

Management of Supracondylar Humeral Fracture in Children

Manejo da fratura supracondiliana do úmero em crianças

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Abstract

Supracondylar humeral fracture represents ~ 3 to 15% of all fractures in children. It is the fracture that most requires surgical treatment in the pediatric population. Advances in treatment and care have contributed to a reduction in the most dramatic complication: Volkmann ischemic contracture. Nevertheless, the risks inherent to the fracture remain. Absence of palpable pulse in type-III fractures is reported in up to 20% of the cases. Careful sensory, motor, and vascular evaluation of the affected limb is crucial in determining the urgency of treatment. Older children, male patients, floating elbow, and neurovascular injury are risk factors for compartment syndrome. Medial comminution can lead to varus malunion, even in apparently innocent cases. The recommended treatment of displaced fractures is closed reduction and percutaneous pinning. Technical errors in pin placement are the main cause of loss of reduction. There is enough evidence for the addition of a third lateral or medial Kirschner wire in unstable fractures (types III and IV). Medial comminution may lead to cubitus varus even in mild displaced fractures. Based on current concepts, a flowchart for the treatment of supracondylar humeral fracture in children is suggested by the authors.

Keywords

- ▶ humeral fractures
- ▶ elbow
- ▶ child
- ▶ fracture fixation

Resumo

A fratura supracondiliana do úmero representa cerca de 3 a 15% de todas as fraturas na criança, sendo a que mais requer tratamento cirúrgico na população pediátrica. Apesar de os avanços no tratamento e na assistência terem contribuído para uma redução drástica da complicação mais temida, a contratatura isquêmica de Volkmann, os riscos inerentes à fratura permanecem. Ausência de pulso palpável em fraturas tipo III é reportada em até 20% dos casos. Uma cuidadosa avaliação sensitiva, motora e vascular do membro acometido é fundamental na determinação da urgência do tratamento. Crianças mais velhas, sexo masculino, cotovelo flutuante e lesão neurovascular são fatores de risco para a síndrome de compartimento. A cominuição medial pode levar à consolidação em varo, mesmo nos casos aparentemente inocentes. O método de escolha para o tratamento da fratura desviada é a redução fechada e fixação percutânea. Os erros na fixação e posicionamento inadequado dos implantes são as principais causas de perda de redução. Já existem evidências suficientes para a utilização de um terceiro fio de Kirschner, lateral ou medial, nas fraturas instáveis (tipo III e IV). Baseado nos conceitos atuais, um fluxograma para o tratamento da fratura supracondiliana do úmero na criança é sugerido pelos autores.

Palavras-chave

- ▶ fraturas do úmero
- ▶ cotovelo
- ▶ criança
- ▶ fixação de fratura

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Introduction

Among the traumatic injuries of the immature skeleton, supracondylar humeral fracture [SHF] stands out not only for its high frequency, but also for the risks that accompany it. Advances in treatment and care have contributed to better results and drastically reduced the most feared complication: Volkmann ischemic contracture.¹⁻⁴ But the risks inherent to the fracture remain, as well as the justified apprehension of surgeons who routinely deal with this injury.

Most common in patients between 3 and 10 years of age, SHF has its peak incidence at 6 years of age.^{1,4-7} It represents about 3 to 15% of all fractures in children, reaching 70% between those in the elbow. With an estimated incidence of 1.7 per 1,000 individuals, it is the fracture that most requires surgical treatment in the pediatric population.^{4,8-12}

The most frequent trauma mechanism is falling on the palm of the hand, causing the elbow hyperextension. Thus, the olecranon acts as a posterior fulcrum in the humerus, resulting in an extension-type fracture, responsible for 97 to 98% of cases.^{1,4} The rarest flexion-type fracture is caused by posterior trauma to the flexed elbow, resulting in anterior displacement of the distal fragment.⁴

Classification

Gartland divided the fractures into three types: no displacement, moderate displacement, and severe displacement.^{3,13} Later, Wilkins modified the classification to include the concept of posterior cortical contact.^{3,14} It is the most used classification, with high intraobserver and interobserver agreement (►Figure 1).^{1,3}

Type I: nondisplaced or minimally displaced (< 2 mm). The intact periosteum around its entire circumference maintains stability.³ The fracture line may not be visible on the initial radiograph, with the fat pad sign being the only evidence of the injury.⁴ In this case, the periosteal reaction that usually appears after the second week confirms the clinical suspicion.

Type II: displaced fracture, maintaining posterior cortical contact with a preserved hinge.³ In lateral radiography, the anterior humeral line does not pass through the middle third

of the capitellum. It is the type with the greatest disagreement between the authors, with some considering that any deviation from the coronal plane would be sufficient to classify it as type III.^{1,4} However, the integrity of the posterior cortical hinge maintains some stability even in the presence of some rotation or comminution. The alternative suggested by Wilkins is the subdivision into II A (displacement only in extension) and II B (anteroposterior radiography[AP] showing rotational or angular deviation, but with posterior cortical contact preserved in the lateral radiography).³ The differentiation in subtypes II A and II B is valid because it helps to identify stable fractures with displacement only in extension and that could be subjected to an initial attempt at non-surgical treatment. Fractures with rotational or angular deviation tend to be more unstable and prone to loss of reduction when not fixed (►Figure 2).^{7,15-17} A potential pitfall is to underestimate the fracture with mild displacement, but with comminution of the medial column, as its collapse can lead to varus malalignment, even in apparently innocent cases.^{1,4}

Type III: displaced fracture without meaningful cortical contact, with a higher risk of neurovascular injuries and interposition of soft tissues.^{3,11} They are unstable fractures and generally difficult to reduce. However, the partially preserved posterior periosteum helps to reduce and stabilize the fracture when the elbow is flexed, facilitating fixation.⁴

Type IV: multidirectional instability, the periosteum ruptured in all its circumference makes the fracture extremely unstable.^{1,18} Described by Leitch et al,¹⁸ this injury can be confirmed during the reduction attempt under fluoroscopy, when the fracture is unstable both in flexion and in extension.^{3,19}

Treatment

The treatment of type-I fracture is non-surgical: immobilization of the elbow with posterior axillary-palmar splint in flexion from 60 to 80° for 3 weeks.^{1,9} Radiographic control around 7 days is essential for the early detection of any displacement.⁴

Some studies suggest that stable fractures with displacement only in extension (type II A) can be treated initially with

Classification	
Type I	Nondisplaced or minimally displaced
Type II	Extension displacement, posterior cortical contact with intact posterior hinge II-A: no displacement in the coronal plane II-B: rotational displacement or angulation in the coronal plane.
Type III	Complete displacement, no meaningful cortical contact.
Type IV	Multidirectional instability, incompetent periosteal hinge circumferentially defined by instability in both flexion and extension during the reduction attempt under fluoroscopy.

Fig. 1 Modified Gartland classification, including type-IV and type-II B fractures.



Fig. 2 Examples of type-II fractures. (A) Type-II A fracture, displacement only in extension. (B) Fracture with extension, rotation and angulation, type-II B. (C) Fracture with medial comminution, type-II B.

closed reduction, immobilization, and strict monitoring to identify loss of reduction.¹⁵⁻¹⁷ However, according to the American Academy of Orthopedic Surgeons guideline, the method of choice for the treatment of displaced SHF is closed

reduction and percutaneous fixation.^{9,10,20} Fracture in which the anterior humeral line does not pass through the capitulum, or any fracture with coronal translation, rotation or angulation, must be reduced and fixed.^{1,4,7}

Physical examination helps in determining the urgency of surgical treatment.^{11,21,22} It is essential that a careful sensory, motor and vascular evaluation of the affected limb be carried out.^{1,4,7} Marked edema, presence of volar ecchymosis, and skin tension in the cubital region are signs of severity, indicate greater soft tissue injury and increased risk of associated neurovascular injury (–Figure 3).^{4,11}

The limb must be immobilized with a well-padded splint in flexion between 30 and 40° until it can be subjected to definitive treatment.^{1,4,7} In extreme cases, with gross deviation or without a palpable pulse, a partial fracture reduction with an elbow flexion maneuver up to 40° and light traction can improve perfusion and relieve the tension in the soft tissues.^{4,8} The forced reduction attempt in the emergency room, with immobilization of the elbow in flexion greater than 80°, is contraindicated due to the risk of compartment syndrome.⁴ In case of severe displacement, the patient must be kept under observation in the hospital until the surgical treatment.⁷

There is no consensus on the time limit that a closed fracture with a palpable pulse could wait.^{9,23} Several studies show that

postponing surgical treatment for up to 24 hours, in some series, does not imply a higher incidence of complications, the need for open reduction, or unsatisfactory results.^{1,4,7,24–26} However, these clinical studies are subject to selection bias, since the most severe cases tend to be addressed early.^{4,26} The decision must be individualized and treatment carried out as early as possible, with special attention to signs of severity and neurovascular status.^{4,11,21–26}

Fixation Methods

Percutaneous pin fixation can be done with two or three pins, lateral or crossed.^{1,20,27} The lateral entry pins must be divergent, seeking maximum spacing in the fracture site and fixation of both the lateral and medial columns.^{4,28} They can be parallel, but never convergent, they must not cross at the fracture site, and bicortical fixation with two pins or more is fundamental.^{1,6,7,27} In general, two lateral Kirschner wires are sufficient for type-II fractures; however, there is already sufficient evidence to indicate three wires for type-III fractures.^{4,6,27,29–32} The addition of a third Kirschner wire is related to a lower risk of fixation failure and the need for



Fig. 3 Examples of type-III fractures and signs of severity, indicating greater soft-tissue injury and increased risk of associated neurovascular injuries. (A) Type-III fracture fixed with 3 diverging lateral pins. (B) Fracture with major displacement, severe edema, and gross deformity. (C) The proximal fragment penetrates the brachialis muscle and the anterior fascia of the elbow pucker sign. (D) Kirrison signal, transverse volar ecchymosis in the elbow flexion crease.

surgical revision.^{6,31,32} More stability is ensured by 2.0-mm wires, which should be considered for larger patients.^{4,7,30,33}

Although some biomechanical studies suggest that cross fixation may be more stable than just two lateral pins, clinical studies show that fixation only by lateral entry pins is sufficient in most cases, and that the routine use of the medial pin should be avoided due to the risk of iatrogenic injury to the ulnar nerve.^{1,7,20,25,34-40} It is estimated that ulnar neurapraxia occurs in 1 out of 28 patients, about 4% of cases, when cross fixation is performed.^{4,20,41,42} However, some more unstable fractures, with an oblique or comminuted characteristic, may require a medial entry pin to achieve adequate stabilization after fixation with two or three lateral pins.^{30-32,39,43,44} In this case, some precautions reduce the risk of injury: extend the elbow up to at least 80° to relax the ulnar nerve, which may subluxate anteriorly during flexion, or perform small access for direct visualization of the medial entry point.^{4,31,34,44}

Open Reduction

Open reduction is indicated in cases of failed closed reduction, open fractures or when there is a decrease in perfusion after reduction.^{1,4} The anterior approach allows the release of interposed structures, usually volar, with direct visualization of the brachial artery and median nerve, being the most recommended approach.^{4,7,45} Lateral approach is also described with good results.⁴ The posterior approach presents the following disadvantages: risk of avascular necrosis of the trochlea; increased instability with the opening of the posterior periosteum; and higher incidence of stiffness.^{1,4}

Type-IV Fracture

The fracture with multidirectional instability offers greater difficulty in reduction, but does not necessarily require an open reduction.^{18,43} The joystick technique described by Novais et al¹⁹ consists of manipulation with insertion of a 2.0-mm lateral Kirschner wire only in the distal fragment, through the capitellum and pointing to the center of the fracture site. The fluoroscopy unit must be positioned parallel to the operating table to allow rotation of the C-arm and alternate between the AP and lateral views without interfering with the elbow position. The assistant corrects the rotation of the proximal fragment until obtaining a true lateral image of the humerus and maintains this position throughout the procedure. Then, the surgeon manipulates the distal fragment with the aid of an already inserted pin to correct rotation, translation, and angulation. After obtaining the proper alignment, the pin is progressed to the proximal fragment and the fracture is stabilized with two more lateral Kirschner wires diverging from the first. Despite the technical difficulty, prolonged surgical time, greater incidence of open reduction and greater need for medial pin for adequate stabilization, satisfactory results can be obtained in type-IV fractures. (► **Figure 4**).^{18,19,43}

Flexion Fracture

Although the Gartland classification has been described for extension fractures, it is also applied for flexion fractures.²⁰ The treatment follows the logic described above: fracture

without displacement must be treated conservatively and displaced fracture must be reduced and fixed.⁴ Some authors suggest an attempt to reduce type-II fractures with immobilization in elbow extension.¹⁴ However, the tolerance for displacements should be low. The surgeon must be aware of the greater incidence of nerve damage and the need for open reduction in these fractures.^{12,41,46,47} Irreducible fractures can be addressed anteromedially, medially, or posteriorly, preserving the intact anterior periosteum and allowing direct visualization of the ulnar nerve.^{4,46}

Complications

Postoperative loss of reduction

Loss of reduction occurs in about 4% of cases and its main cause is inadequate fixation.^{4,6,27,28} Pins too close together, converging or crossing at the fracture site, make osteosynthesis unstable.²⁸ Another potential error is not being able to fix with at least two bicortical pins. This usually occurs when one of the pins is intramedullary in the proximal fragment or passing through the fracture site.^{6,27} If there is doubt about the proper positioning of the implants or the stability of the fixation, the insertion of a third or even a fourth pin increases the chance of success.^{4,27,29-32} One factor to be considered is the inadequate reduction: the rotation decreases the support of the lateral and medial columns in the distal fragment and predisposes the angular displacement.^{4,29,31} Radiographic control around 7 days is essential to identify possible loss of reduction.⁴⁸ In the first 2 weeks, manipulation with closed reduction may be possible.⁴

Neurological Injury

Neurological deficit is found in about 11% of displaced fractures.^{41,49} Documenting preoperative sensory and motor status is essential: the presence of the deficit indicates greater severity and risk of associated vascular injury, and helps to differentiate the traumatic preoperative injury from the iatrogenic one.^{11,50}

Historically, radial nerve deficit has been described as the most common.^{1,14} However, studies show that isolated neurapraxia of the anterior interosseous nerve (AIN) is the most frequent type of injury in extension fractures, with an occurrence rate of about 34%.^{1,7,14,41} As it is an exclusively motor branch of the median nerve, the diagnosis is less evident. Together, complete or isolated AIN lesions of the median nerve account for about 60% of neurapraxias.⁴⁹ In flexion fractures, however, the ulnar nerve is the most affected one, representing more than 90% of neurapraxias.^{7,41}

The prognosis of nerve injury associated with SHF is generally good, with complete recovery in most patients.⁵¹ The average time to resolve the deficit is just over 2 months, with 60% of the cases showing improvement by the 3rd month, and more than 90% with full restoration of the function.^{1,49,52} Thus, surgical exploration is not routinely recommended in cases of isolated neurapraxic lesion.^{1,4,49}

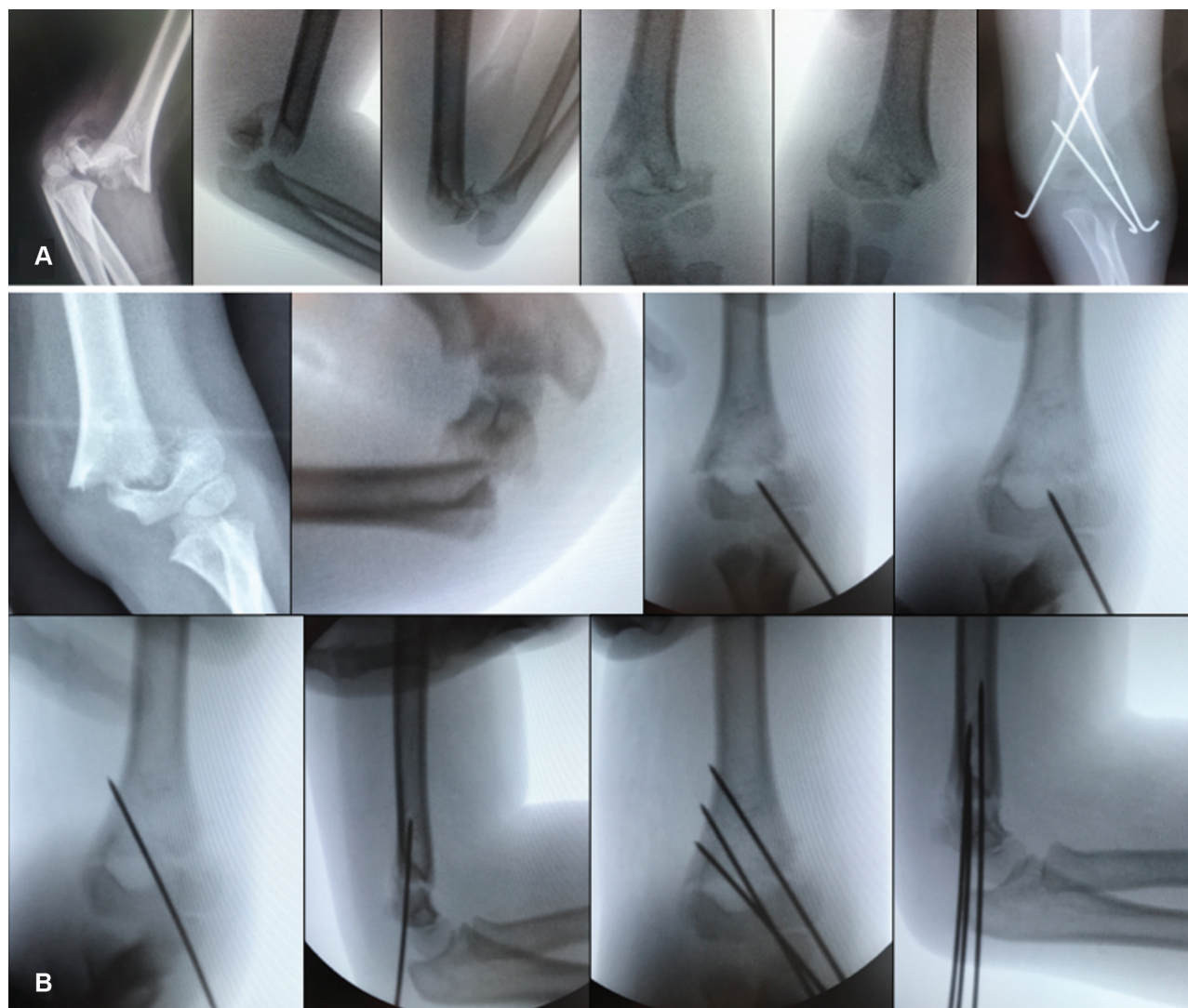


Fig. 4 (A) Type-IV fracture, multidirectional instability confirmed during the reduction attempt under fluoroscopy. (B) Type-IV fracture reduced and fixed using the joystick technique.

Vascular Injury

Absence of a palpable pulse in the initial presentation is reported in 1 to 15% of cases, reaching 20% in displaced fractures in some series.^{1,4,8,22} There is a risk of incarceration of the neurovascular bundle between the fracture fragments, injury of the intima with the formation of a late thrombus, partial laceration, pseudoaneurysm or even full brachial artery transection and compartment syndrome.⁸ However, a non-palpable radial pulse, despite indicating the urgency of treatment, does not necessarily mean tissue ischemia. The vessels may be compressed by the edema of the adjacent soft tissues, showing spasm or even incarcerated at the site of the fracture, but with an adequate collateral flow and enough distal perfusion. Vascular reconstruction is rarely necessary.^{4,8}

Two situations need to be differentiated: absence of a palpable radial pulse with a perfused, pink and warm hand; absence of radial pulse with decreased distal perfusion, pale and cold hand.^{1,8,22} The first is an urgency, requires special attention and priority in treatment. The second is an emergency that requires an immediate approach.⁴ Under no circumstances we should wait for a vascular study to be

performed with angiography or doppler. Closed reduction with percutaneous fixation is the first approach.^{8,9,50} If the patient remains without a pulse after anatomical reduction and fracture stabilization, but with a well-perfused, pink and warm hand, the patient is kept under strict observation until the pulse is palpable.²² Arterial flow assessment with doppler is indicated and hospital discharge postponed for at least 24 hours. Vascular exploration should be performed if perfusion worsens during this period.⁸

If the hand presents with decreased perfusion, pale and cold after closed reduction and fixation, pin removal, open reduction and vascular exploration are indicated.^{4,9} Due to the possibility of arterial spasm, a tolerance of 10 to 15 minutes is allowed with the limb heated and the elbow partially extended before starting vascular exploration.⁴ In the absence of reperfusion, the approach must be immediate. In this case, it is prudent to request the presence of a vascular surgeon or microsurgeon for possible arterial reconstruction.⁸

Anterior transverse approach is recommended; it can be extended to distal or proximal, and it allows direct exploration of the neurovascular bundle and reconstruction of the

brachial artery when necessary.^{1,4} In the absence of laceration or transection, warming the limb and applying papaverine or topical lidocaine can help to decrease the arterial spasm.⁴ Strict monitoring, due to the risk of compartment syndrome, is mandatory.⁷ Although there is no consensus on the indication of prophylactic decompressive fasciotomy of the forearm, this should be considered if the ischemia time exceeds 6 hours.⁴

Compartment Syndrome

Compartment syndrome, although increasingly rare, with an incidence of around 0.1 to 0.5%, is the most devastating complication of SHF.^{1,4,22} The improvement of assistance, with greater attention to immobilization techniques and surgical treatment of displaced fractures, contributes to the reduction of this complication;^{2,4} however, the risk remains. High index of suspicion and early approach are

mandatory and can contribute to satisfactory results even in the most severe cases. Immobilization should never be flexed above 80°, and cylindrical casts should be avoided, giving preference to well-padded posterior splints.² Risk factors are: older children, male, ipsilateral fracture of the forearm (floating elbow) and neurovascular injury.^{2,50} Deficit of the median nerve requires even more attention, as the change in painful sensitivity can mask the condition.^{1,4,14}

Articular Stiffness

Limitation of range of motion (ROM) in the recent postoperative period is common; however, most patients evolve with complete improvement.²⁷ Kirschner wires must be removed between 3 and 4 weeks, enough time for consolidation, avoiding immobilization beyond this period. Active exercises are recommended to ROM gain, and physical therapy is rarely

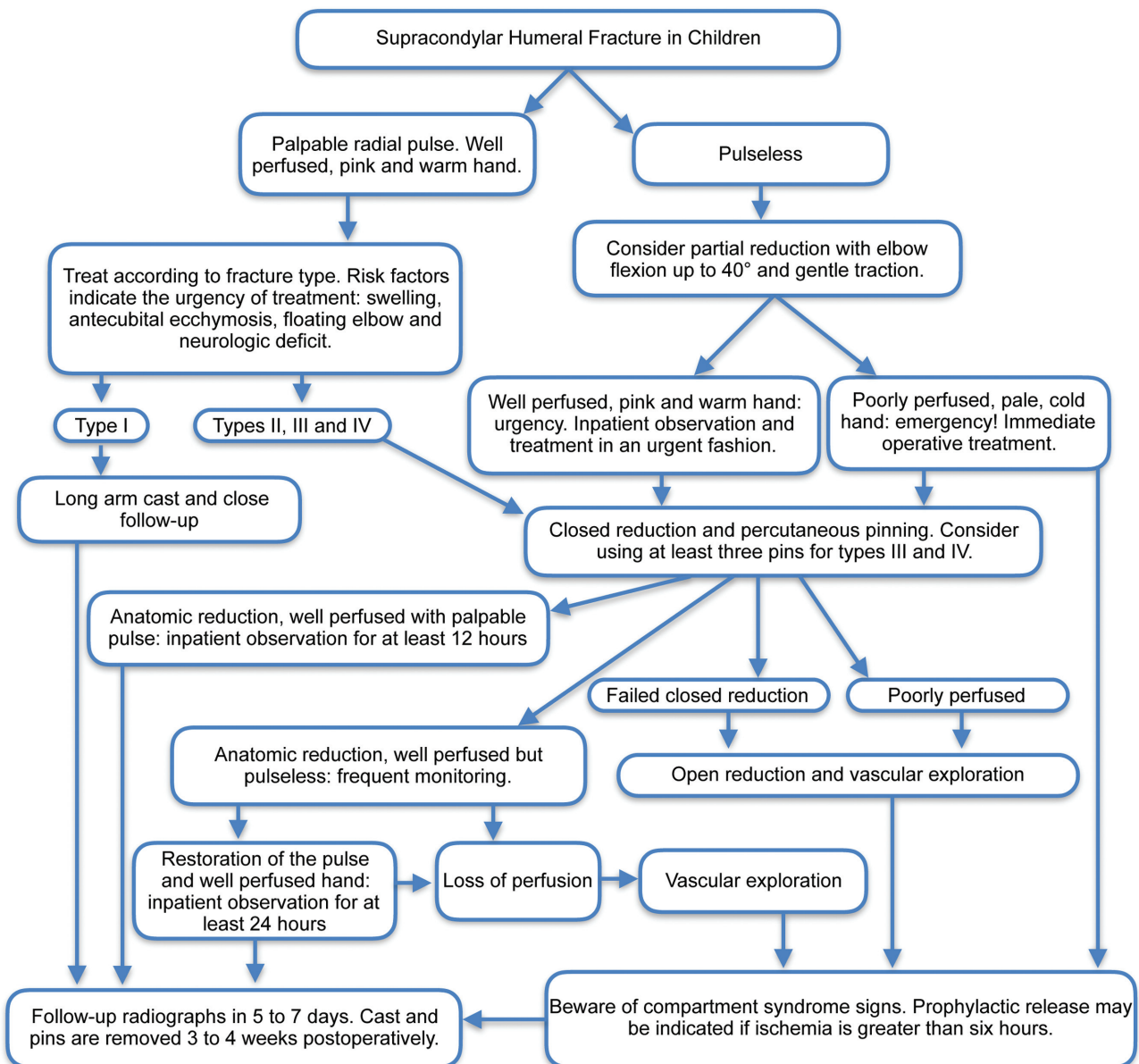


Fig. 5 Flowchart for the treatment of supracondylar fracture of the humerus in children.

indicated.⁵³ The main factors associated with joint stiffness are significant soft tissue injury, open reduction (especially when posterior access is used), prolonged immobilization and older patients.^{54,55}

Malunion

Physeal injury (secondary to trauma or surgery) is an unlikely cause of late deformity. Malunion is a consequence of poorly reduced fracture or failure of fixation.⁴ In general, fracture with posteromedial displacement generates varus deformity and fracture with posterolateral displacement leads to valgus deformity. Cubitus varus is described as a more frequent complication than cubitus valgus.^{15,56} This can be explained not only by the higher incidence of fracture with posteromedial displacement, but also by the fact that varus deformity is more evident, while an increase in valgus can be neglected.

The radiographic measurement of the angle between the capitellum physeal line and the axis of the humeral diaphysis, as described by Baumann, helps to identify angular displacement and prevent malunion.^{4,57} The evaluation must be comparative with the contralateral elbow, but, in general, a value above 80° suggests varus malalignment.⁴ The criteria described by Flynn⁵⁸ for outcome assessment are based on the elbow ROM (flexion-extension) and the carrying angle. The author defined as a poor outcome a loss greater than 15° in any of these two factors when compared to the contralateral elbow.⁵⁸

In a study with a mean follow-up of 6.6 years, Moraleda et al⁵⁶ found 36.9% of unsatisfactory outcome in 46 patients with type-II fracture, who were treated conservatively with immobilization only. Although a good functional result was reported in most cases, non-reduced type-II fractures evolved with hyperextension deformity, flexion limitation, and cubitus varus in a significant number of patients.⁵⁶

Although cubitus varus has been considered a mainly aesthetic complication, other consequences of malunion are described: increased risk of lateral condyle fracture, posterolateral rotatory instability, pain and tardy ulnar nerve palsy.^{4,7,59,60} Varus deformity medially displaces the mechanical axis, the olecranon and the triceps traction vector. Repetitive torque in the elbow leads to chronic stretching and consequent insufficiency of the lateral collateral ligament, resulting in posterolateral rotatory instability.⁵⁹ Dislocation of the medial portion of the triceps during elbow flexion pulls the ulnar nerve anteromedially and can lead to frictional ulnar neuropathy or dynamic compression of the triceps against the epicondyle.^{4,60} Correcting cubitus varus in children can prevent long-term sequelae, and the belief that it is only a cosmetic deformity should be reconsidered.

Final Considerations

Careful physical examination is essential in the initial evaluation, with special attention to signs of severity and risk factors for compartment syndrome. The absence of a palpable radial pulse requires urgency and strict observation, whereas decreased perfusion requires an immediate approach. Anatomical reduction and maximum spacing between the pins at the

fracture site should be sought to avoid fixation failure, with the use of three pins being recommended for types III and IV fractures. According to the concepts presented, we suggest a flow chart for the treatment of supracondylar fracture of the humerus in children (–Figure 5).

Conflict of Interest

The authors declare that have no conflict of interests.

References

- Omid R, Choi PD, Skaggs DL. Supracondylar humeral fractures in children. *J Bone Joint Surg Am* 2008;90(05):1121–1132
- Robertson AK, Snow E, Browne TS, Brownell S, Inneh I, Hill JF. Who Gets Compartment Syndrome?: A Retrospective Analysis of the National and Local Incidence of Compartment Syndrome in Patients With Supracondylar Humerus Fractures *J Pediatr Orthop* 2018;38(05):e252–e256
- Alton TB, Werner SE, Gee AO. Classifications in brief: the Gartland classification of supracondylar humerus fractures. *Clin Orthop Relat Res* 2015;473(02):738–741
- Skaggs DL, Flynn JM. Supracondylar Fractures of the Distal Humerus. In: Waters PM, Skaggs DL, Flynn JM, Court-Brown CM, editors. *Rockwood & Wilkins' fractures in children*. Philadelphia: Wolters Kluwer; 2010:754–844
- Holt JB, Glass NA, Shah AS. Understanding the Epidemiology of Pediatric Supracondylar Humeral Fractures in the United States: Identifying Opportunities for Intervention. *J Pediatr Orthop* 2018; 38(05):e245–e251
- Sankar WN, Hebela NM, Skaggs DL, Flynn JM. Loss of pin fixation in displaced supracondylar humeral fractures in children: causes and prevention. *J Bone Joint Surg Am* 2007;89(04):713–717
- Abzug JM, Herman MJ. Management of supracondylar humerus fractures in children: current concepts. *J Am Acad Orthop Surg* 2012;20(02):69–77
- Badkoobehi H, Choi PD, Bae DS, Skaggs DL. Management of the pulseless pediatric supracondylar humeral fracture. *J Bone Joint Surg Am* 2015;97(11):937–943
- American Academy of Orthopaedic Surgeons. *The Treatment of Pediatric Supracondylar Humerus Fractures*. Rosemont, IL: AAOS; 2011
- American Academy of Orthopaedic Surgeons. *Appropriate Use Criteria for the Management of Pediatric Supracondylar Humerus Fractures*. Rosemont, IL: AAOS; 2014
- Ho CA, Podeszwa DA, Riccio AI, Wimberly RL, Ramo BA. Soft Tissue Injury Severity is Associated With Neurovascular Injury in Pediatric Supracondylar Humerus Fractures. *J Pediatr Orthop* 2018;38 (09):443–449
- Flynn K, Shah AS, Brusalis CM, Leddy K, Flynn JM. Flexion-Type Supracondylar Humeral Fractures: Ulnar Nerve Injury Increases Risk of Open Reduction. *J Bone Joint Surg Am* 2017;99(17):1485–1487
- Gartland JJ. Management of supracondylar fractures of the humerus in children. *Surg Gynecol Obstet* 1959;109(02):145–154
- Wilkins KE. Supracondylar fractures: what's new? *J Pediatr Orthop B* 1997;6(02):110–116
- Spencer HT, Dorey FJ, Zions LE, et al. Type II supracondylar humerus fractures: can some be treated nonoperatively? *J Pediatr Orthop* 2012;32(07):675–681
- Ariyawatkul T, Eamsobhana P, Kaewpornsanwan K. The necessity of fixation in Gartland type 2 supracondylar fracture of the distal humerus in children (modified Gartland type 2A and 2B). *J Pediatr Orthop B* 2016;25(02):159–164
- Silva M, Delfosse EM, Park H, Panchal H, Ebramzadeh E. Is the "Appropriate Use Criteria" for Type II Supracondylar Humerus Fractures Really Appropriate? *J Pediatr Orthop* 2019;39(01):1–7
- Leitch KK, Kay RM, Femino JD, Tolo VT, Storer SK, Skaggs DL. Treatment of multidirectionally unstable supracondylar humeral

- fractures in children. A modified Gartland type-IV fracture. *J Bone Joint Surg Am* 2006;88(05):980-985
- 19 Novais EN, Andrade MAP, Gomes DC. The use of a joystick technique facilitates closed reduction and percutaneous fixation of multidirectionally unstable supracondylar humeral fractures in children. *J Pediatr Orthop* 2013;33(01):14-19
 - 20 Mulpuri K, Wilkins K. The treatment of displaced supracondylar humerus fractures: evidence-based guideline. *J Pediatr Orthop* 2012;32(02, Suppl 2):S143-S152
 - 21 Garg S, Weller A, Larson AN, et al. Clinical characteristics of severe supracondylar humerus fractures in children. *J Pediatr Orthop* 2014;34(01):34-39
 - 22 Choi PD, Melikian R, Skaggs DL. Risk factors for vascular repair and compartment syndrome in the pulseless supracondylar humerus fracture in children. *J Pediatr Orthop* 2010;30(01):50-56
 - 23 Mehlman CT, Strub WM, Roy DR, Wall EJ, Crawford AH. The effect of surgical timing on the perioperative complications of treatment of supracondylar humeral fractures in children. *J Bone Joint Surg Am* 2001;83(03):323-327
 - 24 Gupta N, Kay RM, Leitch K, Femino JD, Tolo VT, Skaggs DL. Effect of surgical delay on perioperative complications and need for open reduction in supracondylar humerus fractures in children. *J Pediatr Orthop* 2004;24(03):245-248
 - 25 Abbott MD, Buchler L, Loder RT, Caltoom CB. Gartland type III supracondylar humerus fractures: outcome and complications as related to operative timing and pin configuration. *J Child Orthop* 2014;8(06):473-477
 - 26 Bales JG, Spencer HT, Wong MA, Fong YJ, Zionts LE, Silva M. The effects of surgical delay on the outcome of pediatric supracondylar humeral fractures. *J Pediatr Orthop* 2010;30(08):785-791
 - 27 Skaggs DL, Cluck MW, Mostofi A, Flynn JM, Kay RM. Lateral-entry pin fixation in the management of supracondylar fractures in children. *J Bone Joint Surg Am* 2004;86(04):702-707
 - 28 Pennock AT, Charles M, Moor M, Bastrom TP, Newton PO. Potential causes of loss of reduction in supracondylar humerus fractures. *J Pediatr Orthop* 2014;34(07):691-697
 - 29 Bloom T, Robertson C, Mahar AT, Newton P. Biomechanical analysis of supracondylar humerus fracture pinning for slightly malreduced fractures. *J Pediatr Orthop* 2008;28(07):766-772
 - 30 Wallace M, Johnson DB Jr, Pierce W, Iobst C, Riccio A, Wimberly RL. Biomechanical Assessment of Torsional Stiffness in a Supracondylar Humerus Fracture Model. *J Pediatr Orthop* 2019;39(03):e210-e215
 - 31 Bauer JM, Stutz CM, Schoenecker JG, Lovejoy SA, Mencio GA, Martus JE. Internal Rotation Stress Testing Improves Radiographic Outcomes of Type 3 Supracondylar Humerus Fractures. *J Pediatr Orthop* 2019;39(01):8-13
 - 32 Zenios M, Ramachandran M, Milne B, Little D, Smith N. Intraoperative stability testing of lateral-entry pin fixation of pediatric supracondylar humeral fractures. *J Pediatr Orthop* 2007;27(06):695-702
 - 33 Gottschalk HP, Sagoo D, Glaser D, Doan J, Edmonds EW, Schlechter J. Biomechanical analysis of pin placement for pediatric supracondylar humerus fractures: does starting point, pin size, and number matter? *J Pediatr Orthop* 2012;32(05):445-451
 - 34 Kocher MS, Kasser JR, Waters PM, et al. Lateral entry compared with medial and lateral entry pin fixation for completely displaced supracondylar humeral fractures in children. A randomized clinical trial. *J Bone Joint Surg Am* 2007;89(04):706-712
 - 35 Lee KM, Chung CY, Gwon DK, et al. Medial and lateral crossed pinning versus lateral pinning for supracondylar fractures of the humerus in children: decision analysis. *J Pediatr Orthop* 2012;32(02):131-138
 - 36 Gaston RG, Cates TB, Devito D, et al. Medial and lateral pin versus lateral-entry pin fixation for Type 3 supracondylar fractures in children: a prospective, surgeon-randomized study. *J Pediatr Orthop* 2010;30(08):799-806
 - 37 Lee YH, Lee SK, Kim BS, et al. Three lateral divergent or parallel pin fixations for the treatment of displaced supracondylar humerus fractures in children. *J Pediatr Orthop* 2008;28(04):417-422
 - 38 Skaggs DL, Hale JM, Bassett J, Kaminsky C, Kay RM, Tolo VT. Operative treatment of supracondylar fractures of the humerus in children. The consequences of pin placement. *J Bone Joint Surg Am* 2001;83(05):735-740
 - 39 Silva M, Knutsen AR, Kalma JJ, et al. Biomechanical testing of pin configurations in supracondylar humeral fractures: the effect of medial column comminution. *J Orthop Trauma* 2013;27(05):275-280
 - 40 Woratanarat P, Angsanuntsukh C, Rattanasiri S, Attia J, Woratanarat T, Thakkinstian A. Meta-analysis of pinning in supracondylar fracture of the humerus in children. *J Orthop Trauma* 2012;26(01):48-53
 - 41 Babal JC, Mehlman CT, Klein G. Nerve injuries associated with pediatric supracondylar humeral fractures: a meta-analysis. *J Pediatr Orthop* 2010;30(03):253-263
 - 42 Slobogean BL, Jackman H, Tennant S, Slobogean GP, Mulpuri K. Iatrogenic ulnar nerve injury after the surgical treatment of displaced supracondylar fractures of the humerus: number needed to harm, a systematic review. *J Pediatr Orthop* 2010;30(05):430-436
 - 43 Silva M, Cooper SD, Cha A. The Outcome of Surgical Treatment of Multidirectionally Unstable (Type IV) Pediatric Supracondylar Humerus Fractures. *J Pediatr Orthop* 2015;35(06):600-605
 - 44 Kwak-Lee J, Kim R, Ebramzadeh E, Silva M. Is medial pin use safe for treating pediatric supracondylar humerus fractures? *J Orthop Trauma* 2014;28(04):216-221
 - 45 Ay S, Akinci M, Kamiloglu S, Ercetin O. Open reduction of displaced pediatric supracondylar humeral fractures through the anterior cubital approach. *J Pediatr Orthop* 2005;25(02):149-153
 - 46 Mahan ST, May CD, Kocher MS. Operative management of displaced flexion supracondylar humerus fractures in children. *J Pediatr Orthop* 2007;27(05):551-556
 - 47 Novais EN, Carry PM, Mark BJ, De S, Miller NH. Posterolaterally displaced and flexion-type supracondylar fractures are associated with a higher risk of open reduction. *J Pediatr Orthop B* 2016;25(05):406-411
 - 48 Karalius VP, Stanfield J, Ashley P, et al. The Utility of Routine Postoperative Radiographs After Pinning of Pediatric Supracondylar Humerus Fractures. *J Pediatr Orthop* 2017;37(05):e309-e312
 - 49 Shore BJ, Gillespie BT, Miller PE, Bae DS, Waters PM. Recovery of Motor Nerve Injuries Associated With Displaced, Extension-type Pediatric Supracondylar Humerus Fractures. *J Pediatr Orthop* 2019;39(09):e652-e656
 - 50 Harris LR, Arkader A, Broom A, et al. Pulseless Supracondylar Humerus Fracture With Anterior Interosseous Nerve or Median Nerve Injury-An Absolute Indication for Open Reduction? *J Pediatr Orthop* 2019;39(01):e1-e7
 - 51 Valencia M, Moraleta L, Díez-Sebastián J. Long-term Functional Results of Neurological Complications of Pediatric Humeral Supracondylar Fractures. *J Pediatr Orthop* 2015;35(06):606-610
 - 52 Patriota GS, Assunção Filho CA, Assunção CA. Qual a Melhor Técnica para Fixação no Tratamento de Fratura Supracondilar do Úmero em Crianças? *Rev Bras Ortop* 2017;52(04):428-434
 - 53 Schmale GA, Mazor S, Mercer LD, Bompadre V. Lack of Benefit of Physical Therapy on Function Following Supracondylar Humeral Fracture: A Randomized Controlled Trial. *J Bone Joint Surg Am* 2014;96(11):944-950
 - 54 Spencer HT, Wong M, Fong YJ, Penman A, Silva M. Prospective longitudinal evaluation of elbow motion following pediatric supracondylar humeral fractures. *J Bone Joint Surg Am* 2010;92(04):904-910

- 55 Fletcher ND, Schiller JR, Garg S, et al. Increased severity of type III supracondylar humerus fractures in the preteen population. *J Pediatr Orthop* 2012;32(06):567-572
- 56 Moraleda L, Valencia M, Barco R, González-Moran G. Natural history of unreduced Gartland type-II supracondylar fractures of the humerus in children: a two to thirteen-year follow-up study. *J Bone Joint Surg Am* 2013;95(01):28-34
- 57 Worlock P. Supracondylar fractures of the humerus. Assessment of cubitus varus by the Baumann angle. *J Bone Joint Surg Br* 1986; 68(05):755-757
- 58 Flynn JC, Matthews JG, Benoit RL. Blind pinning of displaced supracondylar fractures of the humerus in children. Sixteen years' experience with long-term follow-up. *J Bone Joint Surg Am* 1974; 56(02):263-272
- 59 O'Driscoll SW, Spinner RJ, McKee MD, et al. Tardy posterolateral rotatory instability of the elbow due to cubitus varus. *J Bone Joint Surg Am* 2001;83(09):1358-1369
- 60 Spinner RJ, O'Driscoll SW, Davids JR, Goldner RD. Cubitus varus associated with dislocation of both the medial portion of the triceps and the ulnar nerve. *J Hand Surg Am* 1999;24(04):718-726