Medialization at the Site of Varus Derotational Osteotomy of the Proximal Femur May Reduce Instability Recurrence in Cerebral Palsy

Frederico C.M. Vallim, MD, PhD, Marcello H. Nogueira-Barbosa, MD, PhD, João A. M. Guimarães, MD, PhD, Henrique A. Cruz, MD, Juliana M.B. Lyra, MD, and H. Kerr Graham, MD, FRCS(Ed), FRACS

Investigation performed at the Royal Children's Hospital, Melbourne, Victoria, Australia

Background: Osseous reconstructive surgery for hip displacement in children with cerebral palsy (CP) consists of proximal femoral reorientation by varus derotational osteotomy (VDRO) combined with pelvic osteotomy when indicated. The rate of recurrent hip instability after the index surgery can be as high as 77%. We evaluated the association between femoral diaphyseal medialization at the VDRO site and recurrent instability. We hypothesized that medialization may modify the hip joint reaction force (HJRF), reducing the femoral remodeling that leads to recurrent coxa valga and instability.

Methods: A retrospective evaluation of the clinical and radiographic records of 140 patients (280 hips) with CP, Gross Motor Function Classification System (GMFCS) Level IV or V, who had been treated with bilateral VDRO as the index surgery for hip displacement between 1998 and 2012 (mean follow-up, 11.3 years) was conducted. Radiographic measurement of medialization was performed using the medialization index (MeI) preoperatively, at 6 weeks and 12 months postoperatively, and at skeletal maturity. Recurrent instability was defined as the need for revision surgery before skeletal maturity or a final migration percentage (MP) of >40%.
The influence of the MeI was determined by Poisson regression with multiple variances. The inter- and intra-observer reliability of the MeI, measured by 4 different observers, was assessed using the Cohen d test.

Results: Groups with and without relapse were comparable preoperatively regarding femoral and acetabular parameters. The baseline MP was higher in the relapse group ($p < 0.001$). The MeI at 6 weeks postoperatively was significantly lower in the relapse group ($p = 0.004$, relative risk [RR] = 0.07, 95% confidence interval [CI] = 0.01 to 0.42) than in the no-relapse group in multivariable analysis. The MeI showed good inter- and intra-observer reliability, with a Cohen d of <0.5.

Conclusions: Patients with greater medialization had lower rates of recurrent hip instability at long-term follow-up. The MeI proved to be reliable as a radiographic measurement, and medialization did not increase mechanical instability.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

The prevalence of hip displacement in children with cerebral palsy (CP) has a linear relationship with gross motor function and can reach 90% in children at Gross Motor Function Classification System (GMFCS) Level V[1,2]. Hip displacement may be associated with pain, impaired sitting ability, difficulties with perineal hygiene, and impairment of health-related quality of life[3-5]. The traditional view of its pathogenesis relates to muscle imbalance, with the hip flexor and adductor muscles overpowering their extensor and abductor counterparts[6]. However, increased valgus and anteversion of the proximal femur may also play an important role, as does secondary acetabular dysplasia[7]. The direction and magnitude of the hip joint reaction force (HJRF) are impacted by hypertonia, an adducted and flexed posture of the hip, and an increased neck-shaft angle (NSA) and coxa valga[8]. Pelvic obliquity has also been implicated as a factor in hip instability in children with CP. A large population-based study of children with CP showed more severe displacement on the high side of the pelvis[9]. Surgical procedures may include adductor and psoas release (APR), osseous reconstruction by varus derotational osteotomy (VDRO)

Disclosure: No external funding was received for this work. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/I559).

of the proximal femur, and pelvic osteotomies (Fig. 1)[5,10-17]. More recently, guided growth of the proximal femur has become more widely used, with promising results, in the correction of coronal plane deformity[18].

The prevalence of recurrent hip displacement in children with CP following surgical management is reported to be up to 77%[14]. Risk factors include a higher preoperative migration percentage (MP), increased coxa valga, severe acetabular dysplasia, nonambulatory functional status, and younger age at the index osseous reconstructive surgery[19-23]. Understanding biomechanical factors related to recurrence may be important to reduce the risk of relapse and revision surgery[7].

The aim of soft tissue surgery (APR) is to correct the flexed-adducted posture of the hip and reduce the HJRF by weakening the hip flexors and adductors[6,8]. In contrast, VDRO changes the lever arms of the muscle groups around the hip and redirects the HJRF by correcting abnormal proximal femoral geometry[12,24]. From a theoretical standpoint, APR and VDRO may be synergistic with regard to their effects on the hip in children with CP[7].

Femoral VDRO corrects excessive valgus and anteversion, but medial displacement at the osteotomy site has received less attention in the literature. The latter decreases the distance from the fulcrum to the point of application of the hip flexor and adductor muscle-tendon units (MTUs) and hence the muscle forces by reduction of the moment arms. The length of the abductor-extensor MTU lever arms are correspondingly increased (Fig. 2). According to both geometric and biomechanical principles, the flexor-adductor moments decrease while the abductor-extensor moments increase, with increasing medial displacement. In geometric terms, this could direct the HJRF more medially and inferiorly. Given that bone remodels orthogonally to the HJRF[25,26], a more medial vector would have less valgus remodeling, theoretically decreasing relapse rates. The purpose of the present study was to evaluate the impact of femoral medialization during VDRO surgery on relapse rates of hip instability in nonambulatory children with CP who had long-term follow-up.

Materials and Methods

This was a retrospective, single-center, long-term follow-up study, conducted after approval by the institutional ethics committee (QA/99386/RCHM-2023). Candidates for inclusion were nonambulatory children with GMFCS Level-IV or V CP, identified through the Statewide Cerebral Palsy Register (SCPR), who had undergone osseous reconstructive surgery between January 1998 and January 2012. Most children had had prior APR surgery and had been followed according to formal hip surveillance protocols[5,7,9]. The index osseous surgery consisted of bilateral VDRO and primary or revision APR surgery[2,7] (see Appendix). The exclusion criteria were other neuromuscular diagnoses; GMFCS Level I, II, or III; previous osseous surgery or pelvic osteotomy; and incomplete records.

All patients were managed in a hip surveillance clinic, where a physiotherapist and a pediatric orthopaedic surgeon

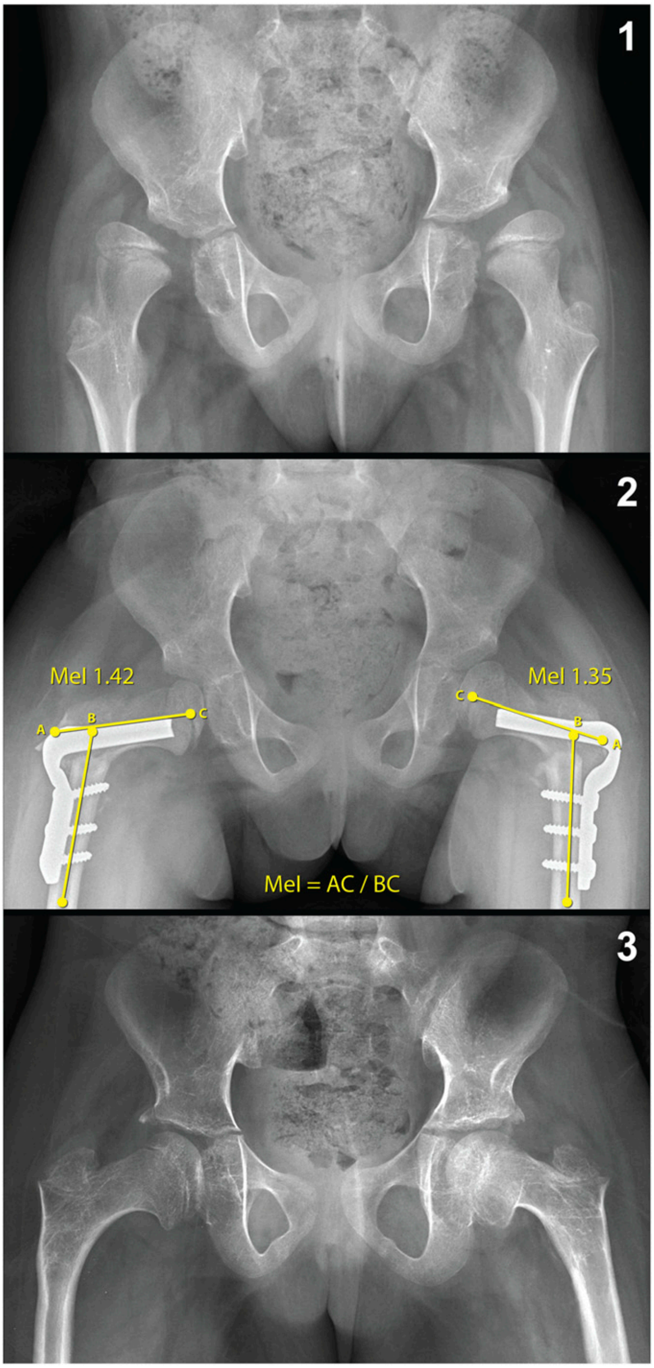

Fig. 1

Figs. 1-A, 1-B, and 1-C Eight-year-old girl with quadriplegic CP (GMFCS IV) who presented with pain, scissoring, and gait deterioration. **Fig. 1-A** Bilateral hip displacement with an MP of >50%, an increased NSA, and mild to moderate acetabular dysplasia. **Fig. 1-B** Three weeks after bilateral hip adductor release and VDRO. The hips are now covered, and the NSA is overcorrected. The medialization indexes (MeI) are highlighted. **Fig. 1-C** At the 5-year postoperative follow-up, the patient was pain-free and had no fixed deformities. The lateral acetabular epiphyses had ossified, and she had femoral head overcoverage. Mild growth disturbance and a "sagging rope sign" were noted on the left hip.

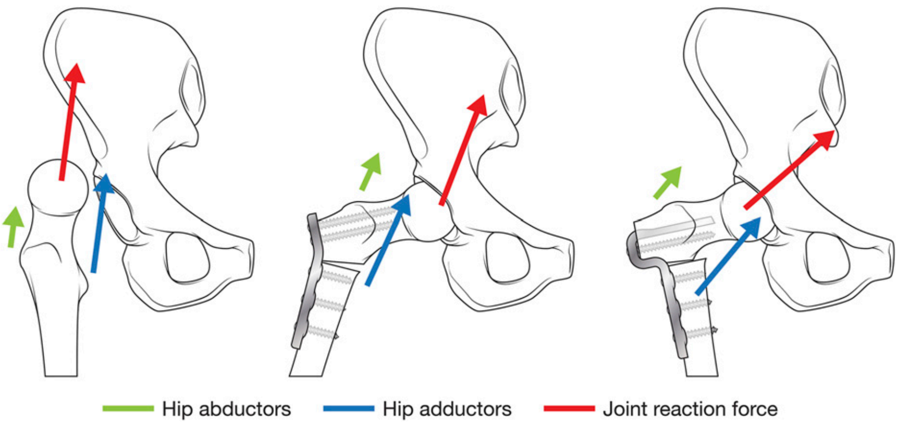

Fig. 2

Schematic representation of the hip joint reaction force (HJRF, red arrows) in a neuromuscular hip dislocation (left), after VDRO without medialization (center), and after VDRO with medialization (right). The green arrows indicate the hip abductors and the blue lines, the hip adductors. The HJRF is directed laterally and superiorly before the reduction and VDRO and is directed more medially and inferiorly after the VDRO. This may explain the improvements in acetabular growth and the progressive decrease (improvement) in the AI noted in our study.

provide written information and illustrations to patients and their families.

Sample size was determined by initially identifying the margin of error of the sample in the SCPR from 1995 to 2014, during which 9,013 newborns were diagnosed with CP (1.2 per 1,000 live births). There were 220 new CP diagnoses per year, and 16.1% to 18% were classified as GMFCS IV or V. A margin of error of 10.94% was calculated, and with a confidence level of 95% in 907 nonambulatory patients with an average 80% prevalence of hip displacement, the sample size was determined to be 44.

Demographic data collected from the medical records included the age at osseous reconstructive surgery, sex, implant design, and GMFCS level[5]. The motor pattern, clinical comorbidities, follow-up duration, postoperative complications, and secondary surgical procedures were also considered.

Of the multiple radiographs available for each patient, those made at 4 time intervals— preoperatively, 6 weeks and 1 year postoperatively, and at skeletal maturity—were selected for detailed analysis. Radiographic measurements at each time point included the MP, NSA[11], head-shaft angle (HSA), acetabular index (AI), and medialization index (MeI) as described by Davids et al.[12,27].

Among the patients included in our cohort, 27% were previously enrolled in a prospective trial of 6 monthly injections of botulinum toxin A to adductors and medial hamstrings, but no benefits were noted. Three patients were managed with intrathecal baclofen for global tone management.

Complications were classified using the Modified Clavien-Dindo (MCD) System, which has good reliability in this population[28,29]. Osteonecrosis was classified with the system proposed by Kruczynski and validated by Koch et al.[30,31]. Recurrent hip instability (relapse group) was determined when the MP was ≥40% in one or both hips and was managed by revision surgery. The no-relapse group was defined as an MP of <40% and no additional surgery apart from revision APR or removal of implants.

The postoperative protocol included epidural analgesia for 4 to 5 days. Children were cared for in bed without any type of immobilization. After hospital discharge, the children's care was supervised by a community physiotherapist (PT), who was given information about the surgery and advice regarding mobilization. Children were encouraged to return to preoperative activities, including the use of walkers and standing frames, 7 to 10 days after surgery.

The inter- and intra-observer reliability of the MeI was assessed on 36 randomly chosen radiographs on which 4 clinicians measured the MeI: 2 pediatric orthopaedic surgeons, 1 pediatric orthopaedic fellow in training, and 1 musculoskeletal radiologist. The MeI was measured in all 72 hips on 2 different occasions, separated by 2 weeks. The differences between pairs of measurements by the same observer and between measurements made by different observers were calculated. The Cohen d test was used to determine a small (d value,

TABLE I Demographic Characteristics According to Relapse or No Relapse of Hip Instability*

	Relapse Group	No-Relapse Group	P Value
Mean age ± SD at VDRO *(yr)*	7.5 ± 3.3	8.3 ± 2.4	0.6
Sex (F:M) *(no.)*	12:18	41:69	0.3
GMFCS (IV:V) *(no.)*	9:21	45:65	0.4
Mean follow-up ± SD *(mo)*	135.8 ± 32.2	139.6 ± 24	0.5

*SD = standard deviation, VDRO = varus derotational osteotomy, GMFCS = Gross Motor Function Classification System. The groups were compared using the Student t test for continuous values and the chi-square test for categorical values.

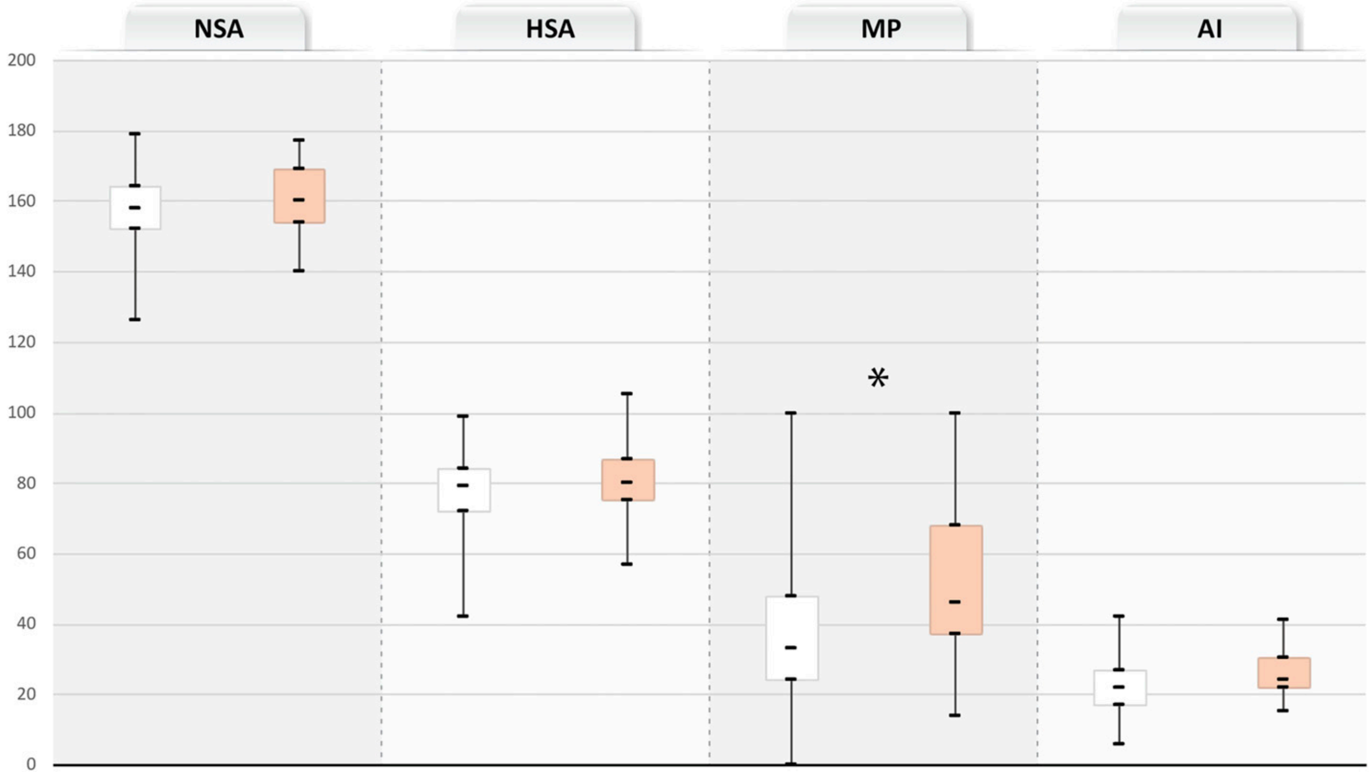

Fig. 3
Baseline radiographic parameters shown as box and whisker plots, with the white boxes representing the no-relapse group and the red boxes representing the relapse group.Only the baseline MP differed significantly (indicated by the asterisk) between the groups (p = 0.0001, Student t test). The interquartile range is shown as a box, the median is shown as a line withinn the box, and the range is shown as whiskers. NSA = neck-shaft angle, HSA = head-shaft angle, MP = migration percentage, and AI = acetabular index.

≥0.2 and <0.5), medium (d value, ≥0.5 and <0.8), or large difference (d value, ≥0.8). Finally, the probability of hip stability after VDRO, as assessed at skeletal maturity, was plotted as a survivorship curve according to the MeI value.

All radiographic measurements were done using anonymized digital images (in a PACS [picture archiving and communication system]) with the aid of a validated radiographic measurement tool, Bone Ninja (International Center for Limb Lengthening). Descriptive analyses of quantitative data are presented as means and standard deviations (SDs), medians, and minimum and maximum values. Qualitative data are expressed as absolute and percentage frequencies. Quantitative data were compared using the Student t test, while comparisons of qualitative data were done with the chi-square or Fisher exact test. Relative risk assessment utilized Poisson logistic regression with multiple variances. All data were compiled using Microsoft Excel. SAS software (version 9.2; SAS Institute) was used for statistical analysis, and R software (version 3.4.1; R Foundation for Statistical Computing) was used for graphics. The significance level was 5% for all comparisons (α = 0.05).

TABLE II Evolution of Femoral and Acetabular Radiographic Parameters from Before Surgery to Skeletal Maturity*

	NSA†			HSA†			AI‡	
	Preoperative	6 Weeks	Skeletal Maturity	Preoperative	6 Weeks	Skeletal Maturity	Preoperative	Skeletal Maturity
Relapse group	157.9 ± 9.1	116.2 ± 11.2	130.8 ± 14.9	78.0 ± 9.4	39.3 ± 12.4	57.4 ± 16.0	22.3 ± 6.8	13.6 ± 5.7
No-relapse group	160.8 ± 10.0	112.1 ± 12.3	128.0 ± 15.4	81.4 ± 10.3	35.9 ± 13.1	53.3 ± 16.0	26.0 ± 7.1	20.1 ± 7.9

*NSA = neck-shaft angle, HSA = head-shaft angle, AI = acetabular index. The values are given as the mean and standard deviation in degrees. †P < 0.05 (Student t test) for preoperative versus 6 weeks and preoperative versus skeletal maturity for both groups. ‡P < 0.01 (Student t test) for difference in skeletal maturity measurements between groups. P < 0.01 (Student t test) for preoperative versus skeletal maturity for both groups.

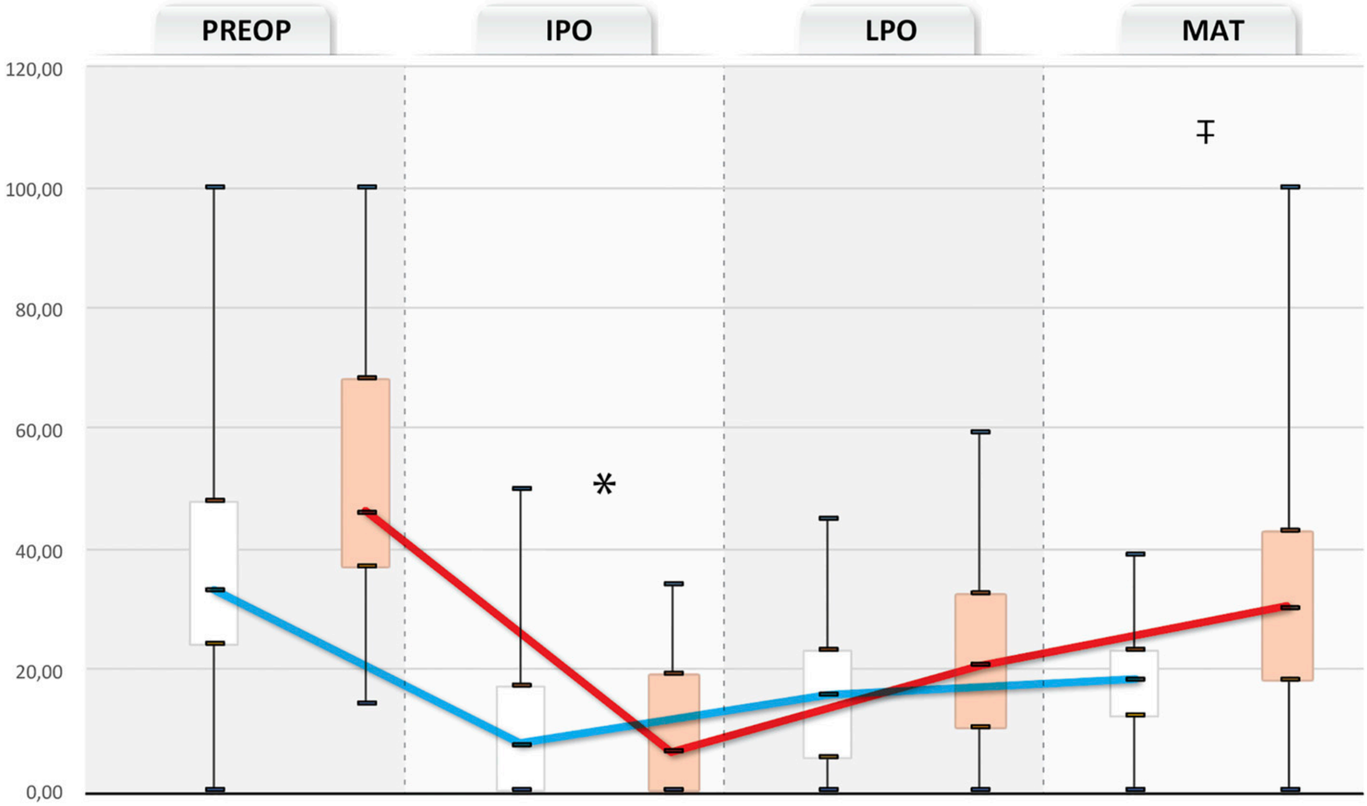

Fig. 4

Evolution of migration percentage (MP) during follow-up shown as box and whisker plots, with the white boxes representing the no-relapse group and the red boxes representing the relapse group. The interquartile range is shown as a box, the median is shown as a line within the box, and the range is shown as whiskers. PREOP = preoperative, IPO = immediate postoperative (6 weeks), LPO = late postoperative (12 months), and MAT = skeletal maturity. *P < 0.01 (Student t test) for preoperative versus 6 weeks for both groups. ∓P < 0.01 (Student t test) for preoperative versus skeletal maturity for both groups.

Results

Of 164 patients identified as having GMFCS Level-IV or V CP who underwent VDRO, 24 were excluded from the analysis: 16 had incomplete records; the diagnosis was revised to “neuromuscular disease/not CP” for 2; 2 were reclassified as being at GMFCS Level III, and 4 had pelvic osteotomy with the index surgery. After application of these exclusion criteria, the study cohort comprised 140 patients, which reduced the margin of error to 5.5% with a 95% confidence level.

There were 87 boys (61%), and the mean age at the first operation was 8.2 years (range, 3.8 to 13.3 years). The mean age in the relapse group did not differ significantly from that in the no-relapse group (7.5 versus 8.3 years; p > 0.05). Relapse occurred in 41 hips (14.6%) in 30 patients. In 30 hips, the relapse was defined by early revision surgery and in 11 hips (3.9%), by an MP of >40% at skeletal maturity. Demographic and functional characteristics are summarized in Table I. No association was found between relapse and GMFCS level (p = 0.4). Ninety percent of the VDRO sites were stabilized with a 90° fixed-angle blade plate (Synthes); 8.6%, with an Intermediate Hip Screw (Richards Medical); and 1.4%, with a locked cannulated blade plate (OrthoPediatrics). The mean follow-up was 136 months (11.3 years), with no significant difference between the relapse and no-relapse groups (135.8 versus 139.6 months; p = 0.5). Four children died before reaching skeletal maturity—i.e., they had open triradiate cartilage at the last follow-up. Another 2 had reached skeletal maturity on the basis of chronological age but had open triradiate cartilage because of delayed puberty.

No significant differences were found between the relapse and no-relapse groups regarding CP pattern, implant type, or the presence or types of medical comorbidities.

With regard to the femoral and acetabular radiographic parameters, the groups were similar regarding the preoperative AI (p = 0.1), NSA (p = 0.5), and HSA (p = 0.4) (Fig. 3, Table II). The femoral parameters improved at 6 weeks (p < 0.05); the angles were closer to the preoperative values at skeletal maturity but remained improved compared with the preoperative values (p < 0.01; Table II). Poisson logistic regression showed all preoperative radiographic parameters to be risk factors for recurrent instability individually, but they were not found to be significant risk factors in the multiple regression model (p = 0.4, 0.6, and 0.4 for AI, NSA, and HSA, respectively).

The mean preoperative MP was 41.6% (range, 0% to 100%) with a significant difference between the relapse group

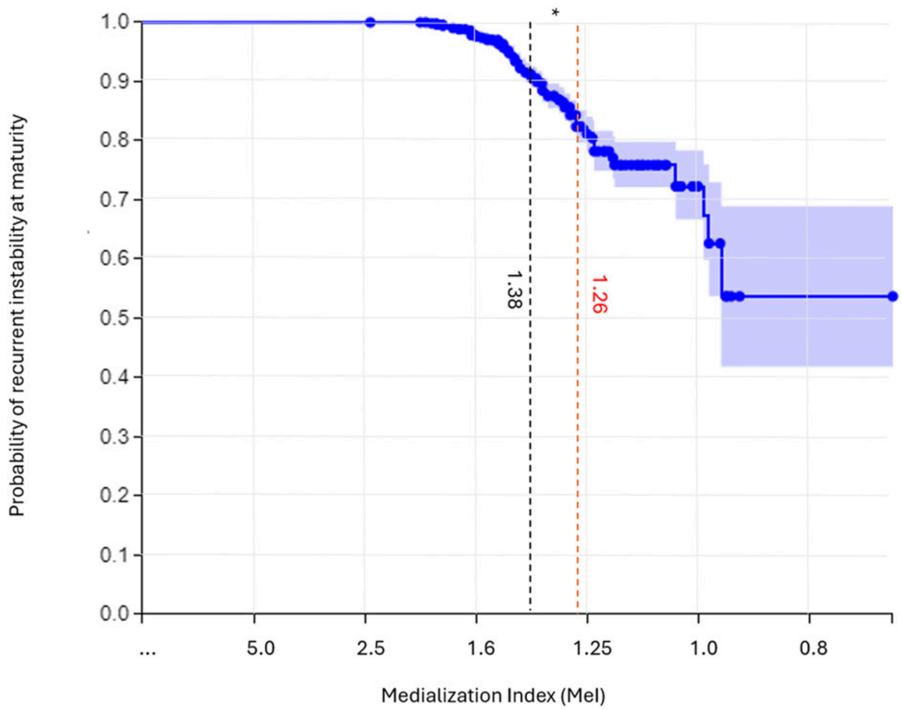

Fig. 5

Survivorship curve relating postoperative MeI and probability of hip instability recurrence at skeletal maturity. The black dashed line depicts the mean MeI of the no-relapse group (1.38) and the red dashed line, the mean MeI of the relapse group (1.26). *P = 0.004 (Poisson regression model with multiple variances).

(52.3%) and no-relapse group (37.9%) ($p = 0.001$, Fig. 3). At 6 weeks, the 2 groups had a similar MP, which increased until skeletal maturity (Fig. 4). The speed of deterioration in the MP in the relapse group was significantly faster (0.2%/month) than in the no-relapse group (0.06%/month) ($p = 0.001$, Student t test). The MP at skeletal maturity was still lower than preoperatively in both groups ($p < 0.001$) (Fig. 4). Logistic regression identified that the baseline MP was not a risk factor for relapse ($p = 0.1$).

The AI decreased in both groups (Table II). At skeletal maturity, the AI differed significantly between the groups ($p < 0.01$). The remodeling rate (i.e., reduction [improvement] in the AI) was 0.06°/month in the no-relapse group compared with 0.04°/month in the relapse group ($p = 0.1$).

With regard to diaphyseal medialization (the MeI), the 6-week measurement was deemed to be the most important for our analysis as it quantified the medialization acquired from the VDRO surgery. It differed significantly between the relapse and no-relapse groups at 6 weeks in both the simple logistic regression ($p = 0.0003$; relative risk [RR] = 0.04, 95% confidence interval [CI] = 0.008 to 0.24) and the multiple regression model ($p = 0.004$; RR = 0.07, CI = 0.01 to 0.42). The average MeI was 1.38 (range, 0.94 to 2.44) in the no-relapse group compared with 1.26 (range, 0.96 to 1.82) in the relapse group. Moreover, assessment of the evolution of the MeI during growth revealed that remodeling toward preoperative values was 5 times faster in the relapse group than in the no-relapse group ($p < 0.05$). Our survivorship analysis showing the

TABLE III Postoperative Complications*

	MCD I	MCD II	MCD III	MCD IV
Type of complication (no. of patients)	HO (3), constipation (2), UTI (2), malunion (2)	Delayed union (1), osteonecrosis Grades I & II (30)	UTI (1), fracture (3), osteonecrosis Grades III & IV (7), early recurrent instability (4)	Osteonecrosis Grade V (4)
Total	9	31	15	4

*MCD = Modified Clavien-Dindo System[27,28], HO = heterotopic ossification, UTI = urinary tract infection. The osteonecrosis grades are according to the Kruczynski classification[30]. There were no MCD V complications (i.e., no postoperative deaths).

inverse proportionality relationship between the MeI and relapse is shown in Figure 5.

Complications were recorded for 59 children (42.1%); 6.4% of the children had an MCD Grade-I complication, 22.1% Grade II, 10.7% Grade III, and 2.9% Grade IV. There were 4 cases of early instability (<12 months postsurgery). Late recurrent instability was recorded in 15 patients (10.7%). These were not considered MCD Grade-III complications as they did not occur in the early postoperative period[27,32]. Osteonecrosis was the most common complication; however, 73.2% were types 1 and 2 according to the Kruczynski classification[28]. Complications are summarized in Table III. There were no perioperative deaths, but 21 patients (15%) died before the age of 30 years, mainly from respiratory disease.

Fifty-six patients (40%) had surgery for neuromuscular scoliosis, which was associated with recurrence of hip instability ($p = 0.006$, chi-square test). Fifteen patients (11%) had revision osseous surgery for recurrent instability.

The inter- and intraobserver reliability of the MeI was high according to the Cohen d test (Tables IV and V).

Discussion

The prevalence of hip displacement is very high in nonambulatory children with CP, and management is fraught with clinical and ethical dilemmas[10]. Osseous reconstructive surgery is the accepted option for moderate to severe hip displacement in children with CP despite the high rate of medical and surgical adverse events, including high relapse and revision surgery rates[22,33]. Hip surveillance has been shown to reduce the rates of dislocation and the need for salvage surgery[7,8]. However, it may result in earlier diagnosis and earlier reconstructive surgery[9]. Surgery at a younger age is a recognized risk factor for relapse and revision surgery[34].

This study provides new insights into the complex remodeling process of the hip after bilateral VDRO in children with CP. There was an acute improvement in the NSA, HSA, and MP after surgery followed by a loss of correction of these 3 parameters until skeletal maturity[31] (Figs. 4 and Table II). This led to recurrent hip instability and revision surgery in 11% of the children. The abnormal biomechanical environment[24] persists in the hip after osseous reconstructive surgery in a child with CP and may adversely impact long-term outcomes[9,20,22,30,31]. Surgeons should be aware of these findings and may choose mitigation strategies such as ensuring adequate APR surgery[8,19], delaying osseous reconstructive surgery until an older age[23,24], ensuring overcorrection of the NSA (more varus) and medialization at the VDRO site, adding pelvic osteotomy in selected hips, and using guided growth to protect against relapse[8,9,33-35].

Delaying osseous reconstructive surgery until an older age is a balancing act as delay will allow an increase in the MP and may lead to femoral head deformity and loss of articular cartilage[9,33]. In addition, the acetabular remodeling recorded in this study does not commence until the hip is realigned and the HJRF is optimized.

The preoperative MP differed significantly between the relapse group and no-relapse group, and the effect of the baseline MP on long-term stability has been identified in multiple studies[35,36].

The AI improved for the whole cohort after osseous reconstructive surgery without pelvic osteotomy, adding complexity to the indications for pelvic osteotomy in osseous reconstructive surgery of the hip. Had we used pelvic osteotomy routinely, it might not have been necessary in the 89% of the hips that showed no relapse and did not require revision surgery.

Despite prior APR surgery, revision APR was required at the time of the VDRO in most hips. Our APR surgical protocol involves use of an abduction hip brace for 6 months; we have not studied compliance[25].

In our study, medialization was measured radiographically using a reliable technique and the MeI at 6 weeks postoperatively, and the amount of medialization acquired during the index operation was found to be the only factor that remained significant in a multivariable analysis for the prediction of recurrent hip instability. Moreover, the amount of medialization was related to both the choice of implant (among plates

TABLE IV Intraobserver Reliability of Measurements of MeI*

	Difference Between Pairs of Measurements					
				95% CI		
	Mean	SD	SEM	Lower	Upper	Cohen D
Observer 1	0.008	0.08	0.01	−0.01	0.03	0.11
Observer 2	−0.01	0.05	0.006	−0.025	0.0004	−0.22
Observer 3	−0.04	0.13	0.016	−0.07	−0.007	−0.28

*MeI = medialization index, SD = standard deviation, SEM = standard error of mean, CI = confidence interval.

TABLE V Interobserver Reliability of the Standard Set of Measurements of MeI*

	Difference Betwen Pairs of Measurements					
				95% CI		
	Mean	SD	SEM	Lower	Upper	Cohen D
Observer 2 vs. 1	−0.02	0.07	0.01	−0.04	0.002	−0.25
Observer 2 vs. 4	−0.03	0.08	0.01	−0.05	−0.005	−0.34
Observer 3 vs. 1	−0.02	0.13	0.015	−0.05	0.01	−0.15
Observer 3 vs. 2	−0.06	0.17	0.02	−0.09	−0.02	−0.34
Observer 4 vs. 1	−0.01	0.15	0.17	−0.05	0.018	−0.11

*MeI = medialization index, SD = standard deviation, SEM = standard error of mean, CI = confidence interval.

with different offsets) and the surgical technique (whether the trapdoor modification described by Howard and Graham was used)[32]. We should emphasize that we did not specifically design a cohort to evaluate medialization at the VDRO site. Rather, it was variability in routine surgical practice and choice of implant that provided an incidental opportunity to study the effects of medialization.

Our study had limitations, including the selection bias inherent to a retrospective cohort analysis. Also, evolution of the surgical technique during the study period may have limited the generalizability of the study. However, the fact that the 3 surgeons operated on most of the patients together could limit that problem. The duration of follow-up and the robust statistical analysis were positive factors in the study.

This study is the first to identify medialization as a variable of interest to reduce recurrence of hip instability after bilateral VDRO in children with CP, and this topic is worthy of further study. New implants with greater offset as well as technical modifications of the surgery might be useful to improve the outcomes of VDRO in children with CP. Moreover, objective determination of a medialization threshold may allow for personalization of the VDRO techniques based on individual hip morphology.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org(http://links.lww.com/JBJS/I560). ■

Note: The authors thank the staff at Royal Children's Hospital, especially the former fellows and colleague orthopaedic surgeons who helped in the treatment of all of the patients enrolled in this study; the statistics professionals who evaluated and helped to correlate the large amount of data; and Igor C. Machado, graphic designer, who helped edit the figures and enhanced their quality for publication.

Frederico C.M. Vallim, MD, PhD[1,2,3,4]
Marcello H. Nogueira-Barbosa, MD, PhD[3,5,6]
João A. M. Guimarães, MD, PhD[2,7,8]
Henrique A. Cruz, MD[1]
Juliana M.B. Lyra, MD[1]
H. Kerr Graham, MD, FRCS(Ed), FRACS[9]

[1]Hospital Estadual da Criança, Rio de Janeiro, Brazil

[2]National Institute of Traumatology and Orthopaedics, Rio de Janeiro, Brazil

[3]Faculdade de Medicina de Ribeirão Preto, Universidade de São Paulo, São Paulo, Brazil

[4]Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

[5]Medical Imaging Department, Faculdade de Medicina de Ribeirão Preto, Universidade de São Paulo, São Paulo, Brazil

[6]Universidade de São Paulo, São Paulo, Brazil

[7]Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

[8]Universidade Federal Fluminense, Rio de Janeiro, Brazil

[9]University of Melbourne, Victoria, Australia

Email for corresponding author: fredericovallim@gmail.com

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