Hand ischemia associated with elbow trauma in children

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Objectives: **Previous observational studies suggest that children with hand ischemia following elbow trauma can be safely observed if Doppler signals are present in the wrist arteries (pink pulseless hand, PPH). Nonoperative management of PPH is predicated on the assumption that PPH results from local arterial spasm, but the mechanism of arterial compromise has not been investigated. We hypothesized that PPH signifies a brachial artery injury that requires surgical repair.**

Methods: **Retrospective review of operations performed on children with hand ischemia following elbow trauma at a level I trauma center pediatric hospital.**

Results: **Between 2003 and 2010, 12 children (seven males, mean age 7.4 years) underwent brachial artery exploration for hand ischemia following elbow trauma (11 supracondylar fractures, one elbow dislocation) due to falls (n = 10) or motor vehicle crashes (n = 2). At presentation, three subjects had normal radial pulses, eight subjects had Doppler signals but no palpable pulses, and one had weak Doppler flow with advanced hand ischemia. Six of the nine subjects without palpable pulses also had neurosensory changes. All 12 subjects underwent brachial artery exploration either initially (n = 2) or following orthopedic fixation (n = 10) due to persistent pulselessness. At operation, eight of 12 patients (67%) had focal brachial artery thrombosis due to intimal flaps, and four had brachial artery and median nerve entrapment within the pinned fracture site. At discharge, all 12 subjects had palpable radial pulses, but three with entrapment had dense median nerve deficits. One of the three subjects with dense neurologic deficit had complete recovery of neurologic function at ten months. The other two subjects had residual median nerve deficits with partial recovery at 5 and 6 months follow-up, respectively. No patient developed Volkman's contracture.**

Conclusions: **Brachial artery injuries should be anticipated in children with hand ischemia associated with elbow trauma. Neurovascular entrapment at the fracture site is a possible complication of orthopedic fixation. Absence of palpable wrist pulses after orthopedic fixation should prompt immediate brachial artery exploration. PPH should not be considered a consequence of arterial spasm in these patients. (J Vasc Surg 2011;54:773-8.)**

Supracondylar fracture (SCF) of the humerus is the most common fracture associated with blunt elbow trauma in children.[1] Volkmann's ischemic contracture has long been recognized as a dreaded complication of SCF, highlighting the risk of neurovascular injury associated with these fractures.[2] Children with SCF have a reported incidence of associated brachial artery injury of 8% to 10%,[3,4] whereas nerve injury has been reported as being 12% to 20%. [3,5,6] Although other patients may have transient hand ischemia due to local arterial spasm, the incidence of reversible ischemia is unknown. It remains controversial whether all patients with hand ischemia after elbow trauma should have brachial artery exploration.

The treatment of hand ischemia in children with elbow trauma has traditionally been based on the degree of ischemia. Exploration of the brachial artery has been clearly indicated in the case of a pulseless, cool, white hand. However, management of a pink, pulseless hand (PPH) following elbow trauma is controversial. Some authors have strongly advocated for routine brachial artery exploration,[2,3,7-9] while others have suggested that affected children can be safely observed if Doppler signals are present in the wrist arteries.[6,10-13] Nonoperative management is predicated on the assumption that PPH results from local arterial spasm, but the mechanism of arterial compromise has not been investigated. Reliance on collateral flow in the forearm may leave the hand viable, but puts the child at risk for long-term sequelae such as contractures and limb-length discrepancy.[2] We have adopted a more aggressive approach to these patients because of concern for late complications of an underlying arterial injury. The purpose of this study is to review our experience with brachial artery exploration in children with blunt elbow trauma to determine how often the vascular findings were due to spasm vs arterial injury.

PATIENTS AND METHODS

The study population consisted of pediatric patients aged 16 years old or younger who underwent brachial artery exploration between June 2003 and June 2010 to evaluate hand ischemia following elbow trauma. Patients were identified from the pediatric surgery operative registry, which is a database of all patients who undergo opera-

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tions on the pediatric surgery service. In our trauma system, all acutely injured patients aged 13 years or younger are admitted to Dallas Children's Medical Center (CMC), a 487-bed designated level I pediatric trauma center serving North Texas. Older children up to the age of 17 years are treated at Parkland Memorial Hospital (PMH), a 700-bed designated level I trauma center serving the population of Dallas County, Texas. Medical records of the study patients were scrutinized to determine demographics, mechanism of injury, duration between injury and initial evaluation, timing of orthopedic and vascular operations, and neurovascular examinations before and after orthopedic operations. Subjects without palpable wrist pulses that had adequate hand perfusion and Doppler signals in the radial and palmar arteries were defined as having a "pink pulseless hand" (PPH). Fractures were classified according to the Gartland classification of supracondylar fractures.[14] Operative reports were reviewed to determine the nature of orthopedic and vascular injuries, type of orthopedic and vascular repairs, and operative details. Outcomes were determined from discharge summaries and from records of outpatient visits, with particular attention to vascular patency, elbow function, and residual neurologic deficits. Duration of follow-up was considered to end at the last outpatient encounter.

To estimate the prevalence of operations for brachial artery injury in children with Gartland types II and III supracondylar fractures, we determined the number of patients who underwent open or closed reductions with fixation to treat supracondylar fractures during the study period. These data were abstracted from the CMC operating room database using current procedural terminology (CPT) code 24538 in combination with codes 24545 to 24546 for open reduction or CPT codes 24530 to 24535 for closed reduction. This study was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center.

RESULTS

During the 7-year study period, 12 children (7 males, 5 females) underwent brachial artery exploration to evaluate hand ischemia following blunt elbow trauma. This represents 0.4% of the 2804 children with supracondylar fractures that underwent open reduction and pinning (n = 649) or closed reduction and pinning (n = 2155) at CMC during the study period. Other than the upper extremity trauma, there were no other injuries identified in the 12 study subjects. The mean age ± SD of the subjects was 7.4 ± 3.8 years (range 2-16 years). Eleven subjects were treated at CMC, and one subject (a 16-year-old male) was treated at PMH. Nine of the subjects treated at CMC were transferred from outside hospitals a mean of 5.4 hours after the initial injury; two were initially evaluated at CMC, and one was initially evaluated at PMH. One of the seven transferred subjects underwent closed reduction and pinning of a supracondylar fracture at the outside hospital and was transferred because of postoperative hand ischemia.

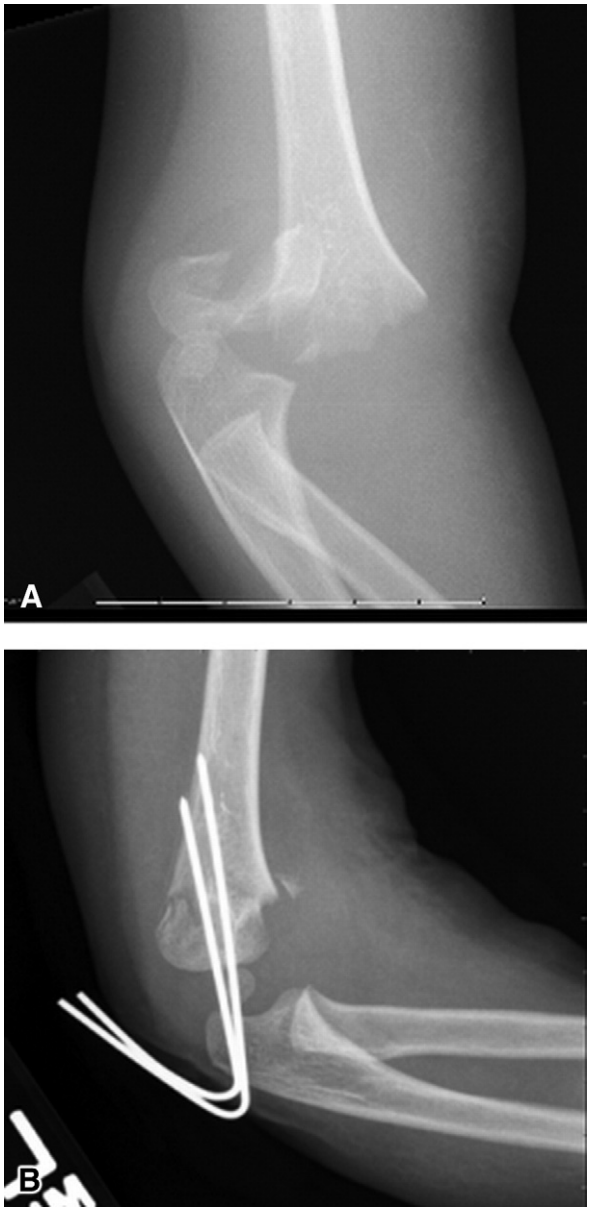

Fig 1. A, Radiograph of a displaced supracondylar fracture of the humerus (*Gartland type 3*). **B,** Radiograph showing supracondylar fracture of the elbow treated with closed reduction and pinning.

Eleven subjects sustained supracondylar fractures from falls (n = 9) or motor vehicle crashes (n = 2), and one subject sustained an elbow dislocation from a fall. Nine of the subjects had complete fractures of the distal humerus with displacement (Gartland type III) (Fig 1, *A*), two had open hinged fractures (Gartland type II), and one had a radial head dislocation.

On initial evaluation at our institution, three subjects had palpable radial pulses. Two of the three had normal neurologic examinations in the affected extremity, and one had a sensory deficit in the median nerve distribution of the

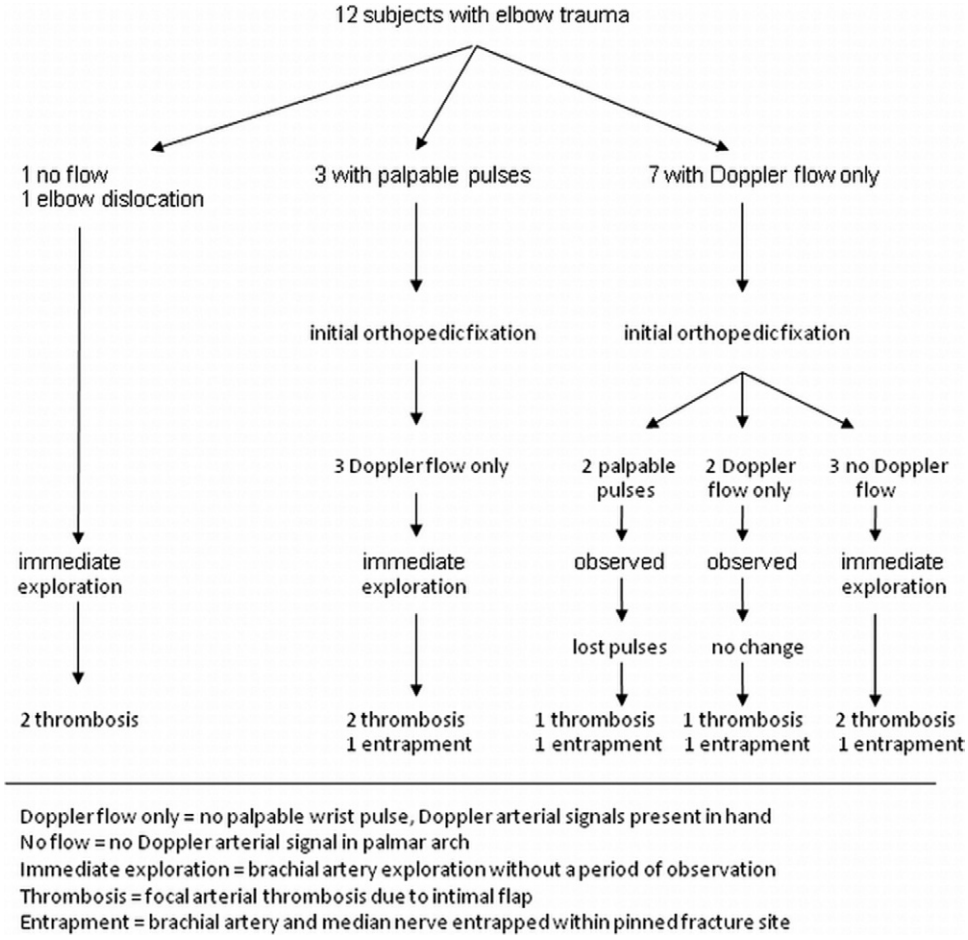

Fig 2. Algorithm depicting clinical outcome of 12 patients with hand ischemia following blunt elbow trauma during a recent 7-year period.

ipsilateral hand (Fig 2). Eight subjects without palpable pulses had monophasic Doppler signals in the radial and palmar arteries (PPH); four of these had normal neurologic examinations, while four had sensory median nerve deficits. One other subject had a weak, monophasic Doppler signal at the wrist but no detectable flow in the hand; he had advanced hand ischemia as well as dense median and ulnar nerve deficits.

Treatment. Ten subjects with palpable radial pulses (n = 3) or Doppler signals (PPH, n = 7) underwent initial orthopedic fixation with closed reduction and pinning (Fig 1, *B*). The subject with advanced ischemia underwent initial brachial artery exploration. The eighth subject with PPH sustained an elbow dislocation that did not require fixation and therefore underwent initial vascular reconstruction. After initial orthopedic fixation, vascular examinations changed in eight patients (Fig 2). The three subjects who originally had had palpable radial pulses did not have pulses after fixation. Two of the seven subjects who had Doppler flow on initial evaluation had return of palpable radial pulses; however, they lost their pulses after 3 and 6 hours of observation. Three subjects had worsening ischemia with loss of Doppler signals in the palmar arch.

Six of the 10 subjects who underwent initial orthopedic fixation underwent immediate brachial artery exploration, while four were observed for up to 12 hours. The other two with PPH underwent delayed vascular operations because the vascular examination did not change after 12 hours of observation. Both of the latter subjects underwent brachial artery duplex ultrasonography that confirmed arterial thrombosis.

Operative results. Brachial artery explorations were performed under general anesthesia using curvilinear incisions in the antecubital fossa. Traumatic brachial artery injuries were identified at operation in all 12 subjects. Eight of the 12 subjects (67%) had focal brachial artery thrombosis due to intimal flaps, and four had brachial artery and medial nerve entrapment within the pinned fracture site. It should be noted that two of the eight subjects with focal brachial artery thrombosis had palpable pulses on initial evaluation and that three of the four with neurovascular

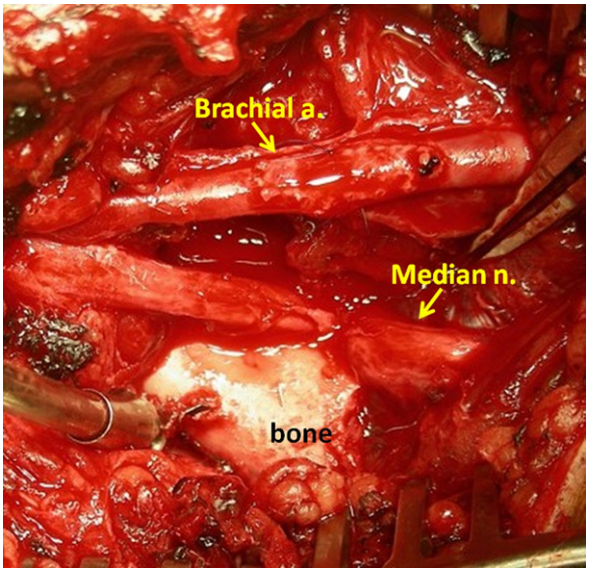

Fig 3. Intraoperative photograph in a subject with entrapment of the brachial artery and median nerve within the pinned fracture site. The artery has been repaired with vein patch angioplasty, and the nerve has been mobilized away from the fracture site.

entrapment did not have palpable pulses before orthopedic fixation.

Six of eight subjects with focal thrombosis required interposition saphenous vein grafts due to extensive intimal disruption, while two with localized intimal flaps underwent thrombectomy, flap excision, and vein patch angioplasty. Standard vascular techniques and loupe magnification were used in all patients, regardless of age. The four subjects with entrapment had localized arterial contusion, prompting arteriotomy and vein patch angioplasty in addition to neurolysis and mobilization of the median nerve away from the fracture site (Fig 3). The mean postoperative length of stay was 2.6 days, and palpable radial pulses were documented in all subjects at the time of discharge. All six subjects that had normal neurologic examinations before operation had normal neurologic examinations postoperatively. Of the six subjects with preoperative neurologic deficits, three with focal thrombosis had complete neurologic recovery by the time of discharge. Three others (three of the four subjects with entrapment) had residual sensory and motor neuropathy affecting the median and ulnar nerves. All patients were discharged on a daily dose of 81 mg of aspirin.

Follow-up. One of the 12 subjects never returned for follow-up. The mean duration of follow-up among the other 11 subjects is 3.6 months. At the latest visit, all subjects had a documented radial artery pulse and a well perfused hand in the affected extremity. Duplex ultrasonography was performed in the 11 patients after orthopedic casts were removed, and all repairs were found to be patent without stenosis or aneurysmal degeneration. Significant neurologic recovery was documented in the three subjects with entrapment that had residual median and ulnar neuropathy at discharge: one had complete recovery of neurologic function at 10 months, one had minimal residual median neuropathy affecting the distal tips of the second and third digits at 5 months, and one had residual median and ulnar nerve deficits with partial recovery at 6 months of follow-up. All 11 subjects had normal elbow extension, flexion, and supination-pronation at last follow-up.

DISCUSSION

Supracondylar fractures represent the most common upper extremity fractures in children up to the age of 7 years, accounting for up to 18% of all pediatric fractures.[1] The supracondylar segment is prone to injury because it is the thinnest portion of the humerus, and nearly all fractures are due to falls on an outstretched hand with the elbow in full extension. The degree and direction of displacement determines the structures at risk: medial displacement of the distal fragment puts the radial nerve at risk, while lateral displacement risks injury to the brachial artery and median nerve.[15] These structures are prone to injury due to stretch forces or direct entrapment. The brachial artery and median nerve are also at risk for stretch injury with posterior elbow dislocations.[16] Although previous reports suggest a prevalence of arterial injury of 8% to 10%, our data suggest that arterial injury is very rare in children with supracondylar fractures. Regardless of the true prevalence, vascular surgeons can expect to be consulted when vascular compromise is suspected.

Optimal treatment of patients with signs of arterial compromise remains controversial. Profound hand ischemia ("white cold hand") clearly merits immediate brachial artery exploration; the vascular surgeon should remain in the operating room during subsequent fixation to be certain that the repair does not become disrupted or entrapped. Surgeons are divided on the proper management of the PPH after successful closed reduction. Garbuz et al reported 22 patients with PPH on admission.[6] After reduction and pinning, 17 subjects had return of pulses, while five with persistent PPH were observed for 48 hours without sequelae and had normal vascular examinations at late follow-up. This experience is similar to those of Shaw et al[17] and Pirone et al[18] that documented return of normal radial pulses in the vast majority of patients within 1 to 4 days after reduction.

Other authors are less optimistic about observing patients with persistent PPH after orthopedic fixation. In a systematic review of the literature, White et al[8] collected a total of 331 reported cases of pulseless supracondylar fractures. Following reduction, 47% of patients remained pulseless, and 82% of these had documented brachial artery injuries. The consequence of missed injury is severe: Blakey et al[2] reported a series of 26 children with persistent PPH seen a mean of 3 months after reduction of supracondylar fractures, only four of whom had undergone brachial artery exploration at the time of initial hospitalization. Twenty-three of the 26 children had an established ischemic contracture of the forearm and hand; only three of the four

who had undergone brachial artery repair had a satisfactory outcome. Thus, brachial artery exploration seems prudent in patients with persistent PPH after fixation.

Unsuspected brachial artery injuries may occur in some patients who experience return of radial artery pulse after fixation. However, the prevalence of this condition is not known. Of 14 subjects with PPH who regained radial pulses after fixation, Copley et al[7] reported that two lost their pulses during 24 to 36 hours of observation and were found to have arterial injuries at exploration. This is similar to our experience: two subjects in the present series lost their pulses between 3 and 6 hours after fixation. Importantly, three other subjects with palpable pulses on admission lost their pulses after fixation. All five of these latter subjects had arterial injuries, underscoring the need to observe these patients for up to 24 hours after operation. It is important to note that none of the subjects in the present series had reversible brachial artery spasm; all ultimately proved to have a localized arterial injury with thrombosis. Based on this experience, we recommend early brachial artery exploration in patients with profound hand ischemia defined as a pale, cool hand without detectable Doppler signals in the palmar arch. We also recommend prompt exploration in patients who experience loss of wrist pulses or worsening Doppler signals after orthopedic fixation out of concern for entrapment. We maintain a high index of suspicion for brachial artery injury in patients with PPH and proceed with brachial artery exploration if there is no return of radial pulse after orthopedic fixation. However, we acknowledge that it may be reasonable to observe patients with persistent PPH, as 11 of the subjects in the present series did not appear to suffer any consequence of delayed treatment associated with transfer from other hospitals or observation by the trauma service for up to 12 hours.

Some authors have used supplemental diagnostic modalities such as duplex ultrasonography and catheter-based angiography to confirm the diagnosis of brachial artery injury. Sabharwal et al[12] used a combination of segmental pressure monitoring, color-flow scanning, and magnetic resonance angiography in 13 patients with PPH. All injuries were confirmed with one or more tests, but the authors did not report any patients for which the tests ruled out injuries. Copley and associates[7] employed catheter arteriography in four of five patients with PPH syndrome, two of whom lost pulses 24 to 36 hours after fixation. The authors reported that angiography did not alter the course of treatment in any case, nor did it help define or localize the vascular injuries. Our limited experience also suggests that these supplemental tests are not necessary to evaluate patients with PPH, as duplex ultrasonography did not alter the course of treatment in the two patients who had the study. However, we acknowledge that our experience is small and retrospective; evaluating the potential role for these tests is beyond the scope of our study. Judging from the data discussed above, any treatment delay associated with supplemental diagnostic tests will probably not have a significant effect on outcome.

Our experience shows that repair of localized brachial artery injuries is straightforward in children, and excellent outcomes should be expected. We favor the thigh saphenous vein as a conduit because of its larger size and thicker walls, but others have found the adjacent basilic vein to be a safe alternative with excellent long-term patency.[19] All arterial repairs have remained patent, and no subjects have developed ischemic contractures or growth discrepancies in the short-term. All subjects have regained full use of the elbow joint, but it should be pointed out that nerve injuries may take several months to resolve. Additional follow-up is needed to ensure vein graft durability and normal extremity growth over the long-term.

Despite being the largest, single-institution series of brachial artery injuries due to elbow trauma, a number of limitations must be acknowledged. First, the study is retrospective in nature, and we have concentrated on those patients who required brachial artery exploration. As consultants at CMC, we may not have been asked to see patients with transient hand ischemia due to arterial spasm, and we may have missed the opportunity to study some patients with minor injuries such as intimal flaps without thrombosis. Furthermore, we are not able to determine how many patients with PPH had return of normal pulses after a period of observation; we acknowledge that many of the 2804 patients who underwent operative reduction and pinning during the study period may have had transient ischemia. This limitation has tempered our conclusions and led to the suggestion that it is reasonable to observe patients with PPH. However, the limitation does not change our current aggressive stance due to the number of injuries seen and concern for the risk of lifelong disability associated with a missed injury. Because we are a consulting service at CMC, the decision to involve us in a case was made by the attending orthopedic or pediatric surgeon. It is entirely possible that some arterial injuries were missed during the study period. Although we are unable to know the outcome of any patient with a missed arterial injury, the experience of Blakey et al[2] lends strength to our conviction that we should maintain a low threshold for intervention in these patients.

A second limitation is the small number of subjects in this series and the limited anatomic information available. Approximately 15% of individuals have a high proximal origin of the radial artery that may make it less prone to injury during elbow trauma.[20] Determining whether this variant provides protection in the case of supracondylar fractures is beyond the scope of the present study. Evaluating the collateral flow reserve in children with focal brachial artery thrombosis is also beyond the study's scope: some children with abundant collateral flow may be able to maintain normal growth and hand function despite brachial artery occlusion. We again stress the findings of Blakey et al who noted a high incidence of permanent disability in children with untreated brachial artery injuries.[2]

A third study limitation is the relatively short follow-up. In particular, the follow-up is too short to know whether these patients will ultimately develop ischemic contractures

or limb-length discrepancy. Although the patients have done well in the short-term, we remain concerned about the long-term durability of the vascular repairs. Some of the anastomoses were performed with running monofilament suture, and we are concerned about the risk of relative narrowing during normal growth. We are also concerned about the possible risk of aneurysmal degeneration of saphenous vein grafts, as has been reported after aortorenal bypass in children.[21] The long-term patency of arterial repairs following elbow trauma has not been reported, and it remains unknown whether late graft failure would lead to arm ischemia or have consequences for limb growth. We remain cautiously optimistic but recognize the need for long-term vascular surveillance.

In conclusion, brachial artery injuries should be anticipated in children who develop hand ischemia following elbow trauma. Neurovascular entrapment at the fracture site is a possible complication of orthopedic fixation. Absence of wrist pulses after orthopedic fixation should prompt immediate brachial artery exploration. Patients with PPH can safely undergo initial orthopedic fixation, but brachial artery exploration is indicated if normal wrist pulses do not return within a reasonable period of observation. PPH should not be considered a consequence of arterial spasm in these patients.

AUTHOR CONTRIBUTIONS

Conception and design: SM, RV
Analysis and interpretation: SM, GC, JM, RV
Data collection: PB, MP, RV
Writing the article: PB, MP, RV
Critical revision of the article: PB, MP, JM, GC, RV
Final approval of the article: PB, MP, JM, SM, GC, RV
Statistical analysis: Not applicable
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Overall responsibility: RV

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