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BRACHIAL AND FOREARM VESSEL INJURIES

Charles E. Fields, MD, Rifat Latifi, MD, and Rao R. Ivatury, MD, FACS

Brachial and forearm injuries are not uncommon traumatic vascular injuries and carry with them significant morbidity. Blunt and penetrating trauma commonly involve vascular injury to the brachial, ulnar, or radial arteries. As the specialty of vascular surgery has evolved, the ability to repair these injuries and avoid amputation while reducing mortality and morbidity rates has greatly improved. This article discusses the history of these injuries and the science behind the success and failure of treatment of these common vascular injuries.

HISTORY

On May 2, 1863, in Chancellorsville, Virginia, McGuire removed a round ball from the right hand of a patient; a second ball had entered the left forearm, and a third fractured the humerus and severed the brachial artery. General Robert E. Lee stated, "General Jackson may have lost his left arm but I have lost my right arm." As Jackson lay dying from his injuries 8 days later, arguably the history of the United States was changed forever.[11]

The mortality rate for upper extremity amputation during the US Civil War was approximately 10% to 40%.[11] No options for repair of brachial or forearm arterial injuries existed, and an upper extremity injury usually ended in amputation. Furthermore, ligation of major arteries would be the mainstay of therapy for upper extremity vascular trauma until the Korean conflict. The advancement of surgical techniques

From the Division of Trauma Surgery, Department of Surgery, Virginia Commonwealth University, Medical College of Virginia Campus, Richmond, Virginia

and antibiotics would result in an amputation rate of 13% in Vietnam.[17] Data from the Vietnam Vascular Registry also reveal a rate of amputation for brachial artery injuries of approximately 5%. Only 2% of injured brachial arteries required ligation[18]; however, almost 60% of radial artery injuries and 75% of ulnar artery injuries were ligated in Vietnam because there is much less potential for ischemia.[17]

ANATOMIC AND PHYSIOLOGIC ASPECTS

Similar to the leg, the upper extremity contains a common, superficial and profunda brachial artery. As would be suspected, ligation of the common brachial artery (55%) results in much higher amputation rates than below the profunda (25%)[4]; however, in either case, the amputation risk after ligation of the brachial artery is quite high.

The brachial artery is a continuation of the axillary artery as it passes the teres major. Here, the artery lies in close proximity to the median nerve as it passes down the arm becoming very superficial at the elbow, where it passes under the bicipital aponeurosis to give off the larger ulnar and smaller radial arteries. This bifurcation usually occurs at the antecubital crease on the skin; however, anatomic variations may place the division of the three main brachial artery branches much higher or lower in the arm. The ulnar artery gives off the interosseous artery and ends in the hand as the superficial palmar arch. The arch is incomplete in approximately 20% of patients.[22] The radial artery gives off muscular branches down the arm before terminating as the deep palmar arch joining the deep branch of the ulnar artery. Injuries below the brachial artery have the advantage of a rich collateral arterial supply around the elbow, which accounts for the much lower limb loss rate except in the case of injury to both the radial and ulnar arteries (Fig. 1).

INCIDENCE

The incidence of upper extremity vascular trauma from all modern US wars and civilian trauma has been estimated at 30%.[13] Penetrating injuries are much more common than are blunt injuries. Of these injuries, brachial artery injuries occur in approximately 50%, with radial and ulnar artery injuries accounting for approximately 25% each.[13] Modern series of these types of injuries continue to report low mortality rates, with cause of death usually related to concomitant injuries. Amputation rates are very low (0–8%).[1, 2, 9, 12, 13, 15]

MECHANISMS OF INJURY AND RELEVANT ASSOCIATED INJURIES

Arterial injury in the upper and lower arm has been described through a number of mechanisms; however, penetrating trauma is most common. A large number of these injuries occur secondary to broken glass lacerations and gunshot wounds (Fig. 2); however, with the advent

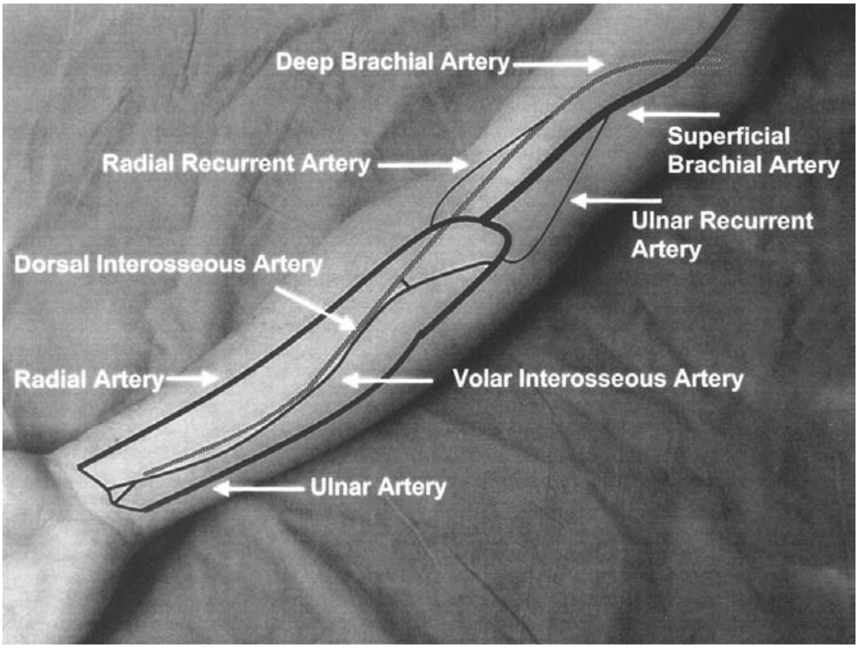

Figure 1. Arterial anatomy of the upper extremity. Note extensive collateral circulation around the elbow by way of recurrent arteries, profunda arteries and collaterals in the forearm and wrist.

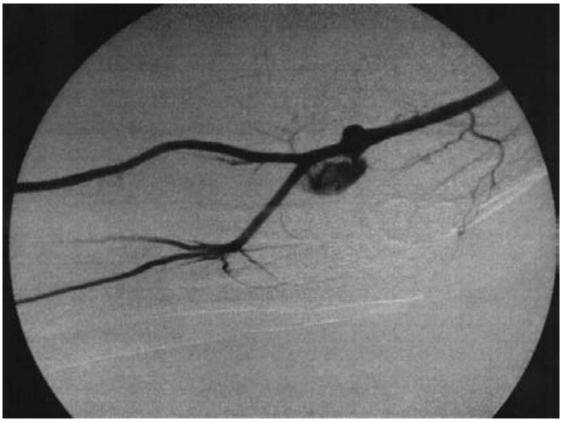

Figure 2. Upper-extremity arteriogram after gunshot wound to the arm illustrating traumatic pseudoaneurysm of the brachial artery.

Figure 3. Upper-extremity arteriogram after gunshot wound to the arm with fracture of radius and cutoff of radial artery just below the bifurcation of the brachial artery.

of minimally invasive cardiovascular therapy, the incidence of catheter-related injuries also has increased. Although accounting for a lesser percentage of these injuries, blunt trauma, especially in the presence of fractures or dislocations of the arm, accounts for a fair percentage of upper extremity arterial injury. Fracture or dislocation of the humerus, especially supracondylar fractures, should raise a high index of suspicion for arterial injury (Fig. 3). Occult injury may result in Volkmann's ischemic contractures in the long term. A variety of other injury mechanisms have been described from dog bites to helicopter crashes. Most series report that penetrating trauma is overwhelmingly the main cause of injury.

Upper extremity vascular injuries also are associated with a variety of concomitant injuries. The mortality rate associated with upper extremity vascular trauma is primarily related to other associated severe injuries of other organ systems; however, the morbidity associated with upper extremity vascular injuries frequently is related to associated injuries. Nerve injury is widely considered to be the most important factor of function.[2] A major cause of morbidity, nerve injury (35%–45%), has been described with upper extremity arterial injuries.[13] In one series, neurologic injury was associated with arterial injury in 58% of patients, whereas blunt injury was more frequently associated with nerve injury.[12] This has also been observed in other series, with Borman et al[3] noting that 73% of upper extremity arterial injuries were associated with bone, nerve, or venous injury. Injury to the median and radial nerves below the elbow provides the best prognosis, whereas ulnar nerve injury above the elbow has the worst outcome.[7, 12]

DIAGNOSIS

The general principles for diagnosis of vascular trauma should be adhered to in upper extremity vascular injury. Patients usually present with a diminished radial pulse; however, other common symptoms include abnormal forearm brachial pressure, active hemorrhage, presence of a thrill, or a palpable pulsatile mass.[12] Other symptoms or "soft signs" that should raise suspicion for injury include hematoma, proximity, and nerve deficit.[23]

Dennis et al[5] studied patients with soft signs and discovered that 20% of patients had intimal flaps compared with the quoted rate of 2% to 5%. Many of these patients eventually required operative therapy. The brachial artery had the highest rate of proximity injury.[6]

Risk factors associated with occult upper extremity vascular arterial injury include shotgun and dog bite injuries and brachial artery proximity. Orcutt et al[15] also noted that 25% of patients in their series had arterial occlusion, intimal tears, or partial transection with no pulse deficit; furthermore, 14% of patients with a radial artery injury had a palpable radial pulse. Borman et al[3] also noted that 16% of the patients in their series who had "normal examinations" with proximity injury had an underlying arterial injury.

The gold standard for diagnosis of upper extremity vascular injuries is still arteriography; however, other noninvasive diagnostic modalities also exist. Duplex is fairly reliable, except in more minimal injuries, in which the sensitivity and specificity of arteriography are superior. Schwartz et al[19] noted that less experienced sonographers were less reliable in establishing the diagnosis of these injuries and that more minimal injuries were frequently missed. In addition, CT angiography has shown some promise in recent studies, with a 4% nondiagnostic rate, 95% sensitivity, and 98% specificity compared with conventional arteriography; however, these findings are supported in small series. This may become a very useful diagnostic modality in the future because average scanning time was approximately 10 minutes and most major trauma centers have quick easy access to CT compared with angiography.[21]

SURGICAL MANAGEMENT

Expediency of repair is required for all brachial and forearm arterial injuries. Brachial artery injuries are thought to have a critical ischemia time of approximately 4 hours.[20] Although collateral circulation can provide blood flow to the hand in forearm injuries, it is thought that these injuries also should be repaired within 12 hours. Of patients whose injuries were repaired after 12 hours, only 25% return to normal arm function.[10] Approximately 20% of patients have incomplete palmar arch and need ulnar or radial repair.[15] Polytetrafluoroethylene (PTFE) has been shown to be a poor conduit.[8]

The extent of repair in brachial artery injuries is very dependent on the type of injury. Nonoperative treatment has been suggested for low-velocity injuries with minimal artery wall disruption (< 5 mm intimal defect, pseudoaneurysm, or downstream intimal flap), intact distal circulation, and no active hemorrhage.[19] In addition, venous injuries should be ligated. They are repaired immediately only if they are uncomplicated and repair can be performed expediently. Lateral arteriorrhaphy should only be attempted for small needle or catheter punctures. Furthermore, traumatic injuries rarely allow for the use of vein patching. Both of these types of repair have a higher frequency of thrombosis and late stenosis.

As a general principle, adequate hemodynamic resuscitation should be accomplished before repair and infusion of intravenous antibiotics. Temporary vascular control usually can be accomplished with digital pressure or a blood pressure cuff. Vascular repair should be performed before orthopedic repair and the repair inspected after orthopedic repair for patency and freedom from tension. Exposure of all upper extremity vessels should be by longitudinal incisions to allow for further extension and exposure of the vessel if necessary. Also, care should be taken to protect the median nerve, which is in close proximity to the brachial artery. During exposure of the vessels, associated nerve and tendon injuries should be tagged for later repair. Completion arteriography should be performed in all upper extremity injuries to examine the anastomosis, assess adequacy of repair, and rule out distal thrombi or concomitant injuries (Fig. 4).

Once the artery is exposed, adequate débridement of the injured segment is crucial to a successful repair. Areas of contusion, subintimal hematoma, and fractured intima should be débrided in addition to grossly devitalized areas of the vessel. Fogarty catheters also should be passed distally to clear all thrombus to the level of the hand. Spasm is also a common problem when repairing small arteries in the upper extremity. This can be treated by application of topical lidocaine or papaverine, administration of dilute papaverine solutions intra-arterially, direct stretch with saline or excision of the spasm segment, and grafting. Shunting can be used but may be technically difficult in small upper extremity vessels.[14]

Primary repair is usually possible with brachial injuries unless large sections of artery have been destroyed. This can be accomplished by end-to-end anastomosis with a running or interrupted technique, depending on the size of the artery. If primary repair is not possible, synthetic conduit should be avoided at all costs because of the risk for infection in a contaminated field and because of its inferior patency. Reversed saphenous vein and cephalic vein autogenous grafts both have been shown to be equally successful for interposition grafts (Fig. 5). In the event of severe destruction of the extremity or multiple other life-threatening injuries, the brachial artery can be ligated.

Forearm arterial injuries are treated in similar fashion to brachial artery injuries. The principles of resuscitation, antibiotics, distal clearing of thrombus with Fogarty catheters, and débridement still apply. If both

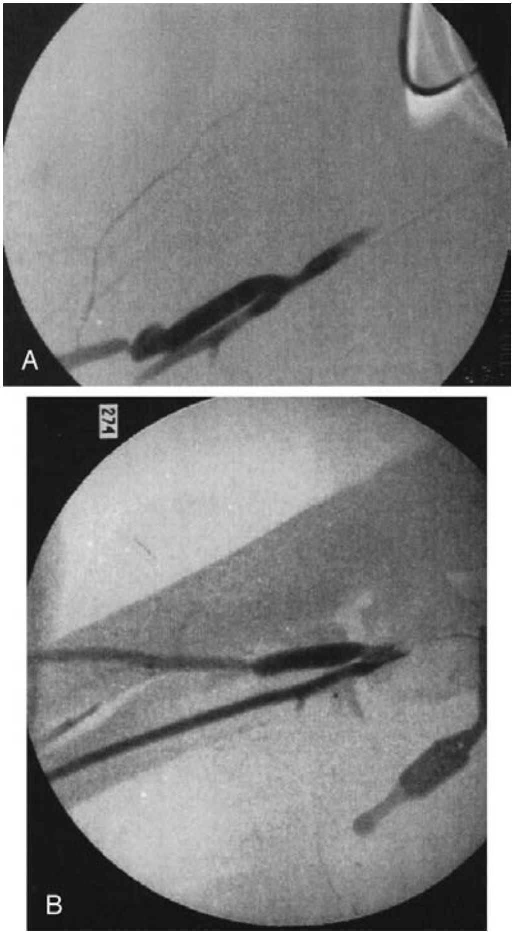

Figure 4. *A*, Completion angiogram after brachial ulnar interposition vein graft. Note the kink in the distal end of the graft secondary to redundancy. *B*, Completion angiogram after revision of the distal anastomosis showing smooth emptying of graft with good runoff by way of the ulnar artery.

the ulnar and radial arteries are injured, and circumstances dictate that only one can be repaired, the larger ulnar artery should preferentially be repaired. Again, in the face of severe or other life-threatening injuries, the artery can be ligated.

As with lower extremity injuries, fasciotomy should be considered with any arterial repair of the upper extremity, although the incidence of compartment syndrome is lower. Care should include inspection of the muscle compartments for tenseness intraoperatively and careful postoperative assessment of compartment pressures and deteriorating

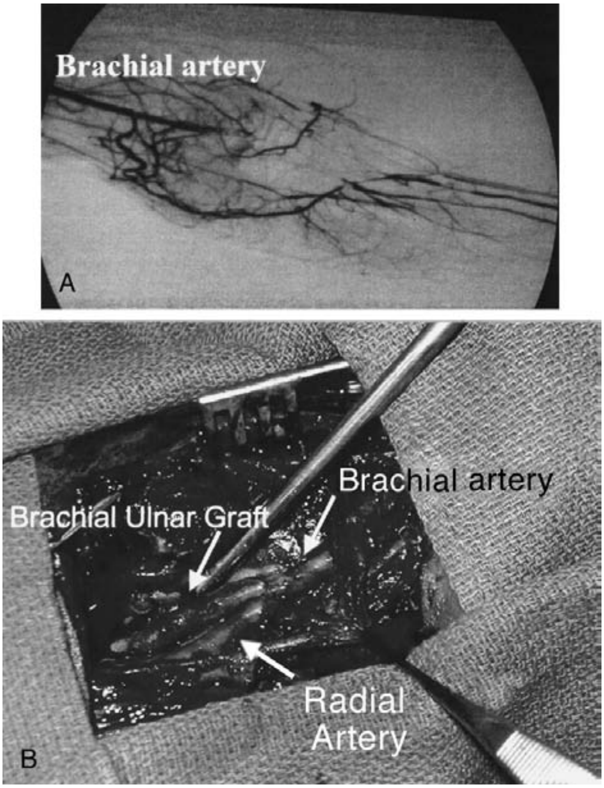

Figure 5. *A*, Upper-extremity angiogram after gunshot wound to the arm in a patient with absent radial and ulnar pulses. The angiogram demonstrates an occlusion of the brachial artery with filling of collaterals to supply the ulnar and radial arteries. *B*, Interpostion brachial to ulnar artery vein graft from basilic vein to repair a transected brachial artery at the bifurcation into the ulnar and radial arteries.

sensory examination. The first sign of compartment syndrome is usually pain on passive stretch.

The forearm contains three compartments: volar, dorsal, and mobile wad. The hand has four dorsal and three interosseous compartments, as well as the thenar and hypothenar adductor pollicis compartments. Fasciotomy should be performed for measured compartment pressures of 10 to 30 mm Hg less than diastolic blood pressure, with normal tissue pressure being less than 10 mm Hg. An incision should be made on the proximal forearm to release the antebrachial fascia from the lacertus fibrosus to the carpal tunnel. If pressures are still elevated, then a straight-line dorsal incision on the hand over the second and fourth metacarpals will decompress most of the muscle compartments. The thenar and hypothenar compartments rarely require separate incision for decompression.[16] Commonly, a carpal tunnel release is performed together with fasciotomy.

SUMMARY

Upper extremity vascular injuries are common in trauma. The mortality rate from these injuries is quite low; however, the morbidity rate is quite significant. Prompt diagnosis and treatment can reduce the amputation rate for these injuries to minimal. Furthermore, morbidity from late complications of chronic ischemia, restenosis, and cold intolerance can be decreased as well. Fasciotomy, although less frequently required than in lower extremity injuries, should be used in all cases of suspected compartment syndrome.

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Address reprint requests to

Rao Ivatury, MD
Division of Trauma Surgery
Virginia Commonwealth University
and Medical College of Virginia
1200 East Broad Street
15th Floor West Hospital
P.O. Box 980454
Richmond, VA 23298

e-mail: rivatury@hsc.vcu.edu