



# Management of Severely Displaced Radial Neck Fractures in Children: A Systematic Review and Meta-analysis of Outcomes

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## Abstract

**Background** This systematic review is an attempt to provide an evidence-based analysis of literature on management of severely displaced radial neck fractures (with > 60° displacement) in children.

**Material and Methods** A systematic literature search was conducted to identify all original articles published between 01/01/1999 and 20/01/17 on surgical treatment of radial neck fractures in children in the following databases: MEDLINE, EMBASE, and CINAHL PLUS. Studies reporting pre-operative fracture displacement and post-operative outcomes according to standard outcome measures were included.

**Results** Out of 887 studies identified on initial search, 48 were eligible for full-text review and 14 studies with a total of 173 patients were included in the final review. The overall success rate after severely displaced radial neck fractures in skeletally immature patients was 87% (95% CI, 82%, 92%). Closed reduction methods reported higher success rate of 90% (95% CI, 85%, 95%) compared to open reduction methods 77% (95% CI, 63%, 89%).

**Conclusion** The average rate of patients achieving excellent/good outcomes following surgical management after severely displaced radial neck fractures in this review is better than reports from previous reviews. Considering the limitations in current evidence base including lack of direct comparison of techniques and small study samples, large comparative studies controlling for possible confounders are merited.

**Keywords** Radial neck · Fracture · Children

## Introduction

This systematic review is an attempt to provide an evidence-based analysis of literature on management of severely displaced radial neck fractures (with > 60° displacement) in children. A systematic literature search was conducted to identify all original articles published between 01/01/1999 and 20/01/17 on surgical treatment of radial neck fractures in children in the following databases: MEDLINE, EMBASE, and CINAHL PLUS. Studies reporting pre-operative fracture displacement and post-operative outcomes according

to standard outcome measures were included. Out of 887 studies identified on initial search, 48 were eligible for full-text review and 14 studies with a total of 173 patients were included in the final review. The overall success rate after severely displaced radial neck fractures in skeletally immature patients was 87% (95% CI, 82%, 92%). Closed reduction methods reported higher success rate of 90% (95% CI, 85%, 95%) compared to open reduction methods 77% (95% CI, 63%, 89%). The average rate of patients achieving excellent/good outcomes following surgical management after severely displaced radial neck fractures in this review is better than reports from previous reviews. Considering the limitations in current evidence base including lack of direct comparison of techniques and small study samples, large comparative studies controlling for possible confounders are merited.

*Rationale* Radial neck fractures account for approximately 1% of all paediatric fractures and about 5–10% of all elbow injuries in children [1, 2]. These injuries most commonly occur between 8 and 12 years of age. The commonest

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mechanism is a fall on the outstretched arm with the forearm in supination and an associated valgus thrust, causing compression on the radiocapitellar joint [3]. Other mechanisms include dislocation of the elbow joint. About 30–50% cases are associated with further injuries such as fractures of the olecranon, lateral or medial epicondyle, or dislocations of the elbow [4]. The treatment algorithm of radial neck fractures is complex. Various factors determine the management, including the age of the patient, the fracture displacement, and angulation. For classification of such injuries, various classifications have been described in the literature; however, the most commonly used classifications for radial neck fractures are O'Brien Classification, Judet Classification with Metaizeau modification, and Steele and Graham Classification [2, 5–7]. Most of these fractures are minimally displaced and can be treated conservatively with plaster immobilization. However, radial neck fractures with  $> 30^\circ$  angulation need operative intervention in the form of closed reduction, percutaneous pin reduction and fixation, elastic stable intra-medullary nailing (ESIN), and open reduction with or without internal fixation [8]. Worse outcomes have been reported after fractures angulated more than  $60^\circ$  (O'Brien type III, Judet type IV or Steele type III/IV) and their treatment poses a challenge to the operating surgeon [8]. Common complications after these severely displaced fractures include limited range of movement, residual pain or instability, neurovascular injury, premature physal closure, cubitus valgus, overgrowth of the radial head, and avascular necrosis [8].

Most studies reporting outcomes on radial neck fractures in paediatric age group are limited by small sample sizes and generalized reporting of outcomes for all types of fractures, without separate data on severely displaced injuries. An attempt to synthesize evidence on treatment of radial neck fractures in children was made by conducting a meta-analysis of literature by Evans et al. [4]. However, the applicability of the findings of this study to severely displaced fractures was restricted due to the inclusion of all cases of radial neck fractures and limited evidence of severely displaced fractures with small number of subjects in this subgroup.

**Objective** We conducted this systematic review with the aim to summarize the evidence on outcomes following surgical treatment of radial neck fractures with  $> 60^\circ$  angulation in skeletally immature patients. Furthermore, this review examined the current literature to determine if there was any significant scientific evidence to support a standard algorithm for management of these complex injuries. The findings of this review will help to inform the operating surgeon to provide evidence-based explanation about the prognosis at the time of consenting parents of patients with these complex injuries.

## Materials and Methods

**Protocol and Registration** This systematic review was conducted following a predesigned review protocol, registered with PROSPERO, an international prospective register of systematic reviews. (PROSPERO Registration number: CRD42017058318). The findings are reported following the Preferred Reporting Items for Systematic Reviews & Meta-analysis (PRISMA) Guidelines [9].

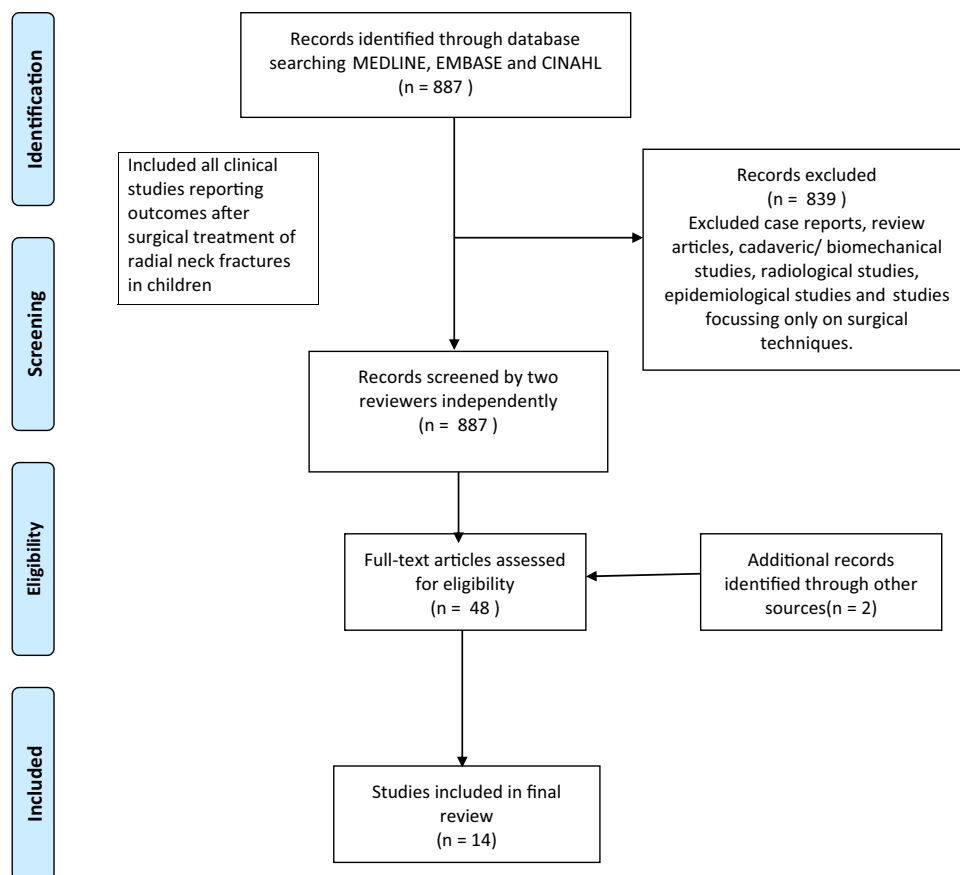
**Eligibility Criteria** Studies were deemed eligible if they reported on: (1) radial neck fractures in skeletally immature patients; (2) included classification of fractures pre-operatively as per fracture displacement using either the O'Brien, Judet Classification or Steele and Graham Classification; (3) studies with at least one or more cases of displacement  $> 60^\circ$  i.e. O'Brien type III or Judet type IV or Steele type III/IV; (4) studies with outcomes reported as per initial fracture displacement; (5) studies with outcomes reported using one of the standard scoring systems: Metaizeau outcome classification, Mayo Elbow Performance Score, Tibone and Stoltz classification, and Linscheid–Wheeler score [2, 10–12]. Exclusion criteria included case reports, review articles, cadaveric/biomechanical studies, radiological studies, epidemiological studies, and studies focussing only on surgical techniques. If the studies reported management of different degrees of radial fractures, they were included if subgroup analysis was available for outcomes in severely displaced fractures ( $> 60^\circ$ ).

**Information Sources** A systematic search of published literature was conducted for original articles on surgical treatment of radial neck fractures in skeletally immature patients in the following databases: MEDLINE, Excerpta Medica database (EMBASE), and Cumulative Index to Nursing and Allied Health Literature (CINAHL) PLUS on 20/01/17. The search was limited to English language articles on human subjects published from 01/01/1999 till 20/01/2017 as there was a meta-analysis on the same topic by Evans et al. [4].

**Search** The search strategy included the following keywords: (1) (radius OR radial OR elbow); (2) (fracture OR dislocation); (3) neck; (4) (treatment OR surgery OR management); (5) (child OR children OR paediatric OR paediatric OR preschool OR adolescent OR teen); (6) 1 AND 2 AND 3 AND 4 AND 5.

**Study Section** The same strategy was used in all three databases with modifications to meet the syntax requirement of individual databases. A total of 887 studies on treatment of radial neck fractures in children were identified in the three databases. Two reviewers (AMN and AAP) independently

**Fig. 1** Inclusion of articles in systematic review



searched for eligible articles to ensure consistency. Review of title and abstracts was done, independently by two reviewers (AMN and AAP) using predefined inclusion and exclusion criteria. The list of included studies by both reviewers was compared, where there was discrepancy in inclusion, it was discussed between all three reviewers and a mutual consensus was reached. A total of 48 studies were thus included for full-text article review. Both the reviewers (AMN and AAP) independently reviewed the full text of these articles. Based on full-text screening, only 14 articles met the inclusion criteria to be incorporated in the review.

**Data Collection Process** A total of 14 studies were included in the final review (Fig. 1). Data were extracted independently by the two reviewers (AMN and AAP), using pre-piloted data extraction forms.

**Data Items** Data were extracted on general characteristics of studies, like author, country, year of publication; patient characteristics like age, sex, injury; details of surgical technique; and clinical outcomes.

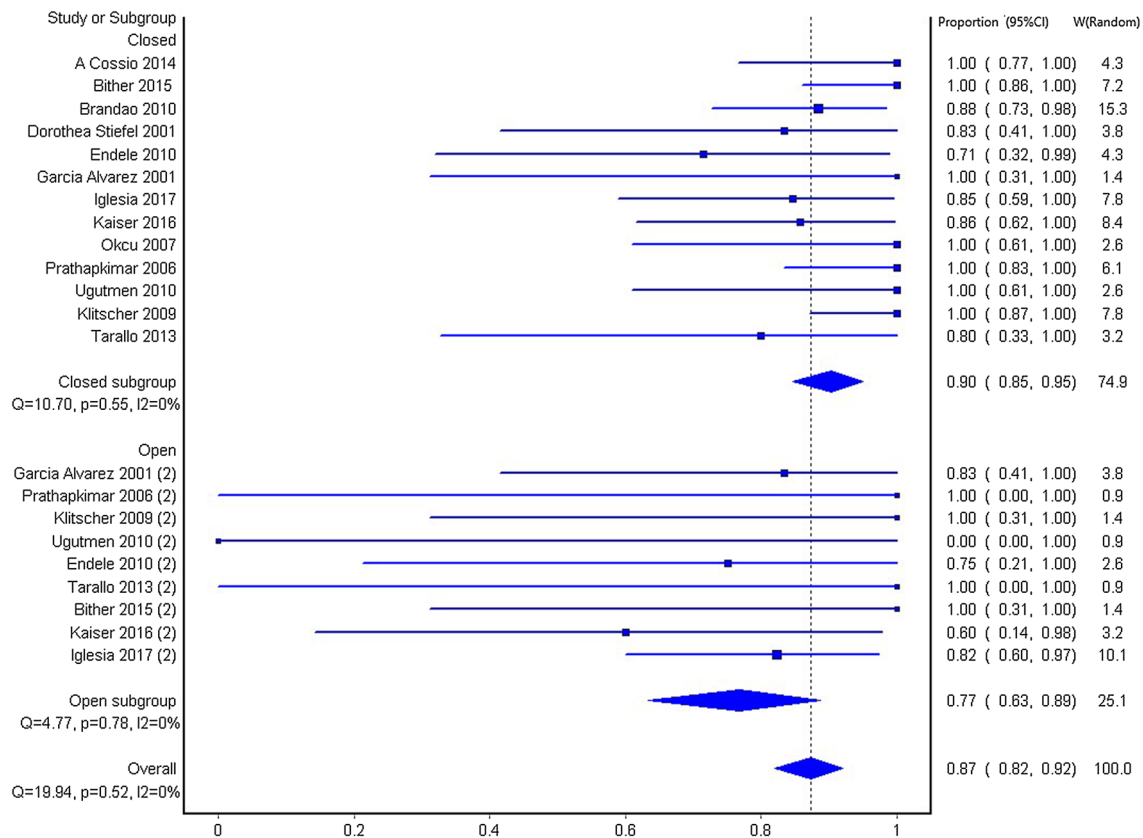
**Risk of Bias in Individual Studies** Quality assessment of included studies was done using the NHLBI Quality

Assessment Tool for Observational Cohort and Cross-Sectional Studies [13].

**Summary Measures of Studies** For outcomes following surgical management, ‘excellent’, ‘good’, ‘fair’, and ‘poor’ results were identified as reported by the authors. For the purpose of analysis, all the results of the same category were combined and reported together. The percentage of excellent and good results together were considered as “success rate” and reported accordingly (Fig. 2).

**Synthesis of Results of Studies** Meta-analysis was conducted using random effects model to estimate the pooled sample proportion. The pooled proportion was calculated as the back-transformation of the weighted mean of the transformed proportions. Statistical heterogeneity was measured using the Cochran  $Q$  statistic score and the  $I^2$  test. Subgroup analysis was conducted to examine the differences between subgroups, and reported as  $p$  values.

**Risk of Bias Across Studies** Risk of bias assessment across studies was not conducted. Only studies with good/fair quality were included in our final review.



**Fig. 2** Forest plot of pooled proportions of successful outcomes following surgical management of severely displaced radial neck fractures

*Additional Analyses of Studies* Subgroup analysis was done separately for closed and open reduction techniques.

### Results

Fourteen studies reporting on 173 patients with radial neck fractures displaced  $>60^\circ$  were included in the final review (Table 1). The average number of patients included in the studies was 12.4 (range 4–30 patients). The age of patients included in the studies varied from 1 to 16 years. For classification of injuries, 13 of the 14 studies included used the Judet Classification with Metaizeau modification, while one study used the O’Brien Classification. For reporting outcomes, Metaizeau classification was the most commonly used, reported in six studies. The others were Mayo Elbow performance score (4 studies), Tibone and Stoltz classification (2 studies), and Linscheid–Wheeler score (1 study), and in one study, authors used a clinical and radiological criteria to grade outcome which has not been described elsewhere in literature [8]. A total of 150 patients (86.7%) were reported to have excellent/good outcomes, varying from 63.6% in one study to 100% in others [14–19]. Factors which were found to be associated with fair/poor outcomes were initial

fracture displacement, especially if there is no bony contact between the two fragments [8, 20, 21]. Other factors were presence of associated injuries such as displaced olecranon fractures and elbow dislocations, age more than 10 years, and inadequate reduction [22–27]. Even though there are studies which were associated open reduction with poorer outcomes, many recent studies refute these claims [8, 14, 20, 21, 24].

Ten out of fourteen studies reported management of severely displaced fractures using three different surgical techniques, i.e., closed reduction using Metaizeau technique or its modifications, percutaneous reduction using different techniques, and open reduction with or without capsulotomy. Three studies included cases with either closed reduction or percutaneous reduction [16, 22, 25]. One reported all cases treated with percutaneous reduction and fixation [18]. The follow-up period varied considerably between studies, from 4 months to 11 years. The largest study had a mean follow-up of 14 months and range of follow-up from 8 to 39 months [20]. The time interval of removal of an intra-medullary K wire/nail ranged from 6 weeks to 24 months with the median average time around 10–12 weeks. The time of intervention (duration after injury), when reported, varied between immediately

**Table 1** Studies reporting clinical outcomes after treatment of severely displaced radial neck fractures

S. no.	Investigators	Study design	Level of evidence	Quality of the included study <sup>a</sup>	Age range	Patients with displacement > 60°	Timing of treatment	Treatment	Average duration of follow-up (range)	Outcome measure
1.	Garcia-Alvarez et al. [27]	Retrospective	Level 3	Good	7–14 years	8	As soon as possible after injury or when unacceptable displacement was observed in serialised X ray controls	Closed reduction/percutaneous leverage reduction	43 months (33–72 months)	Metaizeau outcome classification Excellent—3 Good—4 Poor—1
2.	Stiefel et al. [25]	Retrospective	Level 3	Fair	7–10 years 9 months	6	3 h–5 days	Closed reduction/percutaneous leverage	4.25 months (6 weeks–8 months)	Author's definition <sup>c</sup> Excellent—5 Poor—1
3.	Schmittbencher et al. [14]	Prospective	Level 3	Fair	1 year 10 months–14 years 4 months	11	Not clear	Closed reduction/percutaneous leverage reduction	6 months	Metaizeau outcome classification Excellent—7 Fair/poor—4
4.	Prathapkumar et al. [15]	Not mentioned	Level 3	Good	7–12 years	11	< 48 h except one pt. (9 days)	Closed reduction/percutaneous leverage reduction	28 months	Metaizeau outcome classification Excellent—10 Good—1
5.	Okcu and Aktuğlu [16]	Retrospective	Level 3	Fair	7–15 years	4	1st–5th day	Closed reduction/percutaneous leverage	2 years	Tibone and Stoltz outcome classification Excellent/good—4
6.	Klitscher et al. [17]	Retrospective	Level 3	Good	5–11 years	15	Not clear	Closed reduction/percutaneous leverage reduction	32 months	Mayo Elbow performance score Excellent—10 Good—5
7.	Brandão et al. [22]	Not mentioned	Level 3	Good	6–13 years	26	Mean 36 h (6–50 h)	Closed reduction/percutaneous leverage	52 months (1.7–10 years)	Tibone and Stoltz outcome classification Excellent—17 Good—6 Fair—2 Poor—1

**Table 1** (continued)

S. no.	Investigators	Study design	Level of evidence	Quality of the included study <sup>a</sup>	Age range	Patients with displacement > 60°	Timing of treatment	Treatment	Average duration of follow-up (range)	Outcome measure
8.	Ugutmen et al. [28]	Not mentioned	Level 3	Fair	6–13 years	5	< 24 h	Closed reduction/percutaneous age/open reduction	24 months (18–40 months)	Metaizeau outcome classification Excellent—3 Good—1 Fair—1
9.	Endele et al. [21]	Retrospective	Level 3	Good	1–13 years	11	Not clear	Closed reduction/percutaneous age/open reduction	4 years (0.5–11 years)	Metaizeau outcome classification Excellent—6 Good—2 Fair—2 Poor—1
10.	Tarallo et al. [23]	Retrospective	Level 3	Good	6–16 years	6	Not reported	Closed reduction/percutaneous age/open reduction	42 months (15–63 months)	Mayo elbow performance score Excellent—3 Good—2 Fair—1
11.	Cossio et al. [18]	Retrospective	Level 3	Good	6–12 years	7	< 12 h	Percutaneous leverage and fixation	26.6 months (12–36 months)	Mayo elbow performance score Excellent—7
12.	Bither et al. [19]	Not mentioned	Level 3	Good	5–13 years	14	Not reported	Closed reduction/percutaneous age/open reduction	39 months (6–80 months)	Mayo elbow performance score Excellent—14
13.	Kaiser et al. [8]	Retrospective	Level 3	Good	4–13 years	19	Not reported	Closed reduction/percutaneous age/open reduction	3.5 (1–8 years) <sup>b</sup>	Linscheid–Wheeler score Excellent—12 Good—3 Poor—4
14.	Gutiérrez-de la Iglezia et al. [20]	Retrospective	Level 3	Good	6–15 years	30	Not reported	Closed reduction/percutaneous age/open reduction	14 months (8–39 months)	Metaizeau outcome classification Excellent—18 Good—7 Fair—5

<sup>a</sup>Quality assessment conducted using National Heart, Lung, and Blood Institute (NHLBI) Study Quality Assessment Tools

<sup>b</sup>Median duration of follow-up (range)

<sup>c</sup>Authors described > 20° loss of movement as poor, but the single case with poor outcome had severe restriction in pronation and supination, so would be classified as poor in Metaizeau outcome classification as well

**Table 2** Summary of common complications reported in the included studies

S. no.	Complication	Number of cases	Comments
1	Superficial radial nerve palsy	4	This resolved spontaneously within 6 months in all except one study
2	Heterotrophic ossification	4	In one child, exostosis was removed after 6 months, and in another, radial head was excised after skeletal maturity
3	Avascular necrosis	3	In a child aged 13 years, radial head was excised 5 months after injury <sup>a</sup>
4	Pseudobursa	2	Did not need any treatment
5	Radio-ulnar synostosis	2	In one study, this was treated with resection of synostosis and interposition of fascia-fat flap with complete resolution
6	Superficial skin infection	1	This occurred in case of percutaneous reduction and K wire fixation
7	Intra-articular extension of intra-medullary K wire	1	The patient presented with immediate post-operative pain and restricted ROM which required early revision with good outcome
8	Transient posterior interosseous nerve palsy	1	This happened in a case of open reduction and resolved spontaneously in 6 weeks

<sup>a</sup>This patient had an open reduction and ESIN; patient developed pain with loss of motion and increased density of radial head suggestive of necrosis of head. The patient wanted definitive treatment, so radial head was excised at 5 months. As per the authors at follow-up of 2.4 years, patient showed improved range of motion, occasional pain, and no instability

after injury to up to 9 days. The longest duration of 9 days was reported in one case in the study by Prathapkumar et al., which was due to delayed referral to the hospital.

Data for comparison of treatment approaches were not available from one study (Schmittenbecher et al.), and hence, 13 studies were included in the meta-analysis. Quantitative synthesis of success rate from these studies showed an overall success rate of 87% (95% CI, 82%, 92%). Closed reduction techniques showed a higher success rate of 90% (95% CI, 85%, 95%), compared to open reduction techniques, showing a success rate of 77% (95% CI, 63%, 89%).

The common symptomatic complications which were described in the studies are listed in Table 2 in decreasing order of frequency. The other complications described were premature arrest of proximal radial physis, increased carrying angles, malunion with angulations up to 30°, and enlargement of radial heads.

## Discussion

The management of severely displaced radial neck fractures in skeletally immature patients remains controversial. The consensus on management of such injuries is restricted due to rarity of cases with more than 60° displacement and limited evidence available to guide the treatment of these complex injuries. A meta-analysis of literature looking into treatment of radial neck fractures in children by Evans et al. summarized the available evidence on this topic and also suggested a management algorithm [4]. However, newer techniques of closed reduction and percutaneous reduction as well modifications to open

reduction have been described in recent literature. Unlike the Evans systematic review which looked at treatment outcomes of all radial neck fracture injuries, the present study focussed on management of severely displaced radial neck fractures. Recent studies have also challenged the conventional wisdom that open reduction is associated with poorer functional outcomes [8, 20, 21]. The average rate of 87% patients with excellent/good outcomes in the studies included in this review is higher than 77% achieved in the series by Metaizeau et al. for these types of fractures [2]. Furthermore, five studies reporting 100% excellent/good outcomes show that, with use of meticulous surgical techniques, optimum outcomes can be achieved [15–19].

Four studies combined the use of percutaneous reduction followed by intra-medullary nailing as described by Metaizeau with 100% excellent/good outcomes [15–17, 19]. In one study, the entry point for the intra-medullary wire was made 4 cm proximal to the distal radial physis which helped to prevent iatrogenic radial nerve injury [19]. Reasons for failure of closed reduction were interposition of soft tissues in two studies and the disruption of the lateral periosteal hinge in another study [19, 27, 28]. Data from some studies challenged the previous view associating open reduction of fracture to poor functional outcomes. This is corresponding to 75% excellent/good outcome as per Metaizeau outcome classification and is comparable to ESIN/percutaneously treated groups in other studies. However, most authors advised judicious attempts of closed and percutaneous reduction before resorting to open reduction. In clinical practice, fractures not reduced by closed reduction are likely to be treated with open reduction. This should be considered while comparing the results of the two surgical techniques of open and closed reduction. The

purpose of this study was to look into the current literature on treatment of severely displaced radial neck fractures in children and to draw best possible conclusion based on the current evidence available. Therefore, we looked into the clinical outcomes after different surgical treatments of these fractures and recorded outcomes as excellent/good/fair/poor as per the individual scoring systems used in these studies. This methodology was used because of the lack of a single standard outcome measure after these fractures and is similar to recently published meta-analysis on similar topic in adults [29].

## Summary of Evidence

The overall success rate after severely displaced radial neck fractures in skeletally immature patients was 87% (95% CI, 82%, 92%). Closed reduction methods reported higher success rate of 90% (95% CI, 85%, 95%) compared to open reduction methods 77% (95% CI, 63%, 89%). The average rate of patients achieving excellent/good outcomes following surgical management after severely displaced radial neck fractures in this review is better than reports from previous reviews. Our study has a number of strengths, including being, to our knowledge, the updated review and meta-analysis of management of severely displaced radial neck fractures in skeletally immature subjects. Previous reviews on this topic have looked at all fractures, and thus not focussed special attention to this group.

## Limitations

There are also limitations in this review which need consideration. The included studies were retrospective case series with number of patients varying from 4 to 30. This reduces the level of evidence to IV. The follow-up time in some studies was as less as 4 months, but that is assumed to be in patients with excellent outcomes.

## Conclusion

Findings from the current systematic review demonstrate overall effectiveness of surgical management of severely displaced radial neck fractures in skeletally immature subjects. The findings can be a useful aid for the surgeon managing such injuries, for management plan and discussing prognosis with patients. Our review also identified evidence gaps in the current evidence, and it is recommended to have long-term, prospective, multicentre studies on this topic with pre-established inclusion criteria and use of a standard clinical

outcome measure for best possible evidence on this complex topic.

**Author contributions** Concepts: AMN, AAP, and MB. Design: AMN, AAP, and MB. Definition of intellectual content: AMN, AAP, and MB. Literature search: AMN and AAP. Data acquisition: AMN, AAP, and MB. Data analysis: AMN, AAP, and MB. Statistical analysis: AMN and AAP. Manuscript preparation: AMN, AAP, and MB. Manuscript editing: AMN, AAP, and MB. Manuscript review: AMN, AAP, and MB. Guarantor: AMN.

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## Compliance with Ethical Standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical standard statement** This article does not contain any studies with human participants or animals, performed by any of the authors.

**Informed consent** For this type of study formal consent is not required.

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