Supracondylar Fractures of the Humerus in Children

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Abstract

The treatment of type II and type III supracondylar fractures of the humerus in children with closed reduction and percutaneous pinning has dramatically lowered the rate of complications from this injury. The incidence rates of malunion (cubitus varus) and compartment syndrome have both decreased. Nerve injury accompanying this type of fracture (prevalence, 5% to 19%) is usually a neurapraxia, which should be managed conservatively. Vascular insufficiency at presentation (prevalence, 5% to 17%) should be managed initially by rapid closed reduction and pinning without arteriography. Persistent vascular insufficiency necessitates exploration and vascular reconstruction.

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Supracondylar fracture of the humerus is a common elbow injury in children. Two thirds of all hospitalizations for elbow injuries in children are for supracondylar fractures,[1] but the incidence of supracondylar fractures has yet to be documented. In his review of 8,672 pediatric fractures, Landin[2] found that supracondylar fractures accounted for only 3.3%. Supracondylar fractures are most common in children aged less than 10 years, with a peak incidence between ages 5 and 8 years.[3] These fractures often require surgery and historically are associated with significant morbidity due to malunion, neurovascular complications, and compartment syndrome.[4,5] As a result, controversy still exists as to what constitutes optimal management of this type of fracture and its complications.

Classification

Supracondylar fractures of the humerus are categorized as extension or flexion injuries. The extension type is the most common, accounting for 90% to 98% of cases. It is caused by a fall on an outstretched hand with the elbow hyperextended.[6] The characteristic displacement of the distal humeral fragment in extension-type injuries has been reported to be posteromedial in 90% of cases and posterolateral in 10%.[7] In our study,[8] 49% of the supracondylar fractures were displaced posterolaterally. The flexion-type fracture, which is caused by falling on a flexed elbow, is a rare occurrence.

There have been numerous attempts in the literature to classify supracondylar fractures. Gartland's classification[9] is simple and widely used. In that system, type I fractures are nondisplaced. Type II fractures are displaced with a variable amount of angulation, but the posterior cortex of the humerus is intact. Type III fractures are completely displaced with no cortical contact. A medial periosteal hinge is intact in type III fractures with medial displacement of the distal humerus; a lateral periosteal hinge is intact with lateral displacement.

Physical Examination

The initial evaluation of the child with an elbow injury must include an overall assessment to rule out associated trauma. Fractures of the midshaft of the ipsilateral humerus are uncommon, but distal forearm fractures are common; both injuries may be overlooked if attention is focused solely on the elbow.

The elbow with a supracondylar fracture is characterized by swelling and deformity. With type III fractures, an S-shaped deformity of the elbow develops due to angulation and translation of the fracture fragments. A thorough neurovascular examination of the involved

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upper extremity is mandatory because this fracture is associated with neurovascular injuries, with a reported incidence of 11% to 49%.[8]

In the initial assessment, particular attention should be paid to radial nerve function. Posteromedial displacement of the fracture is associated with median and anterior interosseous nerve dysfunction; posterolateral displacement is associated with brachial artery injury.[8] It is important to document the initial neurovascular examination as a baseline for comparison before any treatment is instituted and to identify any subsequent deterioration of the neurovascular status.

At the end of the clinical assessment, the injured elbow should be immobilized with a splint in a position of 20 to 30 degrees of flexion to prevent further displacement of the fracture and additional neurovascular damage. Splinting in full elbow extension is to be avoided because it stretches the neurovascular bundle over the distal tip of the proximal fragment.

Radiographic Examination

The radiographic examination of the injured elbow must include an anteroposterior (AP) and a lateral view. Oblique views may be necessary to visualize minimally displaced fractures. The fat-pad sign, which is representative of an intra-articular effusion, will be seen on the lateral view of a minimally displaced supracondylar fracture.

On the lateral view of a normal elbow, the ossification center of the capitellum is partially transected by a line drawn along the anterior aspect of the humerus (the "anterior humeral line"). In a type I fracture, this relationship persists, as neither significant translation nor angulation exists (Fig. 1, A). The lateral view of a type II fracture shows an anterior humeral line that does not transect the capitellum, and there is an intact but plastically deformed posterior cortex (Fig. 1, B). In a type III fracture, the distal fragment is totally displaced, and the proximal fragment may be seen to penetrate through the brachialis muscle (Fig. 1, C).

On the AP view, Baumann's angle is an important landmark for the assessment of supracondylar fractures. This angle, created by the intersection of a line drawn down the humeral axis and a line drawn along the growth plate of the lateral condyle of the elbow, maintains a constant relation with the carrying angle (Fig. 2). Baumann's angle of the contralateral elbow should be used for comparison. The distal fracture fragment is often rotated medially or internally and into varus deviation in relation to the proximal humerus, which produces an increase in Baumann's angle.[10]

Some authors do not advocate use of Baumann's angle because of

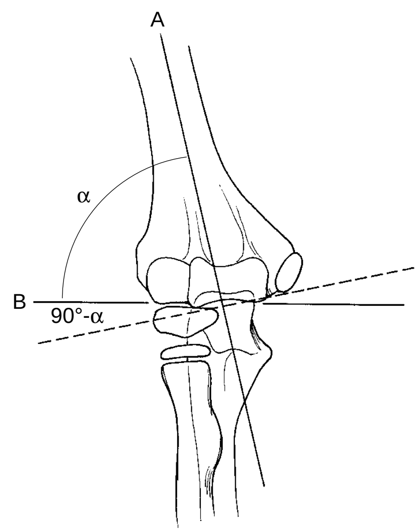

Fig. 2 Baumann's angle is a radiographic angle demonstrated on an anteroposterior view of the elbow. This angle is created by the intersection of a line drawn down the humeral axis (A) and a line drawn along the growth plate of the lateral condyle of the elbow (B). This angle is useful in determining the adequacy of reduction.

Fig. 1 **A,** Type I supracondylar humeral fracture. Solid arrow defines the fracture line. The anterior humeral line partially transects the capitellum, and there is a posterior fat-pad sign (open arrow). **B,** Type II supracondylar fracture with an intact posterior cortex (arrow). **C,** Type III supracondylar fracture with a totally displaced distal humeral fragment.

the difficulty of identifying the capitellar growth plate. An alternative to Baumann's angle, the medial epicondylar epiphyseal angle, has recently been described as a means of evaluating supracondylar fractures.[11] This angle is created by the intersection of a line drawn down the humeral axis and a line drawn along the medial epicondylar epiphyseal plate.

Both Baumann's angle and the medial epicondylar epiphyseal angle are also useful in determining the adequacy of reduction of supracondylar fractures. In practice, we use three criteria to determine the adequacy of reduction: (1) Baumann's angle, (2) the relationship of the capitellum to the anterior humeral line, and (3) restoration of the anatomy of the olecranon fossa. In radiographic evaluation of type I fractures treated in a cast, we have found that the best films are obtained by using a fiberglass cast and ordering an AP view of the distal humerus rather than an AP view of the elbow.

Treatment

We believe the treatment of choice for displaced supracondylar fractures is closed reduction and percutaneous pinning. Nondisplaced (type I) fractures may be managed in a cast or splint. Traction is useful when supracondylar comminution is present.

Type I Fractures

Type I fractures are nondisplaced and are not associated with neurovascular injury. These fractures can be treated with immobilization in a splint or circular cast with the elbow flexed to 90 degrees and the forearm in neutral position. Children may be admitted to the hospital for observation and elevation of the arm, depending on the degree of soft-tissue swelling, but this usually is not necessary. A radiograph should be taken 1 week after injury to be sure that displacement has not occurred, which usually is evidenced by an increase in varus angulation. After 3 weeks of immobilization, protected active range-of-motion elbow exercises may be started. Usually, no further treatment or observation is necessary for these nondisplaced fractures.

Type II Fractures

Type II fractures are angulated but not translated, because the posterior cortex remains intact. Reduction can be achieved by flexion of the elbow and pronation of the forearm with the patient under anesthesia. Rang described the use of a figure-of-eight cast for immobilization in hyperflexion and pronation without encircling the elbow in plaster.[1] Millis et al[12] showed that flexion of the elbow by more than 120 degrees was required to maintain reduction. After reduction and immobilization, patients should be observed in the hospital overnight for swelling and circulatory changes. Casting should be maintained for 3 weeks, after which protected active range-of-motion exercises can be begun.

Maintenance of hyperflexion in a circular cast carries a high risk of compartment syndrome. Therefore, we believe these fractures should be pinned percutaneously if there is significant swelling, if there is inadequate circulation when the elbow is flexed, or if the fracture might become unstable. Potentially unstable type II fractures are those with a possible fracture of the posterior cortex, especially when rotational deformity is present. Two lateral pins, rather than crossed pins, may be used to decrease the risk of ulnar nerve injury by the medial pin (Fig. 3). The use of two lateral pins is less secure than the use of two crossed pins.[13] If two lateral pins are used,

A B

Fig. 3 Anteroposterior **(A)** and lateral **(B)** views of a supracondylar humeral fracture pinned with two lateral percutaneous Kirschner wires placed parallel to each other.

they should be placed either parallel to each other or crossing well above the fracture line. If swelling of the elbow does not allow reduction, traction can be used until swelling has decreased enough that reduction can be attempted. In general, traction is not required.

Type III Fractures

Type III fractures are the result of more severe injuries and are associated with greater soft-tissue damage and swelling, difficult reduction, compartment syndromes, and neurovascular injuries. These fractures are completely displaced with most of the periosteum torn, and there is significant risk of injury to the brachialis muscle and neurovascular bundle. Residual deformity is also a potential problem. The incidence of cubitus varus (Fig. 4) has been reported to be as high as 58%.[7] Closed reduction and cast immobilization should not be used in treating this fracture. Patients should be observed in the hospital after this injury to monitor neurovascular status.

Fig. 4 Child with cubitus varus deformity of the elbow after a supracondylar humeral fracture.

Closed Reduction

Accurate reduction of the fracture is important in the prevention of cubitus varus deformity. Under fluoroscopic control, traction is first applied to disengage the proximal fragment from the brachialis muscle. The distal fragment must then be translated into proper medial-to-lateral orientation relative to the shaft. The internal rotation deformity is then corrected. Next, with the examiner's thumb over the olecranon, the distal fragment is pushed forward while flexing the patient's elbow to 120 degrees and pronating the wrist to tighten the periosteal hinge (Fig. 5). In the posterolateral fracture, the wrist is supinated to tighten the lateral periosteal hinge. The reduction is then checked on AP and lateral views with the use of fluoroscopy. The fracture is generally stable in external rotation, which allows a lateral view of the elbow to be obtained by externally rotating the shoulder while holding the elbow in hyperflexion.

Fig. 5 After traction and centralization, the distal fragment is reduced by direct pressure over the olecranon as the elbow is flexed.

The adequacy of reduction in the coronal plane can be assessed with Jones views of the distal humerus with the hyperflexed elbow in slight internal and external rotation. These views can be difficult to evaluate, however, because of imposition of the proximal radius and ulna. As described previously, Baumann's angle and the medial epicondylar epiphyseal angle are useful ways to assess reduction. A deviation of more than 5 degrees relative to the Baumann's angle measured in the noninjured extremity represents an inadequate reduction.[1] Webb and Sherman[14] report that the humeroulnar angle (the angle between the midhumeral line and a line drawn down the ulna) is a more accurate means of assessing the adequacy of reduction. Because the position of the reduced distal humerus is usually evaluated with the elbow flexed, we have not found this view to be particularly helpful. Lagrange and Rigault[15] and Conn and Wade[16] described the "crescent sign" (overlapping of the ossification centers of the lateral condyle and the olecranon) on the lateral view as an indicator of inadequate reduction, but we have found that Baumann's angle, the relationship of the capitellum to the anterior humeral line, and restoration of the normal anatomy of the olecranon fossa are the best indicators of an acceptable reduction.

Percutaneous Pinning

After anatomic reduction, percutaneous pinning of the elbow can be performed with use of the sterilely draped screen of the fluoroscopy (C-arm) unit as the operating surface. The distal fracture fragment is usually stable in 120 degrees of flexion in pronation, and the arm can be moved from neutral to external rotation so that imaging of the elbow can be done in different planes without moving the C arm. Slight internal and external rotation of the arm will allow the medial and lateral columns of the distal humerus to be visualized. For comminuted fractures or fractures that are unstable, crossed pinning with one lateral and one medial pin is advised (Fig. 6). Two lateral pins may be satisfactory if a stable reduction has been achieved.

Percutaneous pinning is performed with the maximally flexed and pronated arm resting on the sterile C-arm screen. The lateral side is approached first. A smooth Kirschner wire is inserted through the lateral condyle, crossing just lateral to the olecranon fossa and engaging the medial humeral cortex. A 0.062-mm wire is appropriate for a small child aged less than 4 years; a 5/64-inch wire is appropriate for an older child. The wire is passed through the capitellum and the distal humeral physis. The position of the wire should be checked fluoroscopically on AP and lateral views. For the lateral view, the arm can be externally rotated at the shoulder while flexion and pronation of the elbow is maintained.

Fig. 6 Supracondylar humeral fracture that has been pinned with lateral and medial Kirschner wires. Note that the medial wire enters through the medial epicondyle above the ulnar groove.

The medial wire is placed with the arm in 80 to 90 degrees of flexion; additional elbow flexion may cause the ulnar nerve to subluxate volarward into the path of the Kirschner wire. Because the lateral wire provides sufficient stability, hyperflexion is no longer necessary. A medial incision is then made over the medial epicondyle. A hemostat is used to separate tissues down to the medial epicondyle to ensure that the ulnar nerve is not injured. An AO tissue protector can be used to protect soft tissues. The position of the Kirschner wire should be checked with the C arm before insertion to ensure that it is piercing the medial epicondyle and not the ulnar groove. The wire is then driven up the medial column so that it crosses the lateral wire proximal to the olecranon fossa. The medial wire is usually more transverse than the lateral wire.

The reduction and wire placement should then be checked again with the C arm. The wires are bent and generally left protruding from the skin for easy removal in 3 weeks. Before the drapes are removed, the vascular status of the arm should be checked. The elbow is splinted in 60 to 90 degrees of flexion with the forearm in neutral rotation. A bivalve cast or splint is applied, and the patient is admitted for observation overnight.

The Kirschner wires are removed without anesthesia in the office 3 to 4 weeks postoperatively after healing of the fracture. Physical therapy is generally not required, as the child will regain full use of the elbow over the ensuing 3 weeks.

Traction

Traction has lost popularity as percutaneous pinning of supracondylar fractures has gained broad acceptance. However, traction is a treatment option for the severely swollen arm, the irreducible or comminuted fracture, and the fracture that cannot be pinned because of an associated skin disorder or a life-threatening condition. Traction necessitates constant supervision and adjustment to prevent varus deformity.

Our primary indication for traction is supracondylar comminution (Fig. 7). Dunlop's skin traction[17] or modifications involving skeletal traction have been described. A variation of skeletal traction involves insertion of the Ormandy screw[18] or the Palmer winged screw[19] into the ulna. Traction can be applied overhead or in a side-arm manner. We find that overhead traction with use of an olecranon screw is the easiest to manage. Traction can be used with a short arm cast if there is also a forearm fracture. Once swelling has resolved, the elbow can be placed in plaster, remanipulated, or pinned percutaneously.

Pirone et al[20] compared three methods for treatment of supracondylar fractures: closed reduction with casting, skeletal traction, and closed reduction with percutaneous pin fixation. They found that the results for patients treated with skeletal traction were equal to those for patients treated with closed reduction with percutaneous pinning.

Indications for Open Reduction

The indications for open reduction of supracondylar fractures include (1) a fracture that is irreducible by closed methods, (2) vascular compromise necessitating exploration and repair of the brachial artery, and (3) an open

Fig. 7 Traction applied through an olecranon wing screw can be valuable when supracondylar comminution is present.

fracture requiring irrigation and debridement.

It is uncommon for a supracondylar fracture to be irreducible by closed methods. Elstrom et al[21] reported that in cases of entrapment of the brachial artery and median nerve between the fracture fragments, attempts at closed reduction resulted in vascular compromise. Wilkins[22] reported that buttonholing of the proximal fracture fragment through the brachialis muscle can block reduction. When reduction cannot be obtained, one must always beware of entrapped neural or vascular structures. This occurs most frequently in posterolaterally displaced fractures.

In general, the surgical approach should be through the area of disrupted periosteum. The neurovascular deficit present should also be considered in planning the surgical approach. An anterior or anteromedial approach should be used for a posterolaterally displaced fracture associated with vascular compromise or a median nerve deficit. In general, the most versatile approach is through an anterior transverse incision over the antecubital fossa, with extension of the medial side proximally and the lateral side distally as needed. It is often the case that only the transverse part of the incision is required. Once reduction has been achieved, fixation with crossed Kirschner wires is recommended. A posterior approach may jeopardize the blood supply to the distal humerus and is not indicated.

Flexion-type Fractures

Flexion-type supracondylar fractures are very uncommon, reportedly occurring in only 1% to 10% of all supracondylar injuries[1] (Fig. 8). Flexion-type fractures can be classified like extension-type fractures on the basis of the degree of displacement. The reduction maneuver for type II and type III flexion fractures is opposite to that used for extension-type fractures, and reduction is done in extension. The medial periosteum may be disrupted, with a valgus component that requires a varus moment to gain reduction.

Pinning is necessary for most flexion-type fractures that require reduction, because casting the elbow in extension is awkward. Pinning a flexion-type fracture must be done in extension. The C arm is rotated about the distal humerus because the fracture will not be stable in flexion.

Complications

Nerve Injuries

Nerve injuries associated with displaced supracondylar fractures are common, with reported prevalences ranging from 5% to 19%. In a 1995 review of type III supracondylar fractures, Campbell et al[8] found a median nerve deficit in 52% of cases and a radial nerve deficit in 28%. A high frequency of median nerve palsy was associated with posteromedial displacement of the distal fragment. Fortunately, most deficits that occur at the time of injury are neurapraxias.[23] Motor function can take from 7 to 12 weeks to return, but sensory recovery may take more than 6 months.[24] Culp et al[25] found that if there was no clinical or electromyographic evidence of return of neural function 5 months after injury, exploration and neurolysis were indicated. If the nerve was seen to be in continuity intraoperatively, the prognosis for neurolysis was excellent.

Early exploration is indicated when there is an open injury over a nerve that is not functioning. Exploration is also indicated if nerve function becomes compromised after closed reduction of the fracture.[26]

Nerve injury can also occur during pinning of supracondylar fractures. In a retrospective review of 143 supracondylar fractures, four cases of nerve palsy were identified after percutaneous fixation.[27] All four nerve palsies were associated with a medial pin. Royce et al[27]

Fig. 8 In a flexion-type supracondylar fracture, the distal fragment is displaced anteriorly.

found that the rate of iatrogenic nerve injury after percutaneous pinning was 2% to 3%. Nerve palsies without transection of the nerve should be treated conservatively; resolution will generally occur within 6 months.

Arterial Injuries

The prevalence of vascular insufficiency accompanying supracondylar fractures has been reported to range from 5% to 12%.[28,29] Shaw et al[29] recommend immediate closed reduction and Kirschner-wire stabilization of fractures accompanied by vascular insufficiency. This treatment protocol resulted in restoration of pulse in 13 of their 17 patients (12% of 143 type III fractures). Arterial exploration was performed in 3 patients who had an intact pulse preoperatively but no pulse after reduction; in each case, there was a discrete arterial lesion at the level of the fracture. Shaw et al concluded that preoperative arteriography would not have contributed to the management of these injuries with strong clinical signs suggestive of vascular compromise. Their indications for arterial exploration were (1) the absence of a palpable pulse after reduction with any suggestion of decreased capillary refill, increased compartment pressure, or pallor, and (2) the total absence on Doppler imaging of a pulse in a nonischemic extremity. They also asserted that delaying treatment of a pulseless extremity to obtain an arteriogram before reduction and pinning is not warranted.

A dreaded complication of vascular compromise or injury is Volkmann's ischemic contracture. Ottolenghi[28] reported that this complication occurred in fewer than 1% of his 830 patients with supracondylar fractures. An aggressive surgical approach to prevent Volkmann's ischemic contracture is necessary. It should be recognized that the pain and signs of compartment syndrome may be absent if the median nerve has been injured, resulting in an anesthetic hand.[30] Mubarak and Carroll[31] have recommended that forearm fasciotomy be performed if there are clinical signs of compartment syndrome or if intracompartmental pressure measurements are greater than 30 mm Hg.

Deformity

Angular deformities of the distal humerus are common after supracondylar fractures. The remodeling potential of the distal humerus is limited because the distal physis contributes only 20% of the growth of the humerus. Although remodeling of posterior angulation can occur, angular deformities in the coronal plane will not remodel, resulting in a cubitus varus or cubitus valgus deformity.

Cubitus varus deformity is primarily a cosmetic, rather than a functional, disability. The deformity is most apparent with full extension of the elbow. The primary indication for surgical correction is also cosmetic. The techniques for corrective osteotomy include lateral closing-wedge osteotomy, dome rotational osteotomy, and step-cut lateral closing-wedge osteotomy.[1] However, these osteotomies are associated with a significant complication rate. Labelle et al[32] reported a loss of correction and / or nerve injuries in 33% of their patients.

In a 1994 study, Voss et al[33] found that the cubitus varus deformity was generally the result of malreduction, but disruption of medial growth was the cause in 11% of their patients with progressive deformity. If medial growth arrest was present, these authors suggested that a lateral epiphysiodesis should accompany the osteotomy to reduce the risk of recurrent deformity. Corrective osteotomy provided permanent correction of the deformity in the absence of growth arrest. A corrective osteotomy for cubitus varus deformity should be delayed until at least 1 year after injury to evaluate the possible presence of medial growth arrest.

Cubitus valgus deformity does not occur as commonly as cubitus varus and is not as well documented in the literature. This deformity causes functional loss of extension and the development of a tardy ulnar nerve paralysis.

Stiffness and Myositis Ossificans

Loss of motion in the anatomically reduced supracondylar fracture is uncommon. Significant loss of flexion can occur after fractures with posterior angulation of the distal fragment. In a review of supracondylar fractures in children, Henrikson[3] reported that fewer than 5% were ultimately associated with flexion or extension loss exceeding 5 degrees as compared with the noninjured side. Although extensive manipulation and physical therapy have been noted to incite myositis ossificans, this complication is extremely rare.

Summary

Although supracondylar fractures of the humerus are common in children, management of the injury and treatment of complications are still controversial. Expedient management of the fracture with reduction and stabilization markedly decreases the incidence of neurovascular complications. Anatomic reduction and Kirschner-wire fixation with special attention given to soft tissues and careful monitoring of neurovascular function are key to management of this injury in children.

References

1. Wilkins KE: Fractures and dislocations of the elbow region, in Rockwood CA Jr, Wilkins KE, King RE (eds): *Fractures in Children*, 3rd ed. Philadelphia: JB Lippincott, 1991, vol 3, pp 526-617.
2. Landin LA: Fracture patterns in children: Analysis of 8,682 fractures with special reference to incidence, etiology and secular changes in a Swedish urban population, 1950–1979. *Acta Orthop Scand Suppl* 1983;202:1-109.
3. Henrikson B: Supracondylar fracture of the humerus in children: A late review of end-results with special reference to the cause of deformity, disability and complications. *Acta Chir Scand Suppl* 1966;369:1-72.
4. Hanlon CR, Estes WL Jr: Fractures in childhood: A statistical analysis. *Am J Surg* 1954;87:312-323.
5. Arnold JA, Nasca RJ, Nelson CL: Supracondylar fractures of the humerus: The role of dynamic factors in prevention of deformity. *J Bone Joint Surg Am* 1977;59:589-595.
6. Minkowitz B, Busch MT: Supracondylar humerus fractures: Current trends and controversies. *Orthop Clin North Am* 1994;25:581-594.
7. Kasser JR: Percutaneous pinning of supracondylar fractures of the humerus. *Instr Course Lect* 1992;41: 385-390.
8. 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.
9. Gartland JJ: Management of supracondylar fractures of the humerus in children. *Surg Gynecol Obstet* 1959;109: 145-154.
10. Camp J, Ishizue K, Gomez M, et al: Alteration of Baumann's angle by humeral position: Implications for treatment of supracondylar humerus fractures. *J Pediatr Orthop* 1993;13: 94-97.
11. Biyani A, Gupta SP, Sharma JC: Determination of medial epicondylar epiphyseal angle for supracondylar humeral fractures in children. *J Pediatr Orthop* 1993;13:94-97.
12. Millis MB, Singer IJ, Hall JE: Supracondylar fracture of the humerus in children: Further experience with a study in orthopaedic decision-making. *Clin Orthop* 1984;188: 90-97.
13. Herzenberg JE, Koreska J, Carroll NC, et al: Biomechanical testing of pin fixation techniques for pediatric supracondylar elbow fractures. *Orthop Trans* 1988;12:678-679.
14. Webb AJ, Sherman FC: Supracondylar fractures of the humerus in children. *J Pediatr Orthop* 1989;9:315-325.
15. Lagrange J, Rigault P: Fractures supra-condyliennes. *Rev Chir Orthop* 1962:48:337-414.
16. Conn J Jr, Wade PA: Injuries of the elbow: A ten-year review. *J Trauma* 1961;1:248-268.
17. Dunlop J: Transcondylar fractures of the humerus in childhood. *J Bone Joint Surg* 1939;21:59-73.
18. Ormandy L: Olecranon screw for skeletal traction of the humerus. *Am J Surg* 1974;127:615-616.
19. Palmer EE, Niemann KMW, Vesely D, et al: Supracondylar fracture of the humerus in children. *J Bone Joint Surg Am* 1978;60:653-656.
20. 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.
21. Elstrom JA, Pankovich AM, Kassab MT: Irreducible supracondylar fracture of the humerus in children: A report of two cases. *J Bone Joint Surg Am* 1975;57:680-681.
22. Wilkins KE: The operative management of supracondylar fractures. *Orthop Clin North Am* 1990;21:269-289.
23. Ippolito E, Caterini R, Scola E: Supracondylar fractures of the humerus in children: Analysis at maturity of fifty-three patients treated conservatively. *J Bone Joint Surg Am* 1986;68:333-344.
24. McGraw JJ, Akbarnia BA, Hanel DP, et al: Neurological complications resulting from supracondylar fractures of the humerus in children. *J Pediatr Orthop* 1986;6:647-650.
25. Culp RW, Osterman AL, Davidson RS, et al: Neural injuries associated with supracondylar fractures of the humerus in children. *J Bone Joint Surg Am* 1990;72:1211-1215.
26. Martin DF, Tolo VT, Sellers DS, et al: Radial nerve laceration and retraction associated with a supracondylar fracture of the humerus. *J Hand Surg [Am]* 1989;14:542-545.
27. 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.
28. Ottolenghi CE: Prophylaxie du syndrome de Volkmann dans les fractures supra-condyliennes du coude chez 1'enfant. *Rev Chir Orthop* 1971;57:517-525.
29. Shaw BA, Kasser JR, Emans JB, et al: Management of vascular injuries in displaced supracondylar humerus fractures without arteriography. *J Orthop Trauma* 1990:4:25-29.
30. Harris IE: Supracondylar fractures of the humerus in children. *Orthopedics* 1992;15:811-817.
31. Mubarak SJ, Carroll NC: Volkmann's contracture in children: Aetiology and prevention. *J Bone Joint Surg Br* 1979;61:285-293.
32. Labelle H, Bunnell WP, Duhaime M, et al: Cubitus varus deformity following supracondylar fractures of the humerus in children. *J Pediatr Orthop* 1982;2:539-546.
33. Voss FR, Kasser JR, Trepman E, et al: Uniplanar supracondylar humeral osteotomy with preset Kirschner wires for posttraumatic cubitus varus. *J Pediatr Orthop* 1994;14:471-478.