Original Article

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Evaluation of Radiological and Functional Outcomes of Proximal Femoral Varus Derotation Osteotomy in Perthes' Disease: An Ambispective Cohort Study

Orthopaedics Section

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ABSTRACT

Introduction: Perthes' disease is an idiopathic, self-limiting avascular necrosis of the capital femoral epiphysis in children. Varus Derotation Osteotomy (VDRO) is a widely practised surgical containment method aimed at preventing femoral head deformation. However, evidence regarding its radiological and functional outcomes, particularly from the Indian subcontinent, remains limited.

Aim: To evaluate the radiological and functional outcomes of proximal femoral VDRO in Perthes' disease and to assess the influence of age at surgery and disease stage on the final outcome.

Materials and Methods: This ambispective cohort study was conducted at the Department of Orthopaedic Surgery, St. Stephen's Hospital, New Delhi, India from October 2020 to September 2021. A total of 30 patients (31 hips) who underwent VDRO for Perthes' disease were evaluated. Radiological parameters including Centre-Edge (CE) angle, Reimer's Migration Index (RMI), neck-shaft angle, VDRO angle, and varus angle were measured preoperatively, postoperatively, and at final follow-up. Femoral head sphericity was assessed using Mose's criteria and Stulberg classification. Functional outcome was evaluated using the Iowa hip score. Chi-square test was used for association analysis with p-value <0.05 considered significant.

Results: The mean age at surgery was 8.13±1.43 years (range: 6-11 years) with a male predominance (29/30, 96.67%). The mean CE angle improved from 26.10±4.82° preoperatively to 34.16±3.91° at final follow-up, and the mean RMI decreased from 18.42±4.65 to 3.81±2.18. Twenty-three hips (74.19%) achieved spherical femoral heads, and 21 hips (67.74%) were classified as Stulberg grade 2. The mean Iowa hip score was 96.16±3.04 (range: 90-100). Statistically significant associations were observed between age at surgery and femoral head sphericity (p-value=0.040), Modified Elizabethtown classification and sphericity (p-value=0.019), and Modified Elizabethtown classification and Stulberg grade (p-value=0.023).

Conclusion: Proximal femoral VDRO is an effective treatment for Perthes' disease, yielding favourable radiological and functional outcomes. Early surgical intervention before advanced fragmentation significantly improves femoral head sphericity and overall hip outcome.

Keywords: Avascular necrosis, Containment, Femoral head sphericity, Legg-Calvé-Perthes disease, Stulberg classification

INTRODUCTION

Perthes' disease, also known as Legg-Calvé-Perthes disease, is an aseptic, non inflammatory, idiopathic, self-limiting avascular necrosis of the capital femoral epiphysis in children [1]. The condition predominantly affects children aged 4 to 12 years, with peak incidence between 6 and 8 years, and demonstrates a marked male predilection with a male-to-female ratio of 4:1 to 5:1 [2,3]. Bilateral involvement is observed in 10-20% of cases. The disease follows a predictable course of necrosis, fragmentation, reconstitution, and healing, typically spanning 2 to 4 years [1,4].

The revascularising epiphysis consists of biologically plastic bone that is susceptible to irreversible deformation under weight-bearing forces and muscular stresses transmitted across the acetabular rim [5]. Deformation of the femoral head is virtually inevitable when 20% or more of the epiphyseal width extends beyond the acetabular confines [1,6]. The resultant aspherical femoral head predisposes to secondary degenerative arthritis of the hip in adult life, representing the principal long-term complication of this condition [4,7].

The cornerstone of treatment in Perthes' disease is the principle of containment, which aims to maintain the femoral head deeply within the acetabulum, thereby preventing lateral extrusion and collapse [1,8]. Containment can be achieved through non operative methods such as casting and bracing, or through surgical procedures including femoral varus osteotomy and pelvic osteotomies [8,9]. Femoral VDRO redirects the femoral head into the acetabulum and has the additional advantage of decompressing the hip joint and improving femoral head perfusion [10,11].

Several studies have reported favourable outcomes following VDRO in Perthes' disease [10-16]. However, there is considerable variation in the reported results, and the optimal timing of surgical intervention in relation to disease stage and patient age remains debated [1,10,17]. The Modified Elizabethtown classification proposed by Joseph B et al., provides a framework for staging the disease and guiding treatment decisions [1]. Despite the volume of international literature, contemporary outcome data from the Indian subcontinent - where Perthes' disease often presents at a more advanced stage at first contact and where the resources available for prolonged conservative containment differ from Western settings - remain sparse. There is therefore a need for region-specific evidence describing the radiological and functional outcomes of proximal femoral VDRO and identifying the patient and disease variables that drive these outcomes. The present study was conducted to evaluate the radiological and functional outcomes of proximal femoral VDRO in Perthes' disease and to assess the influence of age at surgery and disease stage on the final outcome. It was hypothesised that younger age at surgery and earlier Modified Elizabethtown stage

at the time of intervention is associated with better femoral head sphericity, superior Stulberg grade, and higher functional scores following proximal femoral VDRO.

MATERIALS AND METHODS

This ambispective cohort study was conducted at the Department of Orthopaedic Surgery, St. Stephen's Hospital, New Delhi, India, where all surgical procedures, patient recruitment, and clinical and radiological follow-up were carried out and the study data were collected. The subsequent data analysis, interpretation, and manuscript preparation were undertaken at Parul Institute of Medical Science and Research, Parul University, Vadodara, Gujarat, India - the present institutional affiliation of all authors. The study comprised two time periods: i) the data acquisition period - patients who had undergone proximal femoral VDRO for Perthes' disease between January 2014 and December 2019 were identified from hospital surgical records; and ii) the study planning, recall, and analysis period - patients were contacted, recalled for clinical and radiological re-evaluation, and the data were compiled, analysed, and interpreted between October 2020 and September 2021. Ethical approval was obtained from the Institutional Ethics Committee (Ref. No. SSHEC/R0166). Written informed consent was obtained from all participants (and from a parent or legal guardian for those below 18 years) before inclusion. The study was conducted in accordance with the Declaration of Helsinki.

A total of 42 patients who had undergone VDRO for Perthes' disease were identified from hospital records and contacted for follow-up. Thirty patients (31 hips) who responded and met the inclusion criteria were enrolled.

Inclusion criteria: All patients who had undergone varus osteotomy for Perthes' disease at the institution and were willing to participate were included in the study.

Exclusion criteria: Patients treated with pelvic osteotomy, conservative management, those presenting in the healed stage without prior treatment, and those unwilling to participate were excluded from the study.

Sample size calculation: Based on the study by Aydin BK et al., the Standard Deviation (SD) of hip Range of Motion (ROM) following VDRO was reported as 18.2° [13]. Adopting an absolute precision (d) of 6° and a two-sided 5% level of significance ($Z\alpha=1.96$), the minimum sample size was calculated using the standard formula for estimating a single mean: $N \geq (Z\alpha^2 \times SD^2)/d^2 = (1.96^2 \times 18.2^2)/6^2 \approx 35.3$, which was rounded up to 36 hips. Of 42 eligible patients identified from records, 30 patients (31 hips) responded to recall and met the inclusion criteria, falling marginally short of the calculated target.

Clinical and radiological assessment: All patients underwent a detailed clinical evaluation including assessment of pain symptoms, hip ROM (flexion, extension, abduction, adduction, internal and external rotation measured with a goniometer), gait pattern (presence of antalgic limp or Trendelenburg gait), and limb length discrepancy (true length, supine, anterior superior iliac spine to medial malleolus). The Iowa hip score (Larson scoring system) was calculated for all patients at final follow-up [18]. In the one patient with bilateral involvement, both hips were treated as independent units for radiological measurements but a single per-patient Iowa score was assigned, reflecting the lower-functioning side, to avoid statistical dependence in functional analysis.

Radiographic evaluation included assignment of the Modified Elizabethtown stage to all hips, as proposed by Joseph B et al., [1]. Standardised standing antero-posterior pelvis and frog-leg lateral radiographs of the hip were obtained at every visit (mean 6.2±1.1 visits per patient: preoperative, immediate postoperative, six weeks, three months, six months, and yearly thereafter until final follow-up) [19]. The CE angle of Wiberg was measured as the angle between a vertical line through the centre of the femoral head and a line joining the centre of the head to the lateral edge of the acetabulum [20]. RMI was calculated as the percentage of the femoral head lying lateral to Perkin's line. The neck-shaft angle was measured between the long axis of the femoral neck and the long axis of the femoral shaft. The VDRO angle (here defined as the resultant proximal femoral angle measured between the lateral cortex of the proximal fragment and the lateral cortex of the distal femoral shaft on the immediate postoperative antero-posterior radiograph) and the varus angle (the angle of varus correction applied at osteotomy, measured as the difference between preoperative and immediate postoperative neck-shaft angles) were recorded; remodelled values of both were calculated at final follow-up. Measurements were performed using calibrated digital tools on the Picture Archiving and Communication System (PACS) and verified with a manual goniometer on hard-copy films where required. All radiographs were independently measured by two orthopaedic surgeons blinded to clinical outcome, and the mean of the two readings was used; inter-observer agreement was assessed using the intraclass correlation coefficient, which exceeded 0.85 for all parameters, indicating excellent reliability. Femoral head sphericity was assessed using Mose's criteria (spherical, irregular, and flat) [16], and the Stulberg classification (grades I to V) was assigned to all hips at final follow-up [7].

STATISTICAL ANALYSIS

Data analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean±SD for continuous variables and as frequencies and percentages (to two decimal places) for categorical variables. Normality of continuous variables was assessed with the Shapiro-Wilk test. Preoperative versus final follow-up radiological parameters was compared using the paired t-test for normally distributed data and the Wilcoxon signed-rank test where the assumption of normality was not met. The Chi-square test (with Fisher's exact test where any expected cell count was below 5) was used to test associations between categorical variables. A two-sided p-value of <0.05 was considered statistically significant.

RESULTS

Thirty patients (31 hips) with a mean age at surgery of 8.13±1.43 years (range: 6-11 years) were evaluated. Twenty-nine patients (96.67%) were male and one patient (3.33%) was female. Left-sided involvement was observed in 17 cases (56.67%), right-sided in 12 cases (40.00%), and bilateral involvement in one case (3.33%). Final follow-up was performed at a mean of 2.54±0.62 years after surgery (range: 2.0-4.0 years), at which time clinical assessment, radiographic measurements, Iowa hip scoring, and Stulberg grading were obtained for every patient.

Clinical findings: Preoperative pain in the affected hip was reported by 28 patients (93.33%); at final follow-up this had reduced to four patients (13.33%) reporting only occasional mild discomfort after prolonged activity. The mean active hip flexion improved from 88.39±12.74° preoperatively to 116.45±8.62° at final follow-up; extension improved from 8.39±4.21° to 16.45±3.86°; abduction improved from 22.74±6.81° to 38.39±5.94°; adduction improved from 12.10±4.43° to 22.26±4.07°; internal rotation in flexion improved from 8.71±5.42° to 22.58±6.18°; and external rotation in flexion improved from 10.32±4.78° to 19.84±5.21°. All movement-wise preoperative versus final follow-up comparisons were statistically significant on the paired t-test (p-value <0.001 for every movement); the complete data are presented in [Table/Fig-1]. Preoperative Trendelenburg sign was positive in 21 hips (67.74%), which decreased to 5 hips (16.13%) at final follow-up. Mean true limb length discrepancy was 1.10±0.65 cm (range 0-2 cm); none of the patients required a shoe-raise of more than 1 cm.

Disease staging: According to the Modified Elizabethtown classification, three hips (9.68%) were in stage 1b, 16 hips (51.61%) in stage 2a, and 12 hips (38.71%) in stage 2b [Table/Fig-2].

Hip movement	Preoperative (Mean±SD)	Final follow-up (Mean±SD)	p-value*
Flexion (°)	88.39±12.74	116.45±8.62	<0.001
Extension (°)	8.39±4.21	16.45±3.86	<0.001
Abduction (°)	22.74±6.81	38.39±5.94	<0.001
Adduction (°)	12.10±4.43	22.26±4.07	<0.001
Internal rotation in flexion (°)	8.71±5.42	22.58±6.18	<0.001
External rotation in flexion (°)	10.32±4.78	19.84±5.21	<0.001

[Table/Fig-1]: Preoperative versus final follow-up hip Range Of Motion (ROM) (mean±SD, n=31 hips).
*Paired t-test; data are mean±SD over 31 hips

Modified Elizabethtown stage	n (%)
Stage 1b	3 (9.68)
Stage 2a	16 (51.61)
Stage 2b	12 (38.71)

[Table/Fig-2]: Distribution of patients according to Modified Elizabethtown classification.

Radiological outcomes: The mean CE angle improved significantly from 26.10±4.82° preoperatively to 34.16±3.91° at final follow-up (p-value <0.001, paired t-test). The mean RMI decreased from 18.42±4.65 preoperatively to 3.81±2.18 at final follow-up (p-value <0.001), indicating marked improvement in femoral head containment. The mean neck-shaft angle was 127.39±6.84° preoperatively and 130.06±5.71° at final follow-up (p-value=0.038) [Table/Fig-3].

Parameters	Preoperative (Mean±SD)	Final follow-up (Mean±SD)	p-value
CE angle (°)	26.10±4.82	34.16±3.91	<0.001
RMI	18.42±4.65	3.81±2.18	<0.001
Neck-shaft angle (°)	127.39±6.84	130.06±5.71	0.038

[Table/Fig-3]: Comparison of radiological parameters preoperatively and at final follow-up.

The mean VDRO angle was 140.66±5.41° immediately postoperatively, which remodelled to 149.13±4.78° at final follow-up. The mean varus angle was 39.33±4.62° immediately postoperatively, remodelling to 30.86±5.07° at final follow-up, representing a mean remodelling of 8.47±3.21° (range: 3°-14°).

Femoral head sphericity and Stulberg classification: Assessment of femoral head sphericity using Mose's criteria revealed that 23 hips (74.19%) achieved a spherical femoral head, six hips (19.35%) had irregular heads, and two hips (6.45%) had flat femoral heads at final follow-up. According to the Stulberg classification, 21 hips (67.74%) were classified as grade II, eight hips (25.81%) as grade III, and two hips (6.45%) as grade IV. No hips were classified as Stulberg grade I or V [Table/Fig-4].

Stulberg grade	n (%)
Grade II	21 (67.74)
Grade III	8 (25.81)
Grade IV	2 (6.45)

[Table/Fig-4]: Distribution according to Stulberg classification at final follow-up.

Functional outcomes: The functional outcomes of the cohort at final follow-up are summarised in [Table/Fig-5]. The mean Iowa hip score was 96.16±3.04 (range: 90-100); all 30 patients (100.00%) were classified in the "excellent" category (IOWA≥90). The mean limb length discrepancy was 1.10±0.65 cm (range: 0-2 cm). Twenty-five patients (83.33%) had no limp on gait examination, whereas five patients (16.67%) demonstrated a residual limp at final follow-up.

A statistically significant negative correlation was observed between age at surgery and remodelling of the varus angle (Pearson correlation r=-0.46, p-value=0.009), with younger patients demonstrating greater remodelling. The complete correlation analysis of age at surgery with all radiological and functional outcome parameters is presented in [Table/Fig-6]. The association between age at surgery and femoral head sphericity was also significant (Chi-square=9.973, p-value=0.040); all four patients aged ≤6 years (100.00%) achieved spherical femoral heads, whereas none of the patients aged >9 years achieved sphericity [Table/Fig-7].

Parameter	Value (Mean±SD or n, %)	Range/Remarks
Iowa hip score	96.16±3.04	Range 90-100; all excellent
Limb length discrepancy	1.10±0.65 cm	Range 0-2 cm
No limp on gait	25 (83.33%)	–
Residual limp	5 (16.67%)	–

[Table/Fig-5]: Functional outcomes at final follow-up.

Outcome parameter	Pearson r/ Spearman ρ	p-value	Inference
Remodelling of varus angle (°)	-0.46	0.009	Significant
Final CE angle (°)	-0.31	0.087	Not significant
Final Reimer's Migration Index (RMI) (%)	+0.27	0.142	Not significant
Final neck-shaft angle (°)	-0.18	0.331	Not significant
Femoral head sphericity (Mose)†	-0.42	0.020	Significant
Stulberg grade†	+0.39	0.030	Significant
Iowa hip score	-0.22	0.234	Not significant

[Table/Fig-6]: Correlation of age at surgery with radiological and functional outcome parameters (n=31 hips).
†Mose grade and Stulberg grade analysed as ordinal variables (Spearman ρ). Pearson r reported for continuous variables

Age group	Spherical	Irregular	Flat
≤6	4	0	0
7-9	19	4	2
>9	0	2	0

[Table/Fig-7]: Association between age at surgery and sphericity of femoral head.
Chi-square value=9.973, p=0.040*

A significant association was found between Modified Elizabethtown classification and femoral head sphericity (Chi-square=11.751, p-value=0.019). The full set of associations between Modified Elizabethtown stage and all radiological/functional outcomes is presented in [Table/Fig-8]. All three stage 1b hips (100.00%) achieved spherical heads, whereas six of 12 stage 2b hips (50.00%) achieved spherical heads. The association between Modified Elizabethtown classification and Stulberg grade was also significant (Chi-square=11.240, p-value=0.023); 89.47% of hips operated before stage 2b achieved Stulberg grade II, compared with only 33.33% of stage 2b hips [Table/Fig-9].

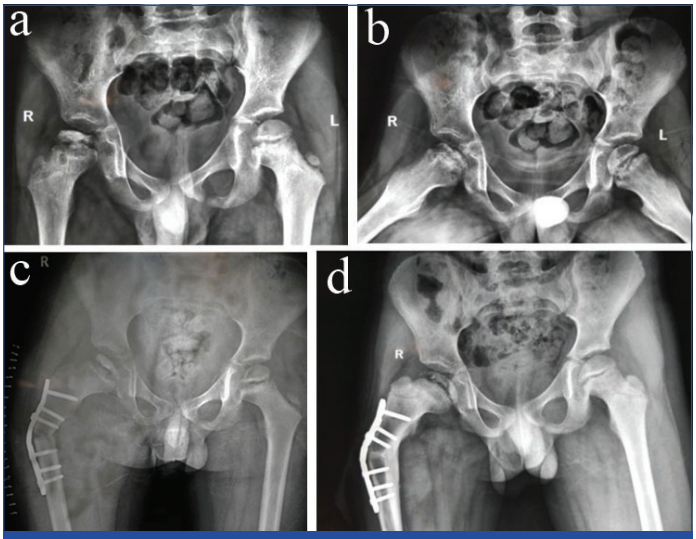
Outcome parameter	Test	Statistic	p-value	Inference
Femoral head sphericity (Mose)	Chi-square	11.751	0.019	Significant
Stulberg grade	Chi-square	11.240	0.023	Significant
Final CE angle (°)	ANOVA	F=3.42	0.046	Significant
Final RMI (%)	ANOVA	F=4.18	0.025	Significant
Remodelling of varus angle (°)	ANOVA	F=2.21	0.128	Not significant
Final neck-shaft angle (°)	ANOVA	F=1.04	0.366	Not significant
Iowa hip score	ANOVA	F=2.96	0.068	Not significant

[Table/Fig-8]: Association of Modified Elizabethtown stage with radiological and functional outcome parameters (n=31 hips).
Sphericity and Stulberg grade analysed by Pearson Chi-square (Fisher's exact when expected count < 5). Continuous variables analysed by One-way ANOVA across the three stages (1b, 2a, 2b)

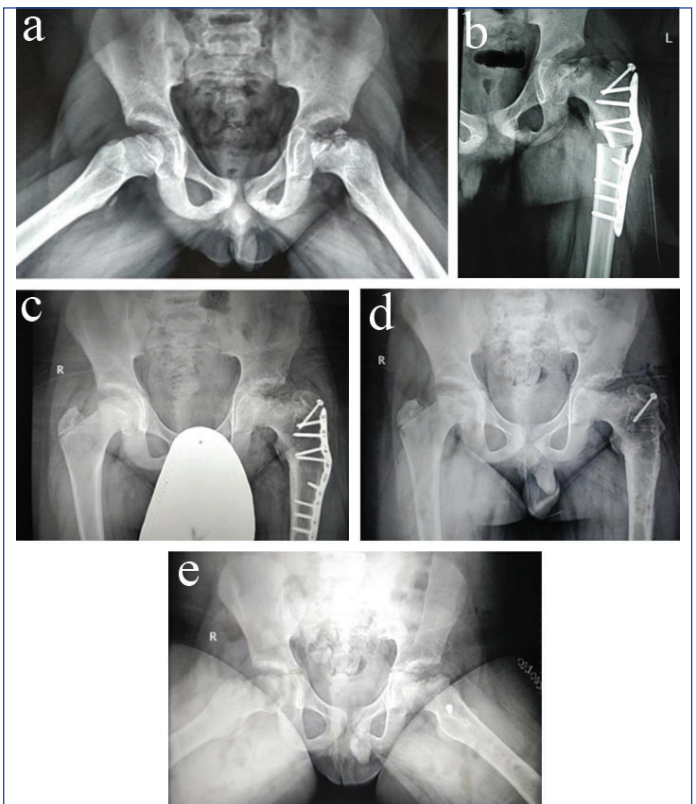
Elizabethtown stage	Stulberg 2	Stulberg 3	Stulberg 4
Stage 1b	3	0	0
Stage 2a	14	2	0
Stage 2b	4	6	2

[Table/Fig-9]: Association between Modified Elizabethtown classification and Stulberg grade.
Chi-square value=11.240, p=0.023*

Representative cases: Preoperative, immediate postoperative and final follow-up radiographs of four representative patients are presented in [Table/Fig-10-13]. Cases 1 and 4 illustrate excellent radiological outcomes with spherical femoral heads (Modified Elizabethtown stages 2b and 1b, respectively); Case 2 demonstrates a suboptimal outcome despite adequate surgical containment (stage 2b) and underscores the residual unpredictability of head sphericity in advanced fragmentation; Case 3 documents the clinical functional range achieved by a typical patient at final follow-up.

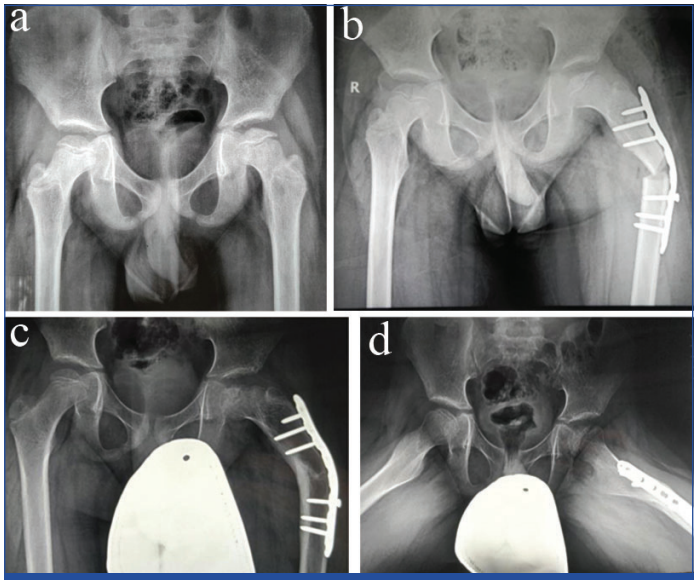


[Table/Fig-10]: Case 1 - Right-sided Perthes' disease in an eight-year-old male, Modified Elizabethtown stage 2b: a) Preoperative AP pelvis: right-sided Perthes' disease, stage 2b; b) Preoperative frog-leg lateral; c) Immediate postoperative AP after VDRO of the right proximal femur; d) Final follow-up at 2.5 years showing remodelled VDRO angle and a healed, well-contained femoral head.



[Table/Fig-11]: Case 2 - Left-sided Perthes' disease in a nine-year-old, Modified Elizabethtown stage 2b, illustrating a sub-optimal radiological outcome despite adequate surgical containment: a) Preoperative AP pelvis: left-sided Perthes' disease, stage 2b; b) Immediate postoperative AP after VDRO with trochanteric epiphysiodesis; c) Final follow-up showing remodelled VDRO angle but an irregular, deformed ossified femoral head; d) AP after implant removal at two years (trochanteric screw retained); image-intensifier examination demonstrated that the apparent osseous defect is filled with un-ossified cartilage; e) Frog-leg lateral at final follow-up.

[Table/Fig-12]: Case 3 - Clinical functional outcome at final follow-up after proximal femoral VDRO: a) Wide and symmetrical hip abduction; b) Comfortable cross-legged sitting (Indian floor-sitting); c) Full squat without pain. The patient's face has been masked for anonymity in accordance with publication guidelines.



[Table/Fig-13]: Case 4- Left-sided Perthes' disease in Modified Elizabethtown stage 1b, illustrating an excellent radiological outcome with a spherical femoral head: a) Preoperative AP pelvis: left-sided Perthes' disease, stage 1b; b) Immediate postoperative AP after VDRO of the left proximal femur; c) Final follow-up AP at 2.5 years showing remodelled VDRO angle and a healed, congruent hip; d) Final follow-up frog-leg lateral demonstrating a well-formed, spherical femoral head.

DISCUSSION

The present study evaluated the radiological and functional outcomes of proximal femoral VDRO in 30 patients (31 hips) with Perthes' disease. The results demonstrated that VDRO is an effective surgical procedure that achieves favourable containment of the femoral head, with 74.19% of hips attaining spherical femoral heads and 67.74% achieving Stulberg grade II at a mean follow-up of 2.54±0.62 years.

The mean age of the present cohort was 8.13±1.43 years, comparable to the study by Elzohairy MM, (mean 7.8 years) and Aydin BK et al., (mean 8.8 years) [12,13]. The marked male predominance

(96.67%, 29/30) in the present study was consistent with the known epidemiology of Perthes' disease, which demonstrates a male-to-female ratio of 4:1 to 5:1 [2,3].

The radiological improvement in containment parameters was notable. The mean CE angle improved from 26.10±4.82° to 34.16±3.91°, and the mean RMI decreased from 18.42±4.65 to 3.81±2.18, confirming effective containment. The preoperative RMI of 18.42 was similar to that reported by Joseph B et al., (18.19) [1]. The proportion of hips with CE angle >20° was 93.55% in the present study, compared with 75.00% reported by Kumar EM et al., and 32.00% by Citlak A [14,15]; this likely reflects the consistently subtrochanteric level of osteotomy employed in the present series, which preserves the integrity of the lesser-trochanteric muscle attachments and provides a longer lever arm for varus correction without compromising rotational stability.

The sphericity of the femoral head is considered the most important determinant of long-term prognosis [7,16,17]. In the present study, 74.19% (23/31) of hips achieved a spherical femoral head, comparing favourably with the results of Joseph B et al., (66%) and McElwain JP et al., (37.5%), and approaching the rate reported by Singh KA et al., (88%) [6,10,21]. These results are also consistent with the large multicentre study by Herring JA et al., and the prospective Norwegian cohort reported by Wiig O et al., both of which emphasised the prognostic importance of femoral head sphericity in determining long-term hip survival [22,23]. The Stulberg classification results in the present series (67.74%, 21/31 grade II; 25.81%, 8/31 grade III; 6.45%, 2/31 grade IV) were superior to those reported by Citlak A (41% grade I-II), Friedlander JK et al., (51% grade I-II) and Terjesen T et al., (43% grade I-II) [11,14,24]. Mechanistically, younger children retain a greater remodelling potential of the femoral head and acetabulum because the cartilaginous epiphysis is more biologically plastic and the triradiate cartilage is still active, allowing both the head and the acetabular rim to mould themselves around the contained shape during the late fragmentation and reossification phases [4,7,16,22]. By containing the lateral pillar within the bony confines of the acetabulum during this remodelling window, VDRO converts what would otherwise be eccentric loading on a soft revascularising epiphysis into more uniform compressive loading, favouring spherical reossification.

The present study demonstrated a significant negative correlation between age at surgery and remodelling of the varus angle (p-value=0.009), consistent with the expected greater remodelling potential in younger children. However, Herceg MB et al., and Talkhani IS et al., reported that remodelling was independent of age [25,26]. This discrepancy may be attributed to differences in follow-up duration and osteotomy level.

The significant association between Modified Elizabethtown stage and both femoral head sphericity (p-value=0.019) and Stulberg grade (p-value=0.023) reinforces the importance of early surgical intervention. When surgery was performed before stage 2b, 89.47% of hips achieved Stulberg grade II, compared to only 33% in stage 2b cases. These findings are concordant with the recommendations of Joseph B et al., who advocated surgery before stage 2b for optimal outcomes [1,6]. Similar results were reported by Axer A et al., who demonstrated that only 9% of patients operated during the necrotic phase had poor sphericity, compared to 56% of those operated during the regenerative phase [27].

The functional outcomes in the present series were excellent, with a mean Iowa hip score of 96.16±3.04. The mean limb shortening of 1.10±0.65 cm was comparable to that reported by McElwain JP et al., (1.0 cm), Citlak A (1.2 cm) and Elzohairy MM et al., (0.9 cm) [10,12,14]. This degree of shortening is generally not clinically significant and, when associated with persistent limp after disease healing, may be addressed by a valgus re-osteotomy.

A clinically important observation in the present cohort was that, even in stage 2b cases, sphericity of the femoral head was achieved in 50.00% of hips. This finding has direct practical implications: while the strongest determinant of a spherical outcome remains operating before fragmentation reaches stage 2b - consistent with Joseph B et al., and Axer A et al., [1,6,27] - VDRO should not be regarded as futile once stage 2b is reached. In a real-world Indian setting, where children frequently present late - as also reported in the Indian VDRO cohort of Mishra S et al., [28] - the option of containment surgery still offers a reasonable chance (1 in 2 in this series) of restoring sphericity and should be discussed with the family rather than reflexively withheld. The overall superior Stulberg distribution in the present series, despite stage 2b accounting for 38.71% of hips, supports a low threshold for offering VDRO whenever the head is still containable.

Limitation(s)

The present study had several limitations. First, the sample size of 31 hips fell short of the calculated target of 36 hips because 12 of 42 eligible patients did not respond to recall; this attrition reduces the statistical power to detect small effect sizes and raises the possibility of selection bias, as patients with better outcomes may have been preferentially motivated to return for follow-up. Second, the partly retrospective historical component of the ambispective design limits the ability to control for unmeasured confounders, including disease severity at first presentation and adherence to postoperative weight-bearing protocols. Third, the mean follow-up period of 2.54±0.62 years is insufficient to assess long-term outcomes, particularly the development of secondary osteoarthritis, which would require follow-up to skeletal maturity and ideally to a minimum of 20 years. Fourth, the rotational component of the osteotomy could not be quantified retrospectively from available records and antero-posterior/frog-leg lateral radiographs, since true rotational measurement requires standardised CT or fluoroscopic data not available for this cohort. Fifth, the inclusion of one bilateral case introduces a degree of within-patient correlation; although this was mitigated by treating bilateral hips as independent units only for radiological measurements and assigning a single per-patient functional score, residual non-independence cannot be excluded. Finally, being a single-centre study from a tertiary referral hospital, the generalisability of findings to community settings and to other regions of India may be limited. The increased lifetime risk of injuries requiring hospitalisation reported among children with Legg-Calvé-Perthes disease [29] could not be evaluated within the available follow-up window of this study.

Future research should address these limitations through prospective, multicentre studies with larger cohorts and longer follow-up extending to skeletal maturity, ideally beyond 20 years, to capture the development of secondary osteoarthritis. Comparative trials are warranted between proximal femoral VDRO and pelvic containment procedures (Salter and triple osteotomies), as well as combined femoral-pelvic procedures, to identify the optimal containment strategy in different Modified Elizabethtown stages. Three-dimensional imaging modalities - such as low-dose CT or magnetic resonance imaging with three-dimensional reconstruction - should be employed to quantify the rotational component of the osteotomy and to objectively characterise the residual head deformity in sub-optimal-outcome cases. Standardised outcome reporting using validated patient-reported tools {such as the PedsQL and the Hip Disability and Osteoarthritis Outcome Score (HOOS)} alongside radiological measures will allow more meaningful inter-study comparison. Finally, prognostic-modelling work integrating age, Modified Elizabethtown stage, lateral pillar height, and inter-observer-validated staging is needed to support individualised preoperative counselling and shared decision-making, particularly in stage 2b cases where outcomes remain partially unpredictable.

CONCLUSION(S)

Proximal femoral VDRO is an effective treatment method for Perthes' disease, providing good functional, clinical, and radiological outcomes in the short term. The procedure significantly improves femoral head containment, as evidenced by improvement in CE angle and RMI. Early surgical intervention before advanced fragmentation (Modified Elizabethtown stage 1b and 2a) is associated with significantly better femoral head sphericity and Stulberg grades. These results support the role of VDRO as a reliable containment procedure in the management of Perthes' disease, with younger age and earlier disease stage being favourable prognostic factors.

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