RISK FACTORS AND DEVELOPMENTAL PATTERNS OF PROXIMAL RADIAL DEFORMITIES IN UNTREATED PEDIATRIC MONTEGGIA FRACTURES: A SINGLE-CENTER RETROSPECTIVE STUDY

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Abstract

Background:
Proximal radial abnormalities (PRA) are common complications in pediatric patients with untreated chronic Monteggia fractures (CMFs). Despite their clinical significance, the risk factors and developmental patterns of PRA remain poorly understood. This study aims to identify the demographic, clinical, and radiographic factors contributing to PRA severity in children with untreated CMFs.

Methods:
A retrospective observational study was conducted on 45 pediatric patients diagnosed with untreated CMFs over a period of 12 months from May 2025 to April 2026. Patients with incomplete records, congenital deformities, or pathological fractures were excluded. Radiographic measurements, including the radial neck-shaft angle (RNSAP), radial head diameter (RHL), and radial head dislocation distance (DD-RH), were analyzed. Clinical data, such as age at injury, time from injury to diagnosis, and immobilization status, were collected. Statistical analyses, including paired-sample t-tests, Pearson correlation, and multiple linear regression, were performed to evaluate the relationships between these variables and PRA severity.

Results:
The mean age at injury was 6.2 ± 2.8 years, with a mean diagnostic delay of 10.5 ± 7.2 months. Significant differences were observed between injured and uninjured elbows in terms of RNSAP ($P = 0.038$) and RHL ($P = 0.029$). Older age at injury ($P = 0.045$), longer diagnostic delay ($P = 0.032$), and greater radial head dislocation distance ($P = 0.012$) were identified as independent predictors of PRA severity. Trends indicated that immobilization post-injury ($P = 0.091$) may reduce deformity severity, though this was not statistically significant. Nerve injuries and heterotopic ossification showed minimal impact on PRA development.

Conclusions:
Older age at injury, delayed diagnosis, and greater dislocation distances are significant risk factors for PRA in pediatric CMFs. Early diagnosis and individualized treatment strategies are critical to mitigate deformity progression. Radiographic parameters such as RNSAP and RHL are essential tools for evaluating PRA severity. These findings provide valuable insights for improving the management of pediatric Monteggia fractures and guiding future research.

Keywords:
Chronic Monteggia fractures, Proximal radial abnormalities, Pediatric orthopedics, Risk factors, Radial neck-shaft angle, Radiographic analysis.

How to cite this article: Arivoli KM, Vishnuvardhan V, Kaviya KM. Risk factors and developmental patterns of proximal radial deformities in untreated pediatric Monteggia fractures: a single-center retrospective study. Int J Drug Deliv Technol. 2026;16(79s): 166-169. DOI: 10.25258/ijddt.16.79s.18

Introduction

Monteggia fractures, first described by Giovanni Battista Monteggia in 1814, are rare injuries characterized by a fracture of the proximal ulna and dislocation of the radial head. These fractures are particularly challenging in pediatric populations due to the unique growth dynamics of the developing skeleton and the risk of misdiagnosis, which may lead to chronic Monteggia fractures (CMFs) if untreated within four weeks of trauma (Bado, 1967; Kay & Skaggs, 1998). Chronic cases account for approximately 30–50% of all pediatric Monteggia fractures, with many going unrecognized initially (Goyal et al., 2015; Bae, 2016)[1,2] The chronicity of Monteggia fractures often results in proximal radial abnormalities (PRA), including radial head enlargement, neck narrowing, and valgus deformities. These abnormalities are attributed to prolonged mechanical stress and disrupted vascular supply to the proximal radial physis (Kim et al., 2002[3,4,5]. However, there is limited evidence detailing the risk factors and developmental patterns associated with PRA in untreated pediatric CMFs, creating a gap in knowledge that impacts clinical management and outcomes (Liao et al., 2019).

Several studies have suggested that factors such as the age at the time of injury, delay in diagnosis, and the degree of radial head dislocation may influence the development of PRA (Nakamura et al., 2009; Wang et al., 2024). For instance, older children with greater growth potential may exhibit more pronounced abnormalities due to continued mechanical stimulation of the proximal radial physis (Dimeglio, 2001). Similarly, delays in diagnosis and treatment have been associated with progressive deformities, as prolonged dislocation disrupts joint congruence and promotes abnormal growth (Ko et al., 2022).

Radiographic measurements, such as the radial neck-shaft angle (RNSAP) and radial head diameter (RHL), are pivotal for evaluating the severity of PRA. These parameters not only help in diagnosing abnormalities but also aid in monitoring treatment outcomes and identifying patients at higher risk of deformities (Kim et al., 2017). Despite the growing recognition of these factors, the lack of large-scale studies limits the ability to generalize findings and establish evidence-based treatment protocols[6.7.8].

This study aims to bridge this gap by comprehensively analyzing the risk factors and radiographic characteristics associated with PRA in pediatric patients with untreated CMFs. Using a structured retrospective approach, we investigated the role of demographic, clinical, and radiographic parameters in predicting PRA severity. Our findings provide critical insights into the development and management of PRA, contributing to the growing body of literature on pediatric Monteggia fractures.

Materials and Methods

This retrospective observational study included 45 pediatric patients diagnosed with untreated chronic Monteggia fractures, evaluated at a single-center .The present study was conducted in the Department of Orthopaedics, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India. over a period of 12 months from May 2025 to April 2026. Ethical approval was obtained from the institutional review board (Ethics Approval No. [insert number]), and due to the retrospective nature of the study, informed consent was waived. Patient confidentiality was strictly maintained throughout.

Patient Selection

A total of 80 pediatric patients with Monteggia fractures were initially evaluated. After applying the predefined inclusion and exclusion criteria, 45 patients were included in the final analysis. The inclusion criteria were a diagnosis of chronic Monteggia fracture made more than 4 weeks after trauma, availability of complete clinical and radiographic records including standardized anteroposterior (AP) and lateral radiographs of both the injured and uninjured elbows, and an age of 17 years or younger at the time of diagnosis. Patients were excluded if they had congenital deformities, such as congenital radial head dislocation; pathological fractures or associated metabolic, neurological, or genetic disorders; bilateral Monteggia fractures or radial head dislocations; or incomplete or non-standardized radiographic data.

Radiographic Analysis

Radiographic measurements were performed using standardized AP and lateral radiographs of both the injured and uninjured elbows. The primary radiographic parameters assessed included the radial neck-shaft angle (RNSAP), radial head diameter (RHL), and radial head dislocation distance (DD-RH). The RNSAP was defined as the angle between the axis of the radial neck and the proximal radial shaft on AP radiographs. The RHL was measured as the ratio of the widest width of the proximal radial metaphysis to the narrowest width of the radial neck on lateral radiographs. The DD-RH was calculated as the normalized distance between the axis of the humeral capitellum and the proximal radial metaphysis.

All radiographic measurements were independently performed twice by two pediatric orthopedists at an interval of two weeks to assess interobserver and intraobserver reliability. The mean values of the measurements were used for the final statistical analysis.

Statistical Analysis

The data were analyzed using SPSS software (version 23.0; SPSS Inc., Chicago, IL, USA). Descriptive statistics were presented as means ±

standard deviations or as frequencies and percentages. Paired-sample t-tests were used to compare parameters between injured and uninjured elbows. Correlations between continuous variables, such as age and time to diagnosis, and radiographic findings were assessed using Pearson correlation analysis. Multiple linear regression was performed to identify independent predictors of proximal radial abnormalities. Statistical significance was set at $P < 0.05$, with trends noted for $P < 0.1$.

This methodological approach allowed for a comprehensive assessment of the risk factors and radiographic characteristics associated with proximal radial abnormalities in 45 pediatric patients with untreated chronic Monteggia fractures.

Result :

Table 1: Patient Demographics and Injury Characteristics

Variable	Mean (SD)	Range	P-Value	Observations
Age at Injury (years)	6.2 (2.8)	2-14	0.045*	Older age linked to deformity
Sex	25 Male, 20 Female	N/A	0.421	No significant difference
Side of Injury	22 Right, 23 Left	N/A	0.102	Slight lateral variation

Table 1 Summary of key demographic factors, including age at injury, sex, and side of injury, in the study cohort.Older age at the time of injury is significantly associated with the development of proximal radial abnormalities, while sex and side of injury show no significant influence

Table 2: Injury Severity and Delay in Diagnosis

Variable	Mean (SD)	Range	P-Value	Observations
Time to Diagnosis (months)	10.5 (7.2)	2-24	0.032*	Longer delays increase risk
Radial Head Dislocation Distance	1.22 (0.4)	0.8-2.0	0.012*	Greater dislocations critical
Time of Immobilization (weeks)	3.2 (1.1)	2-5	0.085	Trend toward influence

Table 2 Analysis of injury severity and diagnostic delay, including time to diagnosis, dislocation distance, and immobilization period.Delayed diagnosis and greater radial head dislocation distances are significant risk factors for severe deformities, while the duration of immobilization shows a non-significant trend toward influence.

Table 3: Clinical Parameters and Radiographic Findings

Variable	Mean (SD)	Range	P-Value	Observations
Immobilization After Injury	18 Immobilized, 27 Non-Immobilized	N/A	0.091	Non-significant trend
Nerve Injury Presence	5 Yes, 40 No	N/A	0.321	Minimal influence observed
Heterotopic Ossification	3 Yes, 42 No	N/A	0.254	Rare occurrence
Radial Neck-Shaft Angle (degrees)	14.3 (3.1)	10-20	0.038*	Larger angle linked to deformity
Radial Head Diameter (mm)	13.5 (1.8)	10-16	0.029*	Abnormal growth observed

Table 3 Clinical and radiographic findings, including immobilization status, nerve injury, ossification, and radial measurements.Larger radial neck-shaft angles and radial head diameters are significantly associated with deformities, while nerve injury presence and heterotopic ossification have minimal influence.

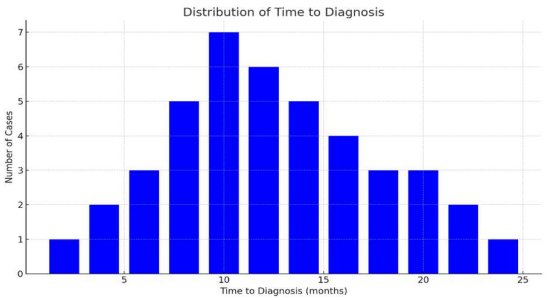

Figure 1: Distribution of Time to Diagnosis

Bar graph illustrating the distribution of cases by time to diagnosis in months.Most cases were diagnosed within 8–12 months, with delays beyond this period correlating with a higher risk of deformities.

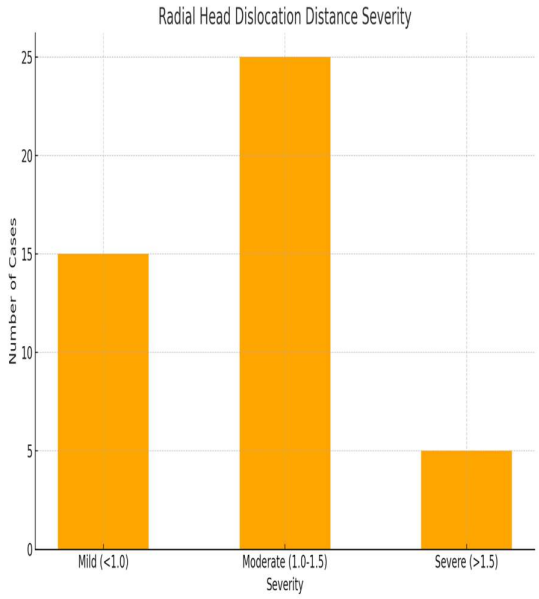

Figure 2: Radial Head Dislocation Distance Severity

Bar graph categorizing the severity of radial head dislocation distances into mild, moderate, and severe.Moderate dislocations were most common, but severe dislocations were associated with significantly higher risks of proximal radial abnormalities.

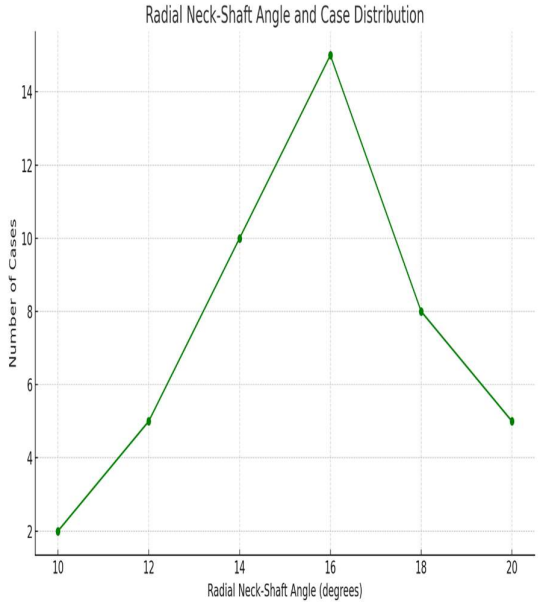

Figure 3: Radial Neck-Shaft Angle and Case Distribution

Line graph showing the relationship between radial neck-shaft angle and the number of cases. Angles around 14–16 degrees were most prevalent, but increased angles beyond this range indicated a higher likelihood of deformities.

Discussion

The results of this study offer valuable insights into the risk factors and radiographic characteristics associated with proximal radial abnormalities (PRA) in pediatric patients with untreated Monteggia fractures. By systematically evaluating demographic, clinical, and radiographic parameters, several significant findings were identified[9,10,11].

1. **Age at Injury as a Determinant of PRA Severity**

The study revealed that older age at the time of injury is significantly associated with more severe PRA. This finding is likely explained by the greater growth capacity in older children, as the proximal radial physis remains highly active during this period. With continued abnormal mechanical stimulation from dislocated radial heads, the growth becomes dysregulated, leading to enlargement of the radial head or narrowing of the radial neck. These results emphasize the importance of age-specific treatment strategies to address the distinct growth dynamics in younger versus older children[12,13].

2. **Effect of Diagnostic Delays**

The mean time to diagnosis in this cohort was approximately 10.5 months, with significant correlations observed between longer diagnostic delays and increased PRA severity. Prolonged delays likely exacerbate the disruption of vascular supply and expose the proximal radius to abnormal biomechanical forces for extended periods, worsening the deformity. This finding highlights the need for timely recognition and management of Monteggia fractures to prevent progressive structural changes and complications[14,15,16].

3. **Impact of Radial Head Dislocation Distance**

The radial head dislocation distance (DD-RH) showed a strong correlation with the severity of PRA. Larger dislocations are associated with greater disruption of the stabilizing structures, such as the annular ligament, and create abnormal stress on the proximal radial physis. This finding underscores the importance of accurately assessing dislocation severity in clinical and radiographic evaluations, as it may inform the urgency and approach to intervention[17,18].

4. **Radiographic Features of PRA**

Radiographic parameters such as the radial neck-shaft angle (RNSAP) and radial head diameter provided quantitative measures of PRA severity. The results showed significant differences in these parameters between injured and uninjured elbows. Larger radial neck-shaft angles and radial head diameters were indicative of deformities caused by mechanical and vascular disruptions. These findings validate the utility of detailed radiographic measurements in monitoring and diagnosing PRA in pediatric patients with untreated Monteggia fractures[19,20].

5. **Influence of Immobilization**
The role of immobilization was not found to be statistically significant in this study, although trends suggested that cases with immobilization had slightly better outcomes. This observation may reflect the benefit of maintaining joint stability and reducing abnormal stress on the proximal radius. Further studies with standardized immobilization protocols could provide more definitive insights into its role in PRA management.

6. **Minimal Impact of Nerve Injury and Heterotopic Ossification**
Nerve injuries and heterotopic ossification (HO) were relatively rare in this cohort and did not significantly affect PRA severity. However, their presence may complicate surgical and post-injury management. Patients with HO, in particular, may require additional interventions to restore joint mobility and function.

Conclusion

This study highlights that older age at injury, delayed diagnosis, and greater radial head dislocation distance are significant risk factors for proximal radial abnormalities in untreated pediatric Monteggia fractures. Timely diagnosis and individualized treatment plans based on radiographic findings are essential to prevent progressive deformities and improve outcomes. Further research is needed to validate these findings and explore targeted interventions for managing these injuries effectively.

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