

Cannulated screw fixation in pediatric femoral neck fractures: outcomes and complication predictors

✉ Mehmet Ali Talmaç, ✉ Melih Civan, ✉ İlyas Kar, ✉ Yiğit Önaloğlu

Department of Orthopedics and Traumatology, Başakşehir Çam and Sakura City Hospital, İstanbul-Türkiye

ABSTRACT

BACKGROUND: Pediatric femoral neck fractures (PFNFs) are rare but are associated with high complication rates due to the precarious vascularity of the femoral head. Cannulated screw fixation (CSF) is the most common surgical technique, though optimal strategies remain debated. The objective of this study was to evaluate the radiological and functional outcomes of proximal femoral neck fractures (PFNFs) treated with CSF and to identify predictors of postoperative complications.

METHODS: The retrospective study was performed of 28 patients (mean age 12.4 years; range 5–18) treated with CSF between June 2020 and December 2024. Fractures were classified using the Delbet–Colonna and Garden systems. Reduction quality was assessed radiographically, and functional outcomes were measured by the Harris Hip Score (HHS). Statistical analyses included univariate and multivariate logistic regression.

RESULTS: Radiographic union was achieved in 92.9% of patients. The overall complication rate was 42.9%, including coxa vara (17.8%), avascular necrosis (AVN, 14.3%), premature physeal closure (PPC, 10.7%), and non-union (7.1%). Patients with AVN (mean HHS 72.5) and non-union (mean HHS 70.0) had the lowest functional scores, while those with coxa vara (82.0) and PPC (85.0) maintained relatively better function. Patients without complications achieved the best outcomes (mean HHS 88.5). Multivariate analysis identified higher Garden grade (OR 4.1, $p=0.038$) and non-anatomical reduction (OR 3.75, $p=0.046$) as independent predictors. PPC was significantly associated with implant removal ($p=0.003$). Despite the small sample, a post-hoc power analysis based on HHS indicated approximately 85% power to detect large effects.

CONCLUSION: PFNFs remain a challenging pediatric injury with high complication rates despite surgical fixation. Precise anatomic alignment is essential to minimize complications, particularly AVN and coxa vara. Close monitoring is recommended for patients with PPC, as it may necessitate implant removal and carries a risk of hip deformity or leg length discrepancy. Larger prospective studies are needed to refine surgical strategies for this rare but clinically significant injury.

Keywords: Avascular necrosis; coxa vara; cannulated screw fixation; Harris Hip Score; pediatric femoral neck fracture; premature physeal closure.

INTRODUCTION

Pediatric femoral neck fractures (PFNFs) are exceptionally rare, accounting for less than 1% of all pediatric fractures.^[1] Despite their low incidence, these injuries are clinically significant because they carry a disproportionately high risk of serious complications. The vascular supply to the femoral head is particularly fragile, being primarily derived from the medial

femoral circumflex artery.^[2] Even minor trauma or surgical intervention can compromise this circulation, leaving the femoral head highly vulnerable to avascular necrosis (AVN).

Historically, PFNFs were managed conservatively with casting. In recent decades, however, early surgical fixation and anatomical reduction have become the standard of care, aimed at minimizing the risk of long-term sequelae. The Delbet–Colonna classification remains widely used for describing PFNFs,

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Address for correspondence: Mehmet Ali Talmaç

Department of Orthopedics and Traumatology, Başakşehir Çam and Sakura City Hospital, İstanbul, Türkiye

E-mail: drtalmac2@gmail.com

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with fracture location correlating to the likelihood of AVN.^[3] Nevertheless, complications extend beyond AVN and may include premature physal closure (PPC), coxa vara, leg-length discrepancy, and non-union, all of which can compromise hip function.^[4]

Cannulated screw fixation (CSF) has emerged as the most common surgical technique, favored for its minimally invasive approach and adaptability to skeletally immature patients. While biomechanical evidence supports the inverted triangle screw configuration for enhanced stability, clinical outcomes in the literature are inconsistent.^[5]

The primary objective of this study was to evaluate the radiological and functional outcomes of PFNFs treated with CSF. The secondary objective was to identify predictors of postoperative complications.

MATERIALS AND METHODS

Study Design and Patient Selection

We retrospectively reviewed the medical records of 28 pediatric patients who underwent CSF for PFNFs at our institution between June 2020 and December 2024. The mean follow-up duration was 30.9 months (range, 12–60 months).

Inclusion and Exclusion Criteria

Eligible patients were aged 5–18 years and sustained PFNFs due to either low- or high-energy trauma. All included cases were managed with closed reduction followed by CSF in an inverted triangle configuration. Patients were excluded if they had Delbet type IV fractures, open fractures, fractures requiring open reduction, concomitant lower-limb fractures, pathological fractures, metabolic bone disorders, or an age greater than 18 years.

Fracture Classification and Reduction Assessment

Fractures were categorized using both the Delbet–Colonna and Garden classification systems. Postoperative radiographs were independently assessed to evaluate reduction quality. In this study, anatomical and acceptable (non-anatomical) reductions were both considered satisfactory. Anatomical reduction was defined as perfect alignment with no displacement or angular deformity, whereas acceptable (non-anatomical) reduction referred to cases with minimal displacement (<2 mm) or angulation $\leq 20^\circ$ compared with the normal neck–shaft angle, representing a slight but clinically tolerable deviation from anatomical alignment.^[6]

Surgical Technique

All patients underwent three-screw inverted-triangle fixation as per institutional protocol; screw diameter was adjusted according to patient age and femoral neck size. Postoperatively, immobilization and non-weight-bearing were maintained for 8–12 weeks.

Data Collection

The following data were recorded: patient demographics, mechanism of injury, fracture classification, reduction quality, complications, and Harris Hip Score (HHS). HHS was assessed at the final follow-up visit, which was at least 12 months postoperatively.

Statistical Analysis

Descriptive statistics were expressed as mean $\pm$ standard deviation, median (range), or frequency (percentage). Normality was tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The independent-samples t-test or Mann–Whitney U test was used for between-group comparisons, and categorical variables were compared using the Chi-square test. Univariable logistic regression was first performed to identify potential predictors, and variables with $p < 0.1$ were entered into the multivariable logistic regression model, with the occurrence of any complication (yes/no) as the dependent variable. Given the limited number of events ($n=12$), the final model included two predictors (Garden classification and reduction quality) to avoid overfitting. A post-hoc power analysis based on HHS indicated a large effect size (Cohen's $d=1.23$) and an achieved power of approximately 85% ($\alpha=0.05$). Analyses were conducted using IBM SPSS Statistics for Windows, Version 28.0 (IBM Corp., Armonk, NY, USA)."

Ethical Considerations

The study was approved by the institutional review board (approval no. 2025-04, date: 15.01.2025) and conducted in accordance with the principles of the Declaration of Helsinki.

RESULTS

The study cohort included 28 patients (15 males, 13 females) with a mean age of 12.4 years (range, 5–18). More than half of the injuries (53.6%) resulted from high-energy trauma, while 46.4% followed low-energy mechanisms. Patient demographics and fracture characteristics are summarized in Table 1.

Most cases (82%, 23/28) involved isolated hip fractures. The remaining five patients (18%) sustained additional systemic injuries, including head, chest, abdominal, spinal, upper extremity, and pelvic trauma.

Surgical fixation was performed within 24 hours in 18 patients (64.3%) and after 24 hours in 10 patients (35.7%). Anatomical reduction was achieved in 13 patients (46.4%), while 15 (53.6%) had non-anatomical reductions. Capsulotomy and joint aspiration were not performed in any case. Surgical timing was not significantly associated with complications ($p=0.413$).

Radiographic union was achieved in 26 of 28 patients (92.9%). The overall complication rate was 42.9% (12 patients). The most frequent complications were coxa vara in 5 patients (17.8%), AVN in 4 patients (14.3%), PPC in 3 patients (10.7%), and non-union in 2 patients (7.1%). Two patients experienced

Table 1. Patient and injury characteristics

Variable	Value
Number of patients	28
Age (years), mean (range)	12.4 (5–18)
Sex, n (%)	Male: 15 (53.6%), Female: 13 (46.4%)
Side, n (%)	Right: 16 (57.1%), Left: 12 (42.9%)
Mechanism of injury	High-energy: 15 (53.6%), Low-energy: 13 (46.4%)
Associated injuries, n (%)	Present: 5 (17.9%), Absent: 23 (82.1%)
Delbet–Colonna classification, n (%)	Type I: 1 (3.6%), Type II: 22 (78.6%), Type III: 5 (17.9%)
Garden classification, n (%)	Type I: 2 (7.1%), Type II: 6 (21.4%), Type III: 4 (14.3%), Type IV: 16 (57.1%)
Surgical timing, n (%)	≤24 h: 18 (64.3%), >24 h: 10 (35.7%)
Reduction quality, n (%)	Anatomical: 13 (46.4%), Non-anatomical: 15 (53.6%)

two complications each: AVN with PPC and coxa vara with PPC. (Figure 1) Therefore, the total number of complications exceeds the number of patients affected.

Among the five patients who developed coxa vara, four (80%) had undergone non-anatomical reduction at the surgical procedure, while only one had an anatomical reduction.

Functional outcomes, stratified by complication type, are presented in Table 2. Patients with AVN (mean HHS 72.5) and non-union (mean HHS 70.0) had the lowest functional scores, while those with coxa vara (mean HHS 82.0) and PPC (mean HHS 85.0) retained relatively better function. Patients without complications demonstrated the best outcomes (mean HHS 88.5).

Univariate analysis identified right-sided fractures ($p=0.008$), higher Garden grade ($p=0.013$), and non-anatomical reduc-

tion ($p=0.037$) as significant predictors of complications. Implant removal was also significantly more frequent in patients with PPC ($p=0.003$) (Table 3). However, Delbet fracture type was not associated with complications ($p=0.626$).

Multivariate logistic regression, with the occurrence of any complication (yes/no) as the dependent variable, confirmed higher Garden grade (OR 4.1, 95% CI 1.08–15.6, $p=0.038$) and non-anatomical reduction (OR 3.75, 95% CI 1.02–13.8, $p=0.046$) as independent predictors (Table 3).

The mean HHS for the entire cohort was 83.7. Good-to-excellent outcomes (HHS ≥ 80) were achieved in 67.9% of patients, while 32.1% had fair outcomes (HHS 70–79).

DISCUSSION

PFNFs are usually caused by high-energy trauma, such as traf-

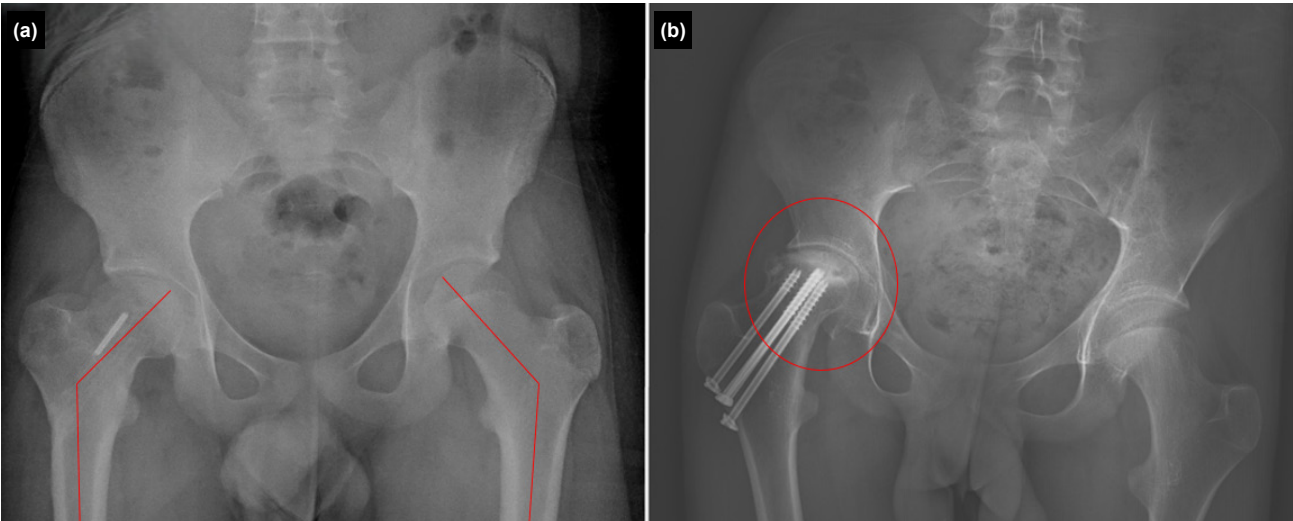


Figure 1. a) Coxa vara with premature physeal closure, 19 months postoperatively (neck–shaft angle $<120^\circ$). b) Avascular necrosis with premature physeal closure, 21 months postoperatively.

Table 2. Radiological and functional outcomes

Outcome	Value	HHS (Mean $\pm$ SD)
Mean follow-up (months)	30.9 (range, 12–60)	–
Radiographic union, n (%)	26/28 (92.9%)	–
Overall complications, n (%)	12 (42.9%)	–
Coxa vara (n=5)	17.8%	82.0 $\pm$ 5.2
Avascular necrosis (n=4)	14.3%	72.5 $\pm$ 4.8
Premature physeal closure (n=3)	10.7%	85.0 $\pm$ 4.0
Nonunion (n=2)	7.1%	70.0 $\pm$ 3.5
No complication (n=16)	–	88.5 $\pm$ 3.7
Mean Harris Hip Score (overall)	83.7 $\pm$ 8.3	–
Functional outcome by HHS, n (%)	Good–Excellent ($\geq$ 80): 19 (67.9%), Fair (70–79): 9 (32.1%)	–

Table 3. Predictors of complications in pediatric femoral neck fractures

Variable	Univariate p-value	Multivariate OR (95% CI)	Multivariate p-value
Right-sided fracture	0.008	2.85 (0.84-9.7)	0.089 (ns)
Higher Garden grade	0.013	4.10 (1.08-15.6)	0.038 *
Non-anatomical reduction	0.037	3.75 (1.02-13.8)	0.046 *
Implant removal (PPC)	0.003	—	—

*Statistical significance at $p < 0.05$; ns: not significant; OR: odds ratio; CI: confidence interval; PPC: premature physeal closure.

fic accidents or falls from a height. They are often accompanied by systemic injuries.^[7] Careful evaluation for associated trauma and early involvement of a multidisciplinary team are therefore essential. In our series, 82% of cases were isolated hip fractures, while 18% were accompanied by other injuries, including head, chest, abdominal, spinal, upper extremity, and pelvic trauma.

PFNFs remain among the most challenging injuries in pediatric orthopedics due to the high risk of complications related to the fragile blood supply of the femoral head. Even with early anatomic reduction and stable fixation, complication rates remain higher than in most other pediatric fractures.^[8] In our series, complications developed in 42.9% of patients, which is consistent with previously reported rates of 27–55%.^[2,4] The most frequent complications were coxa vara (17.8%) and avascular necrosis (14.3%). Functional analysis based on Harris Hip Scores further demonstrated that AVN and non-union were associated with the poorest outcomes, whereas patients with coxa vara and PPC maintained relatively better function.

Predictors of Complications

Multivariate analysis identified higher Garden grade and non-anatomical reduction as independent predictors of complications, while right-sided fractures showed only a non-significant

trend. These findings emphasize that fracture displacement and the precision of reduction are stronger determinants of outcome than fracture laterality. Reduction quality is the most important modifiable factor under surgical control.

Coxa Vara

Coxa vara was the most frequent complication in our series, observed in 17.8% of patients. Previous studies have shown that conservative treatment increases the risk of this deformity.^[1] Anatomical reduction remains the cornerstone of surgical management.^[9] When closed reduction fails to achieve anatomical alignment, open reduction should be performed. Although earlier concerns suggested that open reduction might compromise femoral head vascularity, more recent studies and meta-analyses have demonstrated that it does not significantly increase the risk of AVN, non-union, or delayed union.^[10,11]

In our series, 80% of coxa vara cases followed non-anatomical reduction, reinforcing the importance of precise anatomic alignment. While minor deformities may remodel during growth, more severe cases often require surgical correction. In our series, patients with mild coxa vara were managed conservatively with orthotics, as they demonstrated no limp and had a leg-length discrepancy of <1.5 cm.

Earlier reports indicate that loss of reduction predisposes patients to varus collapse.^[12] To further minimize the risk of varus deformity, alternative fixation strategies, such as valgus-oriented constructs and locking plates, have been recommended.^[13] Additionally, advanced intraoperative imaging tools, including 3D fluoroscopy, may optimize screw placement and alignment, thereby reducing the risk of malreduction.^[14]

Avascular Necrosis

PFNFs are strongly associated with AVN. The role of surgical timing remains controversial.^[15,16] While some authors suggest early surgical intervention may reduce risk, systematic reviews have consistently identified patient age (older 10 years) fracture displacement, and reduction quality as the most important predictors, whereas gender, timing of surgery, reduction method, and mechanism of injury show no significant association.^[17,18] In our series, surgery was delayed beyond 24 hours in 35% of patients, mainly due to late admission. Three patients with AVN underwent surgery within 24 hours, and one after 24 hours, suggesting that timing alone may not fully explain AVN development.

Capsulotomy and joint aspiration were not performed in our series. Although some studies propose that decompression may reduce AVN risk, our data cannot confirm or exclude this association.^[19]

When analyzed by Delbet classification, AVN is generally reported as most common in type II fractures and least common in type IV, with types I and III showing similar rates.^[20] However, multiple studies have emphasized that the Delbet-Colonna system has limited predictive value for AVN, non-union, delayed union, or PPC.^[11,12] In our series, AVN developed in 14.3% of patients, all of whom had three Delbet type II and one Delbet type III fracture (all Garden type IV). This suggests that displacement severity may be more critical than fracture location alone. Recent studies have also identified medial-posterior comminution as an additional risk factor for AVN and impaired healing.^[12,21]

The intramedullary nutrient vessels are another important source of femoral neck blood supply. Accordingly, the number, size, and positioning of fixation devices may further compromise perfusion and contribute to complications such as AVN, delayed union, non-union, or PPC.^[22] Supporting this, a multicenter study reported significantly higher AVN rates with three-screw fixation compared with two.^[23] Because all cases used three screws, between-construct comparisons were not possible; future studies should evaluate whether alternative constructs or lower screw burden mitigate AVN risk. All four patients who developed AVN were aged 13 years or older and were managed conservatively with weight-bearing restrictions and physical therapy.

Premature Physeal Closure

Proximal femoral physis contributes about 15% of total femo-

ral growth, and its premature closure can result in deformities such as leg-length discrepancy, coxa vara, or coxa valga.^[2] PPC is a recognised complication of PFNFs. In children under 10 years old, epiphysis penetration has been shown to increase the rate of PPC.^[9]

In our series, PPC occurred in three patients, two of whom had Delbet type II fractures and one of whom had a Delbet type III fracture. All were over 10 years old. Notably, PPC was found to be significantly associated with the need for implant removal. These patients require close clinical follow-up for growth disturbances, which may necessitate earlier implant removal and tailored management strategies.

Non-Union

Non-union of PFNFs, though uncommon, remains a serious complication. In developed countries, the most common cause of non-union of a femoral neck fracture is failure of fixation or loss of reduction. In developing countries, however, it is delayed presentation.^[24] Several studies have highlighted that anatomical reduction is the key factor in preventing delayed or non-union.^[25,26]

Previous reports have also shown that non-union and PPC rates are comparable between patients treated with open and closed reduction.^[6] In our series, non-union occurred in two patients, both with Delbet type II fractures, who were lost to follow-up after one year. This loss limits the interpretation of their long-term outcomes.

Strengths and Limitations

Despite the limited sample size, a post-hoc power analysis based on HHS demonstrated a statistical power of approximately 85%, indicating that the cohort was sufficient to detect large effects of reduction quality on functional outcome. Nevertheless, several limitations should be acknowledged. The retrospective design, relatively small cohort, lack of standardized imaging protocols, and absence of a control group may all have influenced the findings. The post-hoc nature of the power analysis also reduces its generalizability, even though the achieved power supports the robustness of the results. Furthermore, logistic regression was constrained by the limited number of complication events (n=12); to minimize the risk of overfitting, only two predictors (Garden classification and reduction quality) were included, which restricted the scope of multivariable adjustment. Finally, although follow-up was at least 12 months in all patients, the heterogeneity in follow-up duration may have affected the assessment of long-term outcomes.

CONCLUSION

Closed screw fixation remains an accepted and practical option for managing pediatric femoral neck fractures. However, complication rates remain substantial, particularly for AVN, coxa vara, PPC, and nonunion. In our series, higher Garden grade and non-anatomical reduction were independent pre-

dictors of complications. The significant association between PPC and implant removal highlights vigilant postoperative monitoring, as these patients may require earlier follow-up and individualized hardware management. At the same time, conclusions should be drawn cautiously, given the study's limitations. Larger prospective, multicenter studies are required to validate these predictors and refine treatment strategies in this rare but challenging pediatric injury.

Ethics Committee Approval: This study was approved by the Başakşehir Çam Sakura City Hospital Ethics Committee (Date: 15.01.2025, Decision No: 2025-04).

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ORİJİNAL ÇALIŞMA - ÖZ

Pediyatrik femur boynu kırıklarında kanüllü vida fiksasyonu: Sonuçlar ve komplikasyon belirleyicileri

AMAÇ: Pediyatrik femur boyun kırıkları (PFNK) nadirdir ancak femur başının hassas vaskülaritesi nedeniyle yüksek komplikasyon oranları ile ilişkilidir. Kanüllü vida fiksasyonu (KVF) en sık kullanılan cerrahi yöntemlerdendir, ancak optimal tedavi stratejileri halen tartışmalıdır. Bu çalışmanın amacı, KVF ile tedavi edilen PFNK'lerin radyolojik ve fonksiyonel sonuçlarını değerlendirmek ve postoperatif komplikasyon öngördürücü faktörlerini belirlemektir.

GEREÇ VE YÖNTEM: Haziran 2020-Aralık 2024 arasında KVF ile tedavi edilen 28 hasta (ortalama yaş 12.4; dağılım 5-18) retrospektif olarak incelendi. Kırıklar Delbet-Colonna ve Garden sınıflamaları ile değerlendirildi. Redüksiyon kalitesi radyografik olarak incelendi, fonksiyonel sonuçlar Harris Kalça Skoru (HHS) ile ölçüldü. İstatistiksel analizlerde tek ve çok değişkenli lojistik regresyon kullanıldı.

BULGULAR: Radyografik kaynama %92.9 oranında sağlandı. Genel komplikasyon oranı %42.9 idi: coxa vara (%17.8), avasküler nekroz (AVN, %14.3), prematür epifiz kapanması (PEK, %10.7) ve kaynamama (%7.1). AVN (ortalama HHS 72.5) ve kaynamama (70.0) en düşük fonksiyonel skorlarla ilişkilirdi; coxa vara (82.0) ve PEK (85.0) ise göreceli olarak iyi sonuçlar gösterdi. Komplikasyonsuz hastalarda en iyi sonuçlar elde edildi (ortalama HHS 88.5). Çok değişkenli analizde yüksek Garden sınıflaması (OR 4.1; $p=0.038$) ve anatomik olmayan redüksiyon (OR 3.75; $p=0.046$) bağımsız risk faktörleri olarak belirlendi. PEK, implant çıkarımı ile anlamlı şekilde ilişkili bulundu ($p=0.003$). Küçük örneklem sayısına rağmen, HHS'ye dayalı bir post-hoc güç analizi, büyük etkileri tespit etmek için yaklaşık %85'lik bir güç olduğunu gösterdi.

SONUÇ: PFNK, cerrahi tedaviye rağmen yüksek komplikasyon oranları ile zorlayıcı bir pediyatrik yaralanma olmaya devam etmektedir. Özellikle AVN ve coxa vara'yı azaltmak için anatomik redüksiyon kritik öneme sahiptir. PEK gelişen hastalarda implant çıkarımı gerektirebilmesi ve kalça deformitesi veya bacak boyu eşitsizliği gelişebilmesi riski nedeniyle yakın takip önerilir. Bu nadir ancak klinik açıdan önemli kırık tipinde cerrahi stratejilerin netleştirilmesi için daha geniş, prospektif çalışmalar gereklidir.

Anahtar sözcükler: Avasküler nekroz; coxa vara; erken fiziksel kapanma; Harris Kalça Skoru; kanüllü vida fiksasyonu; kaynamama; pediyatrik femur boynu kırığı.

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