Article

Comparison of Short-Term Radiographic Outcomes Between Femoral Varus Osteotomy and Salter Osteotomy in the Management of Legg-Calvé-Perthes Disease

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AIM: To compare short-term radiographic outcomes of femoral varus osteotomy (FVO) and Salter innominate osteotomy (SIO) in treating Legg-Calvé-Perthes disease (LCPD) and to identify prognostic factors through multivariate analysis.
METHODS: This retrospective study included 33 pediatric LCPD patients (mean age: 6.80 ± 1.82 years) treated between January 2016 and January 2021, with a mean follow-up of 21.09 ± 10.63 months. Patients were categorized into FVO (n = 20) and SIO (n = 13) groups. Radiographic parameters, including center-edge angle, acetabular index (AI), acetabular head index (AHI), and Sharp angle, were evaluated preoperatively and postoperatively. Hip morphology was assessed using the modified Stulberg classification. Multivariate ordered logistic regression was used to identify predictors of radiographic outcome.
RESULTS: Postoperative AI and AHI differed significantly between the two groups ($p < 0.001$). Stulberg classification outcomes showed a higher proportion of excellent results in the SIO group (53.84%) compared to the FVO group (40.00%), although the difference was not statistically significant ($p = 0.091$). Multivariate analysis identified older age and advanced Catterall stage as independent predictors of poorer outcomes ($p < 0.05$).
CONCLUSIONS: Both surgical approaches demonstrate clinical efficacy in the management of LCPD. However, SIO offers enhanced acetabular remodeling potential. Key prognostic factors include skeletal maturity and the degree of epiphyseal involvement (Catterall stage III/IV), suggesting that early surgical intervention may yield improved outcomes.

Keywords: Legg-Calvé-Perthes disease; femoral varus osteotomy; Salter innominate osteotomy; acetabular remodeling; prognostic factors

Introduction

Legg-Calvé-Perthes disease (LCPD), also known as Perthes disease, is a self-limiting pediatric hip disorder that primarily affects children. As early as 1910, three physicians, Legg, Jacques Calvé, and Georg Perthes, independently reported cases of ischemic necrosis of the femoral head. They were the first to describe osteochondrosis of the femoral head, also referred to as epiphyseal hip osteonecrosis or juvenile osteochondritis of the femoral head. The principal clinical manifestations of Perthes disease include limping or a Trendelenburg gait, hip pain, and restricted range of motion [1]. Epidemiological studies have shown significant global variation in its incidence, ranging from 0.4 to 29.0 cases per 100,000 children under the age of 15 [2]. A recent nationwide study from Sweden reported an incidence of 4.2 cases per 100,000 children aged 2–12 years in 2019, with 77% of the cases occurring in boys [3]. LCPD most commonly affects children between the ages of 2 and 14 years, with peak incidence observed in the 5–6 year age group [4].

Although the precise etiology of LCPD remains unclear, several factors, including genetic predisposition, parental smoking, environmental influences, and childhood obesity, are considered significant contributors to disease development [5,6]. The pathophysiological progression of LCPD is divided into distinct radiological stages according to the Waldenström classification, including stages Ia, Ib, IIa, IIb, IIIa, IIIb, and IV. Reversible deformation of the femoral head is observed in stages Ia through IIa, whereas irreversible changes begin in stage IIb and persist through stage IIIa [6]. This pathological process involves various biomarker changes, including impaired linear growth and delayed bone age, reduced growth factor activity (notably decreased growth hormone mediator A and Insulin-like Growth Factor (IGF)), abnormalities in the coagulation pathway (including increased incidence of factor V Leiden mutation and decreased protein C/S levels), and disrupted collagen metabolism, specifically decreased type I collagen metabolism and reduced synthesis of type III col-

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lagen [2]. The widely accepted pathophysiological mechanism involves compromised perfusion of the lateral femoral epiphyseal artery, making the femoral head susceptible to ischemic necrosis. Additional aggravating factors, such as trauma and synovitis, may exacerbate the impairment of blood flow to the femoral head, leading to elevated intraosseous pressure and venous congestion, thereby accelerating disease progression [7].

During the healing phase, treatment primarily aims to preserve the spherical shape of the femoral head and maintain optimal joint alignment, thus preserving a normal anatomical relationship between the femoral head and acetabulum [8]. Over the years, numerous surgical and non-surgical methods have been proposed for symptomatic LCPD of the hip, including femoral varus osteotomy (FVO), Salter osteotomy, combined osteotomies, triple osteotomy, Chiari osteotomy, and acetabuloplasty. However, conclusive evidence to determine the optimal surgical approach for the best outcomes remains insufficient [9].

Among the available options, FVO and Salter innominate osteotomy (SIO) are commonly employed surgical techniques designed to enhance the acetabular head index, redistribute load forces across the hip joint, and promote remodeling and healing of the femoral head [10]. FVO facilitates improved femoral head perfusion by altering femoral alignment, therefore supporting bone regeneration; conversely, SIO reorients the acetabular socket to enhance femoral head containment, maintain sphericity, and prevent further deformation [11,12]. Despite their widespread use, there remains a lack of high-quality comparative evidence on the efficacy of FVO versus SIO in the treatment of LCPD, particularly in terms of immediate postoperative radiographic outcomes and long-term functional recovery.

The primary objective of this study was to compare immediate postoperative radiographic indicators, including acetabular head index (AHI), acetabular index (AI), center-edge (CE) angle, and Sharp angle, between FVO and SIO in the surgical management of LCPD. Additionally, this study identified key prognostic factors affecting treatment outcomes, especially the impact of preoperative Catterall classification, Herring classification, and patient age. Furthermore, the study aimed to determine which surgical approach is more advantageous in restoring femoral head morphology, improving hip joint function, and preventing future deformation of the femoral head.

Materials and Methods

Study Subjects and Basic Information

Between January 2016 and January 2021, a total of 33 pediatric patients diagnosed with LCPD were admitted to the Department of Orthopedics at Kunming Children's Hospital for treatment. This study was approved by the Ethics Committee of Kunming Children's Hospital (Approval No. IEC-C-008-A07-V3.0) and conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from the legal guardians of all patients, ensuring complete protection of patient privacy. The inclusion criteria were as follows:

(1) Patients aged 4–12 years diagnosed with LCPD;
(2) Patients in the necrotic-sclerotic or fragmentation stage of the disease;
(3) Patients who underwent either FVO or SIO;
(4) Patients with complete preoperative and postoperative radiographic data and follow-up records, with a minimum follow-up duration of one year.

Exclusion criteria included:

(1) Patients aged $<$4 years or $>$12 years at the time of surgery;
(3) Patients in the repair or healing stages of the disease;
(3) Patients with comorbid neuromuscular disorders, hip dislocation, septic arthritis, or prior surgeries involving femoral head repositioning or other types of osteotomy;
(4) Patients with incomplete or missing follow-up data.

Sample size determination was based on an expected large effect size (Cohen's d = 0.8) [13–15], with a statistical power of 0.8 (1-β = 0.80) and a significance level of α = 0.05. Accordingly, a total of 33 subjects were included to achieve adequate statistical power to detect significant differences between treatment groups. The final cohort included 33 LCPD cases (33 hips), including 26 boys (78.79%) and 7 girls (21.21%). Left hip involvement was observed in 51.52% of cases, while 48.48% involved the right hip. Among the participants, 60.6% underwent FVO and 39.4% underwent SIO, with a mean age at surgery of 6.80 $\pm$ 1.82 years. Based on the Herring classification, 6 cases were Type B (18.18%), 7 were Type B/C (21.21%), and 20 were Type C (60.61%). According to the Catterall classification, 9 cases were grade 2 (27.27%), 15 were grade 3 (45.45%), and 9 were grade 4 (27.27%).

Surgical Interventions (FVO and SIO)

Two surgical approaches were employed in this study: FVO and SIO. All surgeries were performed by a team of senior orthopedic surgeons to ensure the consistency and reproducibility of surgical techniques.

Femoral Varus Osteotomy (FVO Group)

Patients were positioned supine with the affected hip slightly abducted to facilitate surgical access. A standard lateral approach to the femur was used, involving an 8–10 cm longitudinal incision along the outer thigh, extending distally from below the greater trochanter to expose the proximal femur. The fascia lata and vastus lateralis were carefully retracted to fully expose the femoral shaft and neck.

A transverse osteotomy was performed approximately 1 cm distal to the lesser trochanter. Based on preoperative radiographic planning, a wedge-shaped osteotomy was carried out to reduce the femoral neck-shaft angle. The preoperative femoral neck-shaft angle typically ranged from 130°–140°, with correction targeted at 120°–125°. The average internal rotation angle during osteotomy was 10° ± 2°. Osteotomy angles were precisely controlled using a bone saw to minimize the risk of instability or rotational misalignment.

Following osteotomy reduction, femur stabilization was achieved using a pre-contoured pediatric locking plate (Synthes®, Oberdorf, Switzerland), positioned laterally on the femur and secured with four cortical screws. This fixation method ensured postoperative mechanical stability while preserving the vascular supply to the femoral head. Intraoperative fluoroscopy was used to confirm the correction of the neck-shaft angle within the desired range.

Postoperatively, the affected limb was immobilized in a hip spica cast for six weeks to maintain osteotomy alignment. Passive range-of-motion exercises for the hip joint were started one week after surgery. Gradual weight-bearing training was initiated after cast removal at six weeks, with progressive rehabilitation to enhance joint mobility and promote bone healing.

Salter Innominate Osteotomy (SIO Group)

Patients were positioned supine, with the affected hip slightly elevated to facilitate the pelvic osteotomy. A modified Smith-Petersen anterior approach was used, involving a 5–8 cm incision extending from the anterior superior iliac spine to the anterior inferior iliac spine. Care was taken to avoid injury to the lateral femoral cutaneous nerve during dissection, minimizing the risk of postoperative complications.

A complete innominate osteotomy was performed using a bone saw, extending from the ischial notch to the anterior inferior iliac spine. The goal was to advance the acetabulum anteriorly and laterally. Intraoperative fluoroscopy was used to monitor the osteotomy line and the correction angle. The intended outcome was to increase the acetabular head index by achieving a CE angle correction of 15° ± 3°.

Following the osteotomy, the mobilized iliac bone fragment was advanced and stabilized using two 4.5 mm cortical bone screws placed in a cross pattern. Fluoroscopic imaging confirmed successful anterior and lateral displacement of the acetabulum and improvement in the acetabular head index, verifying that the intended correction had been achieved.

Postoperatively, patients wore a hip abduction brace for four weeks to maintain the surgical correction. Weight-bearing was restricted during this initial period. Active hip joint exercises were initiated thereafter, with a gradual resumption of weight-bearing walking allowed after between 6 and 8 weeks, depending on radiographic evidence of bone healing.

Assessment Indicators

Radiographic evaluations were conducted at standardized intervals: preoperatively, immediately postoperatively, at 3 months, 6 months, 1 year, and at the final follow-up. Data collected included the patient's age at surgery, surgical technique used, and radiographic parameters at the final follow-up. These data were systematically retrieved from the hospital's inpatient electronic medical records. All radiographs were independently reviewed and measured by two senior orthopedic specialists. Measured radiographic parameters included the AI, CE angle, Sharp angle, and AHI. The AHI was defined as the proportion of the lateral diameter of the femoral head that was covered by the acetabulum.

Radiographic Measurements

For anteroposterior pelvic radiographs, patients were positioned supine with both lower limbs internally rotated by 15° to optimize visualization of the acetabulum and femoral head in a standard orientation. The focal film distance was maintained at 100 cm to optimize image clarity. For frog-leg lateral views, patients were positioned supine with the hip joint abducted 45° and flexed 90°, providing improved visualization of the femoral head-acetabulum relationship. Exposure parameters were adjusted based on age and weight, typically ranging from 70–75 kV and 8–12 mAs, to achieve optimal bone contrast.

AI: Measured on standard radiographs as the angle between the lateral margin of the acetabulum and a horizontal reference. This index reflects the degree of acetabular inclination and indicates the acetabular development.

AHI: Defined as the proportion of the femoral head's lateral diameter that is covered by the acetabulum. Measurements were obtained using the Picture Archiving and Communication System (PACS) system to ensure consistency, accuracy, and reproducibility.

CE Angle: Calculated as the angle between a vertical line passing through the center of the femoral head and the line connecting this center to the lateral edge of the acetabulum. A normal CE angle is typically greater than 20°. Postoperative increases in the CE angle indicate improved femoral head coverage by the acetabulum.

Sharp Angle: Defined as the angle formed between lines connecting the inferior margins of both teardrop shapes and the lateral edges of the acetabulum. An increased Sharp angle is associated with acetabular dysplasia, whereas a postoperative decrease suggests improvement in acetabular morphology.

Radiographic Classification

Catterall Staging [16]:

- Stage I: Involvement is limited to the anterior part of the femoral epiphysis. There is no collapse; the affected area undergoes complete resorption without the presence of necrotic bone.
- Stage II: Approximately 50% of the femoral head is affected, showing collapse and necrotic bone formation in the anterolateral region of the femoral head.
- Stage III: Involvement extends to roughly 75% of the

femoral head, including the lateral column, with progressive flattening of the femoral head. Only a small portion of the posterior epiphysis remains unaffected.
- Stage IV: The entire femoral head epiphysis is involved.

Herring Classification [17]:

- Type A: Mild changes in density in the lateral column, with no height loss.
- Type B: Low-density region in the lateral column with height loss of up to 50%. The central column often appears shorter than the lateral column, representing an early manifestation of this type.
- Type C: Lateral column collapse exceeding 50% of its original height, with no distinct boundaries between the lateral and central columns.
- Type B/C: A mixed pattern with features of Type B and Type C type.

Modified Stulberg Classification [18]:

- Group A (Stulberg I and II): The femoral head maintains a spherical shape.
- Group B (Stulberg III): The femoral head is ellipsoid in shape.
- Group C (Stulberg IV and V): The femoral head is flattened.

The modified Stulberg classification, as validated by Huhnstock *et al*. [18], is a reliable tool for evaluating radiographic outcomes in patients with Perthes disease. Postoperative outcomes were classified into three categories based on this system:

- Excellent: Corresponds to Stulberg I or II, indicating near-spherical head remodeling with good joint congruency and a favorable long-term prognosis for joint function.
- Fair: Corresponds to Stulberg III, showing moderate femoral head deformity with preserved joint congruence, potentially resulting in minor functional limitations.
- Poor: Corresponds to Stulberg IV or V, characterized by severe femoral head deformity, often accompanied by acetabular dysplasia, with significant impairment in joint function and increased risk of early-onset osteoarthritis.

Statistical Analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean $\pm$ standard deviation ($\bar{x} \pm$ SD), while categorical variables were expressed as frequencies and percentages (n, %). The Shapiro-Wilk test was used to assess the normality of all continuous variables (e.g., age, preoperative and postoperative radiographic data). For normally distributed data, comparisons were made using the independent samples *t*-test. Categorical variables were analyzed using the Chi-square test. Variables included in the analysis were postoperative AI, AHI, age, and preoperative Catterall and Herring classifications. Multivariate logistic regression analysis was performed to identify risk factors associated with treatment outcomes. A p-value < 0.05 was considered statistically significant.

Results

A total of 33 patients (33 hips) were included in this study, comprising 26 males (78.78%) and 7 females (21.21%). The mean age at the time of surgery was 6.80 $\pm$ 1.82 years, and the mean follow-up duration was 21.09 $\pm$ 10.63 months. Comparison between groups using Chi-square and *t*-tests revealed no statistically significant differences (Table 1). In the FVO group, outcomes were classified as excellent in 40.00% of cases (Stulberg I and II, 8/20), moderate in 30.00% (Stulberg III; 6/20), and poor in 30.00% (Stulberg IV and V; 6/20). In contrast, the SIO group demonstrated a higher proportion of excellent outcomes, with 53.84% (7/13) rated as excellent, 46.15% (6/13) as moderate, and none as poor. These findings suggest that SIO may confer a more favorable long-term effect in preventing femoral head collapse and enhancing hip joint morphology.

Radiographic parameters, including CE, AI, AHI, and Sharp angle, were compared between the FVO and SIO groups (Table 2). Preoperatively, there were no statistically significant differences in CE, AI, AHI, and Sharp angle between the two groups, indicating baseline comparability. Postoperatively, significant differences were observed in AI, Sharp angle, and AHI ($p < 0.05$). Notably, the postoperative AI was significantly lower in the SIO group than in the FVO group ($p < 0.001$), indicating that SIO more effectively improved acetabular tilt and acetabular head index. Furthermore, the AHI improvement was significantly greater in the SIO group compared to the FVO group ($p < 0.001$), suggesting superior restoration of the lateral acetabular head index. Additionally, the postoperative Sharp angle was significantly smaller in the SIO group ($p = 0.034$), indicating that SIO more effectively corrected the acetabular abduction angle, achieving better alignment between the acetabulum and the femoral head.

To further identify independent predictors of postoperative radiographic and clinical outcomes, an ordinal logistic regression analysis was performed, using the modified Stulberg classification (I/II = excellent, III = moderate, IV/V = poor outcome) as the dependent variable. Candidate predictors included age at the time of surgery, Catterall stage, Herring classification, postoperative AI, postoperative AHI, postoperative Sharp angle, surgical side, gender, and type of surgical procedure. Results revealed that age ($p = 0.016$) and Catterall classification (Catterall 2: $p = 0.008$; Catterall 3: $p = 0.006$) were independent predictors of postoperative modified Stulberg outcomes. Specifically, older patients were more likely to exhibit poorer femoral head remodeling, while those classified with higher Catterall stages (III/IV) presented more severe femoral head deformity and unfavorable prognosis (Table 3). In contrast, postoperative AI, AHI, CE angle, Sharp angle, surgical side, gender,

Table 1. Baseline characteristics and radiographic staging of pediatric patients in the FVO and SIO groups.

Variable	Category	Total (n = 33)	FVO (n = 20)	SIO (n = 13)	Test Statistic	*p*-value
Gender (n, %)	Male	26, 78.78%	15, 75.00%	11, 84.61%	0.045	0.835
	Female	7, 21.21%	5, 25.00%	2, 15.38%		
Affected Side (n, %)	Left	17, 51.52%	9, 45.00%	8, 61.53%	0.863	0.353
	Right	16, 48.48%	11, 55.00%	5, 38.46%		
Age (years)		6.80 ± 1.82	6.84 ± 1.89	6.73 ± 1.77	0.161	0.873
Herring Classification (n, %)	B	6, 18.18%	4, 20.00%	2, 15.38%	1.178	0.555
	B/C	7, 21.21%	3, 15.00%	4, 30.76%		
	C	20, 60.61%	13, 65.00%	7, 53.84%		
Catterall Classification (n, %)	II	9, 27.27%	5, 25.00%	4, 30.76%	4.332	0.115
	III	15, 45.45%	7, 35.00%	8, 61.53%		
	IV	9, 27.27%	8, 40.00%	1, 7.69%		
Stulberg Classification (n, %)	I–II	15, 45.45%	8, 40.00%	7, 53.84%	4.798	0.091
	III	12, 36.36%	6, 30.00%	6, 46.15%		
	IV–V	6, 18.18%	6, 30.00%	0, 0.00%		

Type B/C refers to a mixed pattern that exhibits features of both Herring Type B and Type C. Abbreviations: FVO, femoral varus osteotomy; SIO, Salter innominate osteotomy.

Table 2. Comparison of postoperative radiographic parameters between FVO and SIO groups.

Variable	FVO	SIO	Test Statistic	*p*-value
Preoperative				
AI	20.05 ± 4.61	20.92 ± 5.53	–0.492	0.626
AHI	71.12 ± 5.87	72.83 ± 8.70	–0.676	0.504
CE	25.60 ± 6.56	24.08 ± 4.99	0.713	0.481
Sharp Angle	44.55 ± 4.98	45.23 ± 2.01	–0.547	0.589
Postoperative				
AI	19.15 ± 4.75	12.26 ± 4.92	4.752	<0.001
AHI	89.22 ± 4.49	95.32 ± 4.10	–3.943	<0.001
CE	35.65 ± 6.68	39.69 ± 4.97	–1.868	0.071
Sharp Angle	43.60 ± 6.03	39.31 ± 4.29	2.222	0.034

Abbreviations: AI, acetabular index; AHI, acetabular head index; CE, center-edge.

type of surgery, and Herring classification were not significantly associated with modified Stulberg outcomes ($p > 0.05$). These findings suggest that earlier surgical intervention may enhance femoral head remodeling and improve long-term hip joint congruence.

Discussion

Perthes disease encompasses a broad range of treatment methods. However, there is currently a lack of sufficient clinical evidence to guide optimal treatment strategies. The primary objectives of treatment are twofold: first, to prevent deformation of the femoral head and preserve its "spherical" shape; and second, to correct the abnormal relationship between the acetabulum and the femoral head, ensuring adequate containment and maintaining "concentricity of the femoral head and acetabulum" [19]. A study reported a 6.87% incidence of hip arthroplasty among individuals with LCPD [20]. Despite its self-limiting nature, effective intervention remains challenging. Timely treatment across disease stages can reduce or delay the onset of secondary complications, including osteoarthritis and femoroacetabular impingement syndrome.

For children older than six years, especially those classified as Catterall stage III or IV and Herring grade B or higher, surgical intervention is associated with improved prognosis [21]. Currently, FVO and SIO are the most commonly used surgical techniques. FVO, performed on the proximal femur, enhances acetabular coverage of the femoral head, thereby enveloping the affected lateral femoral head region and improving joint stability. This technique aims to reposition the femoral head more deeply into the acetabulum, thereby enhancing containment and joint congruency. A previous study [22] showed that FVO could enable the early necrotic and sclerotic femoral head to bypass the fragmentation stage and progress directly to the repair stage, potentially shortening the disease course.

However, postoperative complications may include limb shortening, gluteus medius gait due to elevation of the greater trochanter, and lateral displacement of the femoral shaft axis. Moreover, optimal surgical outcomes are highly

Table 3. Multivariate logistics regression analysis of factors associated with postoperative outcomes.

Variable	β Coefficient	Standard Error (SE)	Wald Statistic	OR (95% CI)	p-value
AI	–0.039	0.089	0.191	0.962 (0.807–1.146)	0.662
AHI	–0.130	0.118	1.219	0.878 (0.696–1.108)	0.269
CE	–0.046	0.137	0.112	0.995 (0.730–1.249)	0.738
Sharp Angle	–0.602	0.337	3.204	0.547 (0.283–1.059)	0.073
Affected Side	1.231	2.076	0.352	3.426 (0.059–200.465)	0.553
Gender	–3.198	2.228	2.061	0.041 (0.001–3.215)	0.151
Operation Type (SIO vs. FVO)	–2.759	3.375	0.668	0.063 (0.000–47.308)	0.414
Age (years)	0.691	0.286	5.824	1.996 (1.139–3.497)	0.016
Catterall Stage II	–5.942	2.235	7.067	0.004 (0.001–0.210)	0.008
Catterall Stage III	–3.480	1.261	7.616	0.031 (0.003–0.364)	0.006
Catterall Stage IV	Reference	-	-	-	-
Herring Type B	1.161	1.820	0.407	3.193 (0.078–130.573)	0.523
Herring Type B/C	0.341	1.201	0.081	1.406 (0.130–15.211)	0.776
Herring Type C	Reference	-	-	-	-

Abbreviations: OR, Odds Ratio.

dependent on the precision of osteotomy length and the degree of varus correction. Kim *et al*. [23] reported that a varus correction of 10° to 15° during early FVO is associated with better clinical outcomes. In the study by Friedlander and Weiner [24], 43% of patients who underwent femoral varus osteotomy before the age of 9 achieved favorable outcomes classified as Stulberg I or II. These surgical results are slightly marginally superior to those of the present study, suggesting that FVO remains a relatively favorable surgical option.

Salter osteotomy, on the other hand, modifies the orientation of the acetabulum by using the pubic symphysis as the postoperative rotational center, thereby enhancing the acetabulum's capacity to cover the anterosuperior femoral head while preserving its structural integrity. Early study has shown that Salter osteotomy improves the sphericity of the femoral head. Grzegorzewski *et al*. [25] observed that, compared to non-surgical management, Salter osteotomy more effectively restores the femoral head to its normal morphology. The study concluded that acetabular osteotomy significantly aids in femoral head reshaping, and improved sphericity is associated with a reduced incidence of adult-onset degenerative osteoarthritis. In this study, no adverse treatment outcomes were observed in the SIO group. This may be due to preoperative differences in the extent of femoral head necrosis between the groups. In the FVO group, 40.00% of patients were classified as preoperative Catterall grade 4, whereas only 7.69% were classified as such in the SIO group. In cases of severe femoral head necrosis, performing either femoral osteotomy or SIO alone may not yield favorable outcomes, and a combined surgical approach may be more effective.

According to comprehensive literature reports [26,27], favorable prognoses are typically observed when the postoperative Sharp angle is less than 44°, the CE exceeds 22°, and the acetabular head index rate exceeds 80%. In evaluating the efficacy of the two surgical methods in this study, no statistically significant difference in overall clinical outcomes was found between the groups ($p = 0.091$), and both procedures met the aforementioned criteria. Thus, both surgical approaches are beneficial in the management of Perthes disease, and the choice of procedure may be guided by the surgeon's experience and intraoperative judgement. However, significant differences were identified between the two groups in postoperative radiographic parameters, including AI, AHI, and the Sharp angle. AI and Sharp angle are key indicators of acetabular inclination and developmental maturity. Lower AI and Sharp angle values suggest enhanced acetabular containment capacity of the femoral head [26,28]. The results of this study revealed that the postoperative AI in the SIO group was significantly lower than that in the FVO group ($p < 0.001$), with a corresponding significant reduction in the Sharp angle ($p = 0.034$). These findings suggest that SIO is more effective in repositioning and abducting the acetabulum, thereby improving its conformity with the femoral head. Consistent with our findings, previous studies have shown that Salter osteotomy enhances the acetabular head index by rotating the acetabular roof, thus reducing lateral exposure of the femoral head and decreasing the risk of femoral head collapse [29,30].

The AHI is a critical indicator for assessing the compatibility between the femoral head and acetabulum. An increased AHI reflects greater femoral head stability and improved load-bearing capacity of the hip joint [31]. In this study, the improvement in AHI in the SIO group was significantly greater than in the FVO group ($p < 0.001$). This may be attributed to the mechanism of Salter osteotomy, which enhances femoral head containment through acetabular abduction and anterior rotation. In contrast, FVO primarily alters the alignment of the femoral mechanical axis to improve its articulation with the existing acetabulum, offering limited direct improvement in the acetabular head index. Although radiographic assessment in this study revealed superior acetabular containment and femoral head stability in the SIO group, it remains unclear whether these advantages translate into long-term clinical benefits. The follow-up period (21.09 $\pm$ 10.63 months) primarily reflects short-term radiographic outcomes and is insufficient for evaluating long-term joint function or degenerative changes. Some studies have suggested that Salter osteotomy may increase the risk of long-term hip joint degeneration [32,33]. Therefore, while the present findings support Salter osteotomy for improving short-term radiographic outcomes, long-term functional benefits require further prospective investigation.

Multivariate logistic regression analysis was performed in this study, incorporating variables such as postoperative AI, AHI, age at the time of surgery, preoperative Catterall classification, and Herring classification. The results showed that increased surgical age was associated with poorer postoperative femoral head remodeling outcomes (OR = 1.996, $p = 0.016$). This may be due to the declining growth potential of the epiphysis with age, resulting in a reduced capacity for femoral head reshaping. A previous study suggested that LCPD patients undergoing surgery between the ages of 5 and 7 tend to have better prognoses, while those operated on after the age of 8, even with optimal surgical intervention, exhibit a higher proportion of Stulberg III–IV outcomes [34]. This implies that earlier surgical intervention may improve the remodeling potential of the femoral head. Rosenfeld *et al.* [35] reported that 80% of patients treated before age 6 had favorable outcomes. However, children diagnosed at 4–5 years 11 months with Herring Type B/C or C lateral column involvement demonstrated poorer outcomes. Therefore, we believe that earlier disease onset and a smaller area of femoral head involvement may contribute to more favorable surgical outcomes.

Patients with Catterall stages II or III exhibited significantly better postoperative outcomes compared to those classified as Catterall stage IV. Compared to the reference group (Catterall stage IV), patients with Catterall stage II demonstrated a markedly lower likelihood of poor outcomes (OR: 0.004, $p = 0.008$), while those with stage III also showed improved prognosis (OR: 0.031, $p = 0.006$). These findings suggest that patients with extensive necrosis have limited potential for femoral head remodeling, even following surgical intervention. Previous study indicated that Catterall III/IV patients, due to larger necrotic regions and abnormal hip joint stress distribution, are more likely to develop postoperative osteoarthritis [36]. Therefore, in patients with Catterall III/IV disease, careful preoperative assessment of the extent of necrosis is crucial, and supplementary interventions, such as hip joint unloading or rehabilitative therapies, should be considered to optimize treatment outcomes. Notably, although significant differences in postoperative AI, AHI, and Sharp angle were observed between the two surgical methods, these parameters were not identified as independent predictors in the multivariate regression analysis ($p > 0.05$). This may be due to variability in individual femoral head repair potential, adherence to postoperative rehabilitation protocols, and other biomechanical factors. These findings suggest that preoperative disease severity (Catterall classification) and timing of surgical intervention (age) may be more decisive in influencing outcomes. Early surgical intervention may optimize femoral head reshaping, while patients with Catterall III/IV, even with surgical correction, may continue to experience less favorable outcomes. Thus, clinical attention should focus on early screening and tailored treatment strategies for these high-risk patients.

Although this study provides valuable radiographic and clinical follow-up data comparing two surgical approaches, several limitations must be acknowledged. The sample size was relatively small, potentially affecting the statistical power of the analysis. Future larger-scale, multi-center studies are needed to validate these findings. Moreover, the short-term follow-up period primarily reflects radiographic changes and does not provide a comprehensive assessment of long-term joint function, progression of hip joint degeneration, or postoperative complications. Therefore, longer-term follow-up is required to evaluate the long-term efficacy of these procedures. Additionally, this study relied primarily on radiographic measurements and the Stulberg classification to assess surgical outcomes but did not incorporate patient-reported quality-of-life indicators, such as the Harris Hip Score or Western Ontario and McMaster Universities Osteoarthritis (WOMAC). Future studies should integrate both objective radiographic and subjective functional outcomes to provide a more comprehensive evaluation of treatment efficacy. Lastly, the retrospective design of this study introduces potential selection and information biases. For instance, factors such as postoperative rehabilitation compliance, which could influence final outcomes, were not included in the analysis. Future prospective, randomized controlled trials (RCTs) are warranted to further validate the reliability and generalizability of these findings.

Conclusions

This study demonstrates that SIO is superior to FVO in promoting acetabular reshaping and femoral head containment. SIO significantly improved the AI and Sharp angle, thereby enhancing acetabular containment of the femoral head and reducing the risk of femoral head migration, particularly in patients with hip dysplasia or significant femoral head displacement (such as those classified as Herring Type C). Furthermore, the improvement in AHI was significantly greater in the SIO group compared to the FVO group, potentially offering advantages in preventing postoperative hip joint degeneration and reducing the risk of osteoarthritis, especially in high-risk patients with Catterall III/IV classifications. Stulberg classification analysis revealed that SIO is more effective in reducing the incidence of severe deformities (Stulberg IV/V), which may help delay or prevent the need for late-stage total hip arthroplasty. Age and Catterall classification were identified as key predictors of postoperative femoral head remodeling. Early surgical intervention (before growth plate closure) was associated with significantly improved postoperative outcomes. However, for patients with Catterall III/IV classification, surgical treatment alone may not fully restore femoral head function. Additional measures, such as rehabilitation training and hip joint unloading, may be required to optimize clinical results. The findings of this study offer valuable clinical insights for surgical decision-making and underscore the importance of early intervention strategies in the management of LCPD.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

HY, YZ, XHC, ZDT, NM, RX, YH, RZ, and XPK contributed to the study's conception and design. Material preparation, data collection, and analysis were conducted by YZ, XPK, XHC, NM, RX, and YH. The first draft of the manuscript was written by HY. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. This study was approved by the Ethics Committee of Kunming Children's Hospital (Approval No. IEC-C-008-A07-V3.0), and written informed consent was provided by the parents or guardians of all pediatric participants. All procedures were performed following ethical guidelines, and patient confidentiality was strictly maintained throughout the study.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Sobhanian P, Karami S, Saffar H, Shafizad M, Baradaran M, Shahbaznejad L. Investigating Legg-Calve-Perthes disease: a comprehensive review of diagnosis, management and current treatment options. Journal of Pediatrics Review. 2024; 12: 171–182. https://doi.org/10.32598/jpr.12.2.440.1.

[2] Loder RT, Skopelja EN. The epidemiology and demographics of legg-calvé-perthes' disease. ISRN Orthopedics. 2011; 2011: 504393. https://doi.org/10.5402/2011/504393.

[3] Wadström MG, Hailer NP, Hailer YD. Demographics and risk for containment surgery in patients with unilateral Legg-Calvé-Perthes disease: a national population-based cohort study of 309 patients from the Swedish Pediatric Orthopedic Quality Register. Acta Orthopaedica. 2024; 95: 333–339. https://doi.org/10.2340/17453674.2024.40907.

[4] Perry DC, Hall AJ. The epidemiology and etiology of Perthes disease. The Orthopedic Clinics of North America. 2011; 42: 279–83, v. https://doi.org/10.1016/j.ocl.2011.03.002.

[5] Pavone V, Chisari E, Vescio A, Lizzio C, Sessa G, Testa G. Aetiology of Legg-Calvé-Perthes disease: A systematic review. World Journal of Orthopedics. 2019; 10: 145–165. https://doi.org/10.5312/wjo.v10.i3.145.

[6] Joseph B, Shah H, Perry DC. Epidemiology, natural evolution, pathogenesis, clinical spectrum, and management of Legg-Calvé-Perthes. Journal of Children's Orthopaedics. 2023; 17: 385–403. https://doi.org/10.1177/18632521231203009.

[7] Armstrong AR, Tóth F, Carlson CS, Kim HKW, Johnson CP. Effects of acute femoral head ischemia on the growth plate and metaphysis in a piglet model of Legg-Calvé-Perthes disease. Osteoarthritis and Cartilage. 2023; 31: 766–774. https://doi.org/10.1016/j.joca.2023.01.011.

[8] Rodríguez-Olivas AO, Hernández-Zamora E, Reyes-Maldonado E. Legg-Calvé-Perthes disease overview. Orphanet Journal of Rare Diseases. 2022; 17: 125. https://doi.org/10.1186/s13023-022-02275-z.

[9] Maleki A, Qoreishy SM, Bahrami MN. Surgical Treatments for Legg-Calvé-Perthes Disease: Comprehensive Review. Interactive Journal of Medical Research. 2021; 10: e27075. https://doi.org/10.2196/27075.

[10] Braun S, Adolf S, Brenneis M, Boettner F, Meurer A. Legg-Calvé-Perthes disease- surgical treatment options. Archives of Orthopaedic and Trauma Surgery. 2025; 145: 186. https://doi.org/10.1007/s00402-025-05801-3.

[11] Schulze A, Tingart M. Salter innominate osteotomy: Indications, surgical technique, results. Der Orthopade. 2016; 45: 659–665. https://doi.org/10.1007/s00132-016-3290-5. (In German)

[12] An JS, Kley K, Jacquet C, Fernandes LR, Ollivier M. Closing wedge distal femoral osteotomy for knee valgus: indications, technique, rehabilitation and outcomes. Journal of Cartilage & Joint Preservation 2023; 3: 100110.

[13] Larson JH, Brusalis CM, Allahabadi S, Fenn TW, Chapman RS, Browning RB, *et al*. Outcomes of Isolated Endoscopic Gluteal Tendon Repair Compared With Concomitant Endoscopic Gluteal Tendon Repair and Arthroscopic Hip Labral Repair: A Propensity-Matched Analysis With Minimum 2-Year Follow-up. Orthopaedic Journal of Sports Medicine. 2024; 12: 23259671231215340. https://doi.org/10.1177/23259671231215340.

[14] Yamaguchi R, Kamiya N, Kuroyanagi G, Ren Y, Kim HKW. Development of a murine model of ischemic osteonecrosis to study the effects of aging on bone repair. Journal of Orthopaedic Research: Official Publication of the Orthopaedic Research Society. 2021; 39: 2663–2670. https://doi.org/10.1002/jor.25006.

[15] Kamiya N, Kuroyanagi G, Aruwajoye O, Kim HKW. IL6 receptor blockade preserves articular cartilage and increases bone volume following ischemic osteonecrosis in immature mice. Osteoarthritis and Cartilage. 2019; 27: 326–335. https://doi.org/10.1016/j.joca.2018.10.010.

[16] Synder M, Dorman T. Remarks on classification of Perthes disease. Chirurgia Narzadow Ruchu i Ortopedia Polska. 1997; 62: 115–121. (In Polish)

[17] Kollitz KM, Gee AO. Classifications in brief: the Herring lateral pillar classification for Legg-Calvé-Perthes disease. Clinical Or-

thopaedics and Related Research. 2013; 471: 2068–2072. https://doi.org/10.1007/s11999-013-2992-9.

[18] Huhnstock S, Wiig O, Merckoll E, Svenningsen S, Terjesen T. The modified Stulberg classification is a strong predictor of the radiological outcome 20 years after the diagnosis of Perthes' disease. The Bone & Joint Journal. 2021; 103-B: 1815–1820. https://doi.org/10.1302/0301-620X.103B12.BJJ-2021-0515.R1.

[19] Mazloumi SM, Ebrahimzadeh MH, Kachooei AR. Evolution in diagnosis and treatment of Legg-Calve-Perthes disease. The Archives of Bone and Joint Surgery. 2014; 2: 86–92.

[20] Zhi X, Wu H, Xiang C, Wang J, Tan Y, Zeng C, *et al*. Incidence of total hip arthroplasty in patients with Legg-Calve-Perthes disease after conservative or surgical treatment: a meta-analysis. International Orthopaedics. 2023; 47: 1449–1464. https://doi.org/10.1007/s00264-023-05770-5.

[21] Wiig O, Terjesen T, Svenningsen S. Prognostic factors and outcome of treatment in Perthes' disease: a prospective study of 368 patients with five-year follow-up. The Journal of Bone and Joint Surgery. British Volume. 2008; 90: 1364–1371. https://doi.org/10.1302/0301-620X.90B10.20649.

[22] Krátký A, Kraus MJ, Krieg AH. Proximal femoral varus osteotomy in Legg-Calve-Perthes disease. Operative Orthopadie Und Traumatologie. 2022; 34: 307–322. https://doi.org/10.1007/s00064-022-00778-3. (In German)

[23] Kim HKW, da Cunha AM, Browne R, Kim HT, Herring JA. How much varus is optimal with proximal femoral osteotomy to preserve the femoral head in Legg-Calvé-Perthes disease? The Journal of Bone and Joint Surgery. American Volume. 2011; 93: 341–347. https://doi.org/10.2106/JBJS.J.00830.

[24] Friedlander JK, Weiner DS. Radiographic results of proximal femoral varus osteotomy in Legg-Calvé-Perthes disease. Journal of Pediatric Orthopedics. 2000; 20: 566–571. https://doi.org/10.1097/00004694-200009000-00004.

[25] Grzegorzewski A, Synder M, Kozłowski P, Szymczak W, Bowen RJ. The role of the acetabulum in Perthes disease. Journal of Pediatric Orthopedics. 2006; 26: 316–321. https://doi.org/10.1097/01.bpo.0000221926.10148.bf.

[26] Hosalkar H, Munhoz da Cunha AL, Baldwin K, Ziebarth K, Wenger DR. Triple innominate osteotomy for Legg-Calvé-Perthes disease in children: does the lateral coverage change with time? Clinical Orthopaedics and Related Research. 2012; 470: 2402–2410. https://doi.org/10.1007/s11999-011-2189-z.

[27] Serbin PA, Youngman TR, Johnson BL, Wilson PL, Sucato D, Podeszwa D, *et al*. Radiographic Predictors of Reoperation in Adolescents Undergoing Hip Preservation Surgery for Femoroacetabular Impingement. The American Journal of Sports Medicine. 2023; 51: 687–693. https://doi.org/10.1177/03635465221147062.

[28] Varela-García M, Torrijos-Pulpón C, Pino-López L, Farrag Y, Forneiro-Pérez R, Conde-Aranda J, *et al*. A retrospective study describing the acetabular consequences of Legg- Calve-Perthes disease. BMC Musculoskeletal Disorders. 2024; 25: 753. https://doi.org/10.1186/s12891-024-07852-w.

[29] Albayrak M, Ugur F. Evaluating the effectiveness of interventions targeting only the acetabular side in the surgical treatment of Legg-Calvé-Perthes disease. European Review for Medical and Pharmacological Sciences. 2023; 27: 6151–6161. https://doi.org/10.26355/eurrev_202307_32971.

[30] Bellova P, Goronzy J, Blum S, Bürger S, Hartmann A, Günther KP, *et al*. How does former Salter innominate osteotomy in patients with Legg-Calvé-Perthes disease influence acetabular orientation? An MRI-based study. Journal of Hip Preservation Surgery. 2021; 8: 240–248. https://doi.org/10.1093/jhps/hnab063.

[31] Bourantas CA, Behrman EC, Shepherd MC, Lohse KR, Clohisy JC, Harris MD. Dynamic femoral head coverage following periacetabular osteotomy for developmental dysplasia of the hip. Clinical Biomechanics (Bristol, Avon). 2025; 124: 106471. https://doi.org/10.1016/j.clinbiomech.2025.106471.

[32] Rosello O, Solla F, Oborocianu I, Chau E, ElHayek T, Clement JL, *et al*. Advanced containment methods for Legg-Calvé-Perthes disease: triple pelvic osteotomy versus Chiari osteotomy. Hip International: the Journal of Clinical and Experimental Research on Hip Pathology and Therapy. 2018; 28: 297–301. https://doi.org/10.5301/hipint.5000569.

[33] Vukašinović Z, Spasovski D, Živković Z. Femoroacetabular impingement related to Legg-Calvé-Perthes disease. Srpski Arhiv Za Celokupno Lekarstvo. 2011; 139: 834–837. https://doi.org/10.2298/sarh1112834v. (In Serbian)

[34] Adulyanukosol V, Lewsirirat S, Chinvattanachot G. Age and Factors Associated with Clinical and Radiological Outcomes of Surgical Containment in Legg-Calve-Perthes Disease. Journal of Southeast Asian Orthopaedics. 2022; 46: 36–41. https://doi.org/10.56929/jseaortho.v46i1.11.

[35] Rosenfeld SB, Herring JA, Chao JC. Legg-calve-perthes disease: a review of cases with onset before six years of age. The Journal of Bone and Joint Surgery. American Volume. 2007; 89: 2712–2722. https://doi.org/10.2106/JBJS.G.00191.

[36] Cho TJ, Lee SH, Choi IH, Chung CY, Yoo WJ, Kim SJ. Femoral head deformity in Catterall groups III and IV Legg-Calvé-Perthes disease: magnetic resonance image analysis in coronal and sagittal planes. Journal of Pediatric Orthopedics. 2002; 22: 601–606.