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Can the reduction quality of distal humeral transphyseal fractures be determined using reference measurements on conventional radiography?

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Abstract. – OBJECTIVE: Our objective was to compare the radiological outcomes of transphyseal fractures treated using closed reduction and percutaneous fixation, without arthrography, with those of supracondylar humerus fractures treated using the same method within a similar age group. Additionally, we aimed to assess the efficacy of the reference points in the lateral and anteroposterior radiographs utilized for the evaluation of reduction.

PATIENTS AND METHODS: The study included patients aged 0-3 years who underwent surgery for supracondylar and transphyseal fractures between 2013 and 2022. All the patients were diagnosed using anteroposterior (AP) and lateral elbow X-rays. No arthrographic intervention was used either in the diagnosis or treatment phase. On the AP X-rays, we assessed the alignment between the humeral shaft line and the ulnar long axis line to determine the positioning of the distal humeral physis segment in relation to the humerus. Additionally, we evaluated the relationship between the anterior cortex line of the humerus and the coronoid process on lateral radiographs. At the final follow-up visit, Flynn criteria were used for functional assessment.

RESULTS: The study comprised 24 patients with supracondylar humerus fractures and 24 patients with transphyseal fractures. In the early post-operative radiographs, the humero-ulnar angle measured 6.43° (-7° – 16.6°) in the supracondylar group and 9.8° (-4.3° – 25.3°) in the transphyseal group (p = 0.087). The distance between the coronoid and the anterior humeral line was 9.19 mm (4.27 – 16.08) for the supracondylar fracture group and 8.05 mm (3.29 - 14.85) for the transphyseal fracture group (p = 0.513).

CONCLUSIONS: The current study's findings suggest that both the humero-ulnar angle and the distance between the coronoid and the anterior humeral line are valuable indicators for assessing the quality of reduction in transphyseal distal humerus fractures.

Key Words:
Transphyseal fracture, Supracondylar fracture, Closed reduction.

Introduction

Elbow fractures are highly prevalent among children, accounting for approximately 15% of all pediatric fractures[1]. Within this category, transphyseal fractures of the distal humerus are relatively uncommon occurrences. These fractures typically manifest in children under the age of 3 years[2]. The mechanisms of injury encompass events such as falls onto an outstretched hand, traumatic births, cesarean sections, or instances of non-accidental trauma[3-5]. Interestingly, a notable proportion of fractures occur in infants delivered via cesarean section, a method generally considered safer than vaginal birth[6,7]. In infants of a very young age, the distal humerus is primarily composed of cartilage, rendering fractures challenging to discern directly on radiographs.

In children under the age of 3 years, these injuries can sometimes be incorrectly diagnosed as elbow dislocations[8]. Elbow dislocations are rare among children in this age group, and the relatively delicate nature of the cartilaginous physis predisposes them to experience physis fractures rather than dislocations[9]. While the three-point relationship involving the olecranon and the medial and lateral humeral epicondyles can aid in distinguishing between elbow dislocations and fractures of the distal humeral epiphysis, the presence of elbow swelling can complicate the identification of these points[10]. To aid in diagnosis, techniques such as arthrography (AG), magnetic resonance imaging (MRI), ultrasonography (USG), or a combination of these imaging modalities are

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employed[11]. On conventional radiographs, a noticeable medial displacement of the radius and ulna is commonly observed, indicating the likelihood of a displaced fracture[12]. In the existing literature, the prevailing approach to managing transphyseal fractures of the distal humerus primarily involves closed reduction assisted by elbow arthrography and percutaneous pinning. The acceptable criteria for successful reduction align with those applied to supracondylar fractures. Parameters such as the presence of cubitus varus, the division of the capitellum into two parts by the anterior humeral line, and the absence of malrotation are considered essentia[12]. Nonetheless, assessing these criteria becomes intricate when the ossification center of the capitellum has yet to form.

In the literature, reference points were established for assessing reduction on AP X-rays, a corresponding reference point for lateral X-rays that was used in this study has not been identified in the existing literature. Our hypothesis is that reference measurement methods around the elbow are effective in the evaluation of pediatric transphyseal humeral fractures treated with the CRPF method.

The objective of this study is to juxtapose the radiological outcomes of transphyseal fractures treated through closed reduction and percutaneous fixation, conducted without elbow arthrography, with those of supracondylar humerus fractures exhibiting acceptable reduction, which were also managed using the same method within a comparable age range. Additionally, the study aims to assess the efficacy of the reference points we employed in lateral and anteroposterior (AP) radiographs for evaluating the quality of reduction.

Patients and Methods

This study received ethical approval from the local committee (number: 2021/11/04). The study's participants included patients aged 0-3 years who underwent surgery for supracondylar and transphyseal fractures between 2013 and 2022. To establish a comparable group, supracondylar humerus fractures were randomly selected using the "sort by number" function in Microsoft® Excel, based on patient ID numbers. Given the presence of 24 patients with distal humeral transphyseal fractures treated through closed reduction and percutaneous pinning (CRPP) without arthrography, a corresponding number of 24 patients with supracondylar fractures were included in the comparison group. Patients lacking sufficient radiographs for measurements, those with additional fractures in the same extremity, individuals who underwent intra-operative arthrography or open reduction, and patients older than 3 years of age were excluded from the study.

Transphyseal fractures were diagnosed through conventional radiographic assessment. In transphyseal fractures, the relationship between the capitellum and radius appears normal, but their alignment does not align with the humerus metaphysis. Pediatric elbow fractures in this study were addressed with urgent surgical intervention within the first day of trauma at the study center. In cases where surgery was contraindicated, patients received treatment at an appropriate time. All patients included in the study underwent treatment on the first day following the trauma.

The patients' preoperative X-rays were examined, and the fractures were categorized using the Gartland classification[1]. Subsequently, on the anteroposterior (AP) and lateral views taken on the first day following the operation, measurements of the humero-ulnar angle and humeral condyle angle were conducted (Figure 1 A-B). Additionally, the distance between the coronoid and the anterior humeral line was measured in millimeters (Figure 1C). These measurements were carried out by two observers, and the mean values were computed for analysis.

Surgical Method

All fractures were treated under general anesthesia. Maneuvers similar to reduction maneuvers used in supracondylar humerus fractures were used in transphyseal fractures. Fracture reduction was initially performed with traction and closed manipulations. During the intraoperative reduction assessment, in the initial phase, angular deformities were appraised based on the relationship between the line traversing the midpoint of the ulna in the anteroposterior (AP) image and the line drawn from the midpoint of the humeral shaft. Simultaneously, translation was evaluated by assessing the proximity of these two lines. The criteria utilized to ascertain acceptable reduction encompassed: 1. the presence of an elliptical configuration in the olecranon fossa, 2. precise alignment of the medial and lateral columns, and 3. the absence of any disparity between the proximal and distal fragment lines[13]. In the lateral image captured at a 90-degree flexion angle, efforts were made to position the line drawn over the anterior humeral cortex distal to the coronoid, facilitating the assessment of flexion or extension deformities.

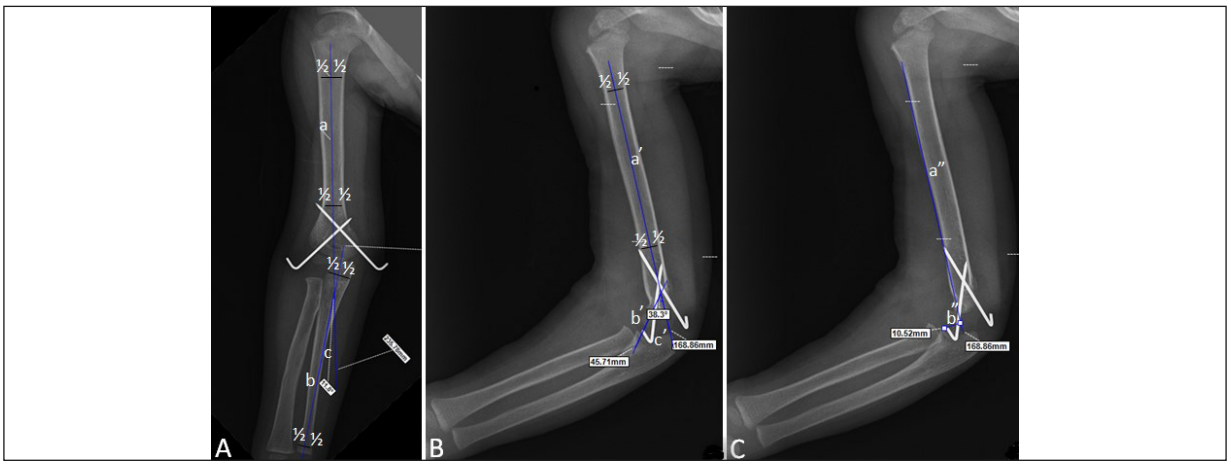

Figure 1. Raiographic of measurement. **A**, Humeral ulnar angle (a: humeral shaft line; b: unlar shaft line; c: humeral ulnar angle). **B**, Humeral condyle angle (a': humeral shaft line; b': axis of the distal humeral condyle; c': humeral condyle angle). **C**, Distance between the coronoid and anterior humeral line (a": anterior humeral line; b": distance between the coronoid and anterior humeral line).

Moreover, emphasis was placed on ensuring that a substantial portion of the olecranon was situated opposite the distal end of the humerus. Upon achieving successful reduction, percutaneous pinning procedures were executed. Subsequent to surgery, all patients underwent postoperative monitoring while wearing a long arm cast, with an average duration of approximately 3 weeks.

Statistical Analysis

Statistical analyses were performed using the IBM Statistical Package for Social Sciences (SPSS) for Windows, version 24.0 (IBM Corp., Armonk, NY, USA). The average values of the outcomes are presented as ± standard deviation (SD), while the frequencies are represented as percentages (%). The adherence of the data from the study participants to a normal distribution was assessed using the Kolmogorov-Smirnov test or the Shapiro-Wilk test. To compare the groups, the *t*-test or the Mann-Whitney U test was employed as appropriate. A significance level of $p < 0.05$ was set for determining statistical significance.

Results

There were 24 patients in the supracondylar humerus fracture group and 24 patients in the transphyseal fracture group. The average age was 2.5 years in the supracondylar fracture group and 1.7 years in the transphyseal fracture group. Among the supracondylar fracture cases, there were 7 females and 17 males, while in the transphyseal fracture group, there were 12 females and 12 males. Gartland classification revealed that all 24 supracondylar fractures were categorized as Type 3. On the other hand, based on the DeLee classification, the transphyseal fractures were classified as Type 3 in 17 cases, Type 2 in 6 cases, and Type 1 in 1 case. The mean duration of follow-up was 14.5 months for supracondylar fractures and 14.2 months for transphyseal fractures, with no statistically significant difference observed ($p = 0.790$). Closed reduction and fixation using K-wires were the predominant treatment methods employed for the majority of patients in both the supracondylar fracture and transphyseal fracture groups. However, the study excluded one patient with a supracondylar fracture who underwent open reduction and fixation after vascular repair, as well as two patients with transphyseal fractures who underwent arthrography for reduction verification during surgery. Regarding the fracture fixation approach, K-wires were used either as a pair from the lateral side or as a single K-wire from the medial side combined with a lateral K-wire.

In the early post-operative radiographs, the humero-ulnar angle measured 6.43° (-7° – 16.6°) in the supracondylar group and 9.8° (-4.3° – 25.3°) in the transphyseal group. No statistically significant difference was observed between the two groups ($p = 0.087$). The humeral condyle angle was recorded as 36.7° (19.1° – 52.4°) in the supracondylar group and 38.1° (12.2° – 49.8°) in the transphyseal group, with no statistically significant distinction detected between the two groups ($p = 0.513$). The coronoid and anterior humeral

line distances were measured 8.62 mm (ranging from 0 to 13.30) in the supracondylar fracture group and 8.05 mm (ranging from 3.29 to 14.85) in the transphyseal fracture group, with no statistically significant difference observed between the groups ($p = 0.513$) (Table I).

Based on the Flynn criteria, the supracondylar group comprised 18 cases with excellent outcomes, 4 cases with good outcomes, and 2 cases with poor outcomes. Similarly, the transphyseal group exhibited 16 excellent, 5 good, and 3 poor outcomes. Notably, no cases of avascular necrosis (AVN) complications were reported during the final follow-up visit.

Discussion

Transphyseal fractures are infrequent and pose diagnostic challenges in pediatric patients. Limited information is available in the literature concerning the diagnosis, treatment, and complications of these injuries[9]. In conventional radiographic examinations, distal epiphyses that have yet to ossify do not appear on X-rays[6,14]. Consequently, methods such as arthrography (AG), magnetic resonance imaging (MRI), ultrasonography (USG), or a combination thereof are utilized for diagnosis[11]. Arthrography is an invasive technique that necessitates expertise in both application and interpretation. MRI incurs additional costs for diagnosis and often requires patient sedation; however, it is favored over arthrography due to its non-invasive nature and reduced interpretational complexity[15]. While USG is a more affordable and accessible option compared to MRI and AG, it demands considerable interpretational experience similar to AG[15]. Notably, in our clinic, the routine diagnostic approach for transphyseal fractures does not involve USG or MRI; all diagnoses were established through conventional radiography.

The crucial aspect of radiological assessment involves determining the relationship between the radial head and the capitellum. Assessing this relationship proves particularly challenging in children under the age of 3, especially considering the absence of ossification in the capitellar center[8]. Jacobsen et al[16] noted that traumatic separation of the distal epiphysis is often diagnosed at a later stage, with a majority of their patients receiving a diagnosis between 9 to 30 days after birth. Notably, delayed diagnoses were not encountered in our clinic; most patients underwent surgery either on the same day or the subsequent day. Only two patients experienced a surgery delay of 3 days due to upper respiratory tract infections.

In the DeLee classification study[17], it was noted that Group A fractures predominantly occurred in children below 9 months, Group B fractures were common among children aged 7 to 36 months, and Group C fractures were observed in children aged 3 to 7 years. However, DeLee's initial study did not provide a precise definition regarding the size of the metaphyseal fragment, which distinguishes Group B from Group C[18]. Zhou et al[18] introduced the patient's capitellum size as a reference for this differentiation; smaller sizes were assigned to Group B and larger sizes to Group C. In our study, the original DeLee classification was utilized, categorizing 17 cases as Group C, 6 cases as Group B, and 1 case as Group A.

For transphyseal fractures, displacement predominantly occurs medially or posteromedially[2,12,19]. Our study also identified posteromedial displacement in the majority of patients, and a statistically significant difference in displacement was observed between the supracondylar fracture group and the displacement group ($p = 0.003$).

Table I. Patient characteristics and measurement results.

	Supracondylar (n-24)	Transphyseal (n-24)	*p*-value
Sex (female/male)	7/17	12/12	0.238
Average age (years)	2.5 ± 0.6 (1 - 3)	1.7 ± 0.6 (1 - 3)	< 0.001
Follow-up time (month)	14.5 ± 4.3 (8 - 24)	14.2 ± 4.3 (8 - 24)	0.790
Displacement (PM/PL/Post)	11/9/4/	22/1/1/	0.003
Humeroulnar angle	6.43 ± 5.9 (-7 - 16.6)	9.8 ± 7.3 (-4.3 - 25.3)	0.087
Humeral condyle angle	36.7 ± 8.2 (19.1 ¬- 52.4)	38.1 ± 9.8 (12.2 - 49.8)	0.265
Coranoid humeral anterior line (mm)	8.62 ± 2.9 (0 - 13.30)	8.05 ± 2.9 (3.29 - 14.85)	0.513
DeLee classification		Group A = 1; Group B = 6; Group C = 17	
Gartland classification	Type 3 = 24		

p-value < 0.05 shows a statistically significant difference. PM: posteromedial. PL: posterolateral. Post: posterior.

While diagnosing transphyseal fractures remains challenging, there exists no unanimous agreement in the literature regarding their treatment. Given the infrequency of this type of injury, the optimal treatment approach has yet to be definitively established[20]. A range of methods have been documented as treatment options, encompassing plaster or splint immobilization as well as Kirschner wire fixation following either closed or open reduction[17].

Several studies[17,21] in the literature propose non-reduction-based treatments for late-diagnosed fractures. It has been indicated that these fractures often exhibit normal alignment even if they have healed in a displaced position. Nevertheless, other studies[22] suggest that the patient's age and the extent of physeal damage sustained during the trauma could influence the potential for remodeling. Paige et al[23] employed closed reduction followed by posterior splint application in one patient, achieving a full range of motion during long-term follow-up. De Jager and Hoffman[4] noted that cubitus varus deformity was frequently observed in patients younger than 2 years, speculating that this could stem from inadequate reduction. However, in cases where presentation is delayed, and reduction might jeopardize the physis, or when there are underlying conditions that heighten anesthesia risk, an immobilization strategy designed to address the deformity later might represent a more viable option[20].

Contemporary guidelines advocate employing reduction criteria akin to those used for supracondylar fractures in the management of distal humeral physeal separations. However, due to the challenges associated with discerning the capitellum in children under the age of 3, determining whether appropriate reduction has been achieved using these parameters remains complicated in cases of transphyseal fractures[24]. In our clinical practice, closed reduction guided by fluoroscopy and subsequent percutaneous pinning are the preferred treatment methods for both transphyseal and supracondylar humeral fractures. Based on our comprehensive radiological assessment, the quality of reduction achieved in transphyseal fractures was found to be comparable to that attained in supracondylar humerus fractures (shaft condyle angle $p = 0.265$; humero-ulnar angle $p = 0.087$). Due to the challenges associated with intraoperative evaluation of reduction quality, certain studies[24-26] suggest the use of arthrography (AG) for this purpose. However, the potential for radio-opaque material leakage resulting from the complexities of applying intraoperative AG in the elbows of patients under 2 years old could exacerbate the difficulty of evaluation under fluoroscopy. Yet, there are studies[20] indicating that AG enables dynamic assessment of fracture stability post-fixation. While ultrasonography (USG) proves valuable in diagnosing injuries, its utility is limited during surgery. The skin fold formed during flexion hinders the probe from achieving sufficient skin contact to obtain a longitudinal image, and it is often inadequate for visualizing the localization of K-wires[20]. Combined approaches have also been suggested, which involve using preoperative USG for diagnosis in newborns and resorting to intraoperative AG to confirm anatomical reduction[20].

In a separate study[4], it was documented that closed reduction and fixation with a K-wire could be conducted under fluoroscopic guidance in children below the age of 3. The same study recommended extending the elbow during the operation to assess the carrying angle on anteroposterior (AP) X-rays, aiming to prevent varus deformity. However, no guidance was provided for evaluating lateral X-rays.

In another investigation[24], the adequacy of reduction for the distal physeal segment was assessed by using the extension of the medial and lateral cortical lines of the humeral shaft to the elbow on intraoperative AP fluoroscopy images. This method was proposed to yield a lower incidence of cubitus varus. Nonetheless, this study did not elaborate on the necessity of interpreting lateral radiographs for evaluating sagittal plane deformities.

In this study, the assessment of reduction quality under fluoroscopy in the coronal plane involved utilizing the carrying angle and the line extending from the anterior humeral cortex on lateral X-rays as criteria for determining adequate reduction. For evaluating reduction quality in the sagittal plane, the assessment commonly centers around the anterior humeral line dividing the capitellum into two[2]. Furthermore, the evaluation of reduction quality can also be based on the distance between the tip of the coronoid and the anterior humeral line, especially in cases where the capitellum has not yet been ossified, as was employed in our study. Both groups were measured similarly in terms of the distance between the coronoid and anterior humeral line. This distance measured 8.62 mm (ranging from 0 to 13.30) in the supracondylar fracture group and 8.05 mm (ranging from 3.29 to 14.85) in the transphyseal

fracture group, with no statistically significant difference observed between the groups (p = 0.513). In this study, there were no instances of lateral condyle avascular necrosis (AVN) identified in the postoperative radiographs of the cases. Additionally, minimal extension deformity was observed in three patients, indicating sagittal plane deformity where the humeral anterior line passed through the anterior 1/3 of the capitellum. A comparison group of patients with supracondylar fractures within the same age range was established. Following our assessment, the quality of reduction achieved in transphyseal fractures was found to be on par with that of supracondylar humerus fractures (p = 0.087). Based on our findings, we conclude that transphyseal fractures in children under the age of 3 can be managed in a manner similar to supracondylar fractures[25,26].

Limitations

This study has several limitations. First, the small number of patients; however, when considering the rarity of this fracture type, our patient count aligns closely with that of existing studies in the literature. Second, sagittal plane comparison. We think that it would be more appropriate to compare the sagittal plane measurements with the intact elbows of the patients. However, our patients did not have contralateral elbow lateral radiographs. So, we compared our sagittal plane measurements with well-reduced supracondylar humerus fractures in the same age group. A notable strength of our study is its contribution to addressing the gap in the assessment of sagittal plane deformities in transphyseal fractures treated with closed reduction and K-wire fixation in children under 3 years old. This aspect remains incompletely understood in the current literature. To comprehensively evaluate the quality of intraoperative reduction in transphyseal fractures, larger series are warranted.

Conclusions

The humero-ulnar and humero-condylar angles in the ap plane are important markers in the evaluation of transphyseal fractures. However, the distance between the coronoid and the anterior humeral line is a useful indicator for sagittal plane assessments without arthrography. Further investigations can be helpful, especially for the determination of sagittal plane reduction in transphyseal fractures.

Conflict of Interest

The Authors declare that they have no conflict of interest.

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Informed Consent

The patient informed consent is not applicable for this research due to the retrospective design of the study.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author.

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Authors' Contributions

Project supervision, writing-reviewing, and editing, data collection, data checking, data entry, and analysis: VZ, MB.

Ethics Approval

This study was conducted with Tepecik Training and Research Hospital, Ethics Committee's approval (Decision number: 2021/11/04).

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