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Authors
Sabharwal, Samir
Margalit, Adam
Swarup, Ishaan
et al.

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REVIEW ARTICLE

The Pulseless Supracondylar Elbow Fracture: A Rational Approach

Samir Sabharwal[1] · Adam Margalit[1] · Ishaan Swarup[2,3] · Sanjeev Sabharwal[2,3]

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Abstract

Background Supracondylar humerus fractures are the most common type of pediatric elbow fracture, accounting for 60–70% of all elbow fractures in children. Initial trauma and subsequent fracture displacement may damage surrounding neurovascular structures, leading to reports of associated neurovascular injury at rates as high as 49%, with vascular compromise reported in 3–19% of cases. This may be attributable to complete transection, kinking of the artery with reduced flow, thrombosis, intimal tear, arterial contusion or spasm, entrapment of the vessel within the fracture site or traumatic aneurysm of the brachial artery with subsequent thrombus formation.

Purpose While there is general agreement that a child presenting with a pulseless white (dysvascular) hand associated with a displaced supracondylar humerus fracture requires emergent operative management, whether or not surgical exploration of the brachial artery is warranted in a patient with a pulseless pink hand is debatable. Given the lack of consensus, an individualized approach based on clinical findings at initial presentation, including quality of distal perfusion including doppler signal, associated median nerve injury, availability of a surgeon with microvascular skill-set, and access to vigilant post-operative monitoring, combined with an open discussion of the pros and cons of various treatment options with the family is prudent.

Methods Herein we outline our management principles, developed with careful consideration of the available literature and informed by practical experience.

Results We recommend emergent management of pulseless supracondylar fractures, especially those that present with a pulseless white hand or with a dense median nerve palsy, with operative fracture reduction and fixation. In all children presenting with a pulseless supracondylar humerus fracture, the vascular status should be reassessed after adequate fracture reduction and fixation, and in patients with continued signs of abnormal distal perfusion, such as weak or absent Doppler signals or sluggish capillary refill, surgical exploration of the brachial artery with reestablishment of adequate distal flow should be conducted immediately.

Conclusion Much of the existing evidence surrounding the supracondylar humerus fracture associated with a pink, pulseless hand is of low quality. This shortcoming should serve as an impetus for establishment of an international registry of all dysvascular pediatric supracondylar fractures, with adequate documentation of the vascular exam before and after reduction, intra-operative and post-operative management and long term follow-up, to provide optimal management guidelines based on robust evidence.

Keywords Supracondylar humerus fracture · Pulseless · Neurovascular injury · Brachial artery exploration · Ischemic contracture

Introduction

Supracondylar humerus fractures are the most common type of pediatric elbow fracture, accounting for 60–70% of all elbow fractures in children, with a peak incidence at 5–8 years [1–3]. Initial trauma and subsequent fracture displacement may damage surrounding neurovascular structures, leading to reports of associated neurovascular injury at rates as high as 49%, with vascular compromise reported in

✉ Sanjeev Sabharwal
sanjeev.sabharwal@ucsf.edu

1 Department of Orthopaedic Surgery, Johns Hopkins Hospital, Baltimore, MD, USA

2 Department of Orthopaedic Surgery, University of California, San Francisco, San Francisco, CA, USA

3 UCSF Benioff Children's Hospital Oakland, 747 52nd Street, OPC 1st Floor, Oakland, CA 94609, USA

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3–19% of cases [4–6]. This may be attributable to complete transection, kinking of the artery with reduced flow, thrombosis, intimal tear, arterial contusion or spasm, entrapment of the vessel within the fracture site or traumatic aneurysm of the brachial artery with subsequent thrombus formation [7, 8].

Anatomy and Fracture Classification

Supracondylar humeral fractures are the result of an extension or flexion force on the distal humerus, usually the result of a fall onto an outstretched hand. In extension-type injuries, which account for 95–98% of cases, the elbow hyperextends with the olecranon serving as a fulcrum, producing a fracture at the level of the olecranon fossa. Conversely, when the mechanism involves a direct force on the posterior aspect of a flexed elbow, a flexion-type injury pattern results, comprising 2–5% of cases [1, 9].

Anteriorly, the median nerve and brachial artery traverse the antecubital fossa. Posteriorly, the ulnar nerve passes posterior to the medial epicondyle. Laterally, the radial nerve crosses from posterior to anterior proximal to the olecranon fossa. In extension-type fractures, the brachialis muscle protects the anterior neurovascular bundle, but in severely displaced fractures, the displaced proximal segment may "buttonhole" through the brachialis, and potentially injure the brachial artery and/or median nerve. Additionally, the brachial artery may be tethered by its supratrochlear branch, which wraps posteriorly along the distal fracture fragment increasing the risk for injury with fracture displacement [2]. The anterior interosseous nerve is frequently injured, via a combined mechanism of direct contusion by the proximal fracture fragment and coronoid fossa, as well as stretch neuropraxia during fracture displacement, due to distal attachment of the nerve to the interosseous membrane [10].

Wilkins's modification of Gartland's original classification categorizes the degree of anteroposterior displacement of the distal fragment on a lateral radiograph for extension type fractures [11, 12]. Leitch and colleagues further modified this schema to include a type IV fracture, one with multidirectional instability secondary to circumferential periosteal disruption [13]. Although posterolaterally displaced fractures (Fig. 1) are less frequent, they are more often associated with neurovascular compromise (64%), as the anteromedially displaced proximal fragment is in close proximity to the neurovascular bundle [12].

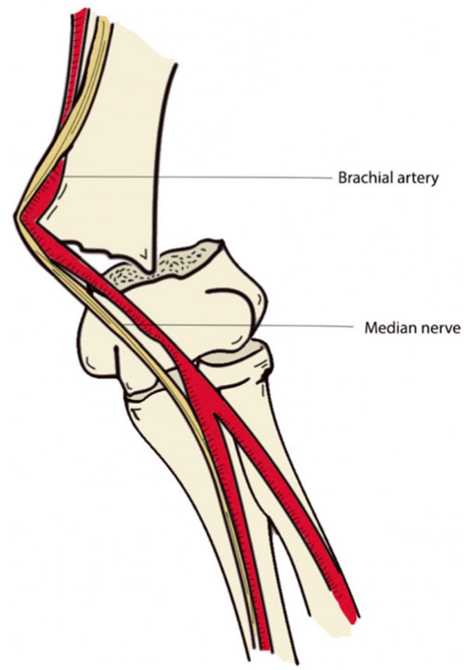

Fig. 1 Anatomical schematic of posterolaterally displaced Gartland III supracondylar humerus fracture, with tenting of the anterior neurovascular structures

Initial Assessment

Comprehensive physical examination and clear documentation of findings at the time of initial presentation is critical [2]. Vascular status should be assessed by inspection of the hand (whether it is pink along the palmar surface and distal pulp, indicative of perfusion, or pale) and palpation of the radial pulse. If not readily palpable, a Doppler ultrasound should be used to assess the presence and quality of radial and ulnar artery signals. Capillary refill should also be assessed and compared to the contralateral uninjured limb. Advanced noninvasive vascular modalities, such as color-coded duplex scanning with ultrasound velocimetry, may provide additional diagnostic information [14], but are not routinely performed if they delay management. In addition, complete motor and sensory neurologic examination including the function of the median, posterior interosseous, anterior interosseous, ulnar and radial nerve distributions should be conducted. Weller and colleagues found a significantly higher incidence of nerve palsy (most commonly the anterior interosseous nerve, followed by the posterior interosseous and ulnar nerves) among patients initially presenting without a palpable radial pulse (31%) versus those with a palpable pulse (9%) [15].

If the skin at the fracture site is disrupted, in the case of an open fracture, the appropriate antibiotics should be promptly administered. Skin puckering or ecchymosis over the antecubital fossa (Fig. 2) indicates that the proximal fragment may have pierced the brachialis with resultant hemorrhage and should heighten suspicion for impending compartment syndrome [2]. Gentle traction and splinting the extremity in approximately 30 degrees of flexion at

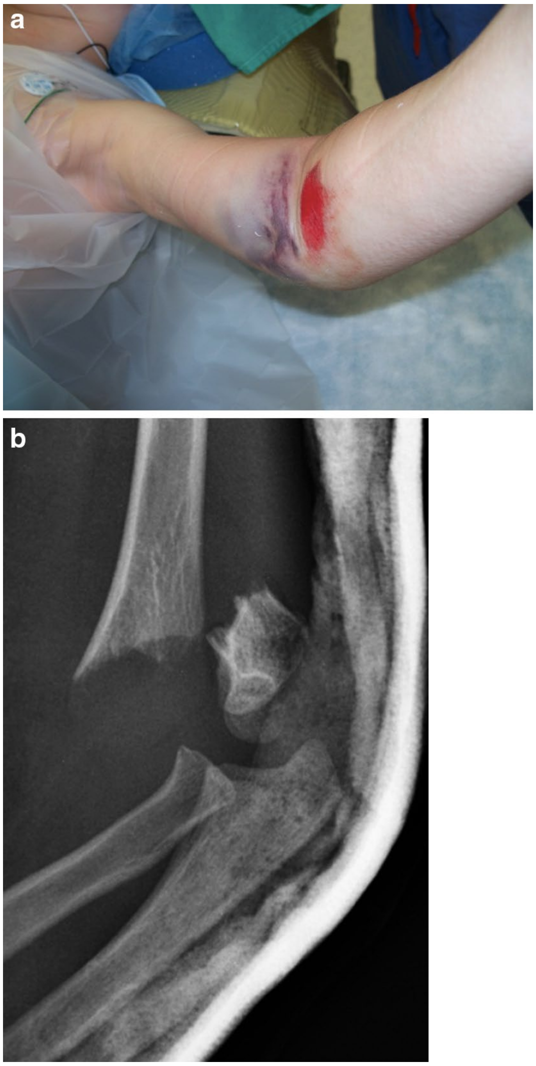

Fig. 2 Clinical picture (**a**) of ecchymosis in the antecubital fossa, in a young child with a Gartland III supracondylar humerus fracture (**b**). This indicates that the proximal fragment may have pierced the brachialis with resultant hemorrhage and potential entrapment of the neurovascular structures. Note the posterolateral displacement of the distal fragment, which is more likely to be associated with neurovascular injury in this setting. This finding should also heighten suspicion for an impending compartment syndrome

the elbow may relieve tension from the anterior structures until definitive reduction and stabilization [2].

Operative Management

Decision Making

While there is general agreement that a child presenting with a pulseless white (dysvascular) hand associated with a displaced supracondylar humerus fracture requires emergent operative management, whether or not a surgical exploration of the brachial artery is warranted in a patient with a pulseless pink hand is debatable. In fact, the clinical practice guidelines for the management of dysvascular supracondylar humerus fractures published by the American Academy of Orthopaedic Surgeons comprises consensus opinion-based recommendations in the absence of reliable evidence [16].

There are two schools of thought regarding the management of a pulseless pink hand following satisfactory closed reduction and fixation of a supracondylar fracture. Proponents of the "wait and watch" philosophy cite the presence of a rich collateral circulation around the pediatric elbow that maintains the viability of the distal extremity despite lack of brachial artery patency, reports of the return of a palpable radial pulse hours or days following reduction and pinning, re-occlusion following vascular repair or interposition vein graft due to the small caliber of pediatric vessels, and limited clinical evidence of any long-term sequelae such as cold- or exercise induced-intolerance in these patients [5, 15, 19, 21, 23]. Others advocate an open approach to reestablish the patency of the brachial artery in a child with a pulseless pink hand, raising concerns of loss of limb viability in the early post-operative period and a missed opportunity to reestablish vascular patency in the acute setting, which may minimize the risk of any long-term sequelae affecting the growth and function of the limb [2, 3, 7, 8, 17, 20]. Given the lack of consensus, an individualized approach based on clinical findings at initial presentation, including quality of distal perfusion including doppler signal, associated median nerve injury, availability of a surgeon with microvascular skill-set, and access to vigilant post-operative monitoring, combined with an open discussion of the pros and cons of various treatment options with the family is prudent. Herein we outline our management principles, developed with careful consideration of the available literature and informed by practical experience (Fig. 3).

Timing

Emergent operative management is recommended in patients presenting with a pulseless supracondylar humerus fracture—although sufficient data regarding specifics of timing is lacking, we recommend that any patient with a pulseless supracondylar humerus fracture be brought to the operating room as soon as safely possible. Given the limb-threatening nature of the injury, a child with an abnormally perfused hand associated with a dense median nerve palsy, or a persistent white hand despite gentle traction and splinting in the emergency department, needs emergent access to the operating room.

Equipment and Personnel

In terms of equipment, in addition to fluoroscopy and a Kirschner wire set with powered collet, a sterile tourniquet,

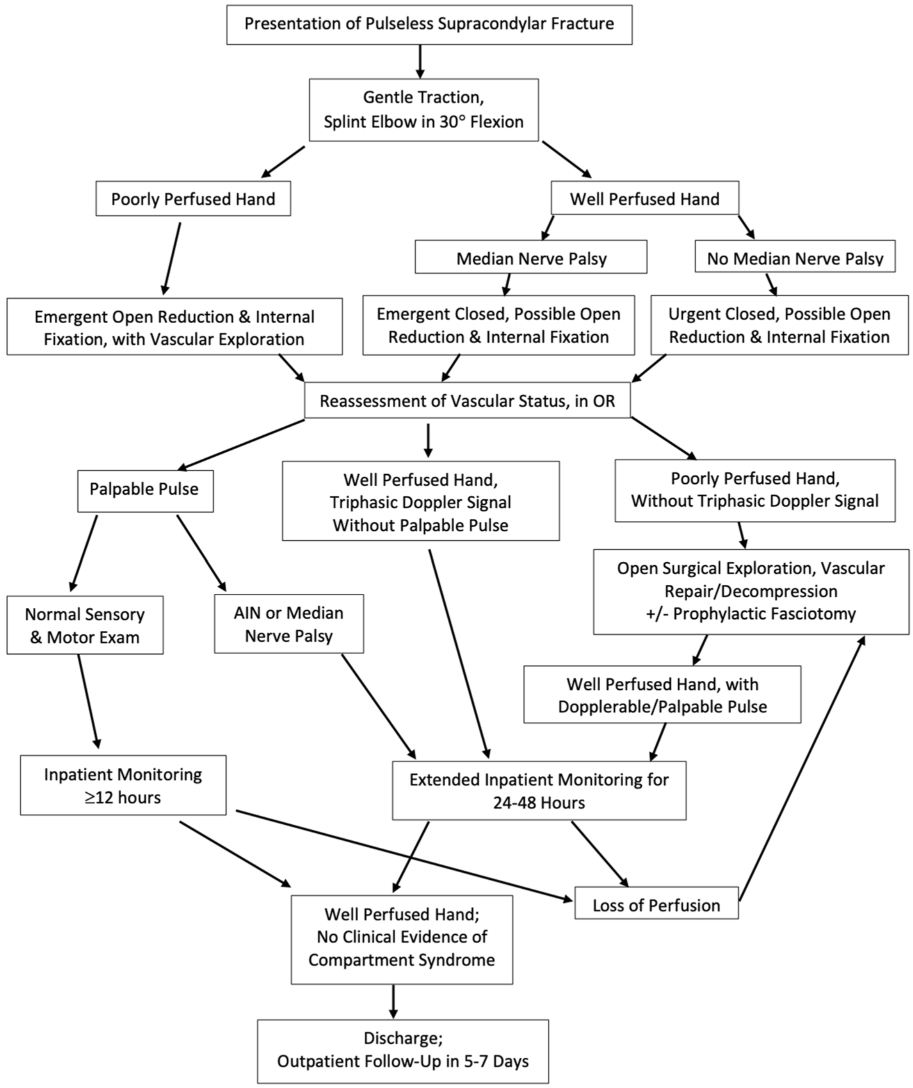

Fig. 3 Algorithm for management of pulseless supracondylar humerus fracture, based on principles outlined and clinical experience

Doppler probe, and appropriate orthopaedic and vascular instrument trays should be available in the operating room, in case open surgical exploration is warranted. Use of a headlight and loupe magnification is also helpful. There should be communication with the vascular surgeon preoperatively, in case vascular exploration or reconstruction is needed and the orthopedic surgeon is not experienced in performing vascular repair.

Fracture Reduction and Fixation

Operative management consists of fracture reduction and internal fixation, which often leads to restoration of pulse and perfusion, as multiple authors have demonstrated [2, 3, 5, 15, 17–21]. The standard reduction maneuver, namely longitudinal traction, with forearm supination followed by elbow hyperflexion, is performed. Surgeons should be aware that neurovascular structures may be interposed in the fracture site and should have a high index of suspicion when a pulseless supracondylar fracture poses a difficult reduction, or there is a "spongy" feel with a residual anterior gap at the fracture site visualized on fluoroscopy. Such interposition should also be considered when previously present triphasic Doppler signals are lost after reduction and fixation, and should prompt pin removal and open exploration via an anterior approach, as discussed in the section below.

Once a satisfactory fracture reduction is achieved, typically 3 percutaneously placed, lateral entry smooth Kirschner wires (1.6 mm or 2.0 mm diameter) may be safely inserted in a divergent fashion with bicortical purchase, starting either at or slightly posterior to the lateral supracondylar ridge, caudal to where the lateral supracondylar ridge line diverges from the proximal extent of the supracondylar ridge on an AP elbow radiograph [22]. In case of an open reduction, while it is tempting to visualize the fracture site while inserting the pins, doing so prior to gaining sufficient stability can lead to loss of fracture reduction related to the extension of the elbow. Thus, fluoroscopic guided pin fixation is recommended, even when performing an open reduction. The fracture site can be inspected for stability after adequate pin fixation has been obtained. Pulse and perfusion status, including the quality of Doppler signal, as well as maintenance of fracture reduction is reassessed in the operating room after obtaining adequate fracture reduction and fixation and positioning the elbow in approximately 60–70 degrees of flexion.

Surgical Exploration

Bae and colleagues, in a recent review and analysis of available evidence, conclude that surgical exploration with direct visualization of the brachial artery is warranted in patients with either a cool, avascular hand at presentation, or a pink, pulseless hand when signs of altered perfusion—such as ischemic pain, sluggish capillary refill, or abnormal Doppler signal—persist after fracture reduction and stabilization [3].

Surgical exploration may be conducted via a sigmoidal anterior incision in the antecubital fossa, with the transverse limb in the elbow crease, allowing direct access to both the fracture site in the region of periosteal disruption and the neurovascular structures of concern [2]. The brachial artery should be identified proximal and distal to the fracture site—if found to be interposed or tethered at the fracture site, it may be gently extricated with blunt dissection. Papaverine or lidocaine may be applied locally to relieve arterial spasm if no intimal injury is suspected [3]. Some have used the direct local injection of thrombolytic agents, such as urokinase, in patients with an intravascular thrombus [19]. If the pulsatile flow is not restored, or if there is clear evidence of arterial transection or intimal injury with a persistently white hand, revascularization via resection of the injured segment and either direct end-to-end repair or interposition reversed cephalic or saphenous vein grafting should be promptly conducted, with consideration of prophylactic forearm fasciotomy in cases of prolonged ischemia [3]. In these cases, a microvascular-trained surgeon should be available to assist with timely management.

Postoperative Monitoring

Patients with the return of a palpable radial pulse and intact distal neurologic function after reduction and fixation may proceed with routine inpatient post-operative monitoring and care for at least 12 h [2, 3]. In cases of a pink hand with Dopplerable but non-palpable radial pulse, prolonged monitoring should be performed for 24–48 h [3]. A splint with the elbow in less than 90 degrees of flexion should be placed to allow close monitoring of vascular status. If there are changes in the vascular status in the postoperative period, vascular surgical intervention may be indicated (Fig. 4).

In a large retrospective cohort study, Weller found 54 patients who were initially pulseless—26 had restoration of palpable pulse, and 20 had a Dopplerable—but not palpable—pulse with a pink hand after operative reduction and fixation. Of those with the return of Doppler signal, only 1 deteriorated post-operatively and ultimately required surgical exploration [15]. They conclude that careful inpatient monitoring of these "borderline" cases is mandatory, to identify a late-developing vascular compromise. This is echoed by Choi and colleagues—of nine patients who presented with pulseless supracondylar fractures and a dysvascular hand who initially demonstrated improved perfusion after operative reduction and fixation, three had subsequent deterioration in perfusion requiring vascular repair and delayed compartment syndrome requiring emergent fasciotomy [17].

Surgeons should be cautious of patients with concomitant vascular and neurologic injury, especially a dense median nerve palsy, as this may impede detection of developing compartment syndrome. In these patients, Bae suggests continuous pulse oximetry and careful clinical evaluation of the forearm compartments, capillary refill, and Doppler signal every 2–3 h [3]. Patients should also be monitored closely for an impending compartment syndrome, by carefully observing for increased analgesic requirement, anxiety, and agitation in children [2].

Late Sequelae

Despite robust collateral vasculature that often allows maintenance of distal limb perfusion in the face of brachial artery occlusion or stenosis, patients may still develop forearm ischemia and subsequent compartment syndrome, which—if missed or discovered late—will result in Volkmann ischemic contracture [19, 23]. In addition to ischemic fibrosis, cold- and exercise-intolerance and the limb-length discrepancy may affect these patients in the long run [2]. Osteonecrosis of the trochlea has also been demonstrated as a potential late complication of patients with dysvascular supracondylar fracture, in patients who remain pulseless but perfused after reduction and stabilization [23]. In a long-term follow-up study of 12 patients who underwent vascular reconstruction for dysvascular supracondylar humerus fractures, all patients had patent flow at last examination, but 7 had developed ectatic lesions of their reconstructed arteries [24]. This prompted the authors to recommend regular follow-up with ultrasonography in patients status post vascular reconstruction, to detect aneurysmal and thrombotic changes. Although venous thromboembolism is rare among pediatric orthopaedic patients, chemoprophylaxis with heparin or aspirin should be considered in those with risk factors such as obesity or baseline coagulopathy, as case-fatality is

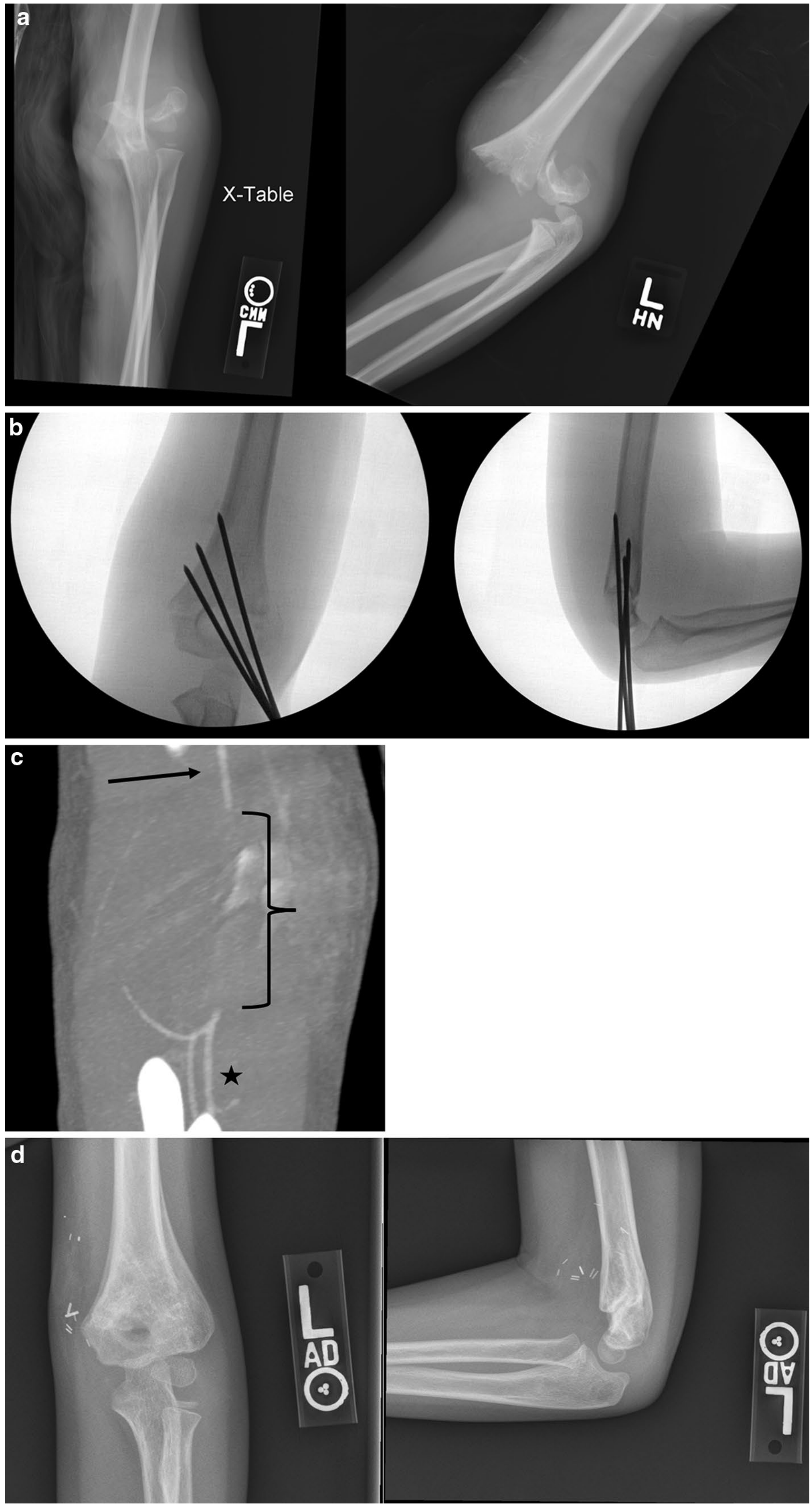

Fig. 4 Case example of 5-year-old boy presenting with a cool, pulseless hand and extension type III supracondylar elbow fracture (**a**). He underwent emergent closed reduction and percutaneous pinning with improved hand perfusion and Dopplerable radial pulse in the operating room (**b**). Within 24 h, he lost Doppler signals and the hand became cool. CT angiogram was obtained urgently, which demonstrated filling defect (bracket) of the brachial artery (arrow) on the selected coronal image, with collateral flow distally (star) (**c**). Emergent vascular surgical exploration revealed an intimal injury with the absent flow in the brachial artery, that was managed with a brachial artery bypass with interposition saphenous vein graft. At three-month follow-up, he has a palpable radial pulse and nearly symmetric elbow range of motion (**d**)

6.4% in pediatric patients with concomitant upper extremity fracture and VTE [25].

Summary

We recommend expedient management of pulseless supracondylar fractures, especially those that present with a pulseless white hand or with a dense median nerve palsy, with operative fracture reduction and fixation. In all children presenting with a pulseless supracondylar humerus fracture, the vascular status should be reassessed after adequate fracture reduction and fixation, and in patients with continued signs of abnormal distal perfusion, such as weak or absent Doppler signals or sluggish capillary refill, surgical exploration of the brachial artery with the reestablishment of adequate distal flow should be conducted immediately. Thorough postoperative monitoring is essential, as a patient may exhibit deterioration of perfusion or eventually develop compartment syndrome and may require a swift return to the operating room. Unfortunately, much of the existing evidence surrounding the supracondylar humerus fracture associated with a pink, pulseless hand is of low quality. This shortcoming should serve as an impetus for establishment of an international registry of all dysvascular pediatric supracondylar fractures, with adequate documentation of the vascular exam before and after reduction, intra-operative and post-operative management and long-term follow-up, to provide optimal management guidelines based on robust evidence.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by any of the authors.

Informed consent For this type of study informed consent is not required.

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