved (1.4%), worsened (5.8%), or remained unchanged (1.0%). Similarly, the MCPHCS displayed no significant variations in AVN rates across this system's severity levels. These similar rates suggest that although AVN has historically been a major concern in hip reconstruction surgery, other factors such as maintaining hip range of motion and preserving femoral head sphericity may be more critical determinants of long-term outcomes in children with CP.

Notably, others have postulated that AVN is due to degree of displacement, and in developmental dysplasia of the hip (DDH) greater AVN rates after open reduction/femoral osteotomy.[19,20] Moreover, some believe AVN develops due to excessive pressure on the head.[21] However, our data suggest that POs are associated with AVN just as other authors in DDH have shown that AVN is related to POs.

In attempts to improve hip and overall health outcomes in children with CP, we concur that screening hips allows for earlier detection of significant displacement and also reduces the odds of needing to perform salvage surgery. As the 2 main risk factors for AVN in this study are MP and PO, earlier detection should decrease the risk of AVN. It is worth noting that (1), the decision regarding pelvic osteotomy varies among centers, with some centers

performing pelvic osteotomies at a much higher rate than at our institution; (2) the MPs described in our cohort are similar to those of other large series, such as those by Shore et al.[22]

Several limitations should be considered when interpreting our results. First, although magnetic resonance imaging (MRI) is considered the generally preferred measure for AVN detection,[23,24] we relied on radiographs for our analysis as MRIs were not consistently available across our cohort. This may have led to an underestimation of AVN incidence, particularly in early onset and/or subtle cases. Second, our analysis of femoral head sphericity was limited by the retrospective nature of the study and the inherent challenges in measuring these parameters in children with CP. Third, Reimers MP alone may not fully capture the severity of one's hip displacement. However, Reimers MP remains the most widely accepted metric in pediatric orthopaedics. Finally, although our cohort is the largest reported to date for this specific research question, the relatively low incidence of AVN (1.7%) limited our ability to perform more detailed subgroup analyses. For example, in the GMFCS III to V cohort, 10/537 hips (1.9%) developed AVN. If this same rate existed in the 56 ambulatory hips, we would not expect to find any hips with AVN. Thus, the lack of ambulatory patients without AVN may be a sample size issue.

CONCLUSIONS

This study's findings hold important clinical implications. The strong association between PO and AVN risk signals that surgeons should carefully weigh the potential benefits of POs against their increased risks. In addition, the similar distributions of femoral head sphericity across both the Rutz classification system and the MCPHCS suggests that other factors besides AVN may be more important for long-term, clinical outcomes in children with CP. Although AVN is commonly thought to be a significant, long-term complication, children with CP can still exhibit favorable clinical outcomes despite having AVN of the femoral head(s). There are other factors, like Rutz and MCPHCS, that contribute to their clinical outcomes and can mask the symptoms of AVN. Future studies using standardized MRI protocols and hip range of motion measurements at regular intervals could help further elucidate the clinical characteristics paramount to achieving optimal hip health in children with CP.

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