# Surgical Technique: Closed Reduction and Percutaneous Pinning of Posterolaterally Displaced Supracondylar Humerus Fractures

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**Summary:** Gartland type III posterolateral (IIIB) supracondylar humerus fractures are common among the pediatric population and can lead to concomitant injury, including compromise of the brachial artery and median nerve and long-term deformity, such as cubitus varus. These fractures can be difficult to reduce, and there is little consensus regarding the optimal technique for closed reduction and percutaneous pinning. Here, we discuss the management of Gartland III posterolateral supracondylar humerus fractures, including an in-depth technical description of the methods of operative fixation. We describe a lateral pin-only fixation technique for Gartland III posterolateral supracondylar humerus fractures that uses the intact periosteum during reduction of the distal fragment to assist in realigning the medial and lateral columns anatomically. We also discuss a safe method for placing a medial-based pin if there is persistent rotational instability at the fracture site after placement of the laterally based pins.

**Key Words:** supracondylar humerus fracture, Gartland IIIB, elbow fracture, closed reduction, percutaneous pinning, lateral pinning, medial pinning, periosteum, cubitus varus deformity, treatment algorithm, technique, pediatrics, anterior interosseous nerve palsy, brachial artery injury, internal rotation stress test, medial pin

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## INTRODUCTION

Supracondylar humerus fractures are the most common type of elbow fracture in the pediatric population, and the second-most common type of pediatric fracture overall.[1] These fractures can be extension type (more common: 98.8%) or flexion type (less common: 1.2%).[2] Extension-type fractures are grouped according to the Gartland classification system based on the extent of displacement (Fig. 1).[3–5] Gartland type I fractures are nondisplaced, type II fractures are angulated with intact posterior cortex, and type III fractures are completely displaced (Fig. 1A).

Pediatric fractures are unique when compared with the adult population in that the periosteum is significantly thicker in children and can play a large role in reduction.[6,7] Determining where the periosteum is disrupted and where the periosteal sleeve remains intact provides information for reduction and fixation. As described by Wilkins, in type III supracondylar humerus fractures, the distal fragment is displaced either posteromedially (Gartland IIIA) or posterolaterally (Gartland IIIB) (Fig. 1B).[8,9]

In posterolaterally displaced supracondylar humerus fractures, the posterior and lateral periosteum remains intact, whereas the anterior and medial periosteum is disrupted.[7] These injuries occur with a fall on an outstretched hand with the shoulder in internal rotation. The proximal metaphyseal anteromedial "spike" of bone places the overlying brachial artery and median nerve at risk.[10] Injury to these structures can lead to neurovascular compromise, compartment syndrome, and Volkmann's ischemic contracture. The anteromedial spike can often be identified on physical examination by the presence of a bruise in the anteromedial aspect of the antecubital fossa and confirmed with radiographs showing the posterior and lateral displacement of the distal fragment (Figs. 1C, D). However, accurately assessing the direction of displacement and extent of soft-tissue injury on radiographs can be misleading as the position of the distal fracture fragment may not reflect the actual displacement that occurred at the time of injury because of the "recoil" effect of the posterior periosteum. Malunion of these fractures can lead to prominent cubitus varus deformity, loss of elbow motion, and loss of function.[11] These risks necessitate operative repair by reduction and percutaneous pinning of displaced fractures.

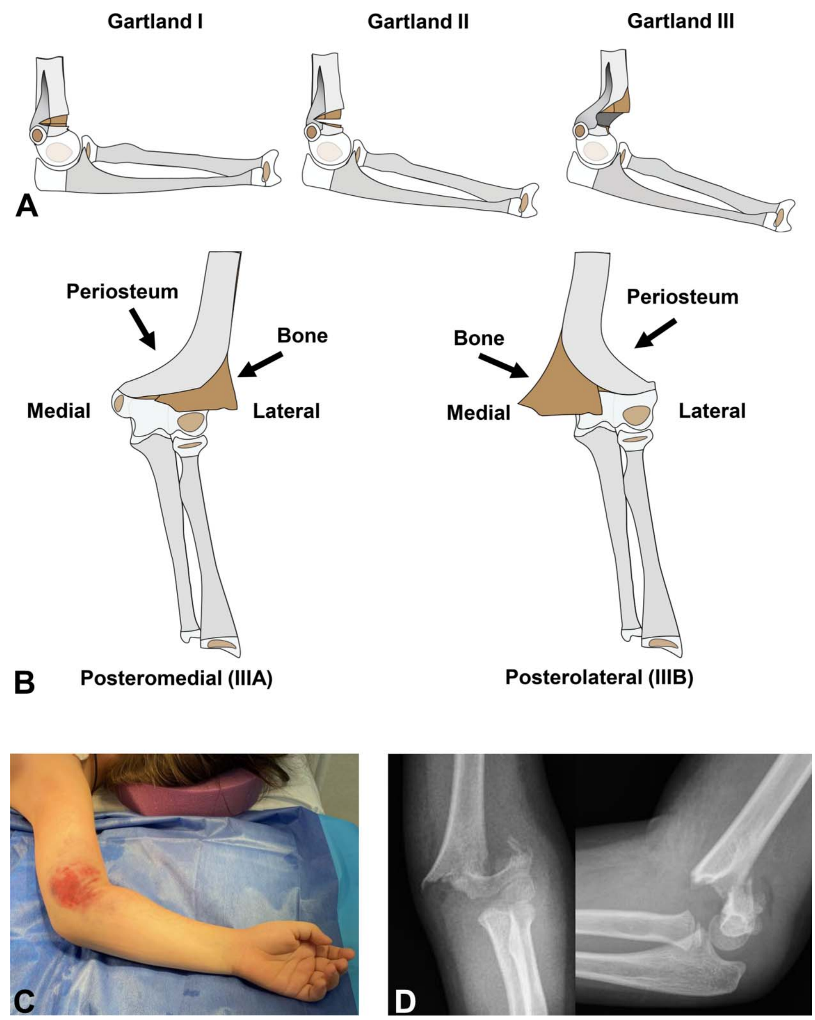


**FIGURE 1.** The Gartland classification of extension-type supracondylar fractures. A, The modified Gartland classification of supracondylar humerus fractures. B, Wilkins modified Gartland type IIIA fractures are posteromedially displaced with intact posteromedial periosteum; type IIIB injuries are posterolaterally displaced with intact posterolateral periosteum. C, Anteromedial bruising pattern seen in posterolaterally displaced supracondylar humerus fractures. D, AP and lateral radiograph demonstrating a posterolaterally displaced supracondylar humerus fracture. White: chondroepiphysis; brown: bone; gray: periosteum (differing shades of gray used for depth effect).

Closed reduction and percutaneous pinning with 2 (or 3) lateral-entry pins is generally accepted as the standard of care for supracondylar humerus fractures. Cross-pinning (with 1 medial and 1 lateral entry pin) configuration has been shown to have high biomechanical stability when compared with lateral-only pin constructs but may have a higher risk of iatrogenic ulnar nerve injury.[12–16] In this article, we describe a closed reduction and lateral-only pinning technique for type III posterolateral supracondylar fractures that uses the intact posterolateral periosteum to both "key in" the reduction and to provide rotational stability of the medial column. This rotational stability is crucial for an alternative to a medial-based pin and preventing cubitus varus deformity, which can be determined by an internal rotation stress-test.[17] We demonstrate the decreased need for medial pin placement with our lateral pin–only technique because of increased medial column stability with internal rotation stress. We describe a safe technique for placing a medial-entry pin should there be persistent rotational instability of the medial column after placement of the lateral pins.

## TECHNIQUE—CLOSED REDUCTION

Our preferred set up for closed reduction and percutaneous pin fixation of supracondylar fractures uses a customized arm board that allows for the child's elbow to be centered on the image intensifier (Figs. 2A, B). The c-arm is positioned at the patient's head, parallel to the operating table and perpendicular to the elbow, and remains in this position throughout the procedure while allowing for internal and external rotation (Figs. 2C–F). Small children are positioned near the edge of the bed to ensure that adequate imagine can be obtained of the elbow. With this technique, a single surgeon can perform the entire procedure without assistance (see **Video**, **Supplemental Digital Content 1**, http://links.lww.com/JOT/B118). If open reduction is necessary, the surgeon can stand within the axilla to gain access to the medial side of the arm to approach the median nerve and brachial artery—the most common structures at risk in association with type III posterolateral supracondylar humerus fractures. A sterile tourniquet can be used if needed.

The initial goal of reduction is to align the coronal plane. With the child under general anesthesia with paralysis,

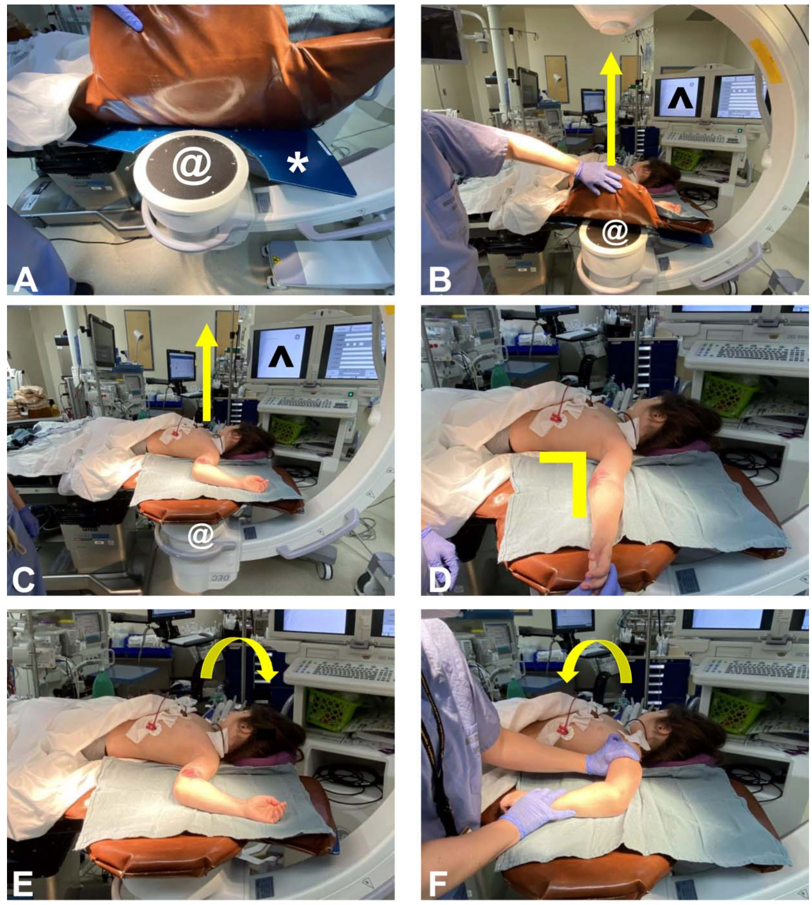


**FIGURE 2.** Operating room set-up and patient positioning to perform reduction and pinning. Proper positioning of the C-arm is essential. Ensure that adequate images can be obtained before prepping and draping the arm. A, C-arm intensifier (@) placed within the side arm table with C-arm cut-out (*) B and C, with the elbow positioned in the center of the intensifier (@), and the C-arm view screens (^) placed for optimal viewing without looking away from the operative field. D, Body positioned for optimal imaging and manipulation places the patient with the shoulder at 90° abducted allowing for an AP and an (E) external rotation lateral view/stress. F, Internal rotation lateral view/stress view. Placing the C-arm at the head of the bed allows for ample room to stand unobstructed in the axilla of the patient if an open approach is required.

gradual longitudinal traction is applied to bring the distal fragment out to length (Fig. 3A—steps 1–4). If the proximal metaphyseal spike has pierced through the brachialis muscle—as indicated by puckering of the skin in the antecubital fossa ("pucker" sign)—gently milking the muscle from proximal to distal releases the brachialis from the metaphyseal spike and is often successful in removing this block to reduction. Care must be taken not to disrupt the intact periosteum with over-aggressive traction. This avoids creating a significantly more unstable fracture (referred to as the Gartland IV) and, consequently, a more difficult reduction.[17] Reduction in the coronal plane is initiated with the elbow in approximately 30 degrees of flexion (Fig. 3A—steps 1–4). By using the intact posterior periosteum as a tether, the distal fragment is brought out to length, and the coronal plane deformity is corrected by the pressure of the surgeon's thumb on the appropriate side of the distal fragment (Figs. 3B, C—step 3). For a posterolateral fracture pattern, pressure on the lateral aspect of the distal fragment should allow medial translation of the fragment until the intact lateral periosteum contacts the lateral column of the metaphysis—thus tethering the distal fragment at or near its anatomic position in the coronal plane. Counter pressure should be applied medially, essentially using the hand as a bone clamp (Fig. 3C—step 3). It has been suggested that pronation may assist with reduction in type III posteromedial (IIIA) fractures; it is therefore supposed that supination may assist with type III posterolateral (IIIB) fractures.[18] However, we have observed that the external rotational reduction of the medial column (described below) plays a more essential role in reduction than the forearm position.

With the fracture out to length and the coronal plane deformity corrected, the elbow is hyperflexed while simultaneously applying pressure on the tip of the olecranon, or the posterior aspect of the distal humeral columns, in an effort to translate the distal fragment anteriorly/out of extension to correct the sagittal plane deformity (Figs. 3B, C—steps 1–4). Again, the intact posterior periosteum is used as a tether to guide the distal fragment into its anatomic position and resist over-correction of the sagittal plane deformity. The coronal plane reduction is re-evaluated in this position along with dedicated visualization of the medial and lateral columns by slightly internally and externally rotating the arm to obtain oblique views of the distal humerus. If coronal alignment is satisfactory, the arm is externally rotated, and a lateral image of the distal humerus is obtained to evaluate alignment in the sagittal plane. When the fracture is acceptably reduced in both planes, fixation can be performed using the techniques described below. If the fracture is not acceptably reduced, the previous steps are repeated with modifications aimed at correcting the residual deformity. After 3 unsuccessful

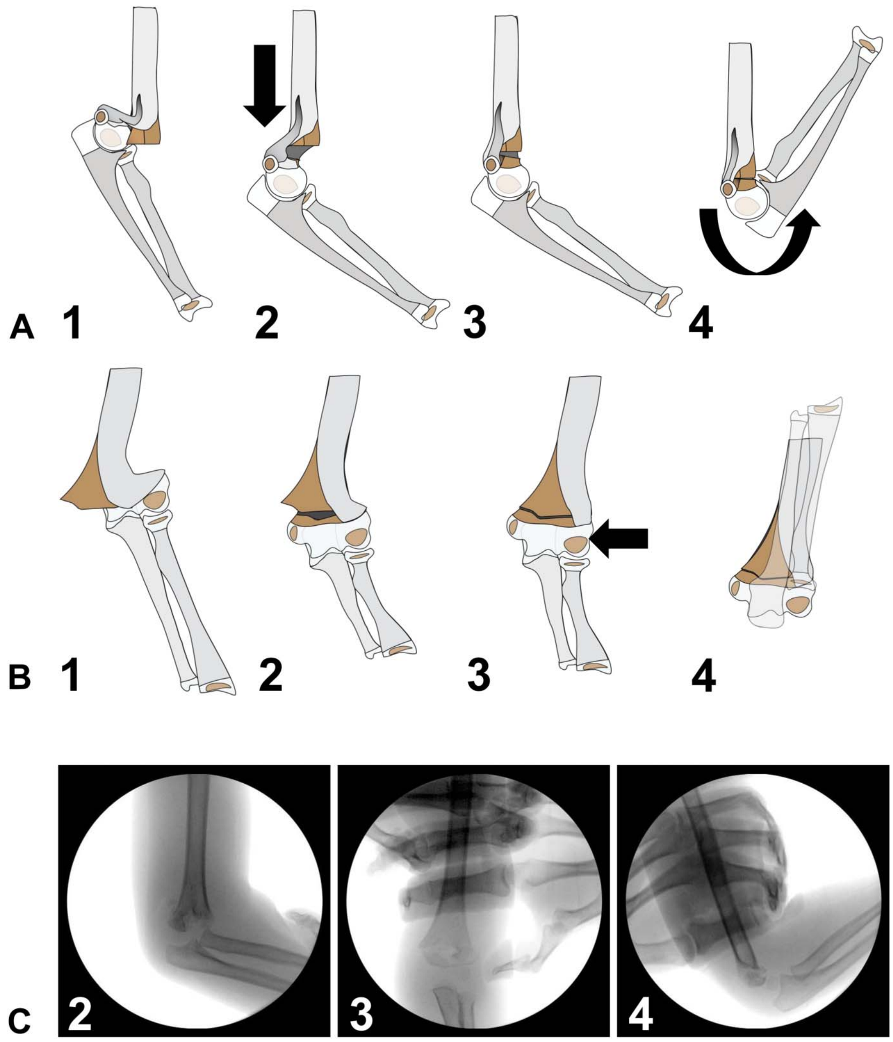


**FIGURE 3.** Using the intact posterior periosteum during reduction. A, Apply longitudinal traction followed by hyperflexion of the elbow to reduce the elbow in the sagittal and coronal planes. B, Pressure applied from the lateral side on a posterolaterally displaced fracture will lead to "keying in" of the distal fragment because of the intact periosteum tightening on the anterolateral side. C, Radiograph images of steps 2–4 shown above. White: chondroepiphysis; brown: bone; gray: periosteum (differing shades of gray used for depth effect).

attempts, an open reduction should be considered.[19] As a stopgap to conversion to open reduction in the event of a difficult closed reduction, an attempt can be made to place a percutaneous pin in the distal fragment to act as a joystick to assist with closed reduction.[20,21]

## TECHNIQUE—LATERAL PINNING

Based on author preference, the lateral column is stabilized with Kirschner wire (K-wire) fixation first. With the arm in neutral rotation and the elbow in a hyperflexed position, the first K-wire is inserted percutaneously into the distal fragment through the capitellum, centered anterior to posterior on the distal fragment. It is directed up the lateral column, avoiding entering the olecranon fossa (Figs. 4A–C), and is advanced through the opposite cortex proximal to the fracture. The lateral column pin is placed first to stabilize the coronal and sagittal planes, thus allowing for the external rotation maneuver to reduce the medial column by rotating around the axis of the stabilized lateral column (see below). The anterior placement of the lateral pin is guided by the theoretical risk of damaging the posterior capitellar arteries that are the principle blood supply of the lateral column.[22,23] The authors' preference is to use 2.0-mm K-wires; although 0.062-inch K-wires may be sufficient for younger patients. With the lateral column stabilized, internal and external rotation stress views can be obtained to further assess the stability of the fracture. With a Gartland III posterolateral fracture, an internal rotation stress view with a single lateral pin will demonstrate stability in flexion, extension, and external rotation but instability with internal rotational stress (see **Video, Supplemental Digital Content 1**, http://links.lww.com/JOT/B118). For this reason, an internal rotation stress view is not necessary without stabilizing the medial column and is displayed for teaching purposes alone. A second lateral-entry pin is then inserted to stabilize the medial column (Figs. 4D–G). This pin starts more medial in the capitellum to the first pin and is directed along a flatter, more parallel to the joint line or more valgus, trajectory. The pin can first be laid anteriorly over the skin so an appropriate path can be determined with fluoroscopy. For best biomechanical advantage in stabilizing the medial column, this pin should exit the medial cortex of the proximal fragment distal to the first pin and as close to the fracture as possible (Fig. 4F). This is a key for maintaining rotational stability of the fracture with only laterally based pins. After the pin is advanced through the capitellum and into the olecranon fossa, the arm can be externally rotated while the pin is still in the fossa (Figs. 4D–E). This maneuver uses the intact posterolateral periosteum to help lock in reduction of the medial column. This places the elbow in the same position, which would be normally used for medial pinning. The pin can then be advanced into the medial column. Placement of a small towel bump under the arm allows for clearance of the wire while driving to advance the pin across the medial column. Rotational stability is assessed by obtaining a lateral c-arm image of the elbow with the arm externally rotated and internally rotated (Fig. 4G; see **Video, Supplemental Digital Content 1**, http://links.lww.com/JOT/B118 and see **Figure, Supplemental Digital Content 2**, http://links.lww.com/JOT/B119).[24] This “internal rotation stress” view tests the stability of the medial column fixation and also gives the surgeon a view of fracture alignment and pin position that will be comparable with subsequent imaging when the patient is awake and ambulatory (Fig. 4G). If the distal fragment is stable on all views (anteroposterior, lateral, and internal/external rotation stress views), pin sites are dressed with Xeroform. The pins are then cut and bent over sterile felt. The patient is placed in a long arm cast at approximately 70 degrees of flexion and the cast is split—all of which allows for postoperative swelling and protects against complications such as compartment syndrome and Volkmann’s ischemia.[19,25,26]

## TECHNIQUE—MEDIAL PINNING

If stress views continue to demonstrate instability of the medial column fixation, either the more medial lateral-entry pin must be redirected, a third laterally-based pin must be inserted, or a medial-entry pin must be placed to prevent collapse into cubitus varus (Figs. 5A, A, B). When choosing to place a medial-entry pin, the first step is to determine if the child has ulnar nerve instability. Initial reports demonstrated instability present in approximately 15% of healthy children 0–5 years of age and 5% of children 6–18 years of age.[27]

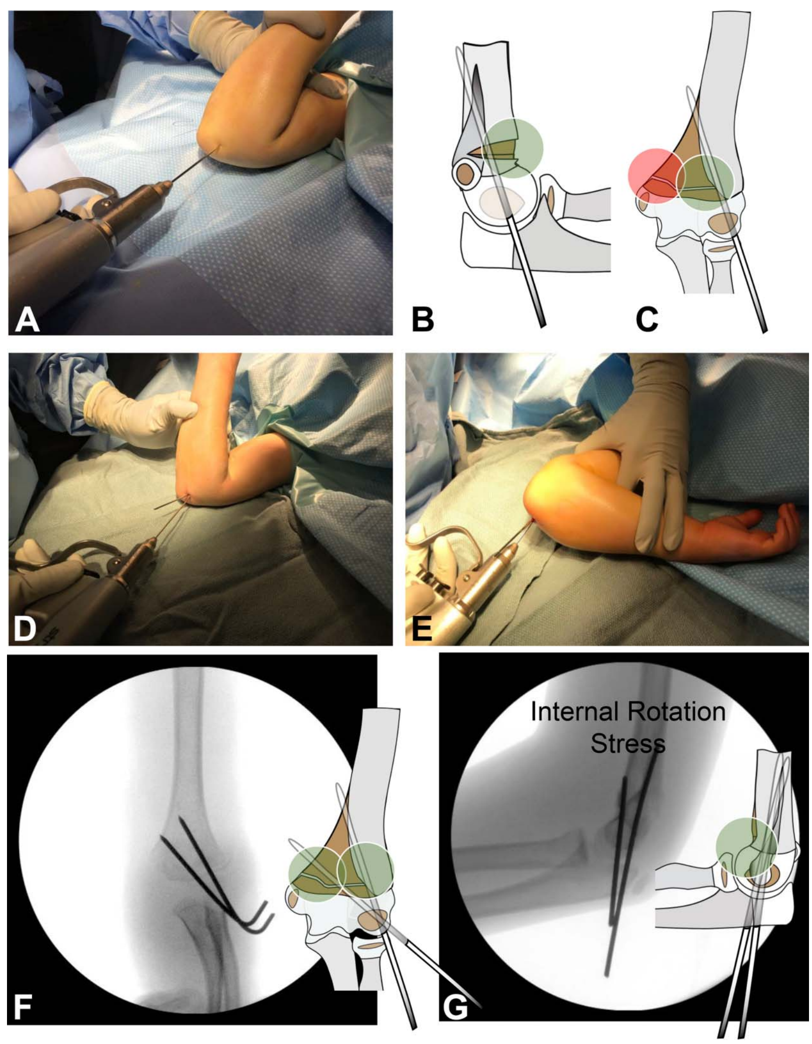


**FIGURE 4.** Lateral-only pin placement. First lateral-based pin—stabilize the lateral column —(A) K-wire is inserted percutaneously into the distal fragment through the capitellum. B, It is directed anterior to posterior on the distal fragment (C) up the lateral column, avoiding entering the olecranon fossa, through the opposite cortex proximal to the fracture. This pin stabilizes the internal rotation at the torn anterolateral periosteum and lateral column (green circle) but not the torn anterioromedial and medial periosteum (red circle) and medial column. D, Second lateral-based pin—stabilize the medial column—is inserted medial to the first pin until the pin crosses the olecranon fossa on radiograph. E, Hyperflex and externally rotate before passing the second pin through the second cortex of the olecranon fossa and the medial cortex of the proximal fragment. F, Radiographs demonstrating the placement of 2 lateral-based pins. The second lateral-based pin has replaced the mechanical function of the disrupted anteromedial and medial periosteum (medial green circle), and G) the medial column is now stable to internal rotational stress (see **Figure 1, Supplemental Digital Content 2**, http://links.lww.com/JOT/B119 for demonstration of stable and unstable IR stress). White: chondroepiphysis; brown: bone; gray: periosteum (differing shades of gray used for depth effect); green circle: mechanically stable due to pin fixation; red: mechanically unstable.

Newer evidence demonstrates subluxation in 27.5% and dislocation in approximately 10% of children.[28] This anomaly almost always occurs bilaterally and can be identified by examining the contralateral elbow to determine if the ulnar nerve subluxates anterior to the medial epicondyle when the elbow is flexed.[27] Once the stability of the ulnar nerve has been determined, the arm is externally rotated, and with the elbow flexed to 50–60 degrees, a 2–3 cm incision is made over the anterior aspect of the medial epicondyle—allowing for visualization of the medial epicondyle or the common tendon of the flexor/pronator wad. Although it is essential to determine that the ulnar nerve is not subluxed over the starting point of the medial pin, we do not typically dissect out the ulnar nerve. If the ulnar nerve is unstable, pinning should be performed with the elbow in less flexion (45 degrees or less) and with a thumb or retractor on the posterior aspect of the medial epicondyle to ensure that the nerve remains posterior to the medial epicondyle and away from the path of the pin.

Dissection is carried down to the origin of the flexor pronator mass. A small incision is made in the tendinous portion of the flexor pronator mass in line with its fibers, and a starting point for the medial pin is identified directly on the medial epicondyle. With the elbow in flexion and the arm externally rotated, the medial pin is advanced across the fracture site, up the medial column, and out the lateral cortex proximal to the fracture. One may consider using a drill sleeve or retractors while advancing the medial pin to avoid wrapping up the surrounding soft tissues and ulnar nerve. Once the pin has been placed, stability of the medial column can be confirmed on internal rotation stress view (Figs. 5C, D). Final radiographs are obtained after pins are cut and bent over felt padding.

## RESULTS

To demonstrate the efficacy of the lateral pinning technique described above, we evaluated the objective need for a medial-entry pin in a single-surgeon series. Importantly, this surgeon used the internal rotation stress view as an objective measure of the need for a medial-entry pin in all cases. Since the implementation of this technique, the percentage of operative type III posterolateral supracondylar humerus fractures requiring a medial pin because of medial column instability with an internal rotational stress test after lateral-only pin placement has significantly decreased (see **Figure**, **Supplemental Digital Content 3**, http://links.lww.com/JOT/B120). When comparing the most recent 25 cases

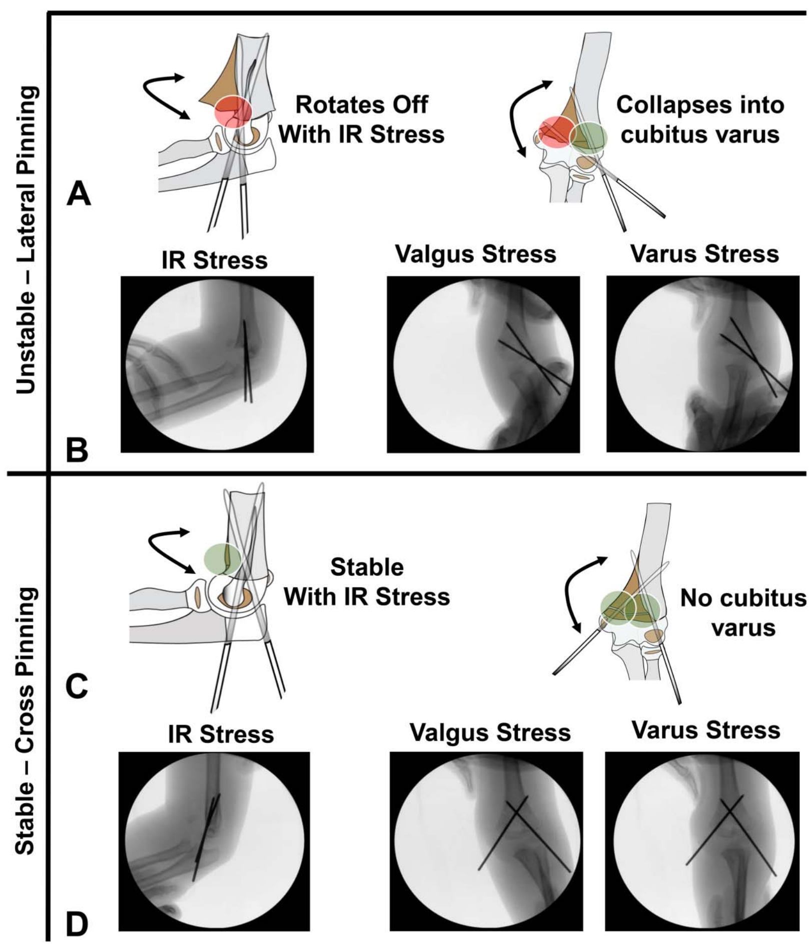


**FIGURE 5.** Stress views indicating medial column instability following the second laterally-based pin. A, Instability of the medial column; red circle represents the inability of the pins to replicate the mechanical stability of the now-torn anteromedial periosteum. B, Radiographs demonstrating medial column instability with internal rotation stress. This instability leads to deformity with valgus and varus stress. Ultimately, this may lead to cubitus varus deformity. C, Stability of the medial column after inserting a medial pin; green circles represent pins successfully replicating the mechanical stability of the now-torn anteromedial periosteum. D, Radiographs demonstrating medial column stability with internal rotation stress. This stability remains with valgus and varus stress. White: chondroepiphysis; brown: bone; gray: periosteum (differing shades of gray used for depth effect); green circle: mechanically stable due to pin fixation; red circle: mechanically unstable.

of both the lateral pin–only technique and medial pinning technique, final Baumann angles were assessed after union as a measure of cubitus varus deformity.[29] Baumann angles were not significantly different between the lateral pin–only technique (mean = 69.2 ± 2.67) and the medial pinning technique (mean = 70.9 ± 1.96) ($P$-value = 0.08, NS). Both groups fell within the normal range of Baumann angles during final follow-up radiographs.[30] No patients in either group required revision or corrective osteotomy for malunion. The exclusion criteria for these cohorts included a lack of initial injury radiographs, patients without at least 2 follow-up visits, previous elbow trauma/deep infection, and patient mortality secondary to polytrauma.

## CONCLUSION

Gartland type III posterolateral supracondylar humerus fractures pose a risk of neurovascular injury, cubitus varus deformity, and compartment syndrome. For these reasons, operative treatment is required. The standard of care is closed reduction with percutaneous pinning; however, there is little consensus regarding the optimal technique of this operation. The authors' surgical algorithm can be seen in **Supplemental Digital Content 4** (see **Figure**, http://links.lww.com/JOT/B121).

The intact posterolateral periosteum can be used as a "check rein" to help reduce and stabilize the fracture. Fracture fixation is initially achieved with 2 divergent laterally based pins. Stability of the medial column can then be assessed fluoroscopically with an internal rotation stress view. If there is rotational instability, a third lateral or a medial-entry pin is added. The technique described above has led to a decrease in the number of operations by a single surgeon requiring medial pin placement. The technique for placing a medial-entry pin must take into account the anatomic proximity and mobility of the ulnar nerve to avoid iatrogenic injury. We believe that safe placement of a medial pin requires an incision, as described. Therefore, in an effort to avoid an incision where possible, our preference is to attempt lateral entry fixation first. Open reduction is indicated if the fracture is irreducible or if there is neurovascular compromise.[31]

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## REFERENCES

1. Cheng JC, Shen WY. Limb fracture pattern in different pediatric age groups: a study of 3,350 children. *J Orthop Trauma.* 1993;7:15–22.
2. Kuoppala E, Parviainen R, Pokka T, et al. Low incidence of flexion-type supracondylar humerus fractures but high rate of complications. *Acta Orthop.* 2016;87:406–411.
3. Alton TB, Werner SE, Gee AO. Classifications in brief: the Gartland classification of supracondylar humerus fractures. *Clin Orthop Relat Res.* 2015;473:738–741.
4. Marquis CP, Cheung G, Dwyer JSM, et al. Supracondylar fractures of the humerus. *Curr Orthop.* 2008;22:62–69.
5. Kumar V, Singh A. Fracture supracondylar humerus: a review. *J Clin Diagn Res.* 2016;10:RE01–RE06.
6. Allen MR, Hock JM, Burr DB. Periosteum: biology, regulation, and response to osteoporosis therapies. *Bone.* 2004;35:1003–1012.
7. Fan W, Bouwense SAW, Crawford R, et al. Structural and cellular features in metaphyseal and diaphyseal periosteum of osteoporotic rats. *J Mol Histol.* 2010;41:51–60.
8. Gartland JJ. Management of supracondylar fractures of the humerus in children. *Surg Gynecol Obstet.* 1959;109:145–154.
9. Wilkins K, King RE. Fractures and dislocations of the elbow region. *Fract Child.* 1984;3:447–457.
10. Campbell CC, Waters PM, Emans JB, et al. Neurovascular injury and displacement in type III supracondylar humerus fractures. *J Pediatr Orthop.* 1995;15:47–52.
11. Brubacher JW, Dodds SD. Pediatric supracondylar fractures of the distal humerus. *Curr Rev Musculoskelet Med.* 2008;1:190–196.
12. Zionts LE, McKellop HA, Hathaway R. Torsional strength of pin configurations used to fix supracondylar fractures of the humerus in children. *J Bone Joint Surg Am.* 1994;76:253–256.
13. Lyons JP, Ashley E, Hoffer MM. Ulnar nerve palsies after percutaneous cross-pinning of supracondylar fractures in children's elbows. *J Pediatr Orthop.* 1998;18:43.
14. Rasool MN. Ulnar nerve injury after K-wire fixation of supracondylar humerus fractures in children. *J Pediatr Orthop.* 1998;18:686.
15. Royce RO, Dutkowsky JP, Kasser JR, et al. Neurologic complications after K-wire fixation of supracondylar humerus fractures in children. *J Pediatr Orthop.* 1991;11:191–194.
16. Skaggs DL, Hale JM, Bassett J, et al. Operative treatment of supracondylar fractures of the humerus in Children : the consequences of pin placement. *JBJS.* 2001;83:735.
17. Leitch KK, Kay RM, Femino JD, et al. Treatment of multidirectionally unstable supracondylar humeral fractures in children. A modified Gartland type-IV fracture. *J Bone Joint Surg Am.* 2006;88:980–985.
18. Omid R, Choi PD, Skaggs DL. Supracondylar humeral fractures in children. *JBJS.* 2008;90:1121–1132.
19. Pirone AM, Graham HK, Krajbich JI. Management of displaced extension-type supracondylar fractures of the humerus in children. *J Bone Joint Surg Am.* 1988;70:641–650.
20. 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;33:14–19.
21. Green BM, Stone JD, Bruce RWJ, et al. The use of a transolecranon pin in the treatment of pediatric flexion-type supracondylar humerus fractures. *J Pediatr Orthop.* 2017;37:e347.
22. Yamaguchi K, Sweet FA, Bindra R, et al. The extraosseous and intraosseous arterial anatomy of the adult elbow*†. *JBJS.* 1997;79:1653–1662.
23. Kimball JP, Glowczewskie F, Wright TW. Intraosseous blood supply to the distal humerus. *J Hand Surg.* 2007;32:642–646.
24. Bauer JM, Stutz CM, Schoenecker JG, et al. Internal rotation stress testing improves radiographic outcomes of type 3 supracondylar humerus fractures. *J Pediatr Orthop.* 2019;39:8–13.
25. Hand C, Bresnahan JJ, Hennrikus WL. A comparison of fluoroscopic exposure and operative time during treatment of displaced supracondylar elbow fractures in children. *Trauma.* 2019;21:40–44.
26. Mapes RC, Hennrikus WL. The effect of elbow position on the radial pulse measured by Doppler ultrasonography after surgical treatment of supracondylar elbow fractures in children. *J Pediatr Orthop.* 1998;18:441–444.

27. Zaltz I, Waters PM, Kasser JR. Ulnar nerve instability in children. *J Pediatr Orthop.* 1996;16:567.
28. Erez O, Khalil JG, Legakis JE, et al. Ultrasound evaluation of ulnar nerve anatomy in the pediatric population. *J Pediatr Orthop.* 2012;32:641–646.
29. Worlock P. Supracondylar fractures of the humerus. Assessment of cubitus varus by the Baumann angle. *J Bone Joint Surg Br.* 1986;68-B: 755–757.
30. Williamson DM, Coates CJ, Miller RK, et al. Normal characteristics of the Baumann (humerocapitellar) angle: an aid in assessment of supracondylar fractures. *J Pediatr Orthop.* 1992;12:636–639.
31. Pretell Mazzini J, Rodriguez Martin J, Andres Esteban EM. Surgical approaches for open reduction and pinning in severely displaced supracondylar humerus fractures in children: a systematic review. *J Child Orthop.* 2010;4:143–152.




 