INTRODUCTION

Radial neck fracture in children is a relatively rare injury and comprises up to 10% of elbow fractures and 5% of all pediatric fractures [1,2]. In most cases, the mechanism of fracture is falling on the arm while the elbow is in extension [3,4]. The presence of radial head blood supply impairment after fracture can lead to avascular necrosis of the radial head and some other complica-
tions, such as closure of the epiphyseal plate, nonunion, synosto-
sis, infection, and limited range of motion (ROM) [5-7]. The me-
dian age of children who sustain this type of injury is 9–10 years, and no difference in sex prevalence was seen [1,3,5].

Controversies about the best treatment of these fractures (es-
pically in angulated or displaced fractures) remain [8]. Recent
studies have relied on the closed reduction technique as a corner-
stone of treatment because of the high rate of side effects report-
ed for open reduction methods [1,3,5,6]. However, open reduc-
tion is unavoidable in some cases. Generally, open reduction
methods are used in patients with severe angulation or dis-
placement, multiple fractures of the elbow, and failure of closed
reduction [3,7,9]. Although previous studies have emphasized
the high rate of complications that occur with open reduction
techniques, our experiments showed the opposite. This study at-
ttempted to evaluate the outcome of surgically treated patients
and determine the prevalence of complications with this treat-
ment.

METHODS
The study was approved by the research ethics committee of Ta-
briz University of Medical Sciences (No. IR.TBZMED.VCR.REC.
1397.143). Written informed consent was obtained from the pa-
tients’ parents for their anonymized information to be published
in this article.

This was a cross-sectional study conducted through evaluation
of the medical records and follow-up visit summaries of patients
who were admitted with a confirmed diagnosis of radial neck
fracture to an orthopedic center between March 2006 and Sep-
tember 2016. Data for all patients with a definite diagnosis of ra-
dial neck fracture and who were younger than 15 years at the
time of fracture were extracted. The diagnosis of radial neck
fracture was confirmed by conventional radiography or comput-
ed tomography scanning of the elbow, and these images were in-
terpreted by two orthopedic surgeons (a pediatric orthopedic
surgeon and a shoulder and elbow orthopedic surgeon). All cases
treated with nonoperative methods, closed reduction, or closed
reduction and percutaneous fixation were excluded from the
study, and only patients who needed open reduction and internal
fixation were included in this investigation. Furthermore, pa-
tients were excluded if the diagnosis was uncertain, the patient
was older than 15 years, medical records were missing, or if fol-
low-up was not possible. Data regarding age at fracture, type of
fracture according to Judet’s classification, angular displacement,
associated fracture, mechanism of injury, duration of immobili-
ization, pin removal time after surgery, postoperative clinical ex-
amination (including ROM, neural examination, and postsurgi-
cal complications), and postsurgical radiographic results were
extracted from the patient medical records. After collecting the
data, all included patients were asked to participate in an in-per-
son examination, which was carried out with all except one par-
ticipant who was not able to come to the orthopedic clinic due to
the great distance. The data for this patient were obtained via a
telephone interview; to assess elbow motions, this patient was
asked to take directed photos of his elbow. Among 251 patients,
184 were treated nonoperatively, 45 were treated using closed
methods, and 22 (11 females and 11 males) fulfilled the inclusion
criteria and entered the study. One of the female patients had bi-
lateral fractures, so we considered her as two cases.

All cases were operated on by two orthopedic surgeons (a pe-
diatric orthopedic surgeon and a shoulder and elbow orthopedic
surgeon) at an orthopedic referral hospital with one technique.
The average duration of the follow-up period was 34.6 ± 5.6
months (range, 6–96 months).

The Mayo clinic elbow performance score was used to evaluate
the function of the elbow [10]. Post-surgical radiographs were
classified using the Metaizeau classification [11]. Our cutoff for a
normal ROM was based on the study of the American Academy
of Orthopedic Surgeons (flexion, 146; supination, 84; extension,
0; pronation, 71). After induction of general anesthesia, closed
reduction or closed percutaneous reduction was attempted under
control of an image intensifier. If there was > 30° of angulation,
> 3 mm translation, or an associated fracture, we continued with
open reduction.

The Kocher approach was used in all cases. Under tourniquet
control, the incision was centered over the lateral epicondyle and
extended proximally over the lateral ridge and distally parallel to
the ulna. Dissection was continued between the anconeus and
extensor carpi ulnaris muscles; when the proximal end of the ra-
dius was visible, the radial head was manipulated, and the fore-
arm was rotated to reduce the fracture and was pinned with two
1.5-mm cross or parallel pins. After surgery, the elbow was im-
mobilized for 4 weeks with a splint that was removed once a day
for elbow motion. No forearm rotation was allowed until pin re-
moval. Pins were removed 4–16 weeks after surgery depending
on the postoperative radiographs.

The recorded information was imported to the IBM SPSS ver.
22.0 (IBM Corp., Armonk, NY, USA). A normal distribution
of the quantitative data was assessed using the Shapiro-Wilk test,
and if the normality was rejected, a Mann-Whitney U-test (non-
parametric) was used. The data are expressed as mean ± standard
deviation or median (interquartile range), as appropriate. A mul-
tivariate analysis was designed to predict the risk factors related
to the quantitative data. A Spearman test was used for continuous variables with a normal distribution. Binomial variables were analyzed with a chi-square analysis. The null hypotheses were rejected if the p-value was < 0.05.

RESULTS

The mean age of the patients was 9.09 ± 0.46 years (range, 1–12 years). The mean age of girls was 9.08 ± 0.63 years, while the average age of boys was 9.09 ± 0.69 years. Fifteen fractures (65.2%) were located on the right side, and eight (34.8%) were found on the left side. In 21 patients (95.7%), the mechanism of the fracture was fall onto the outstretched arm, and only one fracture (4.3%) was due to a car accident. The average angulation at admission was 54.4° ± 3.3°. Based on the Judet classification, two patients (8.7%) had < 30° angulation (type 2), 20 (87%) demonstrated 30°–60° angulation (type 3), and one (4.3%) had > 60° angulation (type 4). Both patients with Judet type 2 fracture also had an associated ulnar fracture (Fig. 1). No patient was diagnosed with a type 1 fracture. Eleven patients (47.8%) had an associated fracture (ulnar shaft, 5; radial head, 3; monteggia, 2; distal radius, 2; olecranon, 1).

Among these 11 patients, 8 had a type 3 radial neck fracture, 2 had a type 2 radial neck fracture, and 1 patient’s fracture was type 4. The average length of immobilization after surgery was 5.5 ± 1 days (range, 0–10 days). The mean time until pin removal after surgery was 6.5 weeks (range, 4–16 weeks). The average length of treatment (from the first day of admission until pin removal) was 51.2 days. Postsurgical radiographs were interpreted based on the Metaizeau classification; in 14 patients (60%), the result was excellent, while 9 patients (40%) experienced good results. The mean angulation after surgery was 3.6° ± 1.1°. Postsurgical radiographs were examined for complications, including avascular necrosis of the radial head, non-union, radioulnar synostosis, degenerative changes in the elbow, heterotopic ossification, and premature epiphyseal closure. No complications were seen on radiographic evaluation. During follow-up examinations, only two patients (9%) complained of hypoesthesia in the radial nerve area, and both improved after 2 weeks without medical intervention. One patient complained of muscle weakness that improved after physiotherapy. Pain with motion after surgery was not reported by any of the patients (Table 1). Upon clinical examination, 16 patients (69.9%) had limitation in supination/pronation, and five (21.7%) demonstrated limitation in flexion/extension. The limitations in pronation in five patients (22%) and in supination in 10 patients (44%) were > 20°.

Table 1. Postoperative forearm range of motion

| Variable | Flexion (°) | Extension (°) | Supination (°) | Pronation (°) |
|----------|------------|--------------|----------------|--------------|
| Mean     | 141.30     | 2.39         | 65.43          | 61.74        |
| Median   | 145        | 0.00         | 70             | 65           |
| Max      | 145        | 20           | 80             | 85           |
| Min      | 130        | -10          | 40             | 40           |

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According to the Mayo elbow performance score, 20 patients (87%) received excellent and three (13%) received a good score (mean score, 96.74). According to the Spearman correlation between different variables and ROM of each elbow movement, there was a strong negative correlation between age and ROM \((p < 0.05)\) (Fig. 2). A negative correlation was seen between pin removal and ROM. In addition, our findings indicated a negative correlation between first angular displacement and ROM \((p < 0.05)\). A negative correlation also existed between duration of immobilization and supination \((r_s = -0.45, p < 0.05)\) (Table 2).

A chi-square test of independence was performed to examine the relationship between associated fracture and limited ROM with supination/pronation and flexion/extension. The relationship between these variables was not significant; \(\chi^2 (2, N = 11) = 0.1, p = 0.75\) and \(\chi^2 (2, N = 11) = 0.1, p = 0.69\), respectively. There was no significant association between sex and limited ROM in supination/pronation and flexion/extension \([\chi^2 (2, N = 23) = 1.5, p = 0.22\) and \(\chi^2 (2, N = 23) = 0.1, p = 0.69\), respectively].

**DISCUSSION**

Although pediatric radial neck fracture is uncommon, this injury can cause serious complications due to its effect on forearm rotation and elbow motion. The reported average age of patients is 9–10 years \([6]\). In our study, the average age was 9 years, and there was no age difference between boys and girls.

Due to the high rate of bone remodeling in children, the standard method of treatment for radial neck fracture with angulation < 30° and displacement < 2 mm is closed reduction \([12-17]\). Some articles have suggested that closed reduction can be the only therapy for angulations up to 45° \([1,3,5,6]\). However, in a study published in 1998, Vocke and Von Laer \([12]\) proposed that multiple tries at closed reduction cause muscular stiffness, bleeding, and additional injury to the joint. Another study from 1993...
by Metaizeau et al. [11] revealed that treatment of fracture only with closed reduction can increase the risk of secondary displacement. Closed reduction was considered for all patients in this study. If the result was not satisfactory, if the angulation was $> 30^\circ$, or if there was $> 3$ mm translation, closed reduction was not a suitable choice, so the patient underwent open reduction.

One of the most important complications of therapy in pediatric radial neck fracture that is considered in almost all studies is limited ROM. Some studies have mentioned the high incidence of limited ROM with the open reduction technique [18]. In 1993, Metaizeau et al. [11] proposed that 40%–45% of type 3 and 4 fractures had a poor to moderate outcome or ROM after surgery. A newer study from 2016 compared the results of open vs. closed reduction. Of the 68 patients who underwent surgery, 14 (21%) experienced limited ROM [8]. In contrast, Steinberg et al. [6] showed that better treatment results were seen in surgically treated patients instead of in the non-surgically treated group. In a study published in 2011 by Tan and Mahadev [19] in Singapore, the age of the patient was important in treatment outcome, and older ages caused poorer outcomes. Other studies have mentioned poorer outcomes in older children [3,20,21]. Similarly, our study found that increasing patient age increased the risk of limited ROM. This result can be attributed to the higher rate of remodeling at younger ages.

In our study, 69.6% of patients had a few degrees of ROM limitation. Except for age, this limitation was related to other matters, like initial angulation degree, post-surgical angulation, and pin removal time, while variables like sex, associated fracture, duration of immobilization after surgery, and initial displacement had no significant correlation. As shown in other studies [20,21], we found that the initial angulation of the bone played an important negative role in the outcome of treatment. One interesting point was that, in our study, this correlation was seen only for supination/pronation; the range of flexion/extension was not affected. Previous studies have mentioned that the rate of the displacement can influence the outcome and ROM [6,11]. Although none of them specifically mentioned the most affected movement of the elbow, our study showed a weak correlation only for supination ($p = 0.2$, $r_s = -0.48$).

Although not mentioned in previous studies, we noted a relatively strong correlation between postsurgical ROM and pin removal time. When the pin removal time was increased, all four movements of the elbow and forearm were limited, indicating that early removal allows earlier joint movements and could reduce the rate of postsurgical complications. However, pin removal time can influence the stability of the bone after reduction. Since this variable was varied in other studies, additional study should focus on this issue to determine the optimal time for pin removal. Radial head deformity is a complication that results from both closed and open reduction methods [3,13,22]. In previous studies, the prevalence of this complication has ranged from 12% [13] to 83% [12]; in our study, there was only one case (4%) with this complication. Early closure of the epiphyseal plate is another complication that can arise and has a prevalence ranging from 9% [1] to 50% [3], but there was no case in our study. Radioulnar synostosis is another important complication in surgically treated patients, with a prevalence up to 10% [3]. Our sample population did not include any patients with this complication. It seems that the prevalence of these complications is related to both the method of treatment and the surgical technique.

In children and adolescents, the functional ROM for the elbow to carry out contemporary tasks is $51^\circ$–$139^\circ$ flexion/extension and $18^\circ$–$55^\circ$ supination/pronation [23]. This finding indicates that children do not require full ROM to perform activities. This result is in accordance with our study findings that, while nearly 70% of our patients had limited ROM upon clinical examination, 87% of them obtained an excellent score on the Mayo Elbow Performance Scale, and 13% had a good score. Therefore, to achieve a good practical result of treatment, it is not necessary to fixate on the degree of ROM.

This study was conducted at a single tertiary orthopedic center with 23 patients. The small number of cases and the lack of a control group were the main limitations of this study. Since this was a retrospective study, only patients who had data available and were referred for follow-up examinations were included. In addition, any variation in immobilization period and pin removal time reduced the accuracy of analysis. Different postoperative care techniques between patients might have affected the final results.

In conclusion, despite the high prevalence of complications reported for the open reduction method in previous studies, many of these complications were either not observed in our study or the prevalence was lower. Therefore, although clinical examination might have indicated a limited ROM in many patients, this difference did not lead to significant functional problems.

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REFERENCES

1. D’souza S, Vaishya R, Klenerman L. Management of radial neck fractures in children: a retrospective analysis of one hundred patients. J Pediatr Orthop 1993;13:232-8.

2. Ursei M, Sales de Gauzy J, Knorr J, Abid A, Darodes P, Cahuzac JP. Surgical treatment of radial neck fractures in children by intramedullary pinning. Acta Orthop Belg 2006;72:131-7.

3. Newman JH. Displaced radial neck fractures in children. Injury 1977;9:114-21.

4. O’Brien PI. Injuries involving the proximal radial epiphysis. Clin Orthop Relat Res 1965;41:51-8.

5. Vahvanen V, Gripenberg L. Fracture of the radial neck in children: a long-term follow-up study of 43 cases. Acta Orthop Scand 1978;49:32-8.

6. Steinberg EL, Golomb D, Salama R, Wientroub S. Radial head and neck fractures in children. J Pediatr Orthop 1988;8:35-40.

7. Flynn JM, Skaggs DL, PM W. Rockwood and Wilkins’ fractures in children. 8th ed. Netherlands: Lippincott Williams & Wilkins; 2014. p. 474-6.

8. De Mattos CB, Ramski DE, Kushare IV, Angsanuntsukh C, Flynn JM. Radial neck fractures in children and adolescents: an examination of operative and nonoperative treatment and outcomes. J Pediatr Orthop 2016;36:6-12.

9. Rodriguez Merchán EC. Displaced fractures of the head and neck of the radius in children: open reduction and temporary transarticular internal fixation. Orthopedics 1991;14:697-700.

10. Turchin DC, Beaton DE, Richards RR. Validity of observer-based aggregate scoring systems as descriptors of elbow pain, function, and disability. J Bone Joint Surg Am 1998;80:154-62.

11. Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J. Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. J Pediatr Orthop 1993;13:355-60.

12. Vocke AK, Von Laer L. Displaced fractures of the radial neck in children: long-term results and prognosis of conservative treatment. J Pediatr Orthop B 1998;7:217-22.

13. Jones ER, Esah M. Displaced fractures of the neck of the radius in children. J Bone Joint Surg Br 1971;53:429-39.

14. Fowles JV, Kassab MT. Observations concerning radial neck fractures in children. J Pediatr Orthop 1986;6:51-7.

15. Kaufman B, Rinott MG, Tanzman M. Closed reduction of fractures of the proximal radius in children. J Bone Joint Surg Br 1989;71:66-7.

16. Monson R, Black B, Reed M. A new closed reduction technique for the treatment of radial neck fractures in children. J Pediatr Orthop 2009;29:243-7.

17. Neher CG, Torch MA. New reduction technique for severely displaced pediatric radial neck fractures. J Pediatr Orthop 2003;23:626-8.

18. Schmittenecker PP, Haevernick B, Herold A, Knorr P, Schmid E. Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. J Pediatr Orthop 2005;25:45-50.

19. Tan BH, Mahadev A. Radial neck fractures in children. J Orthop Surg (Hong Kong) 2011;19:209-12.

20. Steele JA, Graham HK. Angulated radial neck fractures in children: a prospective study of percutaneous reduction. J Bone Joint Surg Br 1992;74:760-4.

21. Evans MC, Graham HK. Radial neck fractures in children: a management algorithm. J Pediatr Orthop B 1999;8:93-9.

22. Bernstein SM, McKeever P, Bernstein L. Percutaneous reduction of displaced radial neck fractures in children. J Pediatr Orthop 1993;13:85-8.

23. Valone LC, Waites C, Tartarilla AB, et al. Functional elbow range of motion in children and adolescents. J Pediatr Orthop 2020;40:304-9.