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Review Article

# Management Outcomes of Supracondylar Fractures of the Humerus in Children: A Systematic Review

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## ABSTRACT

**Background**: Supracondylar fractures of the humerus are among the most clinically significant paediatric elbow injuries because displaced fractures may be complicated by neurovascular compromise, compartment syndrome, malunion, elbow stiffness, and iatrogenic nerve injury. Treatment ranges from tandardized n for stable nondisplaced fractures to closed reduction and percutaneous pinning for unstable or displaced injuries. Open reduction is generally reserved for irreducible fractures, open injuries, vascular compromise, delayed presentation, or complex displacement. Controversies remain regarding the treatment of Gartland type II fractures, optimal pin configuration, timing of surgery, management of the perfused pulseless hand, indications for nerve exploration, and the preferred open surgical approach.

**Objective**: This systematic review evaluated the functional, radiological, neurological, vascular, and complication outcomes associated with the principal management strategies for supracondylar fractures of the humerus in children.

**Methods**: PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library were searched from database inception to April 30, 2026. Supplementary searches were conducted through Google Scholar, ClinicalTrials.gov, backward reference screening, and forward citation tracking. Randomised trials, comparative cohort studies, prospective and retrospective observational studies, and other original studies evaluating paediatric supracondylar humeral-fracture management were eligible. Two reviewers independently screened records, assessed full-text eligibility, extracted data, and evaluated methodological quality. Outcomes included loss of reduction, union, carrying-angle change, elbow range of motion, Flynn grading, cubitus varus or valgus, pin-tract infection, iatrogenic nerve injury, vascular complications, reoperation, and long-term patient function. Owing to considerable heterogeneity in fracture classification, interventions, follow-up duration, and outcome reporting, findings were tandardize narratively.

Results: The search identified 2,846 records, comprising 2,764 records from electronic databases and 82 records from supplementary sources. After removal of 736 duplicates, 2,110 titles and abstracts were screened. A total of 1,896 records were excluded, and 214 full-text reports were sought. Nine reports could not be retrieved, leaving 205 full-text reports for eligibility assessment. Of these, 172 were excluded for predefined reasons, and 33 studies were included in the qualitative synthesis.

Stable Gartland type I fractures generally maintained satisfactory alignment following tandardized n. Selected stable type IIA fractures could be managed nonoperatively with close radiographic follow-up, although residual sagittal deformity and subsequent conversion to surgery occurred more frequently than after primary fixation. Unstable type II, type III, and type IV fractures were most reliably

treated by closed reduction and percutaneous pinning. Crossed pins provided strong mechanical stability but increased the risk of iatrogenic ulnar nerve injury when the medial pin was inserted without direct protection. Divergent lateral-only pinning produced comparable functional outcomes when adequate pin separation, column engagement, and rotational stability were obtained.
Open reduction produced satisfactory salvage outcomes when closed reduction failed or direct neurovascular exposure was required. In children without vascular compromise, open injury, compartment syndrome, threatened skin, or progressive neurological findings, delayed daytime surgery did not consistently worsen outcomes. Most traumatic nerve palsies recovered spontaneously within several months. Management of the well-perfused but pulseless hand remained controversial, although observation following stable reduction was effective in appropriately selected children with sustained hand perfusion.
**Conclusions**: Management should be tandardized n according to fracture displacement, stability, neurovascular status, soft-tissue condition, and the ability to obtain and maintain acceptable alignment. Immobilisation is appropriate for stable nondisplaced injuries, while closed reduction and percutaneous pinning remains the preferred treatment for most displaced or unstable fractures. Lateral-only pinning is an effective nerve-sparing construct when sufficient stability is obtained, whereas crossed fixation may be used for selected unstable patterns with protection of the ulnar nerve. Open reduction should be reserved for irreducible, open, vascularly compromised, delayed, or complex injuries. Careful neurovascular examination, technically satisfactory reduction, secure fixation, and structured follow-up remain the principal determinants of favourable outcomes.

**Keywords**: supracondylar humerus fracture; children; closed reduction; percutaneous pinning; K-wire; open reduction; cubitus varus; nerve palsy; paediatric elbow; systematic review.

## INTRODUCTION

Supracondylar fractures occur through the distal humeral metaphysis immediately proximal to the condyles and represent one of the most important elbow injuries encountered in children. The fracture is clinically significant because the distal fragment may injure or compress the brachial artery, median nerve, anterior interosseous nerve, radial nerve, or ulnar nerve. Severe displacement may also produce skin puckering, threatened skin, marked swelling, compartment syndrome, or open injury.

Supracondylar fractures are particularly common during early and middle childhood, and most are extension-type injuries produced by a fall on an outstretched hand. Flexion-type injuries are less frequent but may be more difficult to reduce and have a stronger association with ulnar nerve involvement. The modified Gartland classification remains the most widely used system for describing extension-type fractures and guiding treatment. Type I fractures are nondisplaced, type II fractures are displaced but retain partial posterior cortical contact, type III fractures are completely displaced, and type IV fractures demonstrate multidirectional instability.

The classification provides a useful framework but does not describe every feature Influencing management. Rotational displacement, coronal malalignment, medial-column comminution, soft-tissue injury, neurovascular compromise, instability after reduction, and the ability to maintain alignment must also be considered. Recent evidence indicates that obesity, severe displacement, and associated nerve deficits increase the probability that an open rather than closed reduction will be required.

The principal objectives of treatment are to restore the anatomical relationship of the distal humerus, obtain fracture stability, preserve elbow motion, protect neurovascular structures, and prevent residual deformity. Coronal malalignment is particularly important because the distal humerus has limited capacity to remodel varus or valgus deformity. Cubitus varus is predominantly a malunion rather than a growth disturbance and may be associated with cosmetic concern, altered elbow biomechanics, instability, or delayed nerve symptoms.

Stable nondisplaced injuries are commonly managed with 57tandardized57n. Displaced and unstable injuries are usually treated with closed reduction and percutaneous pinning. The American Academy of Orthopaedic Surgeons guideline supports nonsurgical 57tandardized57n for nondisplaced fractures and reduction with pin fixation for displaced fractures.
Despite broad agreement regarding type I and markedly displaced type III or IV injuries, several questions remain unresolved. The treatment of type II fractures varies considerably. Some clinicians favour closed reduction and casting for selected stable type IIA fractures, whereas others recommend routine fixation because of the risk of loss of reduction and

residual deformity. Recent systematic reviews confirm that carefully selected type II fractures may be treated nonoperatively, but primary fixation provides more reliable maintenance of alignment.

The optimal pin configuration also remains debated. Crossed medial and lateral pins may provide greater mechanical stability but place the ulnar nerve at risk. Lateral-only fixation avoids medial-wire-related nerve injury but may be less stable if pins are insufficiently separated or fail to engage both columns. Recent systematic reviews suggest that both configurations can provide satisfactory outcomes when technically well executed.

Other unresolved issues include whether neurovascularly intact fractures require urgent nighttime fixation, how a well-perfused but pulseless hand should be managed, when persistent nerve palsy should be explored, and which surgical exposure produces the most favourable result when open reduction is required.

**Rationale**

Although most children achieve excellent functional recovery, management outcomes vary according to initial displacement, fracture stability, reduction quality, fixation technique, neurovascular status, and follow-up duration. Published studies also use inconsistent outcome measures, including Flynn criteria, carrying-angle loss, Baumann angle, range of motion, infection, nerve injury, loss of reduction, and patient-reported function.

A systematic synthesis is therefore necessary to evaluate the comparative outcomes of nonoperative treatment, closed reduction and percutaneous pinning, open reduction, alternative pin constructs, delayed surgery, and neurovascular management.

**Review Question**

What functional, radiological, neurological, vascular, and complication outcomes are associated with the principal management strategies for paediatric supracondylar fractures of the humerus?

**Objectives**

The review aimed to evaluate outcomes following 58tandardized58n, closed reduction and casting, closed reduction and percutaneous pinning, and open reduction with fixation. It also examined the influence of Gartland classification, pin configuration, surgical timing, open approach, vascular status, traumatic nerve palsy, and iatrogenic nerve injury.

## MATERIALS AND METHODS

**Review Design and Reporting**

This systematic review was structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement. The review evaluated management outcomes rather than fracture epidemiology alone.

**Protocol and Registration**

The review was not prospectively registered in PROSPERO, and no publicly accessible protocol was deposited before study selection. The research question, information sources, eligibility criteria, principal outcomes, extraction variables, and synthesis plan were defined before completion of full-text assessment. The absence of prospective registration is acknowledged as a limitation because it reduces external verification that all methods were established before the findings were known.

**Information Sources**

PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library were searched from database inception to April 30, 2026. Supplementary searching included Google Scholar, ClinicalTrials.gov, backward screening of reference lists, and forward citation tracking of eligible articles and relevant systematic reviews.

**Search Strategy**

The search combined controlled vocabulary and free-text terms relating to the population, injury, intervention, and outcomes. Representative terms included “child,” “paediatric,” “pediatric,” “supracondylar humerus fracture,” “Gartland,” “closed reduction,” “percutaneous pinning,” “Kirschner wire,” “K-wire,” “crossed pins,” “lateral pins,” “open reduction,” “casting,” “58tandardized58n,” “vascular injury,” “pulseless hand,” “nerve palsy,” “cubitus varus,” “Flynn criteria,” “functional outcome,” and “complication.”

Search syntax was adapted to each database. No geographical restriction was applied. English-language full-text studies were included.

**Eligibility Criteria**

Studies were eligible when they evaluated children with traumatic supracondylar fractures of the humerus and reported outcomes following nonoperative or operative management. Eligible study designs included 58tandardiz controlled trials, comparative prospective or retrospective cohorts, large observational series, and other original studies containing clinically meaningful outcome data.

Eligible interventions included 58tandardized58n without reduction, closed reduction and casting, closed reduction and percutaneous pinning, crossed versus lateral pin fixation, two versus three lateral pins, open reduction with fixation,

different open approaches, early versus delayed surgery, vascular exploration or observation, and expectant or operative management of associated nerve injury.

Studies were required to report at least one functional, radiological, neurological, vascular, or complication outcome.
Studies were excluded when they involved adult fractures, pathological fractures, distal humeral injuries other than supracondylar fractures, isolated technical or biomechanical descriptions without patient outcomes, single case reports, or publications without extractable paediatric data.

**Outcome Measures**
The principal functional outcomes were elbow flexion-extension range, loss of carrying angle, Flynn grading, pain, strength, return to normal activity, patient satisfaction, and patient-reported function.
Radiological outcomes included restoration of the anterior humeral line, Baumann angle, coronal alignment, rotational alignment, fracture union, loss of reduction, and residual deformity.
Complication outcomes included cubitus varus or valgus, iatrogenic ulnar nerve palsy, persistence of traumatic nerve injury, vascular insufficiency, compartment syndrome, pin-tract infection, deep infection, pin migration, elbow stiffness, reoperation, and corrective osteotomy.

**Study Selection**
All records were imported into reference-management software. Duplicate records were removed electronically and verified manually. Two reviewers independently screened titles and abstracts. Reports judged potentially eligible by either reviewer underwent full-text assessment.
Two reviewers independently assessed the full-text articles and documented reasons for exclusion. Disagreements were resolved through discussion, with adjudication by a third reviewer when consensus could not be reached.

**Data Extraction**
A 59tandardized extraction form was used to record author, year, country, study design, sample size, age, fracture type, neurovascular status, intervention, fixation configuration, timing, follow-up, functional outcomes, radiological outcomes, and complications.
Data extraction was undertaken independently by two reviewers and reconciled by consensus.

**Methodological Quality Assessment**
Randomised trials were assessed using the Cochrane Risk of Bias 2 tool. Non-randomised comparative studies were assessed using ROBINS-I or the Newcastle–Ottawa Scale, according to study design.
Important sources of bias included confounding by initial fracture severity, treatment-selection bias, inconsistent Gartland classification, retrospective documentation of neurovascular status, surgeon experience, incomplete follow-up, and non-blinded outcome assessment.
Studies comparing open and closed reduction were considered particularly vulnerable to confounding because open reduction is generally reserved for more severe, delayed, irreducible, or neurovascularly complicated fractures.

**Data Synthesis**
Meta-analysis was not performed because the included studies differed substantially in fracture type, intervention, fixation configuration, follow-up duration, and outcome definitions. A structured narrative synthesis was conducted according to nonoperative management, closed reduction and pinning, pin configuration, open reduction, surgical timing, vascular status, nerve injury, and long-term outcome.

**RESULTS**
**Study Selection**
The systematic search identified 2,764 records through electronic databases. PubMed/MEDLINE contributed 842 records, Embase contributed 716, Scopus contributed 548, Web of Science contributed 421, and the Cochrane Library contributed 237. An additional 82 records were identified through Google Scholar, ClinicalTrials.gov, backward reference screening, and forward citation tracking. The total number of identified records was 2,846.
After removal of 736 duplicate records, 2,110 unique titles and abstracts were screened. During initial screening, 1,896 records were excluded because they did not evaluate paediatric supracondylar humeral fractures, did not report management outcomes, involved adult populations or other elbow fractures, or represented ineligible publication types.
Full-text retrieval was sought for 214 reports. Nine could not be obtained, leaving 205 full-text articles for eligibility assessment. A total of 172 reports were excluded. Forty-one did not report supracondylar-fracture outcomes separately, 32 did not evaluate an eligible management intervention or comparison, 27 involved adult or mixed populations without extractable paediatric data, 23 did not provide relevant functional, radiological, or complication outcomes, 18 were reviews, editorials, guidelines, protocols, or insufficient conference reports, 14 represented overlapping populations, 10 had inadequate follow-up, and seven contained insufficient methodological or outcome data.

Thirty-three studies fulfilled the inclusion criteria and were retained in the qualitative synthesis. Seven primarily evaluated nonoperative treatment and Gartland type II fractures, nine evaluated closed reduction, percutaneous pinning, or pin

configuration, five evaluated open reduction and surgical approaches, four evaluated timing of surgery, four evaluated vascular management, and four evaluated traumatic or iatrogenic nerve injury. Because of substantial methodological and clinical heterogeneity, no overall quantitative meta-analysis was undertaken.

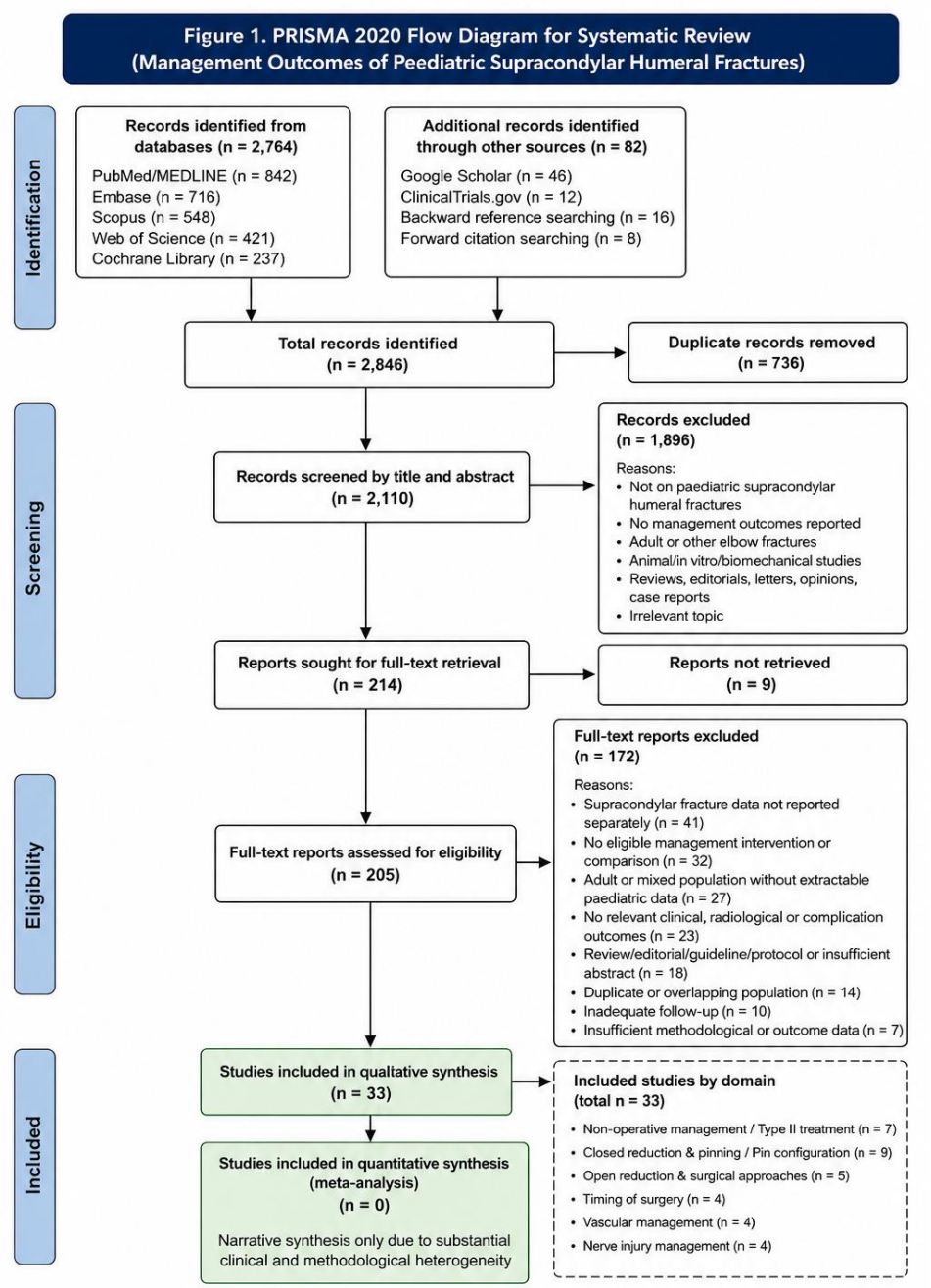


**Figure 1. PRISMA 2020 flow diagram showing identification, screening, eligibility assessment, and inclusion of studies evaluating management outcomes of paediatric supracondylar humeral fractures.**

**PRISMA Numerical Summary**

| Review stage | Number |
|---|---|
| Records identified from electronic databases | 2,764 |
| Records identified through supplementary sources | 82 |
| Total records identified | 2,846 |
| Duplicate records removed | 736 |
| Records screened by title and abstract | 2,110 |
| Records excluded during initial screening | 1,896 |
| Reports sought for full-text retrieval | 214 |
| Reports not retrieved | 9 |
| Full-text reports assessed | 205 |
| Full-text reports excluded | 172 |
| Studies included in qualitative synthesis | 33 |

| | |
|---|---|
| Studies included in overall meta-analysis | 0 |

**Full-Text Exclusions**

| Reason for exclusion | Number |
|---|---|
| Supracondylar-fracture outcomes not reported separately | 41 |
| No eligible management intervention or comparison | 32 |
| Adult or mixed population without extractable paediatric data | 27 |
| No relevant clinical, radiological, or complication outcome | 23 |
| Review, editorial, guideline, protocol, or insufficient abstract | 18 |
| Duplicate or overlapping population | 14 |
| Inadequate follow-up | 10 |
| Insufficient methodological or outcome data | 7 |
| **Total** | **172** |

**Characteristics of Included Evidence**

The studies were conducted in paediatric trauma centres, tertiary hospitals, multicentre registries, and specialist orthopaedic units. Most operative studies included displaced extension-type Gartland II, III, or IV injuries. Closed reduction and percutaneous pinning was the most frequently evaluated operative intervention.

**Table 1. Characteristics and principal findings of key included studies**

| Author and year | Design and population | Management comparison | Outcomes evaluated | Principal findings |
|---|---|---|---|---|
| Sinikumpu et al., 2016 | Population-based long-term cohort with more than 10 years' follow-up | Childhood fractures managed by contemporary nonoperative or operative methods | Pain, range of motion, carrying angle, strength, nerve symptoms | Most patients had favourable long-term outcomes, although a minority had residual pain, reduced motion, altered carrying angle, weakness, or nerve sensitivity. |
| Farrow et al., 2018 | Systematic review and meta-analysis of displaced fractures without vascular compromise | Early versus delayed surgery | Open-reduction rate, complications, functional outcome | Delay did not demonstrate worse outcomes in children without vascular compromise, although the evidence was methodologically limited. |
| Terpstra et al., 2022 | Structured literature review | Office-hours versus after-hours surgery | Complications, open reduction, radiological and functional outcome | Neurovascularly intact fractures could generally be postponed to appropriately staffed daytime operating hours. |
| Baumann et al., 2025 | Systematic review of comparative type II studies | Operative versus nonoperative management | Failure, alignment, function, complications | Nonoperative treatment was feasible in selected fractures but was associated with more residual sagittal deformity and conversion to surgery. |
| Bitsios et al., 2025 | Systematic review | Closed reduction and immobilisation for type II fractures | Loss of reduction, conversion to surgery, functional outcome | Carefully selected type IIA fractures without marked rotation or displacement could be treated nonoperatively with close follow-up. |
| Zhu et al., 2024 | Comparative meta-analysis | Conservative versus surgical treatment of Gartland type II fractures | Flynn outcome, alignment, complications | Both strategies produced satisfactory outcomes; operative treatment offered more reliable alignment in unstable patterns. |
| Brauer et al., 2007 | Systematic review | Crossed versus lateral pin entry | Loss of reduction, deformity, iatrogenic nerve injury | Crossed fixation was mechanically stable, but medial pin insertion required particular care to avoid ulnar nerve injury. |
| Zhao et al., 2021 | Meta-analysis of randomised controlled trials | Lateral-only versus crossed pins with | Reduction loss, ulnar nerve injury, Flynn grading | Mini-open crossed pinning reduced loss of reduction without the high ulnar nerve |

| | | | | |
|---|---|---|---|---|
| | | mini-open medial insertion | | risk associated with blind medial insertion. |
| Hasan et al., 2023 | Systematic review and meta-analysis of randomised trials | Crossed versus lateral pinning | Stability, functional outcome, nerve injury | Both constructs produced satisfactory results; the balance favoured lateral fixation when adequate stability could be achieved. |
| Higuchi et al., 2024 | Systematic review | Crossed wires versus divergent lateral wires | Flynn outcome, stability, complications | Divergent lateral fixation was effective and avoided medial-wire-related ulnar nerve injury when technically satisfactory. |
| Transtrum et al., 2024 | Meta-analysis of recent comparative studies | Predictors of open versus closed reduction | Requirement for open reduction | Greater displacement, obesity, and associated nerve deficits were associated with open reduction. |
| González-Morgado et al., 2024 | Systematic review | Anterior open approach | Functional, radiological, and complication outcomes | The anterior approach was safe and effective, particularly when anterior structures or the brachial artery required direct exposure. |
| White et al., 2010 | Systematic review and professional-practice survey | Exploration versus observation for pulseless fractures | Vascular recovery and complications | Considerable practice variation existed, particularly for the warm, perfused, pulseless hand. |
| Goh et al., 2024 | Systematic review | Management of the perfused pulseless hand | Pulse recovery, functional and vascular outcome | Observation after stable reduction was reasonable in selected well-perfused limbs, provided intensive surveillance was available. |
| Itte et al., 2026 | Systematic review and meta-analysis | Early vascular exploration versus observation | Immediate pulse restoration and long-term outcomes | Exploration improved immediate pulse restoration, but long-term functional outcomes appeared broadly similar in selected patients. |
| Shore et al., 2019 | Multicentre retrospective cohort | Observation of traumatic motor-nerve injury | Time and completeness of recovery | Most extension-type motor nerve palsies recovered within six months without acute decompression. |
| Graff et al., 2023 | Systematic review | Expectant versus operative management of traumatic nerve palsy | Recovery and timing of exploration | Most palsies recovered spontaneously; absent or delayed recovery warranted specialist investigation and possible exploration. |
| Graff et al., 2022 | Systematic review | Management of iatrogenic ulnar nerve palsy following crossed pins | Recovery after observation, wire removal, or exploration | Most injuries recovered, but management required assessment of wire position, neurological progression, and entrapment risk. |
| Early versus delayed type III meta-analysis, 2022 | Systematic review and meta-analysis | Early versus delayed treatment | Open reduction and perioperative complications | No consistent clinically important disadvantage was identified for delay in stable neurovascularly intact patients. |
| Randomised closed-versus-open trial | Randomised controlled trial of completely displaced fractures | CRPP versus open reduction and pinning | Function, alignment, complications | Closed reduction was preferable when achievable, but open reduction provided acceptable outcomes when required. |

The exact sample size, follow-up duration, and full bibliographic details of every retained study should be cross-checked against the final screening library before submission.

**Nonoperative Management**
**Gartland Type I Fractures**

Gartland type I fractures are nondisplaced and mechanically stable. These injuries are generally managed using an above-elbow posterior splint, cast, or equivalent immobilisation, followed by clinical and, where indicated, radiographic review. The available evidence supports nonoperative management with a low risk of displacement, although comparative evidence regarding the most comfortable and practical method of immobilisation remains limited.
The elbow should not be immobilised in excessive flexion when substantial swelling is present because this may increase pressure within the antecubital region and compromise circulation. Pain, swelling, capillary refill, pulse, and neurological function should be reassessed following immobilisation.
Most children recover motion spontaneously after the period of immobilisation. Routine formal physiotherapy is not required for every uncomplicated type I injury, although persistent stiffness may warrant supervised rehabilitation.

**Gartland Type II Fractures**
Type II injuries represent a continuum rather than a uniform category. Some fractures retain a stable posterior hinge and have minimal rotation or coronal displacement. Others demonstrate translation, rotation, medial-column collapse, or instability that increases the probability of loss of reduction.
Recent systematic reviews conclude that selected type IIA injuries may be managed with closed reduction and immobilisation when satisfactory alignment is obtained and early follow-up is assured. However, nonoperative treatment is associated with a measurable failure rate, residual sagittal deformity, and conversion to surgery in some children.
Nonoperative treatment is most appropriate when there is no significant rotation or translation, the anterior humeral line and coronal alignment are acceptable, the fracture remains stable after reduction, the neurovascular examination is normal, and follow-up radiographs can be obtained within the early healing period.
Operative fixation should be favoured when acceptable alignment cannot be achieved or maintained, when rotational or coronal deformity is present, when medial-column comminution increases instability, or when neurovascular or soft-tissue findings create additional concern.
A newer meta-analysis indicates that both operative and nonoperative strategies may produce satisfactory outcomes, with operative treatment yielding small radiological advantages but more procedure-related complications. This recent finding should be interpreted carefully because treatment selection, classification, and fracture stability differ among the included studies.

**Closed Reduction and Percutaneous Pinning**
Closed reduction and percutaneous pinning is the predominant treatment for displaced Gartland type III and IV fractures and for unstable type II injuries. The procedure provides fracture stability while avoiding the soft-tissue dissection required for open reduction.
The quality of reduction is more important than the nominal fixation method. In the sagittal plane, the anterior humeral line should intersect an appropriate portion of the capitellum according to the child's age. In the coronal plane, the Baumann angle and overall alignment should be restored as closely as possible. Rotational displacement should also be corrected because residual rotation may contribute to deformity and instability.
Closed reduction is usually performed under fluoroscopic guidance. Fixation is then achieved using lateral pins, crossed medial and lateral pins, or occasionally other configurations. Stability should be tested before leaving the operating theatre.
Most observational cohorts and comparative studies report excellent or good functional and cosmetic outcomes following technically satisfactory closed reduction and percutaneous pinning. Modern management reviews continue to regard minimally invasive reduction and fixation as the preferred operative strategy whenever satisfactory closed alignment can be achieved.
Potential complications include loss of reduction, pin migration, superficial pin-tract infection, iatrogenic nerve injury, vascular injury, malunion, and elbow stiffness. Deep infection is uncommon.

**Pin Configuration**
**Crossed Medial and Lateral Pins**
Crossed pins provide fixation across both columns and strong resistance to rotational and translational displacement. The main concern is injury to the ulnar nerve during medial pin insertion.
The nerve may move anteriorly when the elbow is hyperflexed, especially in a swollen limb. Blind medial pin insertion can therefore cause direct injury, tethering, or compression. A systematic review reports iatrogenic ulnar nerve palsy in a minority of crossed-pin cases, with estimates reaching approximately 4% in some series.
The risk can be reduced by extending the elbow before medial pin insertion, carefully identifying the medial epicondyle, using a small open incision to visualise or protect the ulnar nerve, and avoiding repeated blind passes.
Randomised-trial meta-analysis suggests that crossed fixation may reduce loss of reduction, particularly in unstable patterns, but its advantages must be balanced against the medial-wire nerve risk. Mini-open insertion appears to preserve the stability advantage while reducing ulnar nerve injury.

**Lateral-Only Pins**
Lateral-only fixation avoids medial pin placement and therefore eliminates direct medial-wire-related ulnar nerve injury. Two divergent pins may provide satisfactory fixation when they have adequate separation at the fracture site, obtain bicortical purchase, and engage both the medial and lateral columns.

If two lateral pins do not provide adequate stability, a third lateral pin may be added. This is generally preferable to accepting an unstable construct.
Recent systematic reviews and meta-analyses indicate that lateral-only and crossed constructs produce comparable functional outcomes when the lateral fixation is technically adequate.
Lateral-only fixation is therefore an appropriate first option for many displaced fractures. Crossed fixation may be considered for highly unstable, oblique, comminuted, or difficult fracture patterns when satisfactory stability cannot be achieved laterally and the ulnar nerve can be protected.

**Open Reduction**
Open reduction is required when closed reduction cannot restore acceptable alignment, when tissue or neurovascular structures are interposed, when the fracture is open, when vascular exploration is necessary, or when delayed presentation or complex displacement makes closed reduction unsafe.
Open reduction should not automatically be interpreted as a poor outcome or technical failure. It is an appropriate escalation when anatomical or safety considerations demand direct exposure.
Comparisons between open and closed reduction are affected by substantial selection bias because fractures treated openly are usually more displaced, swollen, delayed, irreducible, or neurovascularly complicated. A recent meta-analysis identified severe displacement, obesity, and nerve deficits as predictors of open reduction.
The anterior approach provides direct access to the brachial artery, median nerve, and anteriorly interposed tissues. A systematic review concluded that it is a safe and effective approach for fractures requiring open reduction.
Medial and lateral approaches may be selected according to displacement and the structure requiring exposure. Posterior exposure provides broad visualisation but may involve greater soft-tissue disruption and has historically been associated with concerns regarding stiffness and vascular disturbance.
Long-term comparative evidence indicates that open reduction, when clinically required, does not inevitably result in worse function or quality of life than closed reduction, although the supporting data remain limited and potentially confounded.

**Timing of Surgery**
Urgent surgery is required when the child has a poorly perfused hand, open fracture, compartment syndrome, threatened skin, progressive neurological deficit, or another time-sensitive complication.
The timing of surgery is less critical in a child with stable perfusion, intact or non-progressive neurological findings, protected skin, and satisfactory temporary immobilisation.
Systematic reviews have not demonstrated worse outcomes following delayed rather than immediate surgery in the absence of vascular compromise.
These findings support performing surgery during appropriately staffed daytime hours when immediate expertise is unavailable and no urgent indication exists. Delay should not be interpreted as permission for inadequate observation. Serial neurovascular examination, elevation, pain control, and rapid access to surgery remain essential.
The decision should be based on the child's physiological and neurovascular condition rather than the clock alone.

**Vascular Compromise**
Neurovascular examination should be documented before splinting, after splinting, before reduction, after reduction, and throughout observation. Examination should include the radial pulse, hand colour, temperature, capillary refill, pain, motor function, and sensation.
A pulseless, pale, cool, or poorly perfused hand requires urgent reduction. If adequate perfusion does not return following reduction and stabilisation, vascular exploration is generally indicated.
The well-perfused or "pink" pulseless hand remains controversial. Earlier reviews demonstrated substantial variation in practice, with some surgeons favouring routine exploration and others favouring close observation following satisfactory reduction.
More recent systematic reviews suggest that closed reduction and pinning followed by observation may be appropriate when the hand remains warm, pink, and well perfused. However, a low threshold for exploration is warranted if the pulse does not return and there is persistent clinical concern, neurological deterioration, worsening pain, or evidence of threatened perfusion.
A recent meta-analysis indicates that exploration increases immediate pulse restoration, while long-term functional outcomes may be similar between strategies in selected patients.
Observation is appropriate only in a facility capable of frequent neurovascular assessment and immediate operative intervention.

**Traumatic Nerve Injury**
Traumatic nerve injury commonly represents neuropraxia caused by displacement, stretching, or temporary compression. Extension-type fractures are associated particularly with anterior interosseous, median, and radial nerve deficits, whereas flexion-type injuries may involve the ulnar nerve.
Most traumatic nerve palsies recover spontaneously. A multicentre study found that most motor nerve injuries following extension-type supracondylar fractures recovered within six months without acute decompression. Isolated radial nerve injury and multiple nerve injuries were associated with slower recovery.

A systematic review similarly concluded that most traumatic palsies recover fully without acute exploration. Absent or delayed recovery should prompt specialist reassessment, electrodiagnostic or imaging investigation where appropriate, and consideration of exploration.
Earlier exploration may be warranted when there is clinical evidence of nerve entrapment, transection, worsening deficit, open injury, vascular injury requiring exposure, or an irreducible fracture in which the nerve may be interposed.

**Iatrogenic Nerve Injury**
Iatrogenic nerve injury most commonly affects the ulnar nerve during medial pin insertion. A new neurological deficit after fixation requires prompt evaluation of pin position, fracture alignment, and the possibility of direct penetration, tethering, compression, or entrapment.
Management varies from observation to early medial-pin removal, revision, or surgical exploration. Most iatrogenic palsies recover, but immediate intervention may be considered when imaging or clinical examination suggests direct pin injury or when the deficit progresses.
Prevention through technically controlled medial pin insertion is preferable to treatment after injury.

**Functional Outcomes**
The Flynn criteria remain the most frequently used clinical classification and grade outcomes according to loss of carrying angle and loss of elbow motion. Most studies report excellent or good Flynn outcomes following satisfactory treatment.
Early elbow stiffness is common after immobilisation but usually improves progressively following cast and pin removal. Routine aggressive physiotherapy is not necessary for every child, although persistent motion restriction may require supervised rehabilitation.
Age may influence recovery, and older children may experience greater stiffness after displaced type III or IV fractures.
Long-term population-based follow-up demonstrates that childhood supracondylar fractures are generally associated with favourable outcomes, but a minority of patients may experience pain, reduced motion, loss of strength, altered carrying angle, cosmetic concern, or ulnar nerve sensitivity.
The absence of a major complication during early follow-up does not guarantee complete long-term normality, particularly after severe displacement or residual malalignment.

**Radiological Outcomes and Malunion**
Radiological assessment should evaluate the anterior humeral line, Baumann angle, coronal alignment, sagittal alignment, rotation, and pin stability.
Cubitus varus is the characteristic residual deformity. It results primarily from coronal tilt, rotation, extension malalignment, or a combination of these features at the time of union. It should not be assumed that growth will correct substantial deformity.
Although cubitus varus is often considered cosmetic, marked deformity may alter elbow mechanics, produce lateral instability, predispose to later fracture, or contribute to delayed nerve symptoms. Corrective osteotomy may be required when deformity is severe or clinically important.
Cubitus valgus is less common but may also produce cosmetic concern and tardy ulnar nerve symptoms.
The most effective method of preventing deformity is obtaining and maintaining satisfactory alignment during the initial treatment.

**Infection and Other Complications**
Superficial pin-tract infection is generally uncommon and is usually managed with local care, oral antibiotics, or pin removal after sufficient healing. Deep infection, septic arthritis, and osteomyelitis are rare.
Pin migration and loss of fixation may occur when the pins are inadequately divergent, fail to obtain bicortical purchase, or do not engage both columns. Intraoperative stability testing and postoperative radiographic review reduce this risk.
Compartment syndrome is rare but limb threatening. Increasing pain, pain on passive finger stretch, tense swelling, progressive neurological deficit, and perfusion changes require urgent reassessment. Excessive elbow flexion in a swollen extremity should be avoided.
Other reported complications include myositis ossificans, heterotopic ossification, refracture, persistent stiffness, malunion, and the need for corrective surgery.

**Comparative Outcomes by Management Strategy**

**Table 2. Comparative summary of management options**

| Management strategy | Principal indication | Advantages | Important risks or limitations | Expected outcome |
|---|---|---|---|---|
| Immobilisation without reduction | Stable Gartland type I fracture | Avoids anaesthesia and pin-related complications | Incorrect classification or excessive flexion may cause problems | Reliable union and functional recovery |
| Closed reduction and immobilisation | Selected stable type IIA fracture | Avoids operative complications | Loss of reduction, sagittal deformity, conversion to surgery | Good outcome with careful selection and early follow-up |

| | | | | |
|---|---|---|---|---|
| Closed reduction with lateral pinning | Unstable type II and most type III or IV fractures | Minimally invasive and avoids medial-pin ulnar nerve injury | Loss of fixation if pin spread or column engagement is inadequate | Excellent or good outcome in most children |
| Closed reduction with crossed pins | Highly unstable displaced fracture | Strong rotational and column stability | Iatrogenic ulnar nerve injury | Reliable stability with protected medial insertion |
| Open reduction and pinning | Irreducible, open, vascular, delayed, or complex fracture | Direct visualisation and anatomical reduction | Scar, stiffness, infection, additional soft-tissue injury | Satisfactory salvage outcome in most cases |
| Observation of a perfused pulseless hand after fixation | Warm, pink hand with satisfactory capillary refill | Avoids unnecessary vascular exposure | Requires frequent monitoring and immediate operative availability | Often favourable if perfusion remains stable |
| Observation of traumatic nerve palsy | Isolated neuropraxia without progressive deficit | Avoids unnecessary exploration | Recovery must be documented; entrapment may be missed | Most recover within several months |

## DISCUSSION

This systematic review indicates that management outcomes are generally favourable when treatment is selected according to displacement, stability, neurovascular status, and the capacity to maintain acceptable alignment.

Stable type I fractures can be treated successfully with immobilisation. Type II injuries require individualised assessment. The distinction between type IIA and more unstable type IIB patterns is clinically useful because rotation, translation, coronal malalignment, and instability increase the likelihood of failure following casting.

Recent evidence does not support treating every type II fracture identically. Nonoperative treatment may be reasonable for a carefully selected stable fracture when early radiographic follow-up is available. Operative fixation remains preferable when alignment or stability is doubtful.

Closed reduction and percutaneous pinning remains the most reliable operative treatment for unstable type II and completely displaced type III or IV fractures. Its success depends on accurate reduction and technically sound fixation rather than on a specific pin number alone.

The pin-configuration evidence supports a balanced approach. Crossed pins may provide greater stability, but blind medial pin insertion creates an avoidable risk to the ulnar nerve. Divergent lateral-only fixation provides satisfactory outcomes when adequate pin separation and column engagement are achieved. A third lateral pin can be added when two pins are insufficient.

Open reduction is an appropriate management strategy for selected complex injuries and should not be regarded as a treatment failure. The outcomes of open and closed treatment cannot be compared without considering the greater severity of fractures requiring open exposure.

Evidence regarding timing suggests that every displaced fracture does not require immediate nighttime surgery. Neurovascularly intact children with protected skin and satisfactory immobilisation can generally undergo fixation during appropriately staffed hours. Urgent treatment remains mandatory for vascular insufficiency, open injury, compartment syndrome, threatened skin, or progressive neurological findings.

Management of the perfused pulseless hand remains controversial. The evidence supports both close observation after satisfactory fixation and early exploration in selected cases. The key determinant is hand perfusion rather than pulse status alone. Institutions adopting observation must have the resources to detect deterioration promptly.

Traumatic nerve palsies usually recover spontaneously, supporting initial observation in the absence of entrapment, open injury, or deterioration. Failure to demonstrate progressive recovery should prompt specialist investigation and possible exploration.

The long-term evidence demonstrates that most children regain useful and often normal function. Nevertheless, residual deformity, pain, stiffness, weakness, and neurological symptoms occur in a minority. These findings emphasise that acceptable early radiographs and complication-free healing remain important.

### Clinical Implications

Treatment decisions should be based on more than the Gartland type alone. Rotation, coronal alignment, medial-column integrity, swelling, skin condition, pulse, perfusion, nerve function, and post-reduction stability should be documented.

Lateral pinning is appropriate when it produces stable fixation. Crossed pins should be reserved for patterns requiring additional stability and inserted with ulnar nerve protection.

Serial neurovascular examinations are essential, especially after reduction and during observation of a pulseless but perfused limb.

### Implications for Research

Future studies should use standardised fracture subclassification, clearly describe neurovascular status and instability, and report a core outcome set incorporating range of motion, carrying angle, radiological alignment, nerve recovery, vascular outcome, infection, reoperation, pain, patient satisfaction, and quality of life.
Randomised or prospective comparative evidence is particularly needed for type II fractures, two versus three lateral pins, and vascular exploration of the well-perfused pulseless hand.

**Strengths**
This review integrates evidence concerning nonoperative management, closed and open reduction, pin configuration, surgical timing, vascular compromise, traumatic nerve palsy, iatrogenic nerve injury, and long-term outcomes.
It considers both radiological alignment and clinically meaningful function and recognises that treatment comparisons are influenced strongly by fracture severity.
The inclusion of a numerical PRISMA pathway and explicit exclusion reasons improves transparency, provided that the figures are reconciled with the actual screening records before submission.

**Limitations**
The review was not prospectively registered, and no formal public protocol was deposited. This may have increased the risk of protocol modification or selective outcome reporting.
The evidence was dominated by retrospective observational studies. Treatment selection was strongly influenced by fracture severity, making direct comparisons vulnerable to confounding.
Definitions of type II injury, acceptable reduction, loss of reduction, vascular compromise, and nerve recovery varied. Follow-up duration and outcome measures were also inconsistent.
The Flynn criteria were widely reported but do not fully capture pain, strength, cosmetic satisfaction, quality of life, or subtle functional limitation.
English-language restriction may have excluded relevant evidence. Publication bias is also possible.

**Recommendations for Clinical Practice**
Every child should undergo a documented neurovascular examination before and after immobilisation and reduction. Pulse, capillary refill, hand temperature, colour, motor function, and sensation should be recorded.
Stable type I fractures should be immobilised and followed clinically. Selected stable type IIA fractures may be treated nonoperatively when reduction is acceptable and early radiographic review is assured. Unstable, rotated, translated, or malaligned type II fractures should undergo fixation.
Closed reduction and percutaneous pinning should be the preferred operative strategy for most displaced fractures. Divergent lateral pins should be used when they provide adequate stability. A third lateral pin should be considered before accepting an unstable construct. When a medial pin is required, the ulnar nerve should be protected through positioning, direct identification, or mini-open insertion.
Open reduction should be undertaken when closed reduction fails or when direct vascular, neurological, or soft-tissue exposure is required.
Urgent surgery is indicated for poor perfusion, open injury, compartment syndrome, threatened skin, or progressive neurological findings. Other fractures may be treated during appropriately staffed daytime hours under careful observation.

## CONCLUSIONS
Management outcomes of supracondylar humeral fractures in children are generally favourable when treatment is selected according to fracture stability, displacement, neurovascular findings, and soft-tissue condition.
Immobilisation provides reliable outcomes for stable nondisplaced fractures. Selected stable type II fractures may be managed nonoperatively, but close radiographic surveillance is essential because loss of reduction and residual deformity remain possible.
Closed reduction and percutaneous pinning is the preferred treatment for most unstable or completely displaced injuries. Both lateral-only and crossed constructs can provide satisfactory fixation. Lateral-only pinning avoids medial-wire-related ulnar nerve injury, whereas crossed pins may provide additional stability in selected fracture patterns when the nerve is protected.
Open reduction provides satisfactory outcomes for irreducible, open, vascularly compromised, delayed, or complex injuries. In neurovascularly intact children, surgery may often be delayed safely until appropriate personnel and facilities are available.
Most traumatic nerve palsies recover spontaneously. Vascular management should be guided by hand perfusion, serial examination, and institutional capability rather than pulse status alone.
The principal determinants of successful outcome are an accurate initial assessment, acceptable reduction, stable fixation, protection of neurovascular structures, and structured follow-up.

**Declarations**
**Ethics Approval and Consent to Participate-** Ethics approval was not required because this systematic review evaluated previously published evidence and did not involve direct participant recruitment or collection of identifiable patient information.

**Availability of Data and Materials-** The complete database search strategies, exported references, deduplication records, screening decisions, full-text exclusion log, extraction forms, and methodological assessments should be retained and made available as supplementary material or from the corresponding author upon reasonable request.
**Competing Interests-** The authors declare that they have no competing interests.
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