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Radial Neck Fractures in Children: Results When Open Reduction Is Indicated

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Background: Radial neck fractures in children are rare, representing 5% of all elbow pediatric fractures. Most are minimally displaced or nondisplaced. Severely displaced or angulated radial neck fractures often have poor outcomes, even after open reduction, and case series reported in literature are limited. The aim of the study is to analyze the outcomes of patients with a completely displaced and angulated fracture who underwent open reduction when closed reduction failed.

Methods: Between 2000 and 2009, 195 patients with radial neck fractures were treated in our institute. Twenty-four cases satisfied all the inclusion criteria and were evaluated clinically and radiologically at a mean follow-up of 7 years. At follow-up, the carrying angle in full elbow extension and the range of motion of the elbow and forearm were measured bilaterally. We recorded clinical results as good, fair, or poor according to the range of movement and the presence of pain. Radiographic evaluation documented the size of the radial head, the presence of avascular necrosis, premature physeal closure, and cubitus valgus.

Results: Statistical analysis showed that fair and poor results are directly correlated with loss of pronation-supination ($P = 0.001$), reduction of elbow flexion-extension ($P = 0.001$), increase of elbow valgus angle ($P = 0.002$), necrosis of the radial head ($P = 0.001$), premature physeal closure ($P = 0.01$), and associated lesions (olecranon fracture with or without dislocation of the elbow) ($P = 0.002$).

Discussion: In our cases, residual radial head deformity due to premature closure of the growth plate and avascular necrosis were correlated with a functional deficit. Associated elbow injury was coupled with a negative prognosis. In our series, about 25% of patients had fair and 20% had poor results. Outcomes were good in 55% and felt to represent a better outcome than if the fracture remained nonanatomically reduced with residual angulation and/or displacement of the radial head. This study reports the largest series of these fractures with a combination of significant angulation and displacement of the fracture requiring open reduction. We feel that open reduction is indicated when the head of the radius is completely displaced and without contact with the rim of the metaphysis.

Key Words: radial neck fractures, children, open reduction

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Radial proximal metaepiphyseal fractures are uncommon and account for 5% to 10% of all elbow fractures in skeletally immature patients.[1–6]

The frequency of associated lesions is quite variable, 15% to 60% in reported series.[2–5,7–9]

The treatment of radial neck fractures in children varies according to the fracture's displacement, angulation, and skeletal maturity. Most fractures are nondisplaced or minimally displaced and can be treated with closed reduction and casting with a good outcome.[10,11] There is a general agreement that displaced radial neck fractures with >30-degree angulation should be surgically treated.[9,11–13] Treatment options include percutaneous pin reduction,[8,14,15] elastic stable intramedullary nailing,[5,15–18] and open reduction with or without internal fixation.[3,9,17,19] Open reduction is a method of treatment often used in comminuted fractures or in fractures with a completely displaced head anteriorly or posteriorly on the radial metaphysis and when closed reduction has failed. Reports in the literature note higher rates of complications after open compared with closed reduction.[17,19–21]

Most authors agree that worse results may follow open treatment but it is the more severe fractures that warrant a more aggressive approach. Whether poor results are a consequence of treatment or the magnitude of the bony and soft tissue injury is not clear.

In series reported in the literature, when the head of the radius remains displaced >30% and angulated >45 degrees after attempts of closed or percutaneous reduction, an open reduction is indicated.[2,5,19,20]

The aim of the study is to analyze the outcomes of patients with a completely displaced and angulated (> 60 degrees) fracture who underwent open reduction when closed reduction failed. Results were reviewed at a

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TABLE 1. Clinical and Radiologic Data

Case	Age	Sex	Side	FU	Angulation of Radial Neck at Surgery (deg.)	Outcome	Necrosis	Premature Closure	Associated Lesion
1	9.2	M	Right	6.2	90	Poor	Yes	Yes	OF/Disl
2	8.9	F	Right	5.8	90	Fair	No	No	No
3	10	M	Right	8.2	90	Fair	No	No	No
4	9.2	M	Left	3.2	90	Fair	No	Yes	No
5	8.3	M	Left	4.1	90	Poor	Yes	Yes	Olecranon
6	7.8	M	Right	9.3	90	Fair	No	No	OF/Disl
7	6.2	F	Right	9.9	90	Fair	No	No	No
8	8.9	F	Right	7.3	80	Poor	No	No	No
9	10.2	M	Left	5.2	80	Poor	No	Yes	Olecranon
10	6.5	F	Right	10.8	75	Poor	No	No	No
11	10.2	M	Right	3.2	90	Good	No	Yes	No
12	4.3	M	Left	11.2	85	Good	No	No	No
13	6.3	F	Right	9.1	70	Good	No	No	No
14	5.4	F	Right	12.1	75	Good	No	No	No
15	7.4	F	Left	7	65	Good	No	No	No
16	7.3	M	Right	4.4	65	Good	No	No	No
17	5.3	F	Right	11.3	65	Fair	Yes	No	No
18	6.4	F	Right	4.2	65	Good	No	Yes	No
19	5.8	M	Left	6.3	65	Good	No	No	No
20	7.2	F	Left	6.2	65	Good	No	No	No
21	5.1	F	Right	8.4	70	Good	No	No	No
22	5.8	M	Right	7.3	65	Good	No	No	No
23	6.2	F	Right	9.1	65	Good	No	No	No
24	7.1	F	Left	4.7	70	Good	No	No	No

Disl indicates dislocation; F, female; FU, follow-up; M, male; OF, olecranon fracture.

significant follow-up time and factors leading to poor results were identified

METHODS

All patients and their parents gave informed consent before being included in the study. This retrospective research was approved by our institutional ethics committee and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki as revised in 2000.

Between 2000 and 2009, 195 patients with radial neck fractures were treated at our Division, a large, metropolitan, pediatric referral center. All patients had a review of their clinical charts and radiographs from initial injury to final follow-up.

Inclusion criteria for the study were: (a) completely displaced and/or angulated radial neck fractures with or without associated injuries that could not be reduced by manipulation (with or without percutaneous K wires) under general anesthesia, and treated with open reduction; (b) patients with open growth plates of the elbow at the time of the injury; (c) minimum follow-up of 3 years. Exclusion criteria were: (a) open fracture; (b) lack of complete medical records or radiograph series (preoperative, postoperative, at 1 mo, at 6 mo, and at final follow-up).

We used the O'Brien classification[22] based on the angulation of the radial neck. Angulation was measured between the superior articular surface of the displaced radial head and the shaft of the radius. Displacement was also measured as the extent of lateral shift of the fragment by the distance from the center of the radial head to a line along the axis of the upper radius.

Treatment varied: 111 of the 195 patients with nondisplaced or minimally displaced fractures were managed with simple cast immobilization, 56 underwent a manipulative closed reduction, 36 with K wire guidance, and 20 without K wires under general anesthesia and then immobilization in a cast. Twenty-eight patients had fractures with complete displacement and radial neck angulation of >60 degrees that could not be reduced by manipulation (with or without percutaneous K wires) under general anesthesia and underwent an open reduction and formed the cohort for this study.

At follow-up, the carrying angle in full elbow extension and the range of motion (ROM) of the elbow and forearm were measured bilaterally. We recorded clinical results as good, fair, or poor according to the range of movement (pronation, supination, flexion, extension) and the presence of pain as per the Steinberg and Rodriguez-Merchan classification.[23] We also evaluated any change in the carrying angle and axial deformity.

Flexion and extension of the elbow, pronation and supination of the forearm, and the valgus angle of the extended elbow were measured using a goniometer. The uninjured elbows served as controls.

Radiographic evaluation documented the size of the radial head, presence of avascular necrosis, premature physeal closure and cubitus valgus. The final follow-up radiographs included standard antero-posterior and lateral radiographs of both elbows.

Statistics

Descriptive statistics were used for the variables of our group. The paired Student *t* test was used to analyze

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FIGURE 1. A and B, Radial neck fracture of the right elbow in a 6–year-old and 3-month-old girl. C and D, Postoperative radiographs after open reduction of the fracture. Radiographic result 9.1 years after treatment: E and F, Contralateral normal elbow; G and H, Operated elbow (case 13, good result).

the differences between the normal elbow and the injured elbow when the data were parametric, and the Pearson correlation was used to correlate the results with the collected data. Outcome data for each group are presented as the mean and SD, and the mean difference between groups and the 95% confidence interval are provided. A P value of < 0.05 was considered significant. Statistical analysis was performed using a GraphPad prism 5 computer program.

Surgical Technique of Open Reduction

The anconeus-extensor carpi ulnaris interval was used to expose the orbicular ligament. The radial head was gently repositioned and interposed capsular or ligamentous structures that blocked reduction were removed. Rotation can be judged by the fit of the fragments at surgery especially if there was a Salter 2 type fragment. We usually check by fluoroscopy the reduction obtained (in all cases no residual angulation or translation was observed).

The head fragment was stable after reduction and internal fixation was not performed.

Reduction was maintained by cast immobilization in 90-degree elbow flexion and about 45 degrees of pronation for 4 to 5 weeks.

RESULTS

Twenty-eight patients met the inclusion criteria except for the final follow-up, which 4 patients refused to take part in. Twenty-four cases satisfied all the inclusion criteria and were evaluated clinically and radiologically at a mean follow-up of 7 years and 1 month (range, 3.2 to 12.1 y). There were 11 boys and 13 girls with a median age of 7 years and 1 month (range, 4.3 to 10.2 y), the right arm was involved in 16 patients and the left in 8. (In all the 16 patients the right arm was dominant and in 4 of the 8 the left was dominant and it did not play a role in the outcome).

All fractures were completely displaced without contact between the head and the radial metaphysis and had an angulation of > 60 degrees (O'Brien type 3). In 4 cases, there were olecranon fractures, 2 with an associated elbow dislocation (Table 1).

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FIGURE 2. A and B, Radial neck fracture of the left elbow in a 9-year-old and 2-month-old boy. C and D, Postoperative radiographs after open reduction of the fracture. Radiographic result 3.2 years after treatment: E and F, Operated elbow: physeal premature closure of the proximal radius; G and H, contralateral normal elbow (case 4, fair result).

Results were graded as good, (Fig. 1) fair, (Fig. 2) or poor (Fig. 3) as shown in Table 1. Fair (25%) and poor (20%) results were directly correlated with reduction of pronation-supination ROM ($P = 0.001$), reduction of flexion-extension ROM ($P = 0.001$), increase of elbow valgus angle ($P = 0.002$), presence of necrosis of the radial head ($P = 0.001$), premature physeal closure (Fig. 2F) ($P = 0.01$), and an associated lesion, for example, olecranon fracture associated with or without elbow dislocation ($P = 0.002$) (Table 2).

Significant statistical differences were seen between the injured and normal elbow with radial head diameter ($P < 0.0001$), valgus angle of the elbow ($P < 0.0001$), elbow flexion-extension ROM ($P < 0.01$) [due to the reduction of flexion which is correlated with poor results ($P < 0.003$)], and with loss of pronation-supination ROM ($P < 0.0003$) [the reduction of pronation and supination were both correlated with poor results ($P < 0.01$)] (Table 3). The main cause of unsatisfactory results was a limitation in pronation-supination: 6 cases had about 20 degrees less than normal pronation-supination (Table 4; cases 2, 3, 4, 6, 7, 17) and another 5 cases had about 40 degrees less supination than normal pronation-supination (Table 4; cases 1, 5, 8, 9, 10) compared with the noninjured contralateral elbow.

Pain was considered intermittent and slight by 3 patients who practiced intensive sports, which involved use of the injured extremity. Four patients experienced pain and mild loss of strength (loss of strength is defined by the patient self-sensing reduction of strength or by the examiner during manual muscle testing involving tightening the examiner's fingers) and 4 experienced pain and moderate loss of strength.

On radiographic examination there was radial head enlargement of 2 to 5 mm in 90% of patients. Loss of motion was not associated with this morphologic change ($P = 0.08$); poor outcomes were seen in 3 cases with avascular necrosis and in 7 cases with premature closure of the growth plate and residual neck deformity (Fig. 3). The main functional losses were pronation and supination and elbow flexion (Table 1; cases 1, 4, 5, 11, 17, 18).

DISCUSSION

This study reports the largest series of these fractures with a combination of significant angulation and displacement of the fracture requiring open reduction. We feel that open reduction is indicated when the head of the radius is completely displaced and without contact with the rim of the metaphysis. Even minimal contact was noted in other series to help obtain a closed reduction with a Kirschner wire or an intramedullary elastic nail. In our series, the degree of angulation was always >60 degrees and about 90 degrees in most cases.

In our cases, residual radial head deformity due to premature closure of the growth plate and avascular necrosis were correlated with a functional deficit. Associated

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FIGURE 3. A and B, Radial neck fracture of the left elbow associated with olecranon fracture in an 8-year-old and 3-month-old boy. C and D, Radiographs after 1 year showing head necrosis, premature closure of the physis. E and F, Radiographic result after 4.1 years: severe deformity of the radial head and subluxation (case 5, poor result).

elbow injury was coupled with a negative prognosis. In our series, about 25% of patients had fair and 20% had poor results. Outcomes were good in 55% and felt to represent a better outcome than if the fracture remained nonanatomically reduced with residual angulation and/or displacement of the radial head.

Loss of motion, the primary cause of poor results, is felt to be secondary to a combination of loss of joint congruity and fibrous adhesions.[5,7,17,20,21,24,25] Open reduction was performed to provide an anatomic reduction with minimal trauma of soft tissue around the fracture.[26,2] The bloody supply of the radial head is precarious, and meticulous dissection with preservation of soft tissue attachments to the metaphyseal spike may improve the results.[7] In our series, the head was repositioned as gently as possible removing interposed structures that blocked reduction. We found the head fragment to be stable after reduction and internal fixation was not performed.

Complication relative to internal fixation to the fragment blood supply and particular surface was avoided without loss of reduction.

TABLE 2. Correlation Between Steinberg and Rodriguez-Merchan Classification of the Results (1 Good, 2 Fair, 3 Poor) and Clinical and Radiologic Results

Comparison	Correlation Coefficients	Significative	*P*
Results vs. pron-sup F	−0.615	Yes	0.001
Results vs. flex-ext F	−0.631	Yes	< 0.001
Results vs. valgus angle F	0.588	Yes	0.002
Results vs. head necrosis	−0.630	Yes	< 0.001
Results vs. premature physeal closure	−0.482	Yes	0.01
Results vs. associated lesion	−0.606	Yes	0.002
Results vs. head diameter F	0.365	NS	0.08

F indicates fractured side; Flex-Ext, flexion-extension; Pron-Sup, pronation-supination.

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TABLE 3. Paired *t* Test Between Normal and Fractured Side in Radial Head Diameter at Follow-up Antero-posterior Radiograms; Valgus Angle, Flexion-extension, Pronation-supination at Clinical Follow-up

t Test	95% Confidence Interval	Significative	*P*
Radial head diameter: N vs. F	−4.26 to −2.57	Yes	< 0.0001
Valgus angle: N vs. F	−11.83 to −4.92	Yes	< 0.0001
Flexion-extension: N vs. F	0.79 to 6.29	Yes	0.01
Pronation-supination: N vs. F	7.24 to 20.84	Yes	< 0.0003

F indicates fractured side; N, normal side.

Acceptability of reduction has to be related to the type of proximal fragment dislocation and displacement and age of the patient, with a younger child having greater potential of remodeling. The generally accepted upper limit of accepted angulation is 45 degrees at 10 years of age.[9,11–13,17,19–21] This angular value was chosen from series that included multiple methods of treatment, limited follow-up, and, in some cases, not including the amount of fracture translation.

Different techniques are proposed to minimize iatrogenic insults to the vulnerable proximal radius. Potential insults are direct injury from percutaneous pins or cumulative trauma from repeated failed manipulations.[7,13] Greater O'Brien grade, higher fracture angulation, and increased fracture displacement were associated with more invasive interventions in the series reported by Zimmerman et al.[9]

Certain radiographic patterns, such as laterally displaced fractures with potential annular ligament entrapment may represent higher levels of bony and soft tissue injuries as was seen in some of our cases.

Recent works report that closed techniques, especially intramedullary nailing, can be successful for severely displaced fractures, but about 10% of cases still needed open reduction.[20,21,27] The learning curve to gain expertise in this method is significant.

Comparison with other papers on open reduction treatment was difficult, as they did not use similar classification methods of the fractures nor outcome measures at follow-up with metrics used in the current paper.

Twelve percent of the total of 195 patients had a severe displacement and could not be treated by closed reduction. Although we did not use intramedullary nailing, the percentage of cases treated with open reduction is similar to the cases reported in studies in which the Metaizeau technique was used.

TABLE 4. Clinical and Radiologic Data at Follow-up

Case	Carrying Valgus Angle—N	Carryng Valgus Angle—F	Pron-N	Pron-F	Sup-N	Sup-F	Ext-N	Ext-F	Flex-N	Flex-F
1	10	25	5	15	170	140	0	0	150	135
2	10	22	0	10	180	170	0	0	145	145
3	10	30	5	15	165	155	−5	−5	140	140
4	15	30	0	5	175	160	0	0	140	140
5	12	28	0	20	180	160	0	0	153	143
6	5	25	10	10	170	150	0	−3	160	142
7	10	30	5	5	170	150	−5	0	145	135
8	15	28	0	10	170	140	0	0	150	150
9	15	30	0	10	170	140	0	0	140	140
10	10	22	10	30	160	140	−3	−3	140	140
11	10	28	0	0	180	180	0	0	143	143
12	10	10	5	5	160	160	−5	−5	150	150
13	5	5	10	10	160	160	0	0	148	148
14	20	20	0	0	175	175	0	0	150	150
15	18	18	0	0	170	170	0	0	138	138
16	15	15	0	0	165	165	−5	−5	148	148
17	5	15	5	5	180	160	0	0	155	135
18	15	25	5	10	175	163	0	0	155	145
19	12	12	5	5	170	170	−3	−3	145	145
20	18	18	5	5	165	165	0	0	150	150
21	8	8	10	10	160	160	−5	−5	153	153
22	5	5	10	10	170	170	−5	−5	150	150
23	12	12	5	5	173	173	0	0	145	145
24	15	15	5	5	168	168	0	0	143	143

Ext indicates extension; F, fractured side; Flex, flexion; N, normal side; Pron, pronation; Sup, supination.

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The limit of the study is to be a retrospective review without comparing different methods and strategy of treatment.

CONCLUSIONS

In our opinion, proximal radial fractures with totally displaced proximal fragments and residual angulation, especially if associated with a lateral shift, for which closed or percutaneous reduction is not successful should be treated with open surgery.

Open reduction should be performed with minimal injury to osteo-chondral, ligamentous, and muscular structures to reduce complications associated with this injury. The causes of poor results in these significant fractures appear related to the major focal trauma to the bony and soft tissues in this area.

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