Current Concepts Review

Management of the Pulseless Pediatric Supracondylar Humeral Fracture

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- A pediatric supracondylar humeral fracture with a pulseless, poorly perfused hand requires emergency operative reduction. If the limb remains pulseless and poorly perfused after fracture fixation, vascular exploration and possible reconstruction is necessary.
- A pediatric supracondylar humeral fracture with a pulseless, well-perfused hand should be treated urgently with operative fixation of the fracture and subsequent reassessment of the vascular status.
- Controversy exists regarding the optimal management of pediatric supracondylar humeral fractures with a pulseless, well-perfused hand following anatomic reduction and fixation. Options include immediate vascular exploration or twenty-four to forty-eight hours of inpatient observation. If perfusion is compromised during this period of observation, an emergency return to the operating room for vascular exploration and possible reconstruction is indicated.

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Treatment of a perfused but pulseless limb following pediatric supracondylar humeral fracture remains controversial. Recommendations for management range from careful observation after operative reduction[1-5] of the fracture to immediate exploration and vascular reconstruction[6-10]. The objective of this review was to critically evaluate the pertinent literature supporting contemporary management of the pulseless limb following pediatric supracondylar humeral fracture.

Background

Supracondylar humeral fractures are the most common pediatric elbow injury requiring surgical reduction and fixation, accounting for approximately 60% to 70% of all elbow fractures in patients between five and seven years of age[1,11-14]. Fracture displacement may cause injury to the surrounding soft tissues, including the brachial artery as well as median and radial nerves, with a reported risk of neurovascular injury as high as 49%[15,16].

Associated Injuries

Vascular Injury

Vascular compromise in displaced supracondylar humeral fractures can be present in up to 20% of patients[2-4,11,15,17,18]. In most situations, the brachial artery is stretched or kinked over the displaced fracture fragments[19], particularly when it is tethered by the ulnar-sided supratrochlear branch of the brachial artery (Fig. 1). There may also be direct injury to the brachial artery. It may be contused, compressed by adjacent soft tissues, or may have sustained an intimal injury, with development of an aneurysm or delayed occlusive thrombus[6,20]. Additionally, the brachial artery may be partially lacerated or completely transected[15]. In some situations, the artery may become entrapped within the fracture

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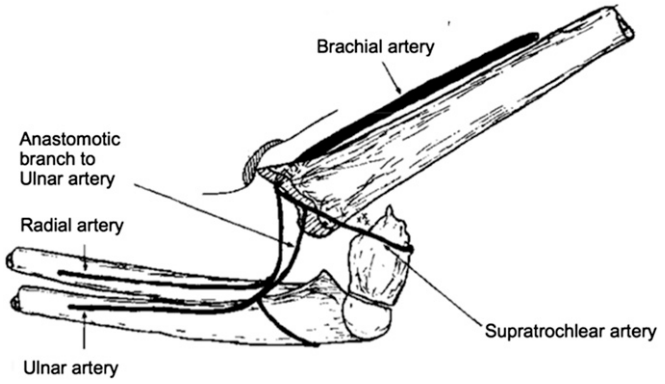

Fig. 1

Supracondylar humeral fracture with a kinked brachial artery over the proximal fracture fragment due to tethering by the supratrochlear branch of the brachial artery. (Reproduced from: Rowell PJ. Arterial occlusion in juvenile humeral supracondylar fracture. Injury. 1975 Feb;6[3]:254-6. Reproduced with permission from Elsevier.)

site at the time of injury or during fracture reduction. Arterial injuries may lead to compromised perfusion of the extremity, resulting in potentially catastrophic consequences if not recognized and treated promptly[6,20].

Neurologic Injury

Nerve injuries occur in 10% to 20% of supracondylar humeral fractures[1,15]. In the majority of cases, nerve injury is a traction neurapraxia that typically resolves with time[21]. In the case of the pulseless limb following supracondylar fracture with a median nerve deficit, the suspicion of arterial injury should be elevated. Given the anatomic proximity of the median nerve to the brachial artery, injury to one structure may predict injury to the other (Fig. 2). Luria et al. found a significant association between median nerve and brachial artery injury[22]. In a study by Mangat et al., seven patients with a pulseless hand following supracondylar humeral fracture with concomitant median nerve deficit underwent operative exploration[23]. In all patients, the brachial artery was tethered or trapped at the fracture site. In a retrospective review of 210 type-III supracondylar humeral fractures, 13.3% had a nerve injury and 59% of those involved a median nerve injury[24]. In that cohort, combined nerve and arterial injuries were seen in 2.9% of the patients. Similarly, Campbell et al., in a report on fifty-nine consecutive type-III supracondylar humeral fractures, noted that 49% had neurovascular compromise and, of those, 52% had a median nerve injury[15].

Examination

The initial evaluation and early management of a supracondylar humeral fracture is frequently performed in the emergency room setting. Emergency providers should perform a thorough vascular and neurologic examination, as well as splint the fractured extremity in approximately 30° to 45° of elbow flexion. Assessment of perfusion may be challenging, since there is no current consensus regarding objective criteria for evaluation of adequate limb perfusion.

The initial examination should establish whether there is a distal (usually radial) pulse, and whether the hand is pink. Establishing a pulse is first done by palpation. Hand color, temperature, and edema, as well as digital pulp turgor, should be assessed. It is generally accepted that arterial capillary refill should be less than two seconds; however, there is no evidence in the literature to support two-second capillary refill as a valid assessment of perfusion[25]. Additionally, there is only fair interobserver variability in assessment of arterial capillary refill[26], which may be confused with venous refill. Healthy children have been shown to have a mean capillary refill of 0.85 second in warm temperatures versus 2.39 seconds in cold temperatures[26]. Because of confounding variables, examination findings of the injured extremity should be compared with those of the contralateral, uninjured side. Prolonged arterial capillary refill of the hand, pulselessness, diminished digital pulp turgor, cooler hand temperature, pallor, and severe upper-extremity edema may be signs of a poorly perfused limb.

Continued serial examinations should include evaluation of the patient's subjective pain levels and interval changes in analgesia requirement. Increasing anxiety, agitation, and need for pain medication may reflect evolving ischemia or an impending compartment syndrome[16]. An insensate extremity due to nerve injury may mask signs of compartment syndrome.

Recognizing clinical and radiographic signs that may be risk factors for the development of compartment syndrome is imperative. A high-energy mechanism of injury is a risk factor for severe trauma to soft tissue and bone, and may lead to the development of compartment syndrome. Antecubital ecchymosis may indicate that the proximal humeral fragment has pierced the brachialis muscle and caused local hemorrhage. Puckering of the anterior skin results from the proximal humeral

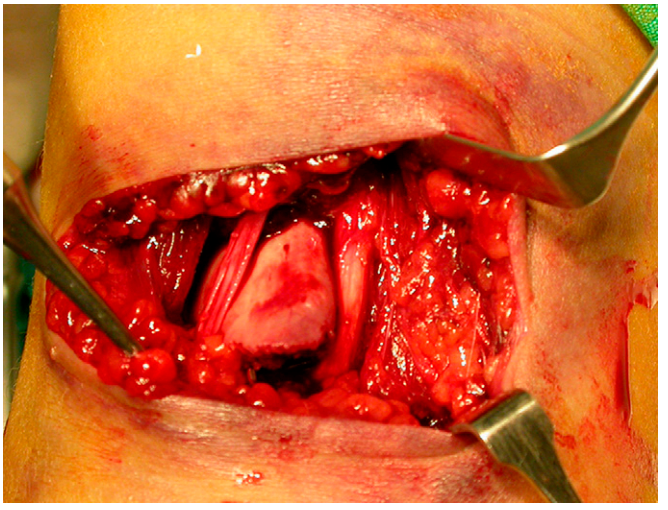

Fig. 2

Supracondylar humeral fracture with the median nerve and brachial artery tethered over the fracture site. (Reproduced from: Aksakal M, Ermutlu C, Sarisözen B, Akesen B. Approach to supracondylar humerus fractures with neurovascular compromise in children. Acta Orthop Traumatol Turc. 2013;47[4]:244-9. Reproduced with permission of Acta Orthopaedica et Traumatologica Turcica.)

fragment piercing deeper tissue and tenting the deep dermis of the anterior aspect of the arm. Gartland type-III fractures have been shown to have volar forearm compartment pressures that are on average 5 to 19 mm Hg higher than those of Gartland type-II fractures[27]. Suspicion of compartment syndrome should be elevated with increasingly displaced fractures.

Skin integrity should be carefully evaluated for open fractures. An open fracture is generally the result of the proximal fragment piercing the brachialis muscle and anterior portion of the skin, but this can occur medially or laterally as well. Areas of tenderness proximal or distal to the elbow; decreased range of motion of the shoulder, elbow, wrist, or hand; and swelling should be evaluated radiographically as these findings may signify concomitant ipsilateral extremity fractures. In a cohort of nine patients with a displaced ipsilateral forearm fracture associated with a supracondylar humeral fracture, three developed compartment syndrome[28].

A pulseless, poorly perfused hand requires emergency treatment, and a pulseless, well-perfused hand should be treated in an urgent fashion (Fig. 3). If the provider is uncertain of the perfusion status in a pulseless limb, the patient should be taken to the operating room emergently. If the limb is dysvascular for greater than six hours, prophylactic volar forearm compartment releases may be indicated; however, sufficient data are lacking. Notifying a general, vascular, or microvascular surgeon of the potential need for subsequent vascular repair or reconstruction may be prudent.

Doppler Ultrasonography

There is little evidence regarding the role of Doppler ultrasonography in guiding the management of a pulseless limb following supracondylar humeral fracture preoperatively or postoperatively. There is no evidence that treatment should be delayed, even if a pulse can be detected with a Doppler ultrasound device[5].

Angiography

Prereduction angiography is not recommended and should not delay fracture reduction in the pulseless limb following supracondylar humeral fracture[2,5,29]. Some authors have argued that defining and localizing the vascular injury is not aided significantly by angiography[2,29], in part because the site of vascular injury may be assumed to be at the fracture site if there is no other substantial trauma to the limb. In fact, angiography and ultrasound may increase ischemic time to the limb and delay definitive treatment[1-4,7,17,29,30]. In the study by Choi et al.[3], thirty-three patients presented with a pulseless limb following supracondylar humeral fracture, and twenty-four of them had a well-perfused hand. None of the twenty-four patients with a perfused but pulseless hand after sustaining a supracondylar humeral fracture had a preoperative angiogram. Twenty-one patients underwent closed reduction and pinning, and three patients had an open reduction and fixation without vascular exploration. All twenty-four had clinical improvement after reduction and fixation of the fracture[3]. Similarly, in another series of 143 Gartland type-III fractures, seventeen patients (11.9%) were reported to have vascular compromise[2]. Preoperative arteriograms were not obtained, and all patients proceeded to the operating room for reduction and pinning. Following surgery, fourteen of the seventeen patients had a well-perfused hand. Three of the seventeen patients required vascular surgical intervention. A preoperative angiogram would not have changed initial medical decision-making or helped to identify the patients requiring vascular surgery in a more efficient manner[2].

There is also limited evidence supporting a postreduction angiogram to assess vascular status. Luria et al. reported on twenty-four children with a pulseless limb after sustaining a supracondylar humeral fracture, eleven of which were explored[22]. Six of the eleven children received a postreduction angiogram for lack of a palpable pulse following reduction. The authors expressed the opinion that postreduction angiography in this cohort aided diagnosis and thus improved management, as five intimal tears and one vasospasm were identified. Further data supporting this opinion are limited.

Other Diagnostic Modalities

There is little information on the role of pulse oximetry in the assessment of the pulseless limb following supracondylar humeral fracture. Soh et al. demonstrated that the presence of a pulse oximeter waveform in the postreduction, pulseless, well-perfused hand predicted good results in all twenty-two patients in their study without the need for further surgery[31]. In four children with a pulseless, well-perfused hand and absent pulse oximeter waveform, arterial surgery was performed with good results; however, no conclusions can be drawn from these data, as we do not know if the patients would have had good results with observation alone. Near-infrared spectroscopy has been used experimentally to determine vascular compromise in pediatric supracondylar fractures, but there are no recommendations as to how this can be used in clinical decision-making and the technology is not routinely available[32].

Management

Initial Immobilization

Partial reduction of a supracondylar humeral fracture in a pulseless limb may be attempted in the emergency room, unless the patient is emergently en route to the operating room[14]. Flexing the elbow to approximately 30° to 45° and applying gentle traction may restore the pulse and improve perfusion, with very little risk of causing harm. This maneuver relieves tension from the anterior structures, and may separate the sharp edge of the proximal fragment from the brachial artery and median nerve. The arm may then be splinted in slight flexion with loose bandages and elevated until surgery. It is recommended that supracondylar humeral fractures not be immobilized in >90° of flexion at any time, as this has been shown to increase compartment pressures and decrease perfusion to the distal part of the extremity. Compartment pressures, however, have not been shown to be significantly different in supracondylar humeral fractures immobilized at 0°, 40°, and 90° of flexion[27,33]. Immobilization in flexion beyond 90° or in full elbow extension should be avoided in the displaced supracondylar humeral fracture.

A Poorly Perfused, Pulseless Limb

The treatment algorithm is clear and widely accepted for the supracondylar humeral fracture with a poorly perfused, pulseless

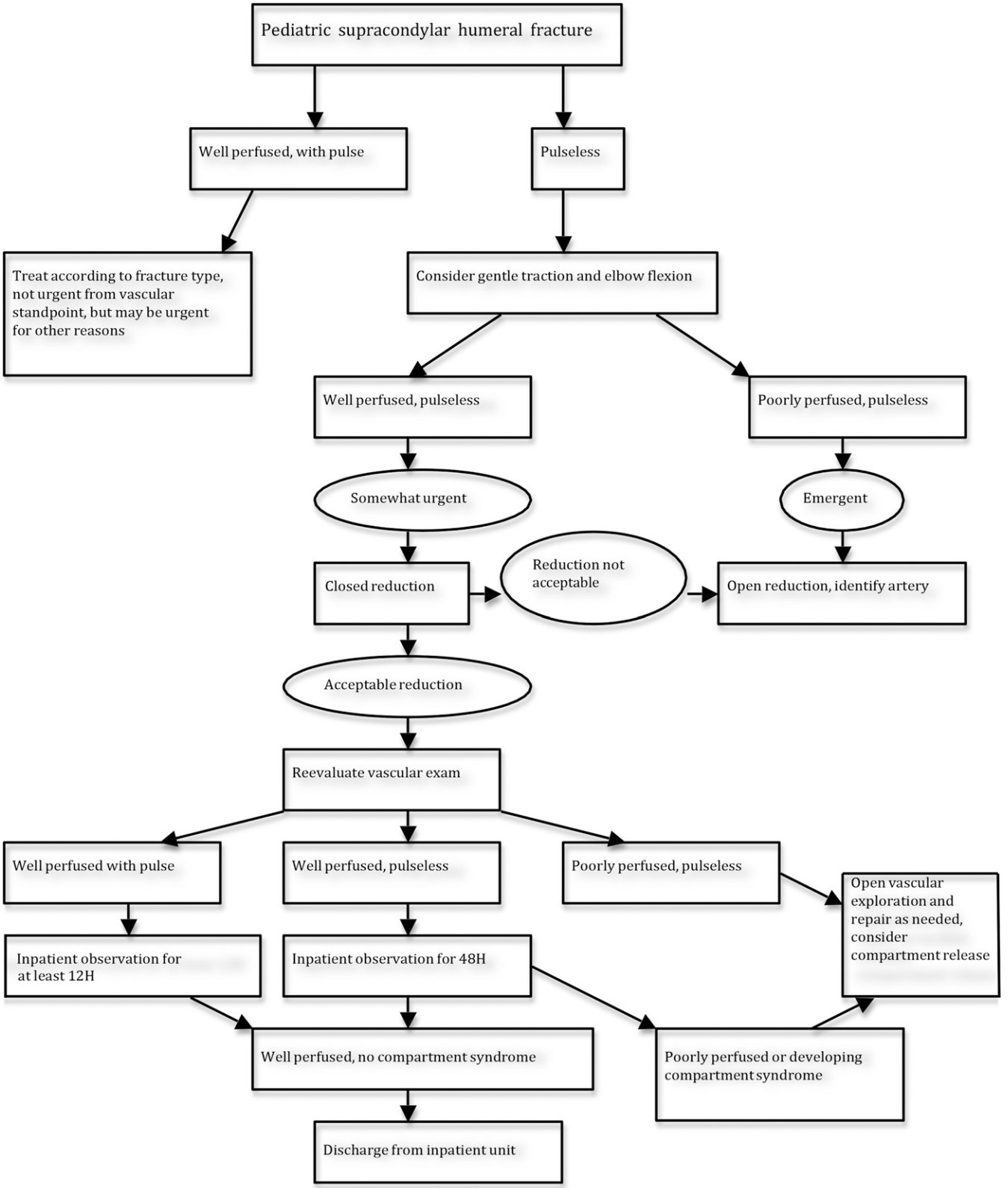

Fig. 3

Flowchart for the management of the pediatric supracondylar humeral fracture with or without vascular compromise.

limb, i.e., one that is lacking a palpable pulse and with signs of distal ischemia such as a cool, pale hand. Standard management includes emergency operative fracture reduction and stabilization, usually with percutaneous pins.

Reduction of a supracondylar humeral fracture often leads to restoration of perfusion and the pulse[1,3,4]. Choi et al., in a report on thirty-three patients with a pulseless limb following supracondylar humeral fracture, noted that nine patients had a poorly perfused and pulseless hand[3]. All nine underwent closed reduction and fixation, which alone resulted in return of the pulse without further vascular intervention in five patients. The remaining four patients required open vascular reconstruction, which was complicated by compartment syndrome in two of the four. In another series, fracture reduction resulted in return of palpable pulses and a well-perfused hand in 157 (47%) of 331 patients who initially presented with a pulseless limb following supracondylar humeral fractures[8]. Furthermore, additional studies have demonstrated return of palpable pulses and a well-perfused hand in 53% to 72% of patients treated with closed reduction and fixation[1,2,5,16]. In patients with a persistent lack of perfusion and pulselessness in the involved limb despite attempted fracture reduction, immediate open vascular exploration is indicated as brachial artery injury rates have been reported to be as high as 82% in this scenario[8]. Under these circumstances, it is prudent to consult general, vascular, or microsurgery services emergently.

When an open exploration and reduction is warranted, a 4 to 5-cm transverse anterior incision in the antecubital flexion crease is recommended. This approach allows access to neurovascular structures and to the fracture site in the region of periosteal disruption. The brachial artery may be surrounded by hematoma, which should be carefully evacuated. The brachial artery is frequently tethered to the fracture by a fascial band or arterial adventitia. Usually, decompression of the artery is sufficient to restore arterial inflow and distal pulses. In a study of twenty-seven patients with a vascular deficit following supracondylar humeral fracture that required open exploration, Rasool and Naidoo found that the neurovascular bundle was anterior to the fracture site in eighteen patients, posterior to the fracture site in five patients, and split by the fracture spike in four patients[19]. If the brachial artery is injured, it is likely injured at the level of the supratrochlear artery. If the brachial artery has been transected, retraction of the proximal and distal ends may require more extensile exposure beyond the zone of injury. The brachial artery may be in continuity without adequate distal flow. Potential etiologies include intimal injury and/or thrombus. Vascular reconstruction with interpositional reverse vein grafting may be required.

If there is still inadequate perfusion and absent distal pulses after exploration and decompression, but the artery is in continuity, the vessel may be in spasm. In these situations, increasing the ambient temperature in the operating room and application of topical agents such as lidocaine or papaverine may allow for resolution of vasospasm and restoration of distal arterial flow[34,35]. Vasodilation and thus perfusion may also be increased with a stellate ganglion block. Catheterization and thrombolysis of a vascular occlusion is not recommended, nor widely accepted, for use in this setting.

A Well-Perfused, Pulseless Limb

In contrast to treatment guidelines for the pulseless, ischemic hand following supracondylar humeral fracture, the treatment algorithm for a pulseless, well-perfused hand following supracondylar humeral fracture, i.e., the so-called pink but pulseless hand, is controversial. To date, the American Academy of Orthopaedic Surgeons (AAOS) has been unable to establish definitive clinical practice guidelines[36]. This is due to the paucity of scientific literature with a high level of evidence.

Following reduction and stabilization of a supracondylar humeral fracture, the vascular status should be reevaluated. Reduction of the fracture can often lead to restoration of palpable distal pulses[1,4,20], and if the pulses are restored, there will be no need for vascular intervention. If the pulse does not return but the hand remains well perfused, optimal management is less clear.

Proponents of more conservative approaches, including watchful waiting with frequent neurovascular monitoring, have argued that perfusion, not the presence or absence of a pulse, has a more important bearing on long-term outcome. The so-called pink, pulseless hand is due to a transient brachial arterial spasm and/or to a brachial artery injury with distal perfusion maintained by rich collateral circulation at the elbow. In the study by Choi et al.[3], twenty-four of thirty-three patients with a supracondylar humeral fracture presented with a well-perfused but pulseless hand. The fractures were reduced and stabilized operatively, and the hand remained perfused through the observation period in all twenty-four patients, with twelve of them having restoration of the pulse. Likewise, in a series of 403 supracondylar humeral fractures[12], nine (2.2%) of 403 had an absent pulse, and only one of nine required exploration due to diminished perfusion. All patients with a perfused but pulseless hand were observed without need for subsequent vascular surgery. In an intermediate-term functional outcomes study[37], thirty-six (9%) of 391 patients had a perfused but pulseless hand following supracondylar humeral fracture. They were managed with closed reduction and pinning, followed by inpatient observation for twenty-four to thirty-six hours. Following discharge, twenty of the thirty-six patients were followed for twenty months. Five of the twenty had a brachial artery occlusion, but none of the patients developed ischemic sequelae and all had eventual return of the distal radial pulse. Doppler signal after surgery was not predictive of long-term brachial artery patency; however, complete median nerve deficit (not isolated anterior interosseous nerve injury) was predictive of brachial artery occlusion. All patients demonstrated normal development of the extremity and had good-to-excellent functional outcomes.

Following operative fracture fixation, conservative management of the "pink but pulseless" limb includes inpatient admission and serial examinations for twenty-four to forty-eight hours with the extremity mildly elevated, in lieu of immediate open exploration and vascular reconstruction[3,5,38]. Weller et al. reported on twenty patients with a perfused but pulseless limb following type-III supracondylar humeral fracture who underwent closed reduction and pinning[38]. These patients did not have return of a palpable pulse after surgery, but a pulse was detectable in all with a Doppler ultrasound. All were admitted for

observation, and nineteen of the twenty patients had a palpable pulse return with no clinical sequelae and without further treatment. One patient required vascular repair after demonstrating loss of perfusion during the observation period. It is recommended that, during the observation period, patients should be monitored closely for increased analgesic requirement, anxiety, and agitation[3-5,39,40]. The threshold for returning to the operating room should be low for compartment release, arterial exploration, and possible reconstruction.

Others have advocated immediate surgical exploration and/or vascular reconstruction[9] because of concern for long-term cold intolerance, exercise-induced ischemia, brachial artery thrombus with potential for propagation, late compartment syndrome, limb-length discrepancy, and limb contracture and loss. White et al. showed that up to 70% of perfused, pulseless limbs following supracondylar humeral fractures had associated vascular injuries[8]. In a long-term outcomes study of twenty-six patients with a pink, pulseless hand after a supracondylar humeral fracture who had delayed presentation, twenty-three had signs of ischemic fibrosis in the affected limb[6]. Proponents of early exploration and/or vascular reconstruction have also reported favorable clinical outcomes with aggressive management. Schoenecker et al. reported on seven patients with a pink, pulseless hand after operative reduction of a displaced supracondylar humeral fracture[7]. All seven patients underwent surgical exploration and either brachial artery untethering from the fracture site or vascular reconstruction with vein grafting. At the latest follow-up visit (mean, thirty months), all seven patients had normal pulse, circulatory status, and elbow function. Reigstad et al. reported similar outcomes following exploration and/or vascular reconstruction in five patients with a pulseless limb following supracondylar humeral fracture[10]. At the one-year follow-up evaluation, all patients had normal and symmetric upper-extremity circulation, neurologic status, range of motion, grip strength, and key pinch strength (Fig. 3).

Reports on long-term patency rates following brachial artery reconstruction in the setting of a pulseless limb following supracondylar humeral fracture have been sparse with mixed results. Sabharwal et al. reported on thirteen patients with a pulseless limb following supracondylar humeral fracture with an injury to the brachial artery, which included an occluding thrombus, entrapment at the fracture site, or an intimal flap[41]. Six of the thirteen patients had vascular reconstruction or open thrombectomy. In all six, the brachial artery became stenotic or reoccluded. In contrast, Konstantiniuk et al. reported on ten patients with a mean follow-up of fourteen years after vascular reconstruction[42]. In this cohort, all ten reconstructions remained patent, although seven of the reconstructed brachial arteries later demonstrated aneurysm formation. It has been shown that vascular repair with use of a microscope may lead to improved outcomes[43].

Recommendations Graded by Level of Evidence

1. Management of a pulseless limb following supracondylar humeral fracture should be based on the perfusion status of the extremity. Grade of Recommendation: B[44].

2. In the setting of a poorly perfused, pulseless limb following supracondylar humeral fracture, emergency operative reduction and fixation should be performed. If perfusion to the extremity does not improve after reduction, immediate open vascular exploration and possible reconstruction is indicated. Grade of Recommendation: B.

3. If there is still no pulse after untethering the brachial artery from the fracture fragments, the brachial artery may be in vasospasm. Increasing the temperature of the operating room or application of topical lidocaine or papaverine may relieve arterial spasm. Grade of Recommendation: B.

4. Urgent operative reduction and stabilization is indicated for the well-perfused, pulseless limb following supracondylar humeral fracture, i.e., the pink but pulseless limb. The pulse may return after reduction. Grade of Recommendation: B.

5. If the extremity remains pulseless but is still well perfused after fracture reduction, either immediate vascular exploration or inpatient observation for twenty-four to forty-eight hours with frequent neurovascular monitoring may lead to satisfactory clinical outcomes. If perfusion becomes compromised during observation, vascular exploration is necessary. Grade of Recommendation: C.

6. Supracondylar humeral fractures with an absent radial pulse and a median nerve injury should raise suspicion for associated vascular injury and compartment syndrome. Grade of Recommendation: B.

Overview

Management of the pulseless limb following supracondylar humeral fracture should be determined on the basis of the presence or absence of perfusion and pulse as well as fracture type. For the perfused but pulseless limb following supracondylar humeral fracture, the trend is away from aggressive management with immediate open exploration and toward conservative management with urgent closed reduction and fixation and close postoperative inpatient observation. Long-term high-quality outcomes research to further inform all branches of the most current treatment paradigm is needed. ■

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