The Swedish experience of capital realignment surgery for slipped capital femoral epiphysis: results from a nationwide retrospective cohort of 28 patients

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Background and purpose — Optimal treatment for slipped capital femoral epiphysis (SCFE) has been controversial for decades. Capital realignment surgery (predominant technique: modified Dunn) is a technique to restore anatomy, but it is associated with varying risks of avascular necrosis (AVN) of the femoral head. The aim of our study was to describe outcomes following capital realignment for severe SCFE in a nationwide cohort.

Methods — A longitudinal, nationwide, retrospective cohort study of SCFE patients treated with capital realignment between 2009 and 2021 was conducted, with radiographic and clinical follow-up 2–15 years after surgery. Primary radiographic outcome was AVN. Clinical outcomes were assessed using patient-reported outcome measures (the Copenhagen Hip and Groin Outcome Score [HAGOS] and the 12-item International Hip Outcome Tool [iHOT12]).

Results — 28 patients were included but 1 patient declined radiographic follow-up. 6/27 (22%, 95% confidence interval [CI] 11–41), developed AVN: 2/19 patients with stable SCFE and 4/8 patients with unstable SCFE. None of the 8 cases in which epiphyseal perfusion was monitored intraoperatively developed AVN. The median total HAGOS and iHOT12 scores were 77 (CI 56–94) and 76 (CI 72–88), respectively. When capital realignment was performed as primary treatment (< 1 month from diagnosis), the corresponding scores were 91 (CI 70–98) and 88 (CI 73–98).

Conclusion — The overall AVN rate was 22%. Our findings suggest that capital realignment should be reserved for stable SCFE and performed as primary treatment, with intraoperative epiphyseal perfusion monitoring.

Optimal treatment for slipped capital femoral epiphysis (SCFE) has been controversial for decades. In-situ fixation is a percutaneous surgical procedure with negligible risk of avascular necrosis (AVN) of the femoral head [1]. However, in-situ fixation does not address the deformity which leads to worse long-term outcomes in severe slips [2]. Capital realignment is a technically demanding surgical procedure that aims to restore anatomy through open reduction of the epiphysis, thereby improving outcomes. Modified Dunn is the predominant technique. The procedure is associated with a risk of iatrogenic damage to the blood supply to the femoral head with subsequent AVN. Rates of AVN in the literature have ranged from negligible [3-5] to 50% or more [6,7].

Some authors argue for modified Dunn in all cases except mild SCFE, an approach that includes the majority of patients [5]. At the same time, in most pediatric orthopedic units, including Scandinavian ones, in-situ fixation is still predominant.

According to current Swedish guidelines [8], capital realignment is considered when the slip angle exceeds 50°. Since such cases are relatively few, the clinical experience with the procedure is still limited. The aim of our study was to describe outcomes in a longitudinal nationwide cohort to provide data for future decision-making regarding the management of severe SCFE. Specifically, we sought to study whether the risk of AVN can be justified by favorable patient-reported outcomes following restoration of proximal femoral anatomy.

Methods

Study design

We conducted a retrospective cohort study with active follow-up. We included all cases of SCFE treated with capital realign-

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ment in Sweden from the first case in 2009 to June 2021. The study is reported according to the STROBE guidelines.

Patients and data collection

Since 2007, children diagnosed with SCFE have been registered in a national Swedish Pediatric Orthopedic Quality register (SPOQ) [9]. There are approximately 50 cases annually and 4 in 5 have a mild or moderate slip (< 50°). The majority are treated with in-situ fixation [10].

Capital realignment as treatment for SCFE was independently introduced in Sweden by 2 consultant pediatric orthopedic surgeons from different orthopedic units (Malmö General Hospital, then Skåne University Hospital Lund, and Linköping University Hospital, then Ryhov County Hospital Jönköping). The first cases were performed in 2009. The following cases were performed at the above-mentioned surgeons' units or by them at another unit. As there were no established national guidelines, it was at the discretion of the treating surgeon to determine whether capital realignment was indicated. National guidelines were first implemented in 2021.

All cases of capital realignment performed through June 2021 were identified by the treating surgeons. Patients were asked about study participation, including active follow-up with plain radiographs and patient-reported outcome measures (PROMs) if the hip was native at follow-up (defined as no total hip arthroplasty, THA). Study follow-up began in June 2023, and the minimum follow-up was 2 years—a period during which a possible AVN was expected to have manifested.

Data, including patients' baseline characteristics and surgical reports, was retrospectively collected from medical records. The data was also checked against the national quality register (SPOQ). Previous radiographs (at diagnosis and after capital realignment) were reviewed. Slip angles were measured by 2 pediatric orthopedic surgeons with high intra- and interobserver agreement, as demonstrated in a previous publication [11]. On a frog leg lateral view (Lauenstein), the slip angle was measured according to the calcar femorale (CF) method [12]. Compared with the similar and internationally more commonly used lateral Southwick head–shaft angle (HSA) [13], accurate measurement can also be done in radiographs where only a small part of the proximal femur is visualized [11]. In cases with an additional Billing lateral view, the slip angle was also measured according to the Billing method [14]. Slip angles between ≥ 30° and ≤ 50° on lateral views (Lauenstein, Billing) were classified as moderate, and angles > 50° as severe [15,16]. If no lateral view was obtained at diagnosis (in cases with unstable slips, the child's pain sometimes only allows for an AP image), the Southwick HSA on the anteroposterior (AP) view was used. HSA ≤ 110° on AP view was classified as severe [10].

Surgical technique

Capital realignment was performed both as the primary treatment for SCFE and at a later stage after percutaneous fixation at diagnosis. The predominant technique in our study was the modified Dunn procedure, which is based on the technique that was introduced by Dunn in 1964 [17]. The modified Dunn technique has been described in detail by Leunig et al. and Tannast et al. [3,5].

The hip was exposed via surgical dislocation. A retinacular soft tissue flap (posteriorly containing the major blood supply to the femoral head) was created by subperiosteal dissection around the femoral neck and the trochanteric region. The epiphysis was then mobilized through the physeal plane until it became mobile but still attached to the soft tissue flap. Callus formation was resected from the deformed metaphyseal stump, which was reshaped (including a slight shortening osteotomy) before the epiphysis was reduced and fixed. Alternatively, instead of prior mobilization through the physeal plane, some cases were operated on with a subcapital closing wedge osteotomy. As both techniques involve subcapital correction after the critical subperiosteal dissection, we assumed comparable risks of AVN and therefore included both techniques in the study.

The epiphyseal perfusion was monitored repeatedly throughout the capital realignment procedure. This was done either by drilling a small hole in the femoral head to observe for bleeding, or by placing an intracranial pressure (ICP) catheter in the femoral head to monitor pulsatile blood flow.

Outcomes

Follow-up radiographs were obtained at the nearest hospital (patients were distributed throughout the country) and then transferred to Skåne University Hospital. Radiographs were reviewed for AVN (primary outcome) and osteoarthritis (OA, secondary outcome), with OA defined as Kellgren–Lawrence grade ≥ 2 [18,19]. In patients who had undergone hip replacement by follow-up, the indication for conversion to THA was recorded (AVN or OA). The α-angle, a measure of cam morphology (secondary outcome), was measured on AP radiographs. As suggested in a cross-sectional study on a large Scandinavian cohort by Gosvig et al., a pathological cutoff was set at a greater angle for males (83°) than for females (57°) due to the inherent anatomical difference between the sexes [20].

Clinical outcomes were assessed with PROMs. Questionnaires were sent to the patients by letter. The Copenhagen Hip and Groin Outcome Score (HAGOS) and the 12-item International Hip Outcome Tool (iHOT12) were used in Swedish versions that have been validated in patients 15 to 75 years old [21,22]. Both HAGOS and iHOT12 have been used to assess clinical outcomes after SCFE in previous publications [23,24]. HAGOS scores were calculated for each subscale and as a total score, and the iHOT12 score was calculated as the mean of the 12 items (ranging from 0 = worst possible to 100 = best possible).

Statistics

Continuous descriptive data was summarized as medians with interquartile ranges (IQR). All estimates were accompanied by 95% confidence intervals (CIs). CIs for binary outcomes (AVN, OA, pathological AP α-angle; yes/no) were calculated using the Wilson score method. CIs for continuous outcomes summarized by medians (AP α-angle, PROM scores) were obtained by bootstrap resampling (5,000 resamples). Correlations between continuous outcomes were analyzed using Spearman's correlation coefficient (r_s). In exploratory subgroup analyses, primary outcomes were compared between groups defined by variables hypothesized to influence the outcome, such as clinical classification of the slip (stable/unstable, the latter meaning patients unable to ambulate even with crutches) [25]. Between-group differences in AVN rate were estimated as risk differences (percentage points), with CIs calculated using the Newcombe method. For PROM scores, between-group differences were estimated as the Hodges–Lehmann location shift. IBM SPSS Statistics version 29 (IBM Corp, Armonk, NY, USA) was used for the statistical analyses.

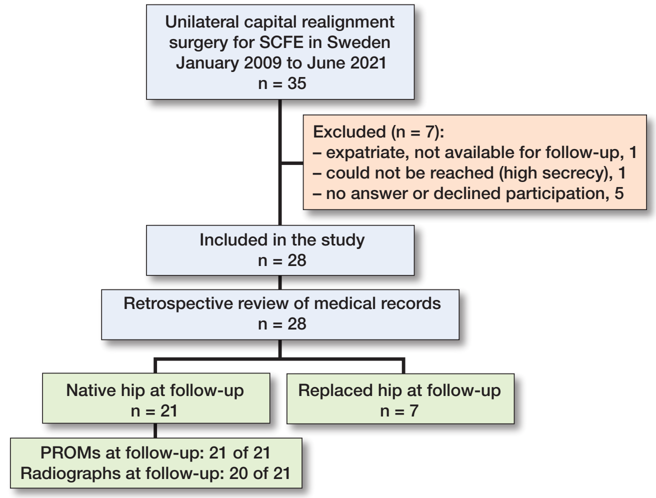

Figure 1. Flowchart of included patients. PROMs = patient-reported outcome measures, SCFE = slipped capital femoral epiphysis.

Ethics, data sharing, and funding

Ethical approval was obtained from the Swedish Ethical Review Authority with diary number 2021-00056 (March 3, 2021). All potential study participants who were reachable were informed by letter. Written informed consents were obtained.

All documents with original data of relevance will be stored for a minimum of 10 years at the Department of Orthopedics, Skåne University Hospital, Lund, Sweden. Pseudonymized study data can be obtained upon request.

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Results

28 patients were included in the study (Figure 1). The patients were evaluated 2–15 years after the capital realignment surgery. Study follow-up was complete for 27 patients (1 patient declined to undergo new radiographs). Descriptive characteristics of the cohort are given in Table 1.

Outcomes

Of 27 patients, 6 (22%, CI 11–41) developed AVN. Of the patients with AVN, 5 had undergone THA by follow-up (Table 2). Figure 2 demonstrates such a case, while Figure 3 exemplifies a case with an excellent outcome following modified Dunn. OA developed in 4 of 27 patients (15%, CI 6–33). In 2 of these patients, OA led to conversion to THA.

Table 1. Descriptive characteristics of the cohort (N = 28). Binary variables are specified in numbers, and continuous summarized in medians (min, IQR, max)

Factors	n	Cohort distribution
Diagnosis-related characteristics		
Sex (male/female)	28	16/12
Affected side (left/right)	28	19/9
Age (years)	28	13 (9, 11–14, 17)
Body mass index	20	24 (16, 19–26, 31)
Clinical classification (stable/unstable)	28	20/8
Severity of slip (moderate/severe [a])	28	4/24
Slip angle frog leg lateral, CF (°)	24	61 (46, 53–74, 89)
Realignment-related characteristics		
Age at capital realignment (years)	28	13 (9, 12–15, 21)
Treating orthopedic unit (Lund-Malmö/Linköping-Jönköping)	28	9/19
Primary capital realignment (yes [b]/no [c])	28	17/11
Capital realignment technique (modified Dunn/closing wedge)	28	20/8
Reduction of the CF slip angle if comparable frog leg lateral pre- and postoperatively (°)	16	53 (40, 45–65, 72)
Use of ICP device to intraoperatively monitor epiphyseal perfusion (yes/no)	28	8/20
Perfusion on postoperative bone scintigraphy if performed (normal/reduced)	22	15/7
Time from capital realignment to radiographs at follow-up if native hip (months)	20	106 (24, 57–151, 181)
Time from capital realignment to PROMs at follow-up if native hip (months)	21	111 (24, 60–147, 170)

[a] Slip angles > 50° according to CF and/or Billing. AP Southwick HSA of ≤ 110° in cases with no lateral view radiographs at diagnosis. 1 slip was assessed as severe based on MRI at diagnosis as no radiographs were obtained at that time.
[b] 1–27 days from diagnosis.
[c] 4–76 months from diagnosis/primary treatment.
CF = calcar femorale , ICP = intracranial pressure, IQR = interquartile range, PROMs = patient-reported outcome measures.

Table 2. Key outcomes in the cohort

Item	n (n [a])	Outcome (CI)
Radiographic outcomes (N = 27)		
Avascular necrosis	6 (5)	22% (11–41)
Osteoarthritis	4 (2)	15% (6–33)
PROMs (native hips)		
HAGOS total score, n median	21	77 (56–94)
iHOT12 score, n median	21	76 (72–88)

[a] number of cases converted to total hip arthroplasty in parentheses.
CI = 95% confidence interval, HAGOS = Copenhagen Hip and Groin Outcome Score, iHOT12 = 12-item International Hip Outcome Tool, N = total number of patients with available data (1 patient with native hip at study follow-up declined new radiographs), PROMs = patient-reported outcome measures.

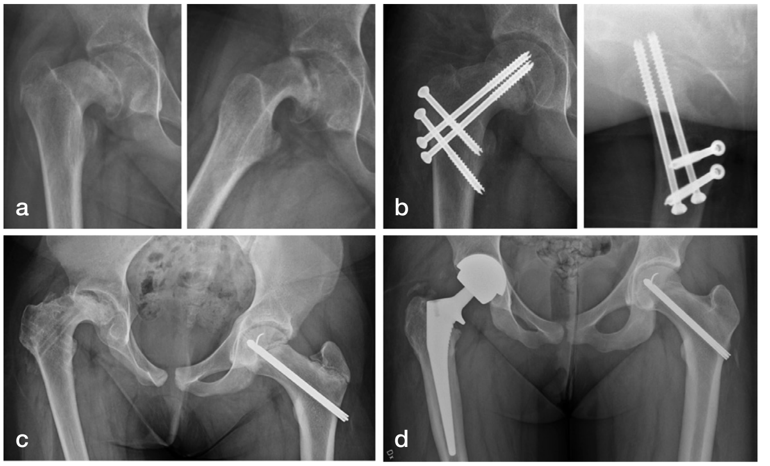

Figure 2. Radiographs (a) of a 12-year-old girl with a 7-month history of hip-related symptoms show a severe, stable right-sided SCFE (slip angle 72°). The girl underwent capital realignment using the modified Dunn technique as primary treatment (b). The patient developed avascular necrosis, and the screws were removed (c). The hip was converted to a THA 16 months after the modified Dunn (d).

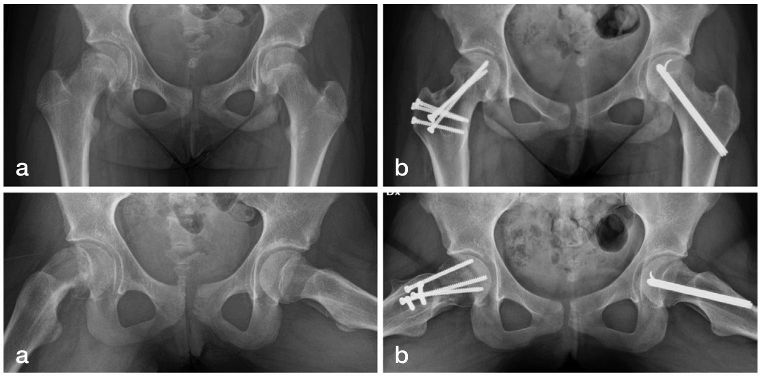

Figure 3. Radiographs (a) of a 12-year-old girl with a 4-month history of hip-related symptoms show a right-sided, severe, stable SCFE (slip angle 60°). The girl underwent modified Dunn surgery at diagnosis, with simultaneous prophylactic nailing on the contralateral side. At 2-year follow-up, the patient reported excellent outcome with normalized hip function (b).

Radiographs at follow-up showed a pathological AP α-angle in 12 of 19 patients (63%, CI 41–81; accurate measurement was not possible in 1 case due to AVN). The median AP α-angle was 89° (CI 49–100).

The median total HAGOS score at follow-up was 77 (CI 56–94), and the median iHOT12 score was 76 (CI 72–88) (see Table 2). PROM score distributions for each HAGOS subscale and the iHOT12 score showed considerable variation and are presented alongside reference scores from asymptomatic young populations [26,27] in Figure 4. The correlation between α-angle and PROM scores was r_s –0.34 (CI –0.75 to 0.17) for the total HAGOS score and r_s –0.38 (CI –0.74 to 0.10) for the iHOT12 score.

Exploratory analyses of differences in primary outcomes across subgroups are presented in Tables 3 and 4. 4 of 8 patients with unstable SCFE developed AVN. There were no cases of AVN among the 8 patients in whom the epiphyseal perfusion was monitored with an ICP device during surgery. When capital realignment was used as the primary treatment, the median total HAGOS and iHOT12 scores were 91 (CI 70–98) and 88 (CI 73–98), respectively.

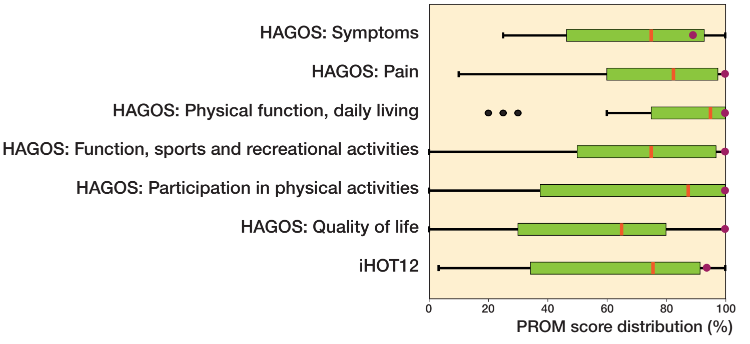

Figure 4. Patient-reported outcome score distributions in the cohort for each Copenhagen Hip and Groin Outcome Score (HAGOS) subscale and the 12-item International Hip Outcome Tool (iHOT12) score. Purple markers = reference scores from asymptomatic young populations [a]. Vertical red line = median, box = upper and lower IQR, whisker = values within 1.5 x IQR, and black dots = outliers.
[a] Median HAGOS scores in asymptomatic soccer players (mean age 23.6) with no pain in the previous season [26]. Normative mean iHOT score in patients < 40 years with no history of chronic hip pain or previous hip surgery [27].

Discussion

To our knowledge, this is the first study of capital realignment surgery in Scandinavia, presenting Sweden's initial 12-year experience with this debated procedure. The 11% AVN rate in stable SCFE, together with the favorable patient-reported outcome in cases operated on within 1 month from diagnosis, may support the use of capital realignment for severe slips. However, the threshold for what is considered an acceptable risk of AVN varies, and long-term com-

Table 3. Exploratory analyses of the differences in AVN rate across subgroups

Subgroups	n of N [a] with AVN	Between-group risk difference in percentage points (CI)
Clinical classification		
Stable	2 of 19	40 (4 to 69)
Unstable	4 of 8	
Use of intraoperative ICP monitor		
Yes	0 of 8	32 (–5 to 54)
No	6 of 19	
Type of capital realignment		
Modified Dunn	4 of 19	4 (–25 to 40)
Closing wedge	2 of 8	
Primary capital realignment		
Yes (< 1 month from diagnosis)	4 of 17	4 (–31 to 30)
No (> 4 months from diagnosis)	2 of 10	
Orthopedic unit		
Lund/Malmö	1 of 9	17 (–19 to 42)
Linköping/Jönköping	5 of 18	
Learning curve per unit		
1st half	4 of 14	13 (–19 to 42)
2nd half	2 of 13	

[a] n of N: n = number of patients with avascular necrosis (AVN); N = total number of patients in the subgroup.
CI = 95% confidence interval, ICP = intracranial pressure.

parative studies of in-situ fixation vs capital realignment are needed.

AVN rates following SCFE treated with percutaneous fixation in Sweden are low. In a nationwide cohort including all SCFE cases from 2007 to 2013, only 5 of 380 (1%) hips with a stable slip developed AVN, including 2 of 41 (5%) severe slips. For unstable slips, AVN developed in 11 of 56 (20%) hips [28]. The overall AVN rate after capital realignment in our cohort (22%) fell within the previously reported extremes of the modified Dunn procedure. It was higher than the overall rate of 14% reported in a previously published meta-analysis [29], mainly because of the unstable slips in our cohort. Regarding stable slips, our AVN rate matched that in the meta-analysis: 11%. In our study, 17 of 19 stable cases had no AVN at follow-up. Still, the correct number is probably 18 of 20 because the patient who declined follow-up radiographs had a native hip and reported a good outcome > 10 years after capital realignment.

Regarding unstable slips, some authors have recommended a modified Dunn procedure to reduce the risk of AVN [30], while others have warned of an increased risk [7]. AVN following unstable slips was frequent in our cohort: 4 of 8 cases. Consequently and according to current Swedish guidelines [8], we no longer treat unstable slips with modified Dunn as first surgical procedure. In stable SCFE, in-situ fixation is recommended for mild to moderate slips whereas capital realignment is considered only in severe cases.

There were no cases of AVN among the 8 cases in which an ICP catheter was used to monitor femoral head perfusion intraoperatively, compared with 6 of 19 cases in which no ICP catheter was used. The subgroup analyses were exploratory and should be interpreted accordingly. However, the use of an ICP device has also been supported previously; Birke retrospectively assessed 217 consecutive modified Dunn procedures and found that, with intraoperative monitoring (ICP device), the AVN rate after stable SCFE decreased from 21% to 0%. In unstable SCFE, the rate remained unchanged [31].

Reported long-term outcomes following in-situ fixation are significantly worse in severe slips compared with mild and moderate slips. At a mean follow-up of 18 years, de Poorter et al. found that 75% of the patients with severe slips had severe OA and their patient-reported outcome was poor [2]. The main goal of capital realignment is improved clinical outcomes. Different outcome scores appear in the literature, whereby comparison across studies is difficult. In a meta-analysis using

Table 4. Exploratory analyses of differences with CI in median PROM scores with IQR across subgroups

Subgroups	n	PROM score, median (IQR) HAGOS	PROM score, median (IQR) iHOT12	Hodges–Lehmann estimate of between-group difference (CI) HAGOS	Hodges–Lehmann estimate of between-group difference (CI) iHOT12
Type of capital realignment					
Modified Dunn	15	70 (38–94)	74 (21–92)	11 (–9 to 44)	11 (–10 to 62)
Closing wedge	6	87 (66–99)	86 (63–100)		
Primary capital realignment					
Yes	14	91 (67–98)	88 (73–98)	29 (7 to 52)	29 (10 to 76)
No	7	47 (28–72)	33 (12–74)		
Orthopedic unit					
Lund/Malmö	8	95 (75–99)	90 (77–99)	23 (2 to 54)	20 (1 to 67)
Linköping/Jönköping	13	68 (35–83)	73 (17–81)		
Learning curve per unit					
1st half	10	76 (47–97)	79 (28–98)	2 (–22 to 26)	1 (–22 to 24)
2nd half	11	77 (38–94)	76 (34–92)		

CI = 95% confidence interval, HAGOS = Copenhagen Hip and Groin Outcome Score, iHOT12 = 12-item International Hip Outcome Tool, IQR = interquartile range.

the Harris Hip Score, the overall mean score was excellent [29], whereas our PROMs were fair to good. However, our PROM scores improved to very good when capital realignment was performed as the primary treatment. Comparable iHOT12 scores following the modified Dunn procedure have been previously reported at shorter follow-up (1 year) [32]. When capital realignment was performed at a later stage, the median PROM scores in our cohort were poor.

SCFE is associated with an increased incidence of femoroacetabular impingement due to cam deformity [33], and FAI is a risk factor for developing OA [34]. In our study, capital realignment did not eliminate the risk of cam morphology. There was a negative trend between a high α-angle and a worse clinical outcome. The weak correlation may reflect a Type II error, a short follow-up time, or both. It is also possible that factors other than the α-angle are more important for the clinical outcome. Delayed capital realignment was associated with OA (all 4 cases), which might be explained by the degenerative process having already started at the time of realignment surgery.

Strengths

The main strength of our study is its nationwide scope. Furthermore, it is a longitudinal study with few patients lost to follow-up.

Limitations

The study describes outcomes from the earliest to the later cases of a technically demanding procedure, thereby reflecting the surgeons' learning curve. The study has selection bias, since the indication for capital realignment was at the discretion of the treating surgeon. A few cases involved capital realignment using a subcapital closing wedge osteotomy, which does not strictly adhere to the modified Dunn technique. The absence of a control group limits the ability to compare outcomes with alternative treatment options. The relatively small cohort size reduces the study's statistical power, and the subgroup findings should be interpreted as exploratory. It is possible that a larger cohort would have provided more robust evidence on the use of an ICP device. The follow-up time may have been too short for some patients to evaluate the effect of FAI on both symptoms and OA onset.

Conclusion

The overall AVN rate was 22%, 11% in stable SCFE, and 50% in unstable SCFE. There were no cases of AVN when the epiphyseal perfusion was monitored with an ICP device during surgery. PROMs were fair to good but improved to very good when capital realignment was used as primary treatment.

In perspective, our findings suggest that capital realignment should be reserved for stable SCFE and used as primary treatment with intraoperative epiphyseal perfusion monitoring. However, further long-term comparative studies are warranted.

Study design: JN, ML, BH, CJT. Data collection: JN, ML, BH, CJT. Review of radiographs: JN, ML. Data analysis: JN. Writing—original draft manuscript: JN. Writing—review and editing of manuscript: JN, ML, JÖ, BH, MS, PM, CJT.

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