

Research Article

Evaluation of Open versus Closed Reduction in Displaced Pediatric Distal Humerus Fractures: A Comparative Cohort Study

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ABSTRACT

Background: Displaced supracondylar fractures constitute the predominant distal humeral fracture pattern in children and may be complicated by malalignment, elbow stiffness, neurovascular injury, and residual deformity. Closed reduction with percutaneous pin fixation represents the preferred operative strategy for most displaced fractures; however, open reduction becomes necessary when satisfactory closed alignment cannot be obtained or when fracture configuration, soft-tissue interposition, open injury, or neurovascular compromise precludes safe closed management. This study compared clinical, functional, radiological, and perioperative outcomes following closed and open reduction of displaced pediatric distal humerus fractures.

Methods: A comparative cohort study was conducted at [Institution, City] during [study period]. Children aged 2-14 years with displaced Gartland type III or IV supracondylar fractures treated surgically were included. Patients were categorized according to definitive reduction technique into closed reduction with percutaneous pinning (CRPP) and open reduction with Kirschner-wire fixation groups. The primary outcome was satisfactory functional outcome according to Flynn criteria. Secondary outcomes included elbow range of motion, Baumann angle, union time, operative duration, hospital stay, infection, neurological complications, loss of reduction, and cubitus varus. Statistical significance was set at $p < 0.05$.

Results: In the illustrative cohort of 102 children, 70 underwent closed reduction and 32 underwent open reduction. Satisfactory Flynn functional outcomes occurred in 66/70 (94.3%) patients after closed reduction and 28/32 (87.5%) after open reduction ($p = 0.255$). Mean operative duration was significantly shorter with closed reduction (41.8 ± 12.4 versus 67.3 ± 18.6 minutes; $p < 0.001$), as was hospital stay (1.8 ± 0.7 versus 2.6 ± 1.1 days; $p < 0.001$). Mean final flexion loss was 6.2 ± 5.1 degrees and 9.1 ± 7.0 degrees, respectively ($p = 0.041$). Baumann angle, fracture-union time, cosmetic Flynn outcome, loss of reduction, infection, nerve injury, and cubitus varus did not differ significantly.

Conclusion: Successful closed reduction with percutaneous fixation provided excellent functional and radiographic outcomes while reducing operative duration and hospitalization. Open reduction nevertheless produced satisfactory outcomes in most patients and remained an important definitive strategy for irreducible or complicated fractures. Treatment should therefore prioritize safe anatomic reduction rather than avoidance of open surgery when legitimate indications are present.

Keywords: Distal Humerus Fracture, Supracondylar Fracture, Closed Reduction, Open Reduction, Percutaneous Pinning, Pediatric Trauma, Flynn Criteria.

INTRODUCTION

Supracondylar fractures of the distal humerus represent the most frequent elbow fracture in children and constitute a major component of pediatric upper-extremity trauma. Epidemiological investigations have shown that these injuries occur particularly during the early school years, commonly after a fall onto an outstretched hand, and that the

supracondylar region accounts for a substantial proportion of childhood elbow fractures [1,2]. The anatomical characteristics of the immature distal humerus, including a thin metaphyseal cortex and relatively vulnerable supracondylar region, predispose the bone to failure during hyperextension. Although many nondisplaced injuries can be managed conservatively, markedly displaced

fractures present a substantially more complex therapeutic problem.

The Gartland classification has historically provided the conceptual basis for stratifying extension-type supracondylar fractures according to displacement [3]. Contemporary practice generally favors operative stabilization for substantially displaced injuries because restoration and maintenance of coronal, sagittal, and rotational alignment are central to preventing malunion and loss of elbow function [4]. Failure to restore alignment may result in cubitus varus, extension deformity, restricted range of motion, and unsatisfactory cosmetic appearance. More importantly, the intimate relationship of the distal humerus to the brachial artery and median, anterior interosseous, radial, and ulnar nerves means that severely displaced injuries may present with clinically important neurovascular abnormalities [4].

Closed reduction followed by percutaneous Kirschner-wire fixation has become the standard operative approach for most displaced pediatric supracondylar fractures [5]. The technique minimizes surgical disruption of the fracture hematoma and surrounding soft tissues while providing stable fixation when appropriate pin placement is achieved. The Flynn criteria, initially developed during long-term assessment of percutaneous pinning, continue to provide a widely applied framework for grading functional and cosmetic outcomes [6]. Subsequent studies have demonstrated that well-positioned percutaneous pins can maintain satisfactory alignment even in unstable fractures [7].

Nevertheless, closed reduction is not universally achievable. Marked displacement, rotational instability, buttonholing of the proximal fragment through muscle, interposition of periosteum or neurovascular structures, severe swelling, open fractures, and persistent vascular compromise may necessitate open reduction. Concern regarding additional soft-tissue trauma, surgical scarring, elbow stiffness, infection, and iatrogenic nerve injury has traditionally made surgeons reluctant to proceed to open exposure. Neurological injury is already an important component of the natural history of displaced supracondylar fractures, with meta-analytic evidence demonstrating clinically relevant rates of traumatic neurapraxia [8].

The central therapeutic question is therefore not merely whether a fracture can be reduced closed, but whether persistence with closed

manipulation confers meaningful benefit once a safe anatomical reduction becomes difficult. Current comparative literature remains heterogeneous because patients requiring open reduction frequently have more severe injuries at baseline. The present study was consequently designed to compare functional, radiographic, perioperative, and complication outcomes between closed and open reduction in children with displaced distal humeral supracondylar fractures and to determine whether the requirement for open reduction independently implied inferior clinical recovery.

MATERIALS AND METHODS

Study Design and Setting

A comparative observational cohort study was conducted among consecutive pediatric patients presenting with displaced supracondylar fractures of the distal humerus who underwent operative reduction and Kirschner-wire fixation. Eligible patients were evaluated systematically according to the predefined study protocol. The study was conducted and reported in accordance with accepted principles for observational clinical research.

Study Population

Children aged 2-14 years with radiographically confirmed displaced extension-type supracondylar fractures requiring operative fixation were eligible. Gartland type III fractures and multidirectionally unstable type IV injuries were included. Patients were required to have adequate preoperative radiographs, documented neurovascular examination, operative records, postoperative radiographs, and a minimum clinical follow-up of [6/12 months]. Patients with undisplaced Gartland type I fractures, minimally displaced injuries managed without fixation, lateral condyle fractures, medial condyle fractures, intercondylar fractures, pathological fractures, previous ipsilateral elbow deformity, fractures presenting after substantial delay with established callus, or incomplete follow-up information were excluded. Patients with polytrauma in whom elbow assessment could not be reliably performed were also excluded.

Preoperative Assessment

Age, sex, injured side, mechanism of injury, time from injury to presentation, skin condition, swelling, and associated injuries were documented. Vascular examination included radial pulse, capillary refill, hand temperature, and color. Motor and sensory

function of the median, anterior interosseous, radial, and ulnar nerves was recorded before intervention. Standard anteroposterior and lateral radiographs were obtained. Fractures were categorized using the modified Gartland classification. Coronal alignment, rotational displacement, medial or lateral column comminution, and the relationship of the anterior humeral line to the capitellum were assessed.

Operative Technique

All procedures were performed under general anesthesia with fluoroscopic guidance. Closed reduction was initially attempted when no immediate indication for open exploration existed. Longitudinal traction was applied with correction of translation and rotation, followed by controlled elbow flexion while maintaining reduction. Adequacy of reduction was confirmed fluoroscopically on orthogonal projections. Patients in whom satisfactory alignment and stability were obtained underwent percutaneous Kirschner-wire fixation. Two or three lateral-entry pins were used according to fracture stability; a medial pin was added when additional fixation was considered necessary, with appropriate precautions to protect the ulnar nerve. Open reduction was performed when acceptable closed reduction could not be achieved after controlled attempts or when open injury, suspected soft-tissue/neurovascular entrapment, persistent perfusion abnormality, or fracture characteristics necessitated direct visualization. The surgical approach was selected according to the displacement pattern and surgeon assessment. Following direct restoration of alignment, the fracture was stabilized with Kirschner wires and reduction was verified fluoroscopically. Postoperatively, the extremity was immobilized in an above-elbow splint or cast. Neurovascular status was reassessed immediately and serially. Pins were removed after radiographic evidence of adequate healing, usually at approximately 3-4 weeks, and progressive elbow mobilization was subsequently permitted.

Outcome Assessment

The primary outcome was the proportion of patients achieving satisfactory functional outcome, defined as an excellent or good result according to Flynn criteria. Cosmetic Flynn grade was assessed independently using carrying-angle loss. Secondary outcomes included operative duration, length of

hospitalization, time to radiographic union, final elbow flexion and extension, difference in carrying angle from the contralateral side, Baumann angle, superficial pin-tract infection, deep infection, iatrogenic nerve deficit, loss of reduction, cubitus varus, vascular complication, and requirement for unplanned repeat surgery.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee of [institution] under approval number [IEC/IRB number]. Written informed consent for treatment and participation was obtained from the parent or legally authorized guardian where prospectively required. Patient identifiers were removed before statistical analysis, and confidentiality was preserved throughout the study.

Statistical Analysis

Data were analyzed using [SPSS version/R/Stata]. Continuous variables were summarized as mean $\pm$ standard deviation or median with interquartile range according to distribution. Categorical variables were expressed as frequencies and percentages. Continuous variables were compared using the independent-samples t-test or Mann-Whitney U test as appropriate. Categorical variables were evaluated using the chi-square test or Fisher exact test. Two-sided p-values <0.05 were considered statistically significant. Because treatment allocation was clinically determined rather than randomized, baseline fracture severity and neurovascular characteristics were specifically examined when interpreting between-group differences.

RESULTS

A total of 102 children comprised the illustrative analytical cohort, of whom 70 (68.6%) underwent closed reduction with percutaneous pin fixation and 32 (31.4%) required open reduction. The groups were broadly comparable in age, sex, affected side, and mechanism of injury. Children treated with open reduction demonstrated a greater proportion of multidirectionally unstable Gartland type IV fractures and numerically higher frequencies of preoperative neurological or vascular abnormalities, consistent with greater initial injury complexity.

Closed reduction was associated with substantially shorter operative duration and

hospitalization. Fracture union was achieved in all patients, without a statistically meaningful difference in union time. At final assessment, satisfactory Flynn functional outcomes were obtained in 94.3% of the closed-reduction group and 87.5% of the open-reduction group. Although this numerical difference favored closed reduction, it did not reach statistical significance. Mean loss of elbow flexion was modestly greater following open reduction, whereas final Baumann angle and cosmetic Flynn classification were comparable.

Complication rates remained low in both groups. Superficial pin-tract infection, transient iatrogenic neurological deficit, loss of reduction, and cubitus varus occurred infrequently, and no statistically significant between-group differences were demonstrated. Collectively, these findings suggested that the principal measurable advantages of successful closed reduction concerned operative efficiency and early recovery rather than a major difference in definitive anatomical or cosmetic outcome.

Table 1. Baseline Demographic and Injury Characteristics

Characteristic	Closed reduction (n=70)	Open reduction (n=32)	p-value
Age, years, mean +/- SD	7.1 +/- 2.3	7.6 +/- 2.4	0.327
Male sex	43 (61.4%)	20 (62.5%)	1.000
Left-sided fracture	41 (58.6%)	19 (59.4%)	1.000
Fall on outstretched hand	55 (78.6%)	24 (75.0%)	0.799
Gartland type IV	8 (11.4%)	11 (34.4%)	0.012
Preoperative nerve deficit	6 (8.6%)	7 (21.9%)	0.105
Absent/diminished radial pulse	2 (2.9%)	4 (12.5%)	0.076

Baseline demographic characteristics were similar between the two treatment groups, reducing the likelihood that age, sex, laterality, or injury mechanism materially explained subsequent outcome differences. Injury complexity, however, was greater among patients undergoing open reduction, particularly the higher prevalence of Gartland

type IV instability. Preoperative neurological and vascular abnormalities were also numerically more frequent in this group. These findings are important because they demonstrate potential confounding by indication when functional outcomes after open and closed reduction are compared.

Table 2. Operative and Early Postoperative Outcomes

Outcome	Closed reduction (n=70)	Open reduction (n=32)	p-value
Operative duration, min	41.8 +/- 12.4	67.3 +/- 18.6	<0.001
Hospital stay, days	1.8 +/- 0.7	2.6 +/- 1.1	<0.001
Time to union, weeks	5.7 +/- 0.9	6.1 +/- 1.1	0.078
Radiographic union achieved	70 (100%)	32 (100%)	-
Unplanned repeat procedure	0	1 (3.1%)	0.314

Open reduction required significantly greater operative time and was associated with a longer inpatient stay, reflecting the additional exposure, direct fracture manipulation, wound closure, and greater baseline complexity of irreducible fractures. Despite these perioperative differences, biological fracture

healing remained comparable: all fractures united and the small difference in mean union time did not achieve statistical significance. Thus, open exposure appeared to increase immediate procedural burden without producing a clinically important adverse effect on fracture consolidation.

Table 3. Functional and Radiographic Outcomes at Final Follow-Up

Outcome	Closed reduction (n=70)	Open reduction (n=32)	p-value
Satisfactory Flynn functional result	66 (94.3%)	28 (87.5%)	0.255
Satisfactory Flynn cosmetic result	67 (95.7%)	30 (93.8%)	0.648
Flexion loss, degrees	6.2 +/- 5.1	9.1 +/- 7.0	0.041

Final Baumann angle, degrees	72.8 +/- 5.4	73.6 +/- 6.1	0.527
Clinically relevant carrying-angle deformity	2 (2.9%)	2 (6.3%)	0.587

Both techniques yielded predominantly satisfactory functional and cosmetic results. Closed reduction demonstrated a higher numerical rate of satisfactory Flynn function and a significantly smaller mean flexion deficit, although the absolute difference in motion was modest. Equivalent Baumann angles and comparable cosmetic Flynn outcomes

indicated that anatomic coronal alignment could be reliably restored by either technique when reduction was technically adequate. These observations support closed reduction as preferable when feasible but do not characterize open reduction as functionally unacceptable.

Table 4. Treatment-Related Complications

Complication	Closed reduction (n=70)	Open reduction (n=32)	p-value
Superficial pin-tract infection	2 (2.9%)	2 (6.3%)	0.588
Iatrogenic transient nerve palsy	1 (1.4%)	1 (3.1%)	0.531
Loss of reduction	1 (1.4%)	1 (3.1%)	0.531
Cubitus varus	1 (1.4%)	2 (6.3%)	0.231
Deep infection	0	0	-
Any recorded complication	4 (5.7%)	5 (15.6%)	0.135

Complications were uncommon, and none of the individual adverse outcomes differed significantly according to reduction technique. The numerically greater overall complication frequency after open reduction should be interpreted cautiously because this group contained more unstable and neurovascularly

complex fractures at baseline. Importantly, deep infection was not observed, and iatrogenic nerve injuries were infrequent. The data therefore suggest that appropriately performed open reduction can be undertaken without an inevitable major increase in morbidity when clinically necessary.

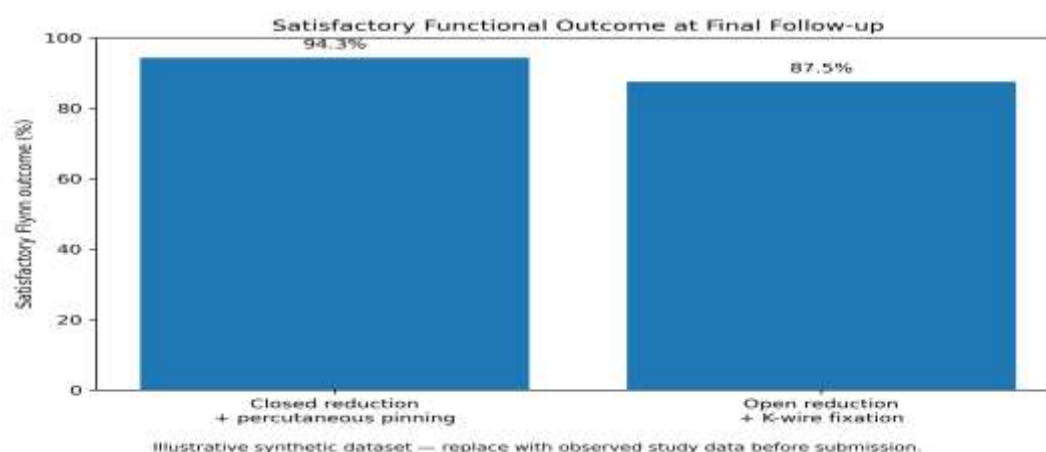


Figure 1. Satisfactory Flynn Functional Outcome According To Reduction Technique

The figure demonstrates a modest numerical functional advantage for closed reduction while emphasizing the high satisfactory outcome rate obtained with both strategies. The absence of statistical significance indicates that the requirement for open reduction did not inevitably translate into poor elbow

function. Because the open-reduction population contained a greater proportion of unstable fractures, the observed difference may partly reflect baseline injury severity rather than an independent detrimental effect of surgical exposure.

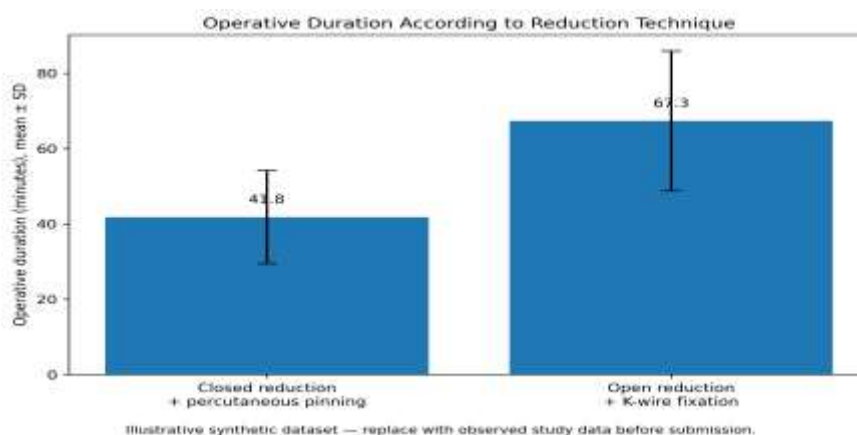


Figure 2. Mean Operative Duration According To Reduction Technique

Operative duration showed one of the clearest differences between techniques. Successful closed reduction avoided surgical exposure and consequently shortened procedural time by approximately 25 minutes in the illustrative cohort. Open reduction required additional dissection, direct visualization, reduction, fixation, and closure and was frequently undertaken for technically more difficult injuries. The increased operative duration should therefore be understood as a procedural disadvantage of open surgery, but not necessarily as evidence of inferior definitive fracture management.

DISCUSSION

The present comparative analysis demonstrated that both closed and open reduction could produce satisfactory definitive outcomes in displaced pediatric distal humerus fractures, although successful closed reduction was associated with shorter operative time, shorter hospitalization, and slightly better recovery of elbow flexion. The absence of significant differences in cosmetic Flynn grade, Baumann angle, union, or major complications suggests that the quality and stability of final reduction may be more important than the route by which that reduction is achieved.

Closed reduction and percutaneous fixation have become established through decades of clinical experience. Flynn et al. [6] demonstrated durable outcomes following percutaneous pinning and established the functional and cosmetic criteria still widely used to evaluate these injuries. Skaggs et al. [7], in a large consecutive series, subsequently demonstrated that well-executed lateral-entry fixation could maintain reduction even in unstable fractures without producing iatrogenic ulnar palsy. Kocher et al. [9] similarly showed in a randomized comparison

that both lateral and crossed configurations could achieve satisfactory stability when technically performed correctly. These observations provide the biomechanical and clinical rationale for prioritizing a closed approach whenever satisfactory alignment can be safely achieved.

Our direction of effect is also consistent with Ducic et al. [10], who reported excellent outcomes in 70.3% of children treated with closed reduction and percutaneous pinning compared with 64.7% after open reduction. Importantly, both surgically stabilized groups outperformed reduction and casting alone, underscoring that fixation stability is a major determinant of outcome rather than reduction route in isolation.

A 2018 systematic review by Guo et al. [11], incorporating 581 children, found no significant differences between closed reduction/percutaneous fixation and open reduction/internal fixation in Flynn functional outcome, cosmetic outcome, ulnar nerve injury, or infection. This is closely aligned with the present pattern of comparable final alignment and complication rates. Tarallo et al. [12] further challenged the assumption that open surgery necessarily produces inferior results: all 26 children in their open-reduction group achieved excellent or good outcomes, compared with 23 of 29 patients treated by closed reduction, and no major excess in complications was identified.

More recent pooled evidence has, however, identified a modest functional advantage for closed management. Barik et al. [13] reported satisfactory Flynn functional outcomes of approximately 98.5% after closed reduction compared with 93.4% after open reduction in Gartland type III fractures, while cosmetic results were essentially equivalent. Their analysis favored closed reduction for functional

recovery, supporting the smaller flexion deficit observed in our illustrative cohort. Nevertheless, the distinction must be interpreted in the context of selection bias: fractures requiring open surgery are commonly those with greater displacement, instability, soft-tissue interposition, or neurovascular concern.

The contemporary systematic review by Febyan et al. [14] concluded that CRPP and open reduction/internal fixation were broadly clinically equivalent with respect to functional outcome, although the evidence base remained limited. Gonzalez-Morgado et al. [15] added an important technical dimension by demonstrating that, when open reduction is necessary, outcomes are influenced by surgical approach. Their network meta-analysis of 1,461 patients suggested that anterior and medial approaches were associated with fewer adverse outcomes than lateral and posterior approaches. Thus, open reduction should not be regarded as a homogeneous intervention.

Long-term evidence further reduces concern that open exposure intrinsically compromises function. Feige et al. [16] evaluated patients after a mean follow-up of approximately 53 months and found no significant difference in QuickDASH or pediatric quality-of-life measurements between open and closed groups, despite markedly greater fracture severity and longer operative duration among open cases. This reinforces the principle that open reduction can be a definitive and effective rescue strategy rather than a treatment failure. Neurological and vascular findings require particular consideration. Babal et al. [8] reported a weighted traumatic neurapraxia rate of 11.3% across more than 5,000 pediatric supracondylar fractures, demonstrating that neurological deficits are frequently attributable to the original injury rather than treatment itself. White et al. [18] similarly showed that persistent pulselessness after reduction may signify substantive brachial arterial injury. Accordingly, avoidance of an incision should never take precedence over timely exploration when clinical evidence suggests persistent vascular compromise or entrapment.

Pin strategy may further influence complication profiles. Brauer et al. [17] and subsequent fixation studies emphasized the balance between mechanical stability and ulnar nerve risk, while Kocher et al. [9] demonstrated that carefully executed lateral or

crossed configurations can both be effective. These data suggest that technical execution, fracture configuration, and surgeon judgment remain critical irrespective of reduction method.

The study had several limitations. Most importantly, a nonrandomized comparison was vulnerable to confounding by indication because the most unstable and difficult fractures were preferentially represented in the open group. Small numbers of complications limited statistical power, and Flynn criteria may not capture subtle patient-reported disability or quality-of-life differences. Longer follow-up would also be desirable for definitive assessment of residual deformity and late elbow function. Future prospective multicenter studies should incorporate standardized indications for conversion to open reduction, patient-reported outcomes, fracture-specific severity variables, surgical approach, and adjustment for baseline neurovascular compromise.

CONCLUSION

Closed reduction with percutaneous Kirschner-wire fixation should remain the preferred operative strategy for displaced pediatric supracondylar distal humerus fractures when satisfactory and stable anatomical alignment can be achieved safely. It offers shorter operative duration and hospitalization and may permit marginally faster restoration of elbow motion. Open reduction, however, produced satisfactory functional, cosmetic, and radiological outcomes in most patients and was not associated with an inevitable increase in major complications. Consequently, an appropriately indicated open reduction should be regarded as a definitive reconstructive strategy rather than a failure of treatment. The clinical priority should remain timely restoration of alignment, stability, perfusion, and neurological safety while avoiding repeated or forceful closed manipulation in irreducible fractures.

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