Efficacy and Safety of Closed versus Open Reduction and Kirschner Wire Fixation for Pediatric Lateral Condyle Fractures of the Humerus: A Meta-Analysis Postprint

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Abstract

Background For displaced lateral humeral condyle fractures in children, the traditional treatment is open reduction and internal fixation. However, reports of closed reduction and Kirschner wire fixation for pediatric lateral humeral condyle fractures have been increasing in recent years, and there remains controversy regarding which surgical approach offers superior efficacy and safety. Objective To evaluate the application effects and safety of closed reduction percutaneous pinning (CRPP) and open reduction Kirschner wire fixation (ORKF) in the treatment of pediatric lateral humeral condyle fractures. Methods A computerized search was conducted in both Chinese and English databases including CNKI, Wanfang Data Knowledge Service Platform, VIP, Chinese Biomedical Literature Database, PubMed, Embase, Cochrane Library, and Web of Science. The search period spanned from the establishment of each database to January 1, 2023. Case-control studies comparing the two surgical methods for pediatric lateral humeral condyle fractures were screened, and their quality was assessed and data extracted. RevMan 5.3 software was used for Meta-analysis to compare relevant efficacy and safety indicators between the two surgical approaches. Results A total of 16 articles involving 1 165 children were included in the Meta-analysis. The Meta-analysis results showed that the CRPP group had shorter operation time than the ORKF group (MD=-11.81, 95%CI=-15.04~-8.58, P<0.000 01), lower intraoperative blood loss than the ORKF group (MD=-3.36, 95%CI=-4.37~-2.36, P<0.000 01), shorter postoperative fracture healing time than the ORKF group (MD=-3.92, 95%CI=-6.80~-1.03, P=0.008), shorter Kirschner wire retention time than the ORKF group (MD=-3.35, 95%CI=-6.33~-0.38, P=0.03), higher excellent/good rate of postoperative elbow function recovery than the ORKF group (OR=0.44, 95%CI=0.25~0.76, P=0.006),

lower overall postoperative complication rate than the ORKF group (OR=0.33, 95%CI=0.19~0.56, P<0.000 1), and lower superficial infection rate than the ORKF group (OR=0.39, 95%CI=0.21~0.73, P=0.003); while no statistically significant differences were found between the two groups in the incidence of deep infection, malunion, or avascular necrosis of the lateral humeral condyle (P>0.05). Conclusion CRPP is superior to ORKF in treating pediatric lateral humeral condyle fractures in terms of both efficacy and overall complications, though further verification with more high-quality literature is needed regarding specific complications.

Full Text

Efficacy and Safety of Closed Reduction Percutaneous Pinning Versus Open Reduction with Kirschner Wire Fixation for Paediatric Lateral Humeral Condyle Fractures: a Meta-analysis

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Abstract

Background: Traditionally, open reduction with Kirschner wire fixation (ORKF) is used to treat paediatric patients with significantly displaced lateral humeral condyle fractures. However, in recent years, the use of closed reduction percutaneous pinning (CRPP) to treat lateral humeral condyle fractures in children has been increasingly reported. There is some controversy as to which surgical technique is more effective and safe.

Objective: To evaluate the efficacy and safety of CRPP and ORKF in paediatric patients with lateral humeral condyle fractures.

Methods: Chinese databases including CNKI, Wanfang, VIP and CBM and English databases including PubMed, Embase, Cochrane Library and Web of Science were searched from inception to 2023-01-01 for case-control studies of CRPP and ORKF to treat lateral humeral condyle fractures. The quality of the literature was evaluated and data were extracted. RevMan 5.3 software

was used to conduct a meta-analysis comparing the relevant efficacy and safety indexes of the two surgical techniques.

Results: A total of 16 studies involving 1,165 cases were included. The results of meta-analysis indicated that CRPP was superior in terms of surgical time (MD=-11.81, 95%CI=-15.04~-8.58, P<0.00001), intraoperative bleeding (MD=-3.36, 95%CI=-4.37~-2.36, P<0.00001), postoperative fracture healing time (MD=-3.92, 95%CI=-6.80~-1.03, P=0.008), Kirschner wire retention time (MD=-3.35, 95%CI=-6.33~-0.38, P=0.03), and postoperative functional recovery of elbow joint (OR=0.44, 95%CI=0.25~0.76, P=0.006). The incidence of overall postoperative complications (OR=0.33, 95%CI=0.19~0.56, P<0.0001) and superficial infections (OR=0.39, 95%CI=0.21~0.73, P=0.003) was lower than that in the ORKF group. However, there was no statistically significant difference in deep infections, poor fracture healing, and ischemic necrosis of the lateral condyle between the two groups (P>0.05).

Conclusion: CRPP was superior to ORKF in the treatment of pediatric lateral humeral condyle fractures, both in terms of efficacy and overall complications, but more high-quality studies are needed to further validate CRPP in terms of specific complications.

Keywords: Fracture fixation; Humeral lateral condylar fracture; Closed reduction percutaneous pinning; Open reduction with Kirschner wire fixation; Child; Meta-analysis

Introduction

Lateral humeral condyle fractures are relatively common among pediatric elbow fractures, accounting for 12%-20% of all elbow fractures in children [1]. They occur most frequently in children aged 5-10 years. Because these fractures involve the articular surface, precise reduction is required after injury. The therapeutic goal is to restore a smooth articular surface to minimize impact on joint function. Surgical treatment is primarily indicated for patients with displacement exceeding 2 mm or fracture fragment rotation. Open reduction with Kirschner wire fixation (ORKF) represents the traditional classic surgical approach [2], followed by robust external fixation postoperatively. In recent years, reports of closed reduction percutaneous pinning (CRPP) for lateral humeral condyle fractures have gradually increased, primarily utilizing X-ray or ultrasound guidance to achieve closed reduction before percutaneous Kirschner wire insertion. However, controversy remains regarding which surgical technique is superior, creating difficulty in clinical decision-making. Currently, no relevant evidence-based medical evidence is available to guide this choice. This study aims to compare the two surgical methods through meta-analysis, analyzing their respective advantages and disadvantages from three perspectives: general clinical data, elbow joint function, and complications, hoping to provide a reference for clinical decision-making.

Methods

1.1 Literature Search

A computerized search was conducted in Chinese databases including CNKI, Wanfang Data, VIP, and CBM, as well as English databases including PubMed, Embase, Cochrane Library, and Web of Science. Chinese search terms included: lateral humeral condyle fracture, children, reduction, closed/open. English search terms included: humeral fractures, distal; humeral lateral condylar fracture; humerus lateral condylar fracture; lateral condylar fracture of the elbow; child; children; pediatric. The search timeframe spanned from database inception to January 1, 2023. The search strategy for PubMed is presented in Table 1 .

1.2 Inclusion and Exclusion Criteria

1.2.1 Inclusion Criteria: (1) Study type: All case-control studies, including retrospective or prospective cohort studies, treating pediatric lateral humeral condyle fractures with either ORKF or CRPP. (2) Study population: Patients under 16 years of age, regardless of race, nationality, or gender. (3) Outcome measures: One or more indicators from general clinical data, elbow joint function, or complications during treatment. (4) Language: Chinese or English publications only.

1.2.2 Exclusion Criteria: (1) Case reports, conference abstracts, or review articles. (2) Multiple fractures or open fractures; or concomitant conditions that might significantly affect treatment and prognosis. (3) Internal fixation materials other than Kirschner wires, such as cannulated screws. (4) Studies where required outcome data could not be obtained.

1.3 Data Extraction

Data were independently extracted by two researchers and then cross-checked. Discrepancies were resolved through discussion, with consultation of a third researcher if necessary. Extracted information included basic article details (first author, publication year, country, study type, sample size, follow-up duration) and key outcome measures (general clinical data, elbow joint function, complications).

Elbow joint function recovery was an important outcome indicator in this analysis. Although different studies employed varying evaluation criteria for elbow function, careful review of the specific content of each standard revealed that the differences were acceptable. Elbow function was assessed using four grades: excellent, good, fair, and poor, with primary comparison of the excellent-good rates between the CRPP and ORKF groups.

1.4 Literature Quality Assessment

The modified Jadad scale was used to evaluate randomized controlled trials, assessing five aspects: randomization method, allocation concealment, blinding, and loss to follow-up/withdrawals. Scores of 1–3 indicated low-quality studies, while 4–7 indicated high-quality studies. Prospective and retrospective cohort studies were evaluated using the Newcastle-Ottawa Scale (NOS), which assesses three domains: patient selection, comparability, and outcome/exposure assessment.

1.5 Statistical Analysis

Meta-analysis was performed using RevMan 5.3 software. Mean difference (MD) served as the effect measure for continuous variables, while odds ratio (OR) was used for dichotomous variables, with point estimates and 95% confidence intervals (CI) calculated for both. Heterogeneity was assessed using the ^{2} test (significance level P=0.05) and I^2 statistic. A fixed-effects model was employed for low heterogeneity (I^2<50%, P>0.05); otherwise, a random-effects model was used, followed by sensitivity analysis. For outcome indicators with $ $10 included studies, funnel plots were generated and Egger' s test conducted to evaluate publication bias. Statistical significance was set at P<0.05.

Results

2.1 Literature Screening Process and Results

The initial database search yielded 904 articles. After removing duplicates using EndNote software, 809 articles remained. Following title and abstract screening, 746 articles were excluded, leaving 63 articles for full-text review. Ultimately, 16 studies [3-18] were included after excluding duplicate reports, case analyses, and other ineligible studies. The literature screening process and results are illustrated in Figure 1 [Figure 1: see original paper].

2.2 Basic Characteristics and Quality Assessment of Included Literature

Among the 16 included studies, there were 2 randomized controlled trials [3,10], 11 retrospective case-control studies [4-9,11-12,15-17], and 3 prospective cohort studies [13,14,18], comprising a total of 1,165 pediatric patients (713 in the ORKF group and 452 in the CRPP group). The basic characteristics and quality assessment results of the included literature are presented in Table 2 .

2.3 Meta-Analysis Results

2.3.1 General Clinical Data 2.3.1.1 Surgical Time: Eight studies [4-7,10-11,14,17] reported surgical time, involving 218 cases in the CRPP group and 397 cases in the ORKF group. Heterogeneity testing revealed substantial

heterogeneity among studies (I^2=69%, P=0.002). Random-effects model meta-analysis showed that surgical time was significantly shorter in the CRPP group compared to the ORKF group (MD=-11.81, 95%CI=-15.04~-8.58, P<0.00001) (Figure 2 [Figure 2: see original paper]).

2.3.1.2 Intraoperative Bleeding Volume: Four studies [4-5,7,10] reported intraoperative bleeding volume, with 117 cases in the CRPP group and 123 cases in the ORKF group. Heterogeneity testing indicated low heterogeneity among studies (I^2=44%, P=0.15). Fixed-effects model meta-analysis demonstrated that intraoperative bleeding was significantly lower in the CRPP group compared to the ORKF group (MD=-3.36, 95%CI=-4.37~-2.36, P<0.00001) (Figure 3 [Figure 3: see original paper]).

2.3.1.3 Fracture Healing Time: Six studies [3-7,11] reported postoperative fracture healing time, including 161 cases in the CRPP group and 173 cases in the ORKF group. Heterogeneity testing revealed high heterogeneity among studies (I^2=76%, P=0.0009). Random-effects model meta-analysis indicated that fracture healing time was significantly shorter in the CRPP group compared to the ORKF group (MD=-3.92, 95%CI=-6.80~-1.03, P=0.008) (Figure 4 [Figure 4: see original paper]).

2.3.1.4 Kirschner Wire Retention Time: Three studies [12,17-18] reported postoperative Kirschner wire retention time, with 113 cases in the CRPP group and 211 cases in the ORKF group. Heterogeneity testing showed low heterogeneity among studies (I^2=33%, P=0.22). Fixed-effects model meta-analysis revealed that Kirschner wire retention time was significantly shorter in the CRPP group compared to the ORKF group (MD=-3.35, 95%CI=-6.33~-0.38, P=0.03) (Figure 5 [Figure 5: see original paper]).

2.3.2 Elbow Joint Function Eleven studies [3-7,9-11,13-14,18] reported postoperative elbow joint function recovery, involving 294 cases in the CRPP group and 401 cases in the ORKF group. Heterogeneity testing indicated minimal heterogeneity among studies (I^2=0%, P=0.52). Fixed-effects model meta-analysis demonstrated that the excellent-good rate of postoperative elbow function recovery was significantly higher in the CRPP group compared to the ORKF group (OR=0.44, 95%CI=0.25~0.76, P=0.006) (Figure 6 [Figure 6: see original paper]).

2.3.3 Complications **2.3.3.1 Overall Complications:** Twelve studies [3-7,9,11-12,14-16,18] reported the incidence of postoperative overall complications, with 339 cases in the CRPP group and 592 cases in the ORKF group. Heterogeneity testing showed I^2=0%, P=0.50. Fixed-effects model meta-analysis revealed that the incidence of overall postoperative complications was significantly lower in the CRPP group compared to the ORKF group (OR=0.33, 95%CI=0.19~0.56, P<0.0001) (Figure 7 [Figure 7: see original paper]).

2.3.3.2 Specific Complications: Specific complications with sufficient data

for extraction and analysis included superficial infection (skin or pin tract infection) [3,5-7,9,11-12,14-16,18], deep infection (including osteomyelitis and septic arthritis) [4,11-12,15-16], poor healing (including delayed union, malunion, or nonunion) [5,7,9,11-12,14], and avascular necrosis of the lateral humeral condyle [9,14-16]. Meta-analysis revealed that the incidence of superficial infection was significantly lower in the CRPP group compared to the ORKF group (OR=0.39, 95%CI=0.21~0.73, P=0.003). However, no statistically significant differences were observed between the two groups in the incidence of deep infection, poor healing, or avascular necrosis of the lateral humeral condyle (P>0.05). Detailed results are presented in Table 3 .

2.4 Sensitivity Analysis

For outcome indicators with substantial heterogeneity ($I^2$$ 50 $0.05), including surgical time and fracture healing time, we first changed the effect model used for meta-analysis, which did not substantially alter the conclusions. Subsequently, we performed sequential removal of each study, which still did not reveal significant changes in heterogeneity. These findings suggest that the conclusions of this meta-analysis are robust and reliable.

2.5 Publication Bias Assessment

Only three outcome indicators—elbow joint function, overall complications, and superficial infection—had $ $10 included studies. Funnel plot analysis revealed asymmetry for elbow joint function, with Egger' s test indicating potential publication bias (t=3.25, P=0.009) (Figure 8 [Figure 8: see original paper]). In contrast, funnel plots for overall complications and superficial infection showed good symmetry, with Egger' s test suggesting no publication bias (t=-1.02, P=0.406; t=0.58, P=0.713) (Figure 9 [Figure 9: see original paper] and Figure 10 [Figure 10: see original paper]).

Discussion

The mechanism of pediatric lateral humeral condyle fractures typically involves indirect violence [19]. Due to the unique location of these fractures, potential complications include poor fracture healing, avascular necrosis of the lateral condyle, cubitus varus/valgus deformity, motor dysfunction [20-21], and even loss of elbow joint function [22-23]. Conservative treatment may be appropriate for nondisplaced fractures or those with displacement <2 mm [24-26]. However, surgical intervention represents the optimal choice for patients with displacement $ $2 mm or fracture fragment rotation [27-29]. Both CRPP and ORKF are widely used surgical techniques in clinical practice, yet considerable debate persists regarding the optimal treatment approach. Postoperative elbow function and surgical complications are primary concerns in the current literature. Some scholars advocate for CRPP, arguing that the layered lateral approach required for ORKF disrupts blood supply to the fracture site, potentially im-

pairing healing and leading to avascular necrosis of the lateral condyle in severe cases [30]. Conversely, other researchers express concern that excessive emphasis on closed reduction with multiple manipulation attempts increases the risk of soft tissue, vascular, and nerve injury. SONG et al. [31] recommended CRPP as the surgical method of choice, while GASTON et al. [32] argued that ORKF offers greater advantages and yields more satisfactory outcomes. In light of these conflicting perspectives, this study systematically searched for relevant literature on both treatment modalities, extracted comprehensive indicators, and further analyzed their respective merits and drawbacks.

Various classification systems exist for lateral humeral condyle fractures. Among the 16 included studies, four [4,5,7,10] used the Jakob classification, all with type II or higher fractures; six [6,9,11-12,17-18] employed the Song classification, all with type III–V fractures; four [8,14-16] utilized the Milch classification, all with type II fractures; one [3] applied the Wadsworth classification, all with type II–III fractures; and one study [13] did not report a specific classification system but described a mean fracture displacement of 9.5 mm. Comprehensive analysis confirmed that all included patients had clear surgical indications, enabling pooled analysis of outcome measures.

The ORKF procedure requires extensive stripping of muscles, ligaments, and other soft tissues to achieve adequate surgical exposure, which undoubtedly compromises blood supply to the bone and impedes fracture healing. In contrast, CRPP effectively avoids this disadvantage. Adequate blood supply is a critical factor for rapid fracture healing, which explains the significantly shorter Kirschner wire retention and fracture healing times observed with CRPP. HUGHES et al. [34] previously used ultrasound to follow up patients with various fracture types treated by closed reduction, finding that callus formation was significantly superior compared to patients undergoing open surgery, which corroborates our findings to some extent.

Some reports suggest that elbow function recovery is faster after CRPP, particularly for fractures with displacement <4 mm [35-37]. However, other studies indicate that CRPP may adversely affect postoperative elbow function recovery in cases with rotated fracture fragments, recommending open reduction instead [38]. Additionally, some literature suggests that surgical technique is not the primary determinant of elbow function recovery, with fracture severity and classification being important influencing factors [39]. SAHU [29] reported on 85 pediatric lateral condylar fracture patients, achieving a 98.8% excellent-good rate after CRPP—higher than the 94.90% in our study—but still demonstrating superior elbow function recovery in the CRPP group. This may be attributed to less postoperative pain and shorter fracture healing time in CRPP patients, enabling earlier Kirschner wire removal and earlier initiation of elbow function exercises, which facilitates rapid functional recovery [40]. Muscle relaxation and contraction effectively function as a circulatory pump, with adequate blood flow and nutrition promoting wound repair and fracture healing while stimulating synovial fluid secretion to facilitate articular cartilage recovery. In contrast, the

ORKF group not only cannot commence exercises as early but also experiences higher complication rates that further impede functional rehabilitation.

The muscles and fascia attached to the fracture site represent important blood supply sources for the pediatric epiphysis. After the initial traumatic injury, additional open reduction further compromises epiphyseal blood supply. Consequently, some scholars believe that open reduction increases the risk of postoperative epiphyseal-related complications. IAMES et al. [41] reported that ORKF can cause iatrogenic complications such as poor fracture healing and avascular necrosis of the lateral condyle. ANIL et al. [42] also found in their follow-up study that soft tissue disruption from ORKF led to epiphyseal-related complications, which inevitably affected elbow function recovery. Our analysis of overall complications similarly found a lower incidence in the CRPP group compared to the ORKF group.

Superficial infectious complications such as pin tract and incisional infections can generally be controlled with antibiotic administration, although some patients only recover after Kirschner wire removal. Deep infections, however, are more complex to treat, and improper management of conditions like septic arthritis or osteomyelitis can result in varying degrees of sequelae. Summary of 11 studies revealed that CRPP offers clear advantages in preventing superficial infections, though no statistically significant difference was observed in deep infection rates between the two surgical approaches. NAZARETH et al. [28] compared 8 patients who underwent closed reduction with 30 who received open reduction for lateral condyle fractures, finding no significant relationship between infection occurrence and surgical technique. However, their study did not differentiate between superficial and deep infections and included both Kirschner wires and cannulated screws as fixation materials without distinction, resulting in conclusions that differ somewhat from our analysis.

Multiple factors contribute to poor healing, including the initial fracture characteristics, soft tissue damage from surgery, disruption of fracture fragment blood supply, and potential fracture instability from premature mobilization. Some research suggests that ORKF compromises blood supply at the fracture site, increasing the risk of poor healing [30] and recommending CRPP as the preferred treatment. Conversely, other studies indicate that poor healing is more likely to occur after CRPP [35]. Our comprehensive analysis of five studies found no significant difference in poor healing rates between the CRPP and ORKF groups.

Avascular necrosis of the lateral humeral condyle represents a severe complication of lateral condyle fractures that can significantly impair elbow function, though its etiology remains unclear. SHABTAILIORL et al. [43] reported an incidence of approximately 1.4%, attributing it anatomically to soft tissue injury and physiologically to loss of blood supply at the fracture site, with the fundamental cause being the combined effects of trauma and surgery. SKAK et al. [44] reported avascular necrosis rates of 0–7% and noted that this complication can lead to subsequent problems such as cubitus valgus. Treatment

of avascular necrosis is complex with poor prognosis, necessitating efforts to minimize its occurrence. Although some reports suggest that CRPP can reduce the incidence of avascular necrosis [45], our comprehensive analysis of four studies found no significant difference in avascular necrosis rates between the two groups, indicating that ORKF does not significantly increase the risk. However, the relatively small sample size may affect the reliability of this conclusion.

This meta-analysis conducted sensitivity analyses for outcome indicators with substantial heterogeneity (surgical time and fracture healing time, $I^2$$ 50 $0.05), confirming the robustness and reliability of our findings. Publication bias assessment revealed some evidence of bias for postoperative elbow function recovery, possibly due to small sample sizes in some studies or methodological limitations. In contrast, no publication bias was detected for overall complications or superficial infection.

In summary, CRPP was associated with shorter surgical time, postoperative fracture healing time, and Kirschner wire retention time, as well as lower intraoperative bleeding volume compared to ORKF. The CRPP group also demonstrated higher excellent-good rates of postoperative elbow function recovery and lower incidences of overall complications and superficial infection. CRPP offers certain advantages in terms of efficacy and safety, suggesting it should be the preferred surgical approach for pediatric lateral humeral condyle fractures. However, this study has several limitations: (1) Only two randomized controlled trials were included, with modest quality scores, and some cohort studies had small sample sizes. More large-scale randomized controlled trials are needed to obtain more reliable results. (2) Specific complications such as joint stiffness and humeral condylar growth arrest were reported in some studies but could not be analyzed due to unavailable data or insufficient reporting. Our analysis was limited to overall complications and four specific complications (superficial infection, deep infection, poor healing, and avascular necrosis), which may not fully demonstrate CRPP' s advantages in reducing postoperative complications. Larger sample sizes are needed for comprehensive validation, covering more complication types with detailed analysis of each. (3) CRPP demands greater technical proficiency from surgeons, and variability in operator skill may have influenced the reported outcomes, potentially reducing the reliability of conclusions.

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