J Shoulder Elbow Surg (2021) 30, 439–448

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

REVIEW ARTICLES

Crossed versus lateral K-wire fixation of supracondylar fractures of the humerus in children: a meta-analysis of randomized controlled trials

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Background: Supracondylar fractures of the humerus are common in children. Whether fixation should be performed with crossed or lateral wires remains controversial. We performed a meta-analysis of randomized controlled trials to evaluate both techniques in terms of the function of the elbow and the risk of neurologic injury and loss of reduction. We also assessed the quality of the evidence currently available.

Methods: The MEDLINE, Embase, Cochrane Library, and LILACS (Latin American and Caribbean Health Sciences Literature) databases, as well as ongoing clinical trial databases, were searched until March 2020. The main outcomes were function, measured by the Flynn criteria, and complications (neurologic lesions and loss of reduction). A meta-analysis was conducted using relative risk (RR) analysis for dichotomous variables and difference in means for continuous variables. Heterogeneity was tested using the I^2 statistic.

Results: Twelve trials, with a total of 930 patients, met the inclusion criteria. Both groups (crossed-wire and lateral-wire fixation) presented satisfactory functional results, with no difference between them (RR, 0.99; 95% confidence interval [CI], 0.96-1.02; $P = .44$). Patients undergoing crossed-wire fixation had a higher risk of iatrogenic neurologic injury (RR, 0.45; 95% CI, 0.21-0.99; $P = .05$). The crossed group showed greater fixation stability, with a lower incidence of loss of fracture reduction (RR, 1.39; 95% CI, 1.04-1.85; $P = .03$). The GRADEpro GDT (Guideline Development Tool) showed that the quality of evidence of the evaluated outcomes was low or very low.

Conclusion: There is evidence of very low quality that fixation with lateral wires is safer regarding iatrogenic nerve lesions whereas fixation with crossed wires is more effective at maintaining fracture reduction.

Level of evidence: Level II; Meta-analysis; Treatment Study

Keywords: Supracondylar humeral fracture; humeral fracture; children; surgical treatment; systematic review; meta-analysis

The study was approved by the Federal University of São Paulo Ethics Committee (no. 108538/2015).

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1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2020.09.021

Supracondylar fracture of the humerus (SFH) is the most common elbow fracture in children, accounting for 60% of elbow fractures and approximately 16% of all fractures in the pediatric population, with a peak incidence between 5 and 7 years of age.[10,11,14,20,30] In a large proportion of cases, surgical treatment is required.[21,22]

There are 2 common fixation techniques for displaced fractures used by orthopedic surgeons: retrograde fixation with crossed K-wires or fixation with lateral insertion of wires.[4,5,9,15,18,38] The main complications resulting from surgical treatment are described as loss of reduction, residual deformity, neurologic lesions, and infection.[12,21,27] Studies have presented conflicting evidence regarding which technique should be used, with some authors reporting an elevated risk of iatrogenic damage to the ulnar nerve with the crossed-wire technique and others reporting lower fixation stability with lateral parallel wires.[7,13,40,43,45] Reviews on the surgical treatment of SFHs have already been published, most of which evaluated primary studies of questionable methodologic quality, such as retrospective case series.[6,7,28,40] Some associated cohort studies with randomized controlled trials (RCTs) in their assessments.[13,31,43] To date, only 2 reviews that included only RCTs have been published, and the most recent review was published 7 years ago.[44,45] Since then, other clinical trials have been issued, which justifies the performance of a new review.[1,2,29,32,35,36] Within the SFH compendium of systematic reviews, no other study has had a previously published protocol, which would increase the external validity of the study.[8]

The objective of this systematic review and meta-analysis of RCTs was to evaluate the effectiveness of surgical interventions with crossed and lateral wires for the treatment of displaced SFHs in children, regarding elbow function, complications resulting from the surgical approach, and the quality of the currently available evidence.

Methods

Search strategy and eligibility criteria

This was a systematic review and meta-analysis of RCTs. RCTs on the surgical treatment of SFHs in children were selected, using the standards recommended in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines.[24] The selected studies were those in which the participants were children with Gartland type II or III displaced fractures and the crossed-wire technique (crossed group) was compared with the lateral-wire technique (lateral group), with the randomized allocation of subjects to the 2 groups.

The research was conducted in the following databases: Cochrane Library, MEDLINE, Embase, and LILACS (Latin American and Caribbean Health Sciences Literature). Studies were retrieved until the end of March 2020. Only articles with full-text versions available were selected, and there were no restrictions on language. In addition to electronic searches, manual investigations of references lists and article citations were performed. The search strategy is presented in Supplementary Table S1. This study was registered on the PROSPERO platform (CRD42014009304). The protocol was published in an indexed journal before the review was performed.[8]

Data extraction

Two authors (O.L.C. and F.T.) evaluated all selected studies. Potentially eligible articles were reviewed in full, and disagreements were resolved by discussion. The study design, inclusion and exclusion criteria, population characteristics, postoperative results, and complications were extracted and compared by the reviewers. Whenever necessary, a third author (M.J.S.T.) was consulted to resolve disagreements.

Quality assessment

The risk of bias in the included studies was assessed by 2 authors (O.L.C. and F.T.M.) independently, and the Cochrane risk-of-bias tool was used.[19]

Outcome measures

The primary outcomes evaluated were function and complications resulting from surgery. Function was assessed using the Flynn criteria.[15] The following complications were analyzed dichotomously (yes or no): iatrogenic neurologic lesion (ulnar, radial, or median nerve) and loss of reduction. Loss of reduction was diagnosed in individuals who experienced a loss $> 6^\circ$ in the Baumann angle, loss $> 10^\circ$ in the carrying angle, loss $> 10^\circ$ in the humeral-capitellar angle, or any alteration in the anterior humeral line (not crossing the center of the capitellum) or as reported by the primary study author.[39]

Statistical and sensitivity analyses

RevMan (Review Manager, version 5.3; The Cochrane Collaboration, London, UK) was used for the statistical analysis. The meta-analysis was performed according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines.[24] Outcomes reported by $\geq$2 studies were grouped in the meta-analysis. For the analysis of dichotomous data, the relative risk (RR) (with 95% confidence interval [CI]) was adopted and assessed with the Mantel-Haenszel test. The number needed to harm (NNH) was evaluated when there was a difference between groups ($P < .05$). Continuous data were analyzed with means and standard deviations.[19]

The heterogeneity of the estimated effects among the included studies was visually analyzed by forest plots and the I^2 statistic. Relevant heterogeneity was identified when the I^2 statistic was >50%. Evaluation of publication bias was performed by reviewing the published protocols and assessing funnel plots, which were used only when there were $\geq$10 studies included in the meta-analysis.

Although no subgroup analysis was predicted in the protocol,[8] this assessment was performed to investigate significant heterogeneity ($I^2 > 50\%$). A sensitivity analysis was planned with the intention of evaluating the influence of studies with high or

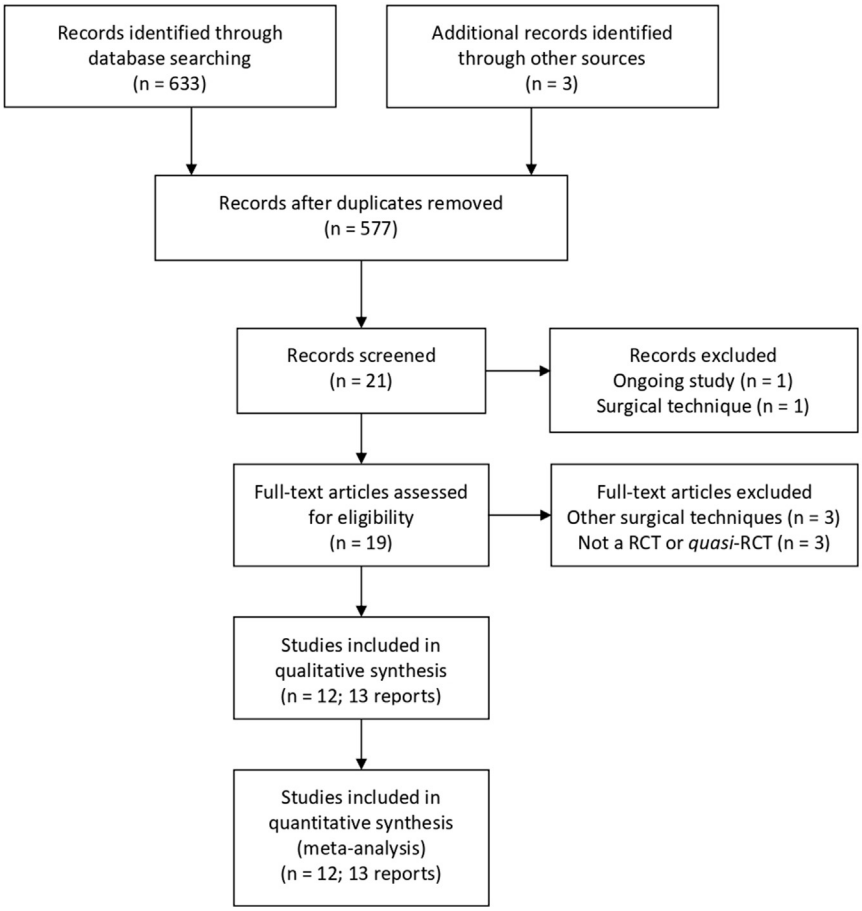

Figure 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram showing identification and screening of studies comparing crossed and lateral K-wire entry in fixation of supracondylar fractures of humerus in children. Overall, 12 randomized controlled trials (*RCTs*) were included.

uncertain levels of the risk of randomization bias regarding the estimated effect on the main outcomes.

The GRADEpro GDT (Guideline Development Tool) was used to evaluate the quality of evidence of the main outcomes analyzed in this review. This analysis was performed by 2 authors.

Results

Search results and study characteristics

From a total of 636 studies initially selected, 607 were excluded because they did not meet the pre-established inclusion criteria or they were duplicates. Eight other articles were excluded because they were identified as literature reviews. Consequently, 21 studies were subjected to a detailed analysis. Finally, 13 RCTs were included in the final assessment: 10 originated from the electronic searches,[1-3,16,17,21,25,32,35,41] and 3 were obtained from the manual investigation of references from other articles.[29,36,42] It was noted that the studies from Shah and Arif[36] (2013) and Shafi-Ur-Rehman et al[35] (2013) presented identical data, leading to the conclusion that they were duplicate publications. Thus, the 2 studies are jointly referred to as "Shafi/Shah 2013" (Fig. 1). The general characteristics of the included studies are found in Supplementary Table S2. Among the 10 studies reporting randomization, 3 did not include the details of the method[1,29,35,36] and 2 randomized the patients according to the surgeon on call.[17,41]

The sample was composed of a total of 930 children, 470 of whom underwent fixation with the crossed-wire technique and 460 of whom underwent fixation with the lateral-wire technique. In total, 71 children were lost to follow-up. The samples ranged from 40 patients[29,41] to 200 patients among the included studies.[35,36] Eight articles included Gartland type II and III fractures, whereas 4 included only type III fractures. Four studies included open fractures (Supplementary Table S3).

Risk-of-bias and publication bias assessment

Regarding the risk of bias, each study was analyzed according to the 7 domains and concepts described by The Cochrane Collaboration.[19] The risk-of-bias summary of the

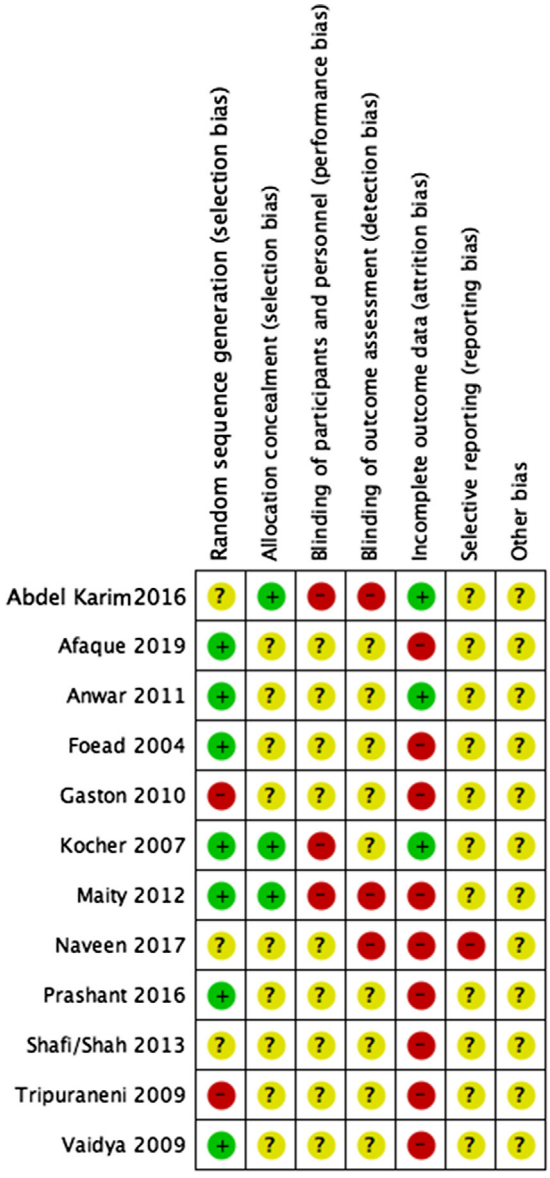

Figure 2 Risk-of-bias summary: review authors' judgments about each risk-of-bias item for each included study. *Green* indicates low risk; *yellow*, unclear risk; and *red*, high risk.

included articles is presented in Figure 2. The justifications for the determinations are summarized in Supplementary Table S4. Because of the small number of included studies, exact conclusions about publication bias could not be established because a funnel plot could not be constructed.

Functional outcome

Eight studies recorded the functional outcome, with a total of 526 patients included in the analysis.[2,3,16,21,25,29,32,42] According to the Flynn criteria,[15] satisfactory results were achieved in 96.19% of the patients in the lateral group and 97.33% in the crossed group. No difference was detected between the groups (RR, 0.99; 95% CI, 0.96-1.02; $I^2 = 0\%$; $P = .44$) (Fig. 3).

Complications

Neurologic lesions

Patients who underwent crossed-wire fixation had an increased risk of neurologic injury. All studies evaluated the occurrence of neurologic lesions, with a total of 930 patients.[1-3,16,17,21,25,29,32,35,36,41,42] The lateral group had an incidence of 1.08%, and the crossed group had an incidence of 3.40%. All lesions were described as ulnar nerve injuries, with the exception of 1 case of radial nerve injury in the lateral group.[16] A difference between the groups was noted, in favor of the safety of fixation with lateral wires (RR, 0.45; 95% CI, 0.21-0.99; $I^2 = 0\%$; $P = .05$) (Fig. 4). The risk of iatrogenic injury to the ulnar nerve was evaluated separately. A difference between the 2 groups was observed, favoring the safety of lateral-wire fixation (RR, 0.40; 95% CI, 0.18-0.91; $I^2 = 0\%$; $P = .03$) (Fig. 5). The NNH was calculated to be 40 (95% CI, 23-146).

Loss of reduction

Patients who underwent crossed-wire fixation had more stable results than those who underwent lateral-wire fixation. Eleven studies with a total of 853 patients were included in the loss-of-reduction analysis.[1,3,16,17,21,25,29,32,35,36,41,42] A difference between the groups was observed, favoring the stability of the crossed-wire fixation technique, which resulted in a lower incidence of loss of reduction (13.9% vs. 19.1%) than the lateral-wire technique (RR, 1.39; 95% CI, 1.04-1.85; $I^2 = 14\%$; $P = .03$) (Fig. 6). The NNH was 20 (95% CI, 10-462).

Sensitivity analysis

In the sensitivity analysis, studies with high or uncertain levels of the risk of randomization bias were excluded from the sample. No difference between the groups was found regarding the functional outcome (RR, 0.99; 95% CI, 0.95-1.02; $I^2 = 0\%$; $P = .43$) (Fig. 7, *a*).[2,3,16,21,25,32,42] The difference in the incidence of neurologic injuries between the groups, with the group undergoing fixation with lateral wires having a lower incidence of injury, was maintained (RR, 0.35; 95% CI, 0.13-0.92; $I^2 = 0\%$; $P = .03$) (Fig. 7, *b*),[2,3,16,21,25,32,42] as was the difference between the groups regarding iatrogenic ulnar nerve lesions (RR, 0.28; 95% CI, 0.09-0.81; $I^2 = 0\%$; $P = .02$) (Fig. 7, *c*).[2,3,16,21,25,32,42] Regarding loss of reduction, the removal of studies at risk of randomization bias nullified the previously observed superiority of crossed-wire fixation,[21,25] and there was no difference between the 2 groups (RR, 1.51; 95% CI, 0.80-2.83; $I^2 = 5\%$; $P = .20$) (Fig. 7, *d*).[3,16,21,25,32,42] A summary of the data and outcome analyses can be found in Table I.

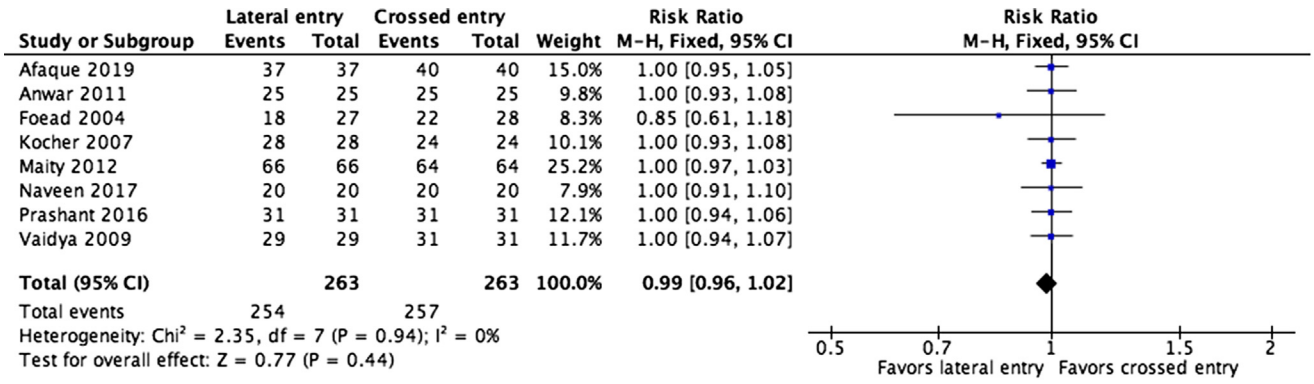

Figure 3 Meta-analysis of functional outcome measured using Flynn criteria[15] in systematic review of fixation of supracondylar fractures of humerus in children with either crossed or lateral K-wire entry. *M-H,* Mantel-Haenszel test; *CI*, confidence interval.

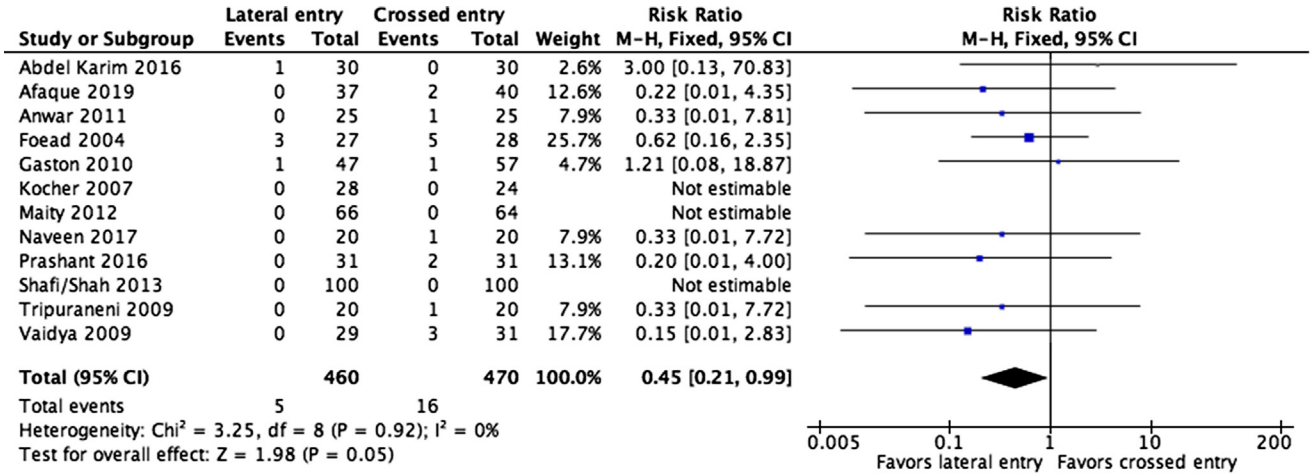

Figure 4 Meta-analysis of neurologic lesion rates after surgical treatment in systematic review of fixation of supracondylar fractures of humerus in children with either crossed or lateral K-wire entry. *M-H,* Mantel-Haenszel test; *CI*, confidence interval.

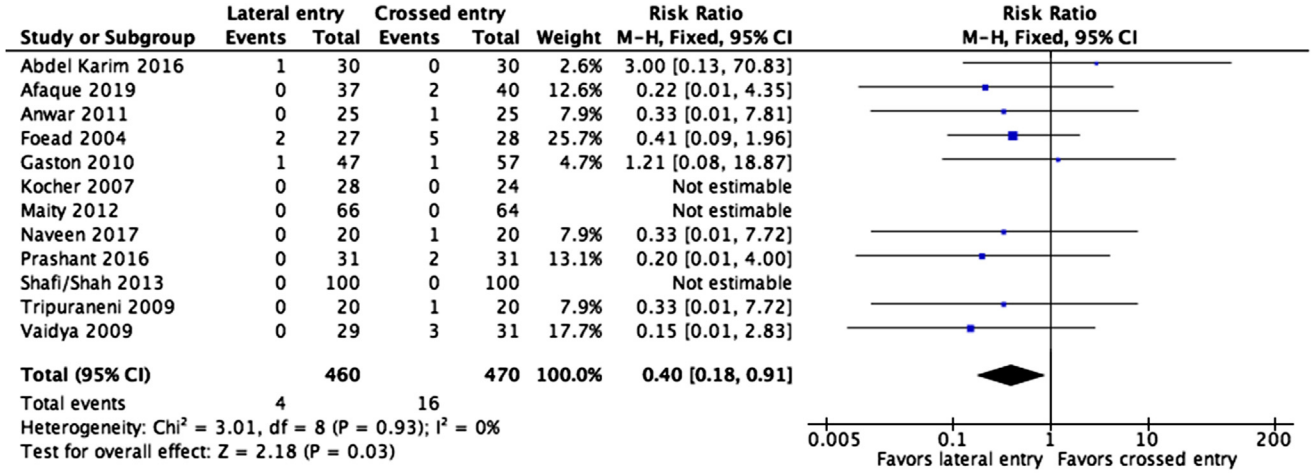

Figure 5 Meta-analysis of ulnar nerve lesions in systematic review of fixation of supracondylar fractures of humerus in children with either crossed or lateral K-wire entry. *M-H,* Mantel-Haenszel test; *CI*, confidence interval.

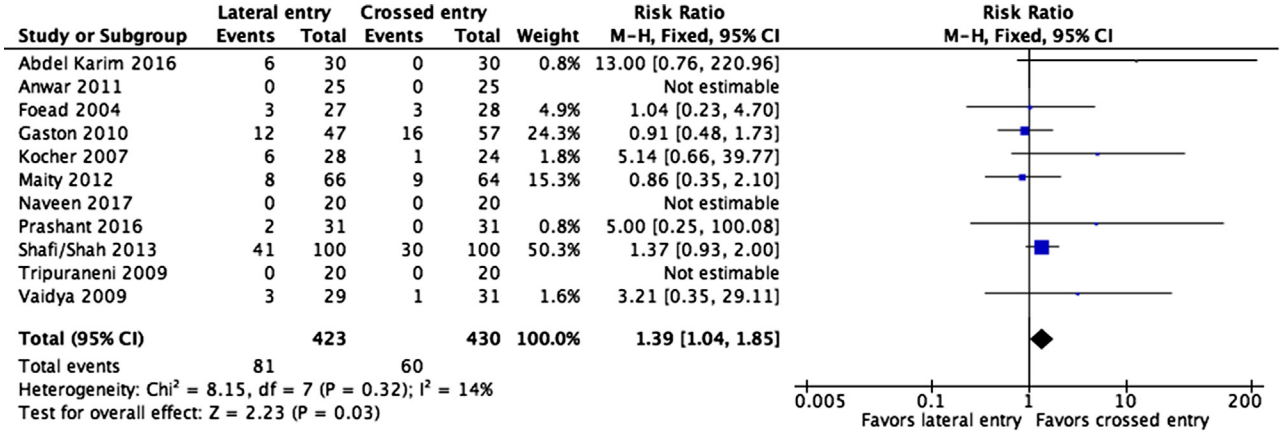

Figure 6 Meta-analysis of loss of reduction in systematic review of fixation of supracondylar fractures of humerus in children with either crossed or lateral K-wire entry. *M-H,* Mantel-Haenszel test; *CI*, confidence interval.

Quality of evidence

Evaluation of the level of confidence in the estimates of the effects was performed with the GRADEpro GDT (Guideline Development Tool). The quality of evidence of the outcomes in this systematic review ranged from low to very low, as shown in Table II.

Discussion

This meta-analysis of RCTs was performed to evaluate 2 widely popularized surgical modalities for the treatment of displaced SFHs in children.[23,26] Other reviews on the topic have already been published,[6,7,13,28,31,40,43] but only 2 reviews included only RCTs: Yousri et al[44] (2012) included 4 RCTs, and Zhao et al[45] (2013) later included 7 trials, analyzed 521 patients, and suggested that fixation with lateral wires should be the standard, owing to the risk of iatrogenic ulnar nerve injury with the crossed-wire technique. Our systematic review is the first conducted with the prior publication of its protocol, providing a clear and transparent record of the entire process of the analysis, reducing the risk of errors or biases that could affect the findings.[8] Additionally, this study has the largest sample size.

The most significant findings in this research were as follows: There is a higher risk of an iatrogenic ulnar lesion with the crossed-wire technique and a greater risk of loss of reduction with the lateral-wire technique. However, these findings should be interpreted with caution because the methodologic quality of the included studies was low.

Regarding the use of the Flynn criteria[15] by the studies included in this review, there were inconsistencies among studies in the manner in which the evaluation was performed. Despite this obstacle, these criteria were used in 8 studies, and we observed high rates of satisfactory results regardless of the method of evaluation. In addition, the analysis included not only functional criteria but also a cosmetic measure that was evaluated as loss in the carrying angle. The development of a functional evaluation method for application in children that is broader in scope and includes neurologic and quality-of-life assessments is needed for use in future studies.

The evaluation of iatrogenic neurologic lesions was performed in all studies included in this review, although the 3 articles that used mini access to introduce a medial wire did not observe any lesions.[21,25,35,36] The overall incidence was 2.25%, with 76% of the injuries occurring in the crossed group and 24% in the lateral group. All were considered to be due to excessive manipulation or uncontrolled traction, with the exception of 1 injury that was justified by Gaston et al[17] (2010) as being the result of the placement of a third medial wire (evaluated according to the intention-to-treat principle). Lesions of the ulnar nerve accounted for 95% of the neurologic injuries and were more likely to occur when the crossed-wire technique was used, with an NNH of 40 (95% CI, 23-146).

It is clear that the inadvertent fixation of a medial wire may result in injury to the ulnar nerve. However, some studies included in this review reported the findings of surgical exploration in patients with ulnar nerve damage after crossed-wire fixation and did not observe direct injury to the nerve. This observation may indicate that a lesion induced by the insertion of the wire may not be the only factor causing neurologic symptoms. There may be extrinsic compression of the ulnar nerve caused by the medial wire when the elbow is immobilized in flexion, given that there is a high incidence of ulnar nerve instability in this position.[1,18,37,42] Despite the risk of sequelae caused by these lesions, it was observed that in 95% of the participants in whom injuries developed, spontaneous recovery of the neurologic condition occurred within 7 months.

Understanding the appropriate surgical technique to select is indispensable for the maintenance of reduction.

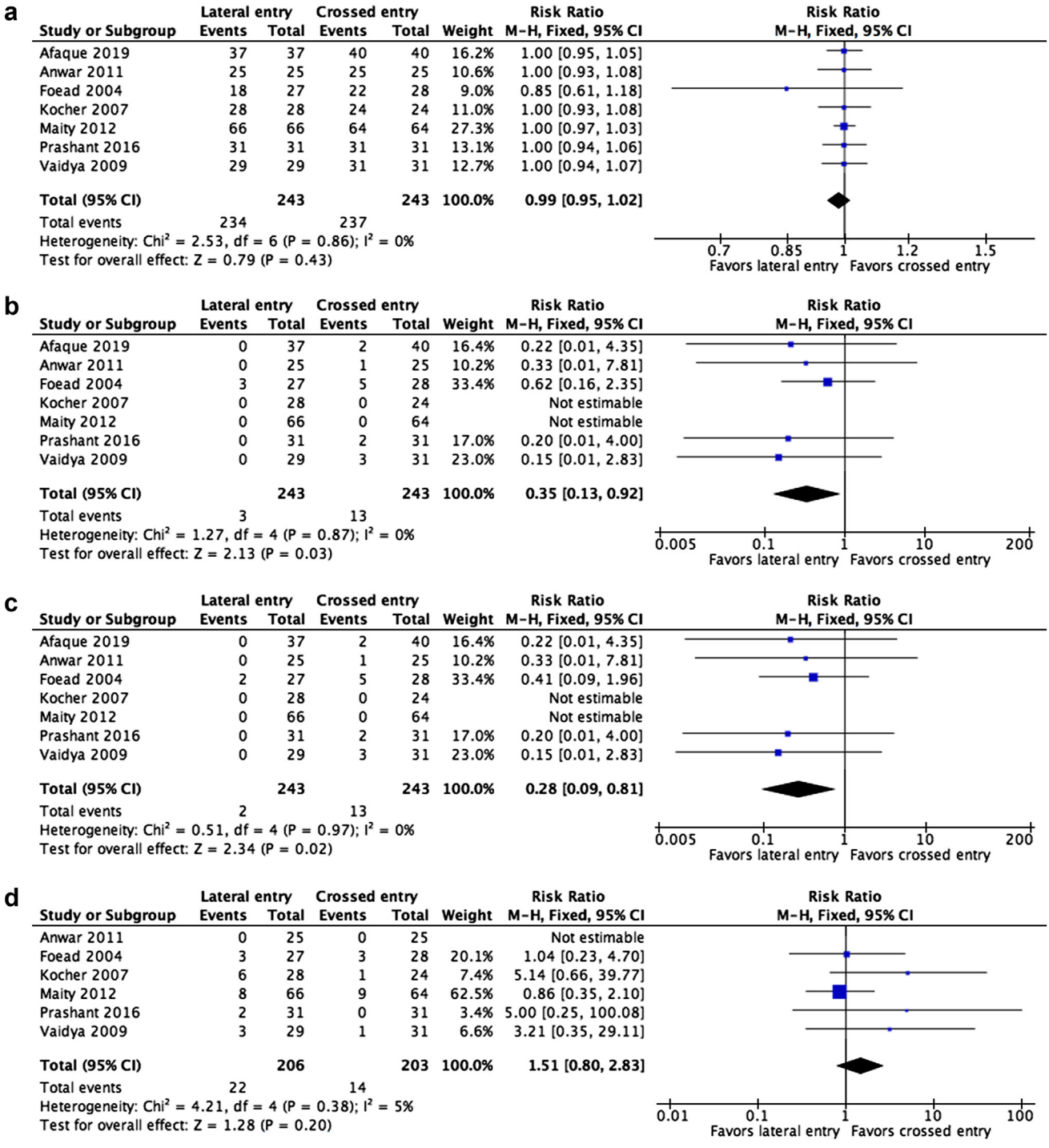

Figure 7 Forest plots for sensitivity analysis: functional outcome measured using Flynn criteria[15] (**a**), neurologic lesions (**b**), ulnar nerve lesions (**c**), and loss of reduction (**d**). *M-H,* Mantel-Haenszel test; *CI*, confidence interval.

The positioning of the fracture within acceptable radiographic parameters and the stabilization and proper positioning of the wires are crucial points for a good evolution.[33] This review showed an overall incidence of loss of reduction of 16.5%, with 81 patients in the lateral group and 60 in the crossed group. Thus, 11 studies with a very low quality of evidence indicated an increased risk of loss of reduction with lateral-wire fixation, with an NNH of 20 (95% CI, 10-462). The low methodologic quality of the studies limited the evaluation of this outcome. Furthermore, a complete lack of standardization of the evaluation of this result was observed.

Table I Data and analysis

	No. of studies	No. of participants	Statistical method	Effect estimate
Outcome				
Satisfactory Flynn criteria[15]	8	526	Risk ratio (M-H, fixed, 95% CI)	0.99 (0.96-1.02)
Neurologic lesion	12	930	Risk ratio (M-H, fixed, 95% CI)	0.45 (0.21-0.99)
Ulnar nerve lesion	12	930	Risk ratio (M-H, fixed, 95% CI)	0.40 (0.18-0.91)
Loss of reduction	11	853	Risk ratio (M-H, fixed, 95% CI)	1.39 (1.04-1.85)
Sensitivity analysis				
Satisfactory Flynn criteria	7	486	Risk ratio (M-H, fixed, 95% CI)	0.99 (0.95-1.02)
Neurologic lesion	7	486	Risk ratio (M-H, fixed, 95% CI)	0.35 (0.13-0.92)
Ulnar nerve lesion	7	486	Risk ratio (M-H, fixed, 95% CI)	0.28 (0.09-0.81)
Loss of reduction	6	409	Risk ratio (M-H, fixed, 95% CI)	1.51 (0.80-2.83)

M-H, Mantel-Haenszel test; *CI,* confidence interval.

Table II Summary of quality of evidence (GRADEpro)

No. of participants (studies)	Certainty assessment					
	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall certainty of evidence
Satisfactory Flynn criteria[15]: 526 (8 RCTs)	Serious*	Not serious	Serious†	Not serious	None	Low
Iatrogenic nerve lesion: 930 (12 RCTs)	Serious*	Not serious	Serious†	Serious‡,§	None	Very low
Iatrogenic ulnar nerve lesion: 930 (12 RCTs)	Serious*	Not serious	Serious†	Serious‡,§	None	Very low
Loss of reduction: 853 (11 RCTs)	Serious*	Not serious	Serious†	Serious‡	None	Very low

RCT, randomized controlled trial.
The GRADE (Grading of Recommendations Assessment, Development and Evaluation) Working Group grades of evidence are defined as follows: High quality indicates that further research is very unlikely to change our confidence in the estimate of the effect. Moderate quality indicates that further research is likely to have an important impact on our confidence in the estimate of the effect and may change the estimate. Low quality indicates that further research is very likely to have an important impact on our confidence in the estimate of the effect and is likely to change the estimate. Very low quality indicates that we are very uncertain about the estimate.
* The trials had methodologic flaws: inclusion of studies with a high risk of bias.
† Studies included mini-open medial or open reduction or included >2 wires for fixation.
‡ The 95% confidence interval included both the lateral and crossed groups.
§ The total number of events was small.

The low quality of the evidence could be partly a result of the different surgical techniques used. The included studies used techniques ranging from mini medial access to open reduction and the placement of a third wire. Nevertheless, with rare exceptions, intention-to-treat analyses were performed. The low or very low quality of the evidence was a result of the high risk of bias in the studies, through the use of indirect evidence and the imprecision resulting from the small number of events (Table II).

Regarding general recommendations for clinical practice, it is worth remembering that closed reduction with percutaneous fixation of displaced SFHs has satisfactory results, regardless of the technique used. This review suggests that the lateral-wire technique should be used whenever possible, owing to the increased risk of neurologic lesions with crossed-wire fixation. However, for unstable fractures, such as type III fractures, for which a medial wire is found to be necessary, we suggest the use of the crossed-wire technique, with special care taken to prevent injury to the ulnar nerve. The use of a mini medial incision to identify the ideal entry point for the wire in the epicondyle is recommended, as corroborated by the 0% injury rate associated with this method.[21,25,35,36]

On the basis of this study, it is proposed that new RCTs with better methodologic quality (as suggested by the CONSORT [Consolidated Standards of Reporting Trials] statement)[34] and large sample sizes should be performed and published.

Conclusion

The findings of this review allow us to conclude that fixation with lateral wires is safer regarding iatrogenic neurologic lesions whereas fixation with crossed wires is more effective for the maintenance of reduction of

supracondylar humeral fractures. These particular findings were based on very low–quality evidence.

Disclaimer

This study was funded by the São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo [FAPESP]; 2015/13159-3).

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.09.021.

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