

Brachial vessel injuries: high morbidity and low mortality injuries

T. Vu · J. A. Asensio · F. N. Mazzini ·
J. D. Sciarretta · J. Chandler · E. H. Lieberman ·
M. Ksycki · L. Pizano

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Abstract

Introduction Reports of arterial injuries from both the civilian and military arenas report the brachial artery as the most frequently injured vessel, accounting for approximately 25–33% of all peripheral arterial injuries. The brachial artery is surrounded by important peripheral nerves—the median, ulnar and radial, and also parallels the humerus and associated veins. Due to its close proximity to these structures, associated nerve and osseous injuries are frequent with residual neuropathy from such nerve injuries, often the main sources of permanent disability.

Materials and methods Systematic review of the literature, with emphasis in the diagnosis, treatment and outcomes of these injuries, incorporating the authors experience.

Conclusions The morbidity and mortality rates associated with brachial artery injuries depend on the cause of the injury itself, which vein or tendon is injured, and whether musculoskeletal and nerve injuries are also present. During the last 20 years, amputation associated with upper extremity arterial injuries has decreased to a rate of 3% because of advances in the treatment of

shock, the use of antibiotic therapy, and increased surgical experience.

Keywords Vascular trauma · Upper extremity

Introduction

Reports of arterial injuries from both the civilian and military arenas indicate the brachial artery as the most frequently injured vessel, accounting for approximately 25–33% of all peripheral arterial injuries. The frequency of injury is similar in some reports to that of the superficial femoral artery, as both arteries are long and located in vulnerable positions in their respective extremities. Experiences from both the Korean and Vietnam conflicts have also revealed that nearly 30% of all arterial injuries involve the brachial injury.

Certain anatomical characteristics are particularly important with regard to brachial arterial injuries. There is a marked difference in the degree of ischemia resulting from injuries proximal and distal to the profunda brachii branch. Accordingly, the risk of gangrene is approximately twice as great following ligation of the common brachial as compared to the superficial brachial artery.

The brachial artery is surrounded by important peripheral nerves—the median, ulnar, and radial—and also parallels the humerus and associated veins. Due to its close proximity to these structures, associated nerve and osseous injuries are frequent, with residual neuropathy from such nerve injuries often being the main source of permanent disability. In the lower extremity, weight-bearing is the principle consideration in rehabilitation; however, in the upper extremity, functional use of the hand remains the most important outcome.

T. Vu · J. A. Asensio (✉) · F. N. Mazzini ·
J. D. Sciarretta · J. Chandler · E. H. Lieberman · M. Ksycki ·
L. Pizano
Division of Trauma Surgery and Surgical Critical Care,
Dewitt Daughtry Family Department of Surgery,
University of Miami Miller School of Medicine,
Ryder Trauma Center, 1800 NW 10 Avenue Suite T-247,
Miami, FL 33136-1018, USA
e-mail: jasensio@med.miami.edu

Historical perspective

Hallowell [1], in 1759, was the first to repair a brachial artery injury utilizing the “veterinarian’s or Farrier’s stitch”, supplanting the original technique of ligation, thus, providing the founding step for the management of vascular trauma. Torrance [2], in 1903, performed a successful suture repair of a brachial artery injury following a blunt trauma, while Jones [3], in 1919, reported two cases of brachial artery ligation following gunshot wounds with a 1-year follow-up reporting that both patients had extensive residual disability of the affected arm. Since that time, there have been many evolutionary and revolutionary advances. Even with these early reported cases, ligation remained the primary treatment during both World War I and World War II, especially in combat situations. Long transport times to definitive care, lack of antibiotics, and inadequate fluid resuscitation necessitated amputation for other than technical reasons. The results were far from desirable, with amputation rates of nearly 50% for these patients (see Table 1).

Incidence and mechanism of injury

Brachial artery injuries are the most commonly reported arterial injury of the upper extremity. In large military and civilian series, brachial artery injury accounts for 15–30% of all peripheral arterial injuries. The reason for this relatively high frequency is that the brachial artery is relatively long, superficial, and exposed when compared to other peripheral arteries. Furthermore, the upper extremity is often used as a lever, hammer, and weapon, as well as a protective or restraining device for the torso, all of which place the brachial artery at risk for injury.

Overall, vascular injuries of the extremities are infrequently reported. A recent review of the National Trauma Database (NTDB) medical records of 1,861,779 patients revealed that 1.6% of all patients sustained vascular injuries, 0.3% of all patients had upper extremity vascular injuries, and 0.1% of all patients sustained brachial arterial injuries. Brachial artery injury comprised 28% of all upper extremities injury and 15.5% of all peripheral vascular injuries; 97% of brachial artery injuries were due to

penetrating trauma [4]. Some reports showed great differences in the rate of reported brachial injuries, ranging from 14 to 50% [5–7].

Data from the military setting revealed that between 3.8 and 6.6% of injuries were vascular related [8, 9]. Brachial artery injuries accounted for 23% of all extremity vascular injuries and as much as 58% of all upper extremity vascular injuries [8]. The mean age of injury has been reported to be from 27 to 31 years of age in both civilian and military populations; males represent about 90% of the injuries in civilian and nearly 100% in all military series.

There was a preponderance of males versus females in the civilian population, with almost 90% being male, while nearly 100% of military brachial artery injuries were male [5, 9–11]. Of these injuries, the vast majority were penetrating (94%) versus blunt (6%).

Penetrating trauma remains the most common cause of brachial artery injury. Most injuries are caused by gunshot wounds, stab wounds, or lacerations from broken glass or other jagged objects, especially in civilian trauma. Rich and Spencer [12], in 1970, reported a large series from the Vietnam conflict consisting of 283 patients with brachial artery injuries; 250 of these patients sustained injuries from either fragments or shrapnel. Over 50% of the brachial artery injuries occurred secondary to fragments from various exploding devices, while, approximately 40% of the patients sustained gunshot wounds [12, 13].

Recently, the increase in the number of diagnostic cardiac catheterizations has resulted in a concomitant increase in the number of brachial artery injuries, often followed by thrombosis that are seen at most tertiary medical centers. In contrast to the civilian experience, in the military setting, thrombosis of either the axillary or brachial arteries occurs infrequently, occurring in less than 1%. With penetrating trauma being the most common mechanism of injury, the majority of brachial artery injuries found at the time of surgery are transections (60–84%), followed by lacerations (13%), thrombosis (5–16%), intimal flaps (3%), and pseudoaneurysms (15.3%), while arterio-venous (AV) fistulas are uncommon (3%) [14, 15]. Interestingly enough, isolated brachial arterial injuries occur with a frequency of 22% [15].

Blunt injury of the brachial artery occurs with a lesser frequency but deserves emphasis, as its diagnosis may be

Table 1 Military experience

Conflict	Authors	Total arteries	Brachial	%
WWI	Makins (1919) [25]	1,191	200	16.8
WWII	DeBakey and Simeone (1946) [26]	2,471	601	24.3
Korea	Hughes (1958) [27]	304	89	29.3
Vietnam	Rich (1970) [28]	1,000	283	28.3

Table 2 Civilian experience

City	Authors (year)	Total arteries	Brachial	%
Houston	Morris (1960) [29]	220	55	25.0
Atlanta	Ferguson (1961) [30]	200	29	14.5
Denver	Owens (1963) [31]	70	14	20.0
Detroit	Smith (1963) [32]	61	13	21.3
Dallas	Patman (1964) ^a [33]	271	46	17.0
St. Louis	Dillard (1968)[34]	85	26	30.6
New Orleans	Drapanas (1970) [35]	226	39	17.3
Dallas	Perry (1971) [36]	508	78	15.4
Memphis	Cheek (1975) [37]	155	21	13.5
Denver	Kelly and Eiseman (1975) [38]	116	37	31.9
Jackson	Hardy (1975) [39]	360	75	20.8
New York	Bole (1976) [40]	126	14	11.1
Indianapolis	Cikrit (1990) [41]	101	23	22.7
Johannesburg	Degiannis (1995) [42]	170	37	21.8
Cape Town (SA)	Zellweger (2004) ^b [43]	N/A	124	N/A
Izmir (Turkey)	Ergunes (2006) ^b [44]	N/A	58	N/A
Tehran (Iran)	Rasouli (2009) [45]	130	18	13.8
Chicago	Kim (2009) ^b [46]	N/A	139	N/A

^a Continuing series^b Only brachial artery injuries included in the series

easily overlooked. Supracondylar fracture of the humerus, particularly with anterior displacement or elbow dislocation, should alert the trauma surgeon to the possibility of an underlying brachial artery injury. This has resulted in the ischemic syndrome of Volkmann's contracture [16]. Fortunately, this is now a rare occurrence due to the awareness and monitoring of high-risk injuries and immediate vascular repair and/or decompression if symptoms of a compartment syndrome are present (see Table 2).

Anatomy

The brachial artery is a continuation of the axillary artery and begins at the lower border of the teres major muscle. Exiting the axilla, the brachial artery is a relatively superficial structure covered only by skin, subcutaneous tissue, and deep fascia. Proximally, it lies medial to the humerus and is accompanied by the median nerve (superiorly and laterally) and the ulnar and radial nerves (medially). Distally, it lies anterior to the elbow and is crossed by the median nerve, which then lies medial to the artery. Just proximal to the elbow, the ulnar nerve is posterior to the artery, as it goes behind the medial epicondyle of the ulna. The brachial artery terminates approximately 3–5 cm below the elbow skin crease, where it divides into the radial and ulnar arteries.

The brachial artery has three main branches. The first (most proximal) is the profunda brachii, which is accompanied by the radial nerve and passes posteriorly between the medial and long head of the triceps muscle. The

profunda brachii provides an important collateral anastomosis with the axillary artery through its posterior circumflex humeral branch. The profunda also has a collateral anastomosis with the radial recurrent artery. The profunda brachii artery has two branches; the anterior branch which anastomoses with the radial recurrent artery and the posterior interosseous recurrent artery. Both branches form additional important collateral pathways. The second main branch of the brachial artery is the superior ulnar collateral, which, accompanied by the ulnar nerve, passes behind the medial epicondyle to provide a collateral anastomosis with the posterior ulnar recurrent. The third (most distal) main branch is the inferior ulnar collateral, which provides a rich anastomotic collateral network around the elbow with the ulnar artery through its anterior recurrent branch.

Diagnosis

The diagnosis of brachial arterial injuries is often made clinically. Hard signs of injury include absent/diminished pulses, active (pulsatile) bleeding, distal ischemia, expanding or pulsatile hematoma, and the presence of a thrill or bruit. Hard signs of injury mandate immediate surgical exploration of the vessel unless the patient harbors multi-systemic injuries which are life threatening.

The use of hard signs as an indication for surgery in patients with gunshot wounds has resulted in a 100% therapeutic exploration rate [14]. Soft signs of injury include associated osseous injuries, proximity of a penetrating wound, significant hemorrhage that has ceased or



Fig. 1 A 26-year-old male with a right brachial artery injury resulting from a gunshot wound to the right axillary region. Grayscale ultrasound images demonstrating an intimal flap (arrow) along the proximal third of the brachial artery

hemorrhagic shock, neurological deficit, and hematomas. Confirmation of arterial injury in this setting requires radiological evaluation. Pulse deficit is the most common finding, occurring in 43–89% of patients with brachial arterial injuries [5, 6, 14].

Brachio-brachial indices (assuming the other extremity is uninjured) must always be obtained. A threshold of <0.9 is an indication for invasive studies or operative exploration. Additional modalities useful in making a diagnosis include non-invasive studies, such as Doppler ultrasound

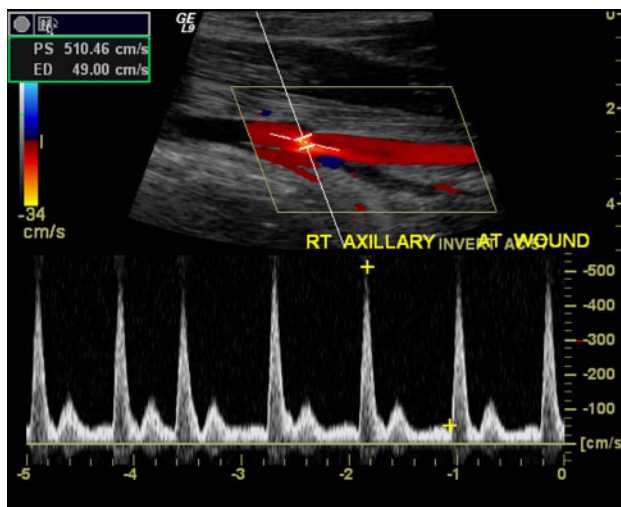


Fig. 2 A 26-year-old male with a right brachial artery injury resulting from a gunshot wound to the right axillary region. Color flow Doppler and spectral waveforms showing focal high peak systolic velocities indicating high-grade stenosis along the injury

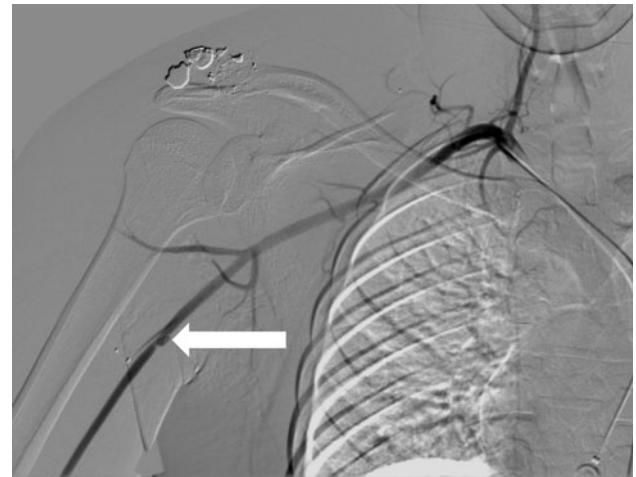


Fig. 3 A 26-year-old male with a right brachial artery injury resulting from a gunshot wound to the right axillary region. Angiogram confirming a brachial injury (arrow) and showing the bullet fragments overlying the acromioclavicular joint

(see Figs. 1 and 2). Angiography remains the gold standard for the diagnosis of vascular injuries (see Fig. 3); however, considerable advances in computed tomography angiography (CTA) are quickly overtaking standard angiography. CTA has the advantage of being quicker, more operator-independent, and more readily available than standard angiography. Approximately 10% of patients may require an angiogram. Common angiographic findings of brachial arterial injury are arterial occlusion, intimal tears, and the presence of pseudoaneurysms [6, 18].

Anatomic location of injury

The brachial artery has an almost equal distribution of injury throughout its course, with the proximal, middle, and distal being each injured about a third of the time each [15].

Surgical management

Hemorrhage can be controlled by direct pressure over an open wound. Blindly attempting to clamp a bleeding vessel in the upper extremity is never necessary and is fraught with the hazard of significant injury to the accompanying median, radial, or ulnar nerves. For suspected proximal injury, the patient should be prepped and draped in a fashion similar to that used to manage an axillary artery injury. For injuries that are more distal, prepare the arm and hand to the fingertips to allow intraoperative palpation of the radial and ulnar pulses, and prepare the contralateral leg for the possible harvesting of a conduit. The arm should be supported on a board but be mobile. The draping should

allow space for one operator to be positioned cephalad and another to be positioned caudad to the arm support.

As with most arteries in the upper extremity, exposure is best obtained by making a longitudinal incision over the bicipital sulcus between the biceps and triceps, which is easily identified by abduction of the biceps muscle from the arm. Care must be exercised in avoiding injury to the superficial basilic vein, which is easily retracted once identified. Distally, the artery dives below the bicipital aponeurosis, which should be divided in order to obtain maximal exposure of the artery. At the level of the antecubital fossa, the incision should make a laterally oriented S-curve to allow access to the bifurcation and to avoid joint contracture.

General principals of vascular exploration are applicable in the management of brachial arterial injuries. They include proximal/distal control, exploration of injured arterial segment, debridement of non-viable, vessel and identification of associated injuries (see Fig. 4). When possible, the brachial artery should be repaired. The exact method of repair is determined by the extent of the injury, the amount of damage to the surrounding tissues, and the length of the arterial segment damaged.

Interposition grafts utilizing reversed autogenous saphenous vein is the standard repair of long segmental injury (see Fig. 5). Its use has been well documented for the repair of a variety of different mechanisms of injury in both military and civil studies [5–10, 14, 17]. Simultaneous harvesting of an autogenous saphenous vein after obtaining proximal and distal control of the vessel is followed by debridement of the injured vessel and end-to-end bypass with either vein and PTFE grafts (see Figs. 6 and 7).

Smaller injuries may be treated with debridement followed by end-to-end anastomosis or simple arteriorrhaphy if the defect is small. Care must be taken, as with all

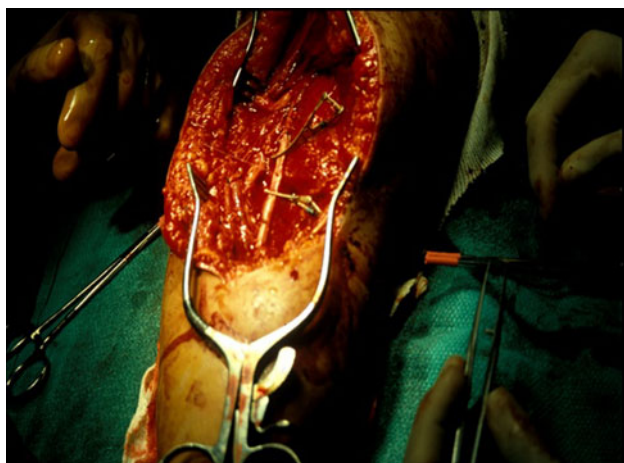


Fig. 4 Stab wound to the distal brachial artery. Notice proximal and distal control with Dietrich bulldog clamps

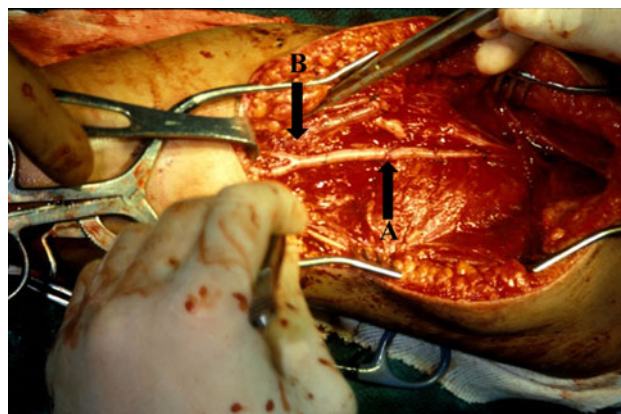


Fig. 5 Gunshot wound to the distal brachial artery. Repaired with autogenous reversed saphenous vein graft. Distal anastomosis (A) is close to the origin of the bifurcation of the brachial artery (B)



Fig. 6 Brachio-brachial bypass with autogenous reversed saphenous vein graft after segmental resection of the brachial artery secondary to gunshot wound. The Jarrell forceps point to the proximal and distal anastomosis

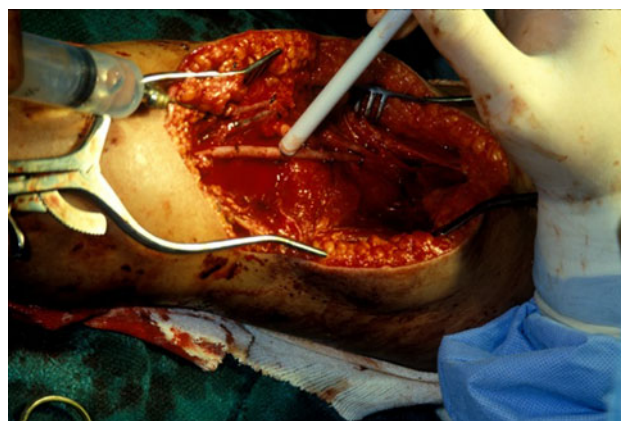


Fig. 7 The assessment of triphasic flow signals as well as flow velocities should always be carried out post-repair with a Doppler probe



Fig. 8 Gunshot wound to the left arm in a 15-year-old male resulting in a complex humeral fracture and associated brachial artery injury

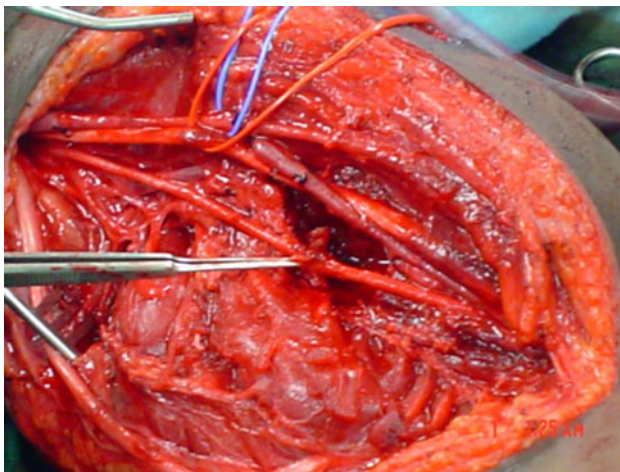


Fig. 9 Segment of thrombosed left brachial artery post-gunshot wound. The Jarrell forceps point to the thrombosed segment in this very small vessel. Red vessel loop is retracting the contused left median nerve

vascular repair procedures, to ensure that there is no undue tension on the artery.

The successful use of temporary vascular shunts has been reported in both the military and civilian arenas [19]. Temporary shunts may be used in the setting of damage control surgery, or in some instances of more complex injury and with associated fractures of the upper arm (see

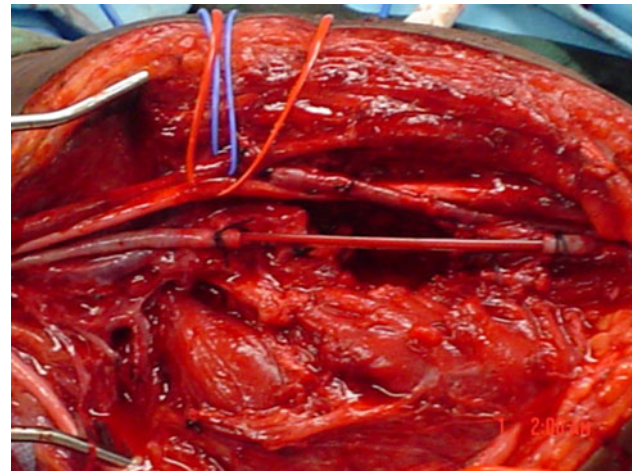


Fig. 10 Segmental resection of the thrombosed left brachial artery. The patient experienced significant vasospasm requiring intra-arterial papaverine and the use of a 3.5 coronary probe in order to dilate the vessel prior to the placement of a #8 Argyle shunt to restore blood flow in anticipation of open reduction and internal fixation (ORIF) prior to definitive vascular repair

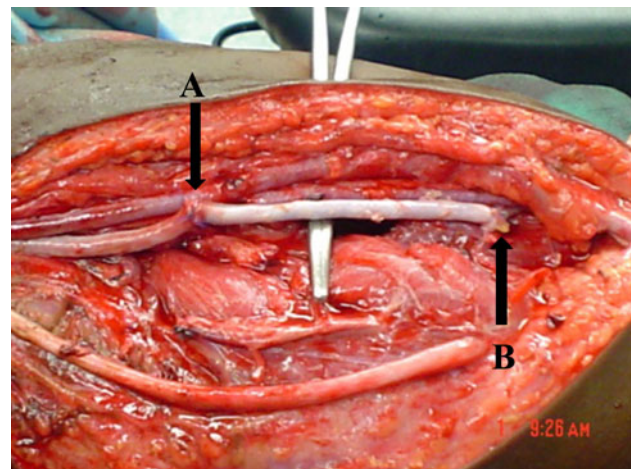


Fig. 11 Definitive vascular repair with autogenous reversed saphenous vein graft. The vessel was quite small and required 6–0 polypropylene single interrupted sutures utilizing the tripartite suture technique of Carrel. Notice the fish-mouth incisions in both the proximal (A) and distal (B) anastomosis in order to increase the luminal size. The clamp is placed through the entrances wound. The median nerve is visualized at the bottom of the picture

Figs. 8, 9, 10, and 11). In a review of shunt usage in severely traumatized patients, there was an 88% limb salvage rate. If associated orthopedic injuries are present, the most popular technique is to place an indwelling temporary shunt to restore arterial flow while the orthopedic surgeons achieve length and stability of the arm before attempting definitive vascular repair. Ligation should rarely be a consideration, as it carries a significant risk for limb loss. If



Fig. 12 A 28-year-old male sustaining a self-inflicted brachial transection injury from broken glass. Tourniquet applied to control life-threatening hemorrhage. Transected basilic vein clamped

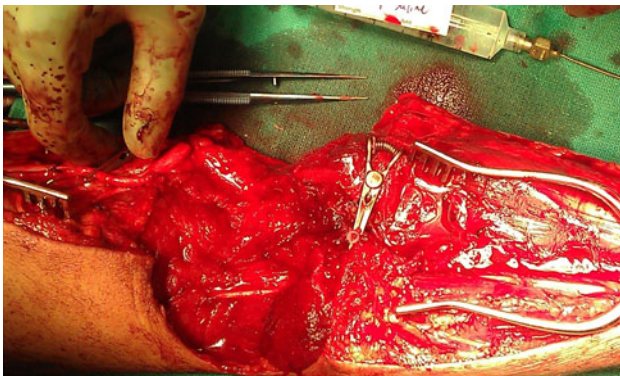


Fig. 13 A 28-year-old male sustaining a self-inflicted brachial transection injury from broken glass. This shows the proximal and distal segment of the transected brachial artery. The distal segment is located approximately 3 cm above the bifurcation. Vessel controlled with Dietrich bulldog clamps. Notice syringe with heparinized saline

the patient is in extremis from other associated injuries, surgical exposure of the brachial artery is rapidly obtained by a longitudinal incision along the course of the artery with an extension as an S-curve either across the axilla proximally or across the antecubital fossa distally, as needed. The median nerve and basilic veins are in close proximity to the artery. A temporary shunt can be placed quickly and left in place for several days without systemic heparinization.

Ligation should be reserved for life-threatening situations, overwhelming damage, or inability to repair. In the absence of ischemic signs prior to ligation, there is often a significant chance for limb survival and preservation of function [20].

Fasciotomies, if not performed initially, are often required in up to 30% of cases (see Figs. 12, 13, 14, and 15). Intraoperative blood loss, combined arterial and venous injury, and open fractures have been found to be

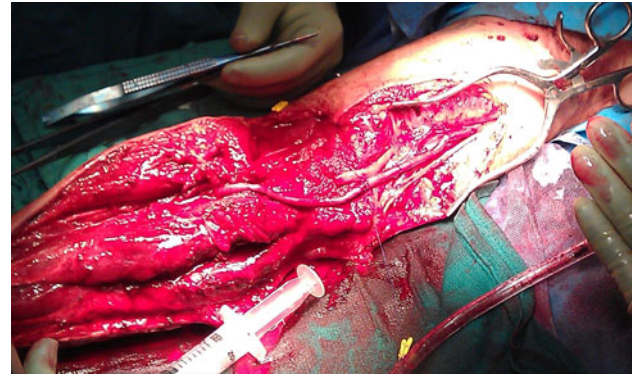


Fig. 14 A 28-year-old male sustaining a self-inflicted brachial transection injury from broken glass. This shows the brachial artery repair with end-to-end bypass with autogenous reversed saphenous vein graft extended distally to the bifurcation. The patient also had a transected proximal radial artery. Notice titanium Castroviejo forceps used for the creation of the anastomosis with 6-0 polypropylene sutures. The patient required extensive fasciotomies and carpal tunnel release

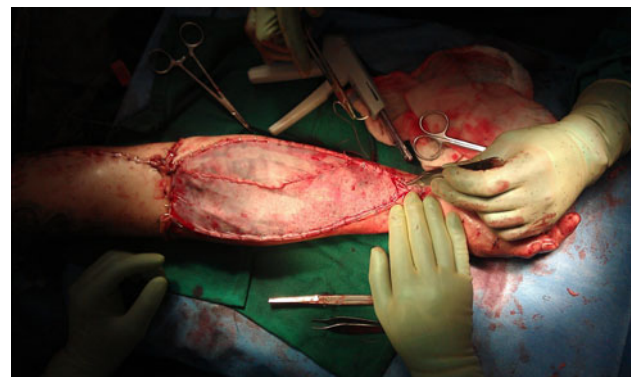


Fig. 15 A 28-year-old male sustaining a self-inflicted brachial transection injury from broken glass. Following bypass repair of the brachial artery with autogenous reversed saphenous vein graft, fasciotomy was performed and covered with cadaveric skin graft in anticipation of definitive reconstruction with autogenous skin graft 5 days after the injury

independent risk factors for the development of compartment syndrome [9, 20, 21] (see Table 3).

Outcomes and mortality

Since the early days of military operations where the primary techniques included ligation and subsequent amputation, most patients today can expect excellent outcomes if their injuries do not involve massive tissue destruction and can be repaired promptly.

Large series have reported successful brachial artery repair with primary patency rates of 92–98% [9, 14, 22].

Table 3 Surgical techniques used for the management of brachial artery injuries: civilian experience

Author (year)	No. of cases	No repair	Primary repair	Saphenous vein interposition	Prosthetic graft interposition	Ligation
Combined series (1984–1994)	223	5 (2.2%)	121 (54.2%)	87 (39.0%)	0 (0%)	3 (1.3%)
Degiannis (1995)	37	0 (0%)	13 (35.1%)	24 (64.8%)	0 (0%)	0 (0%)
Zellweger (2004)	124	0 (0%)	47 (21.1%)	74 (59.7%)	2 (1.6%)	2 (1.6%)
Ergunes (2006)	58	0 (0%)	40 (70%)	18 (30%)	0 (0%)	0 (0%)
Kim (2009)	139	0 (0%)	46 (33.1%)	82 (60.0%)	8 (57.6%)	1 (0.7%)

Kim et al. [9] reported repair failures diagnosed intra-operatively in 7.2% and Padayachy et al. [5] reported 4.4% of repair failures diagnosed immediately postoperatively. Klocker et al. and Kim et al. reported repair failures within a few days after surgery [9, 22]. Up to 10% of war-related injuries required a secondary surgical procedure. Graft replacement, thrombectomy, fasciotomy, ligation of the artery, and, rarely, amputation are the surgical options in this situation [5, 9, 19]. Mortality in this kind of injury is extremely rare and is usually related either to immediate or late complications of associated injuries [9, 14, 22].

Morbidity

Commonly associated injuries are nerve injuries (62%); stratified according to the major nerves, we find 79% of median nerve followed by ulnar nerve (23%), radial (12%), and musculocutaneous nerve injuries (4%), with multiple nerve injuries occurring in a little over 10% [15]. Approximately 13% of explorations will not yield evidence of injury and should not be seen as unnecessary or not indicated. Much like a negative exploratory laparotomy in trauma, the threshold to take the patient to the operating room must be low in order to avoid missed injuries.

Neurologic injury continues to impair the function of the upper extremity, even after a successful arterial repair. Major venous injuries, fractures, and widespread tissue destruction may also influence the long-term function of the extremity [23]. Whether primary and secondary nerve repair procedures are helpful is a point of controversy [12]. The rate of functional disability ranges from 27 to 44% when injury to the upper extremity includes nerve injuries [24].

Conclusions

The morbidity and mortality rates associated with brachial artery injuries depend on the cause of the injury itself, which vein or tendon is injured, and whether musculo-skeletal and nerve injuries are also present. During the last

20 years, amputation associated with upper extremity arterial injuries has decreased to a rate of 3% because of advances in the treatment of shock, the use of antibiotic therapy, and increased surgical experience.

Conflict of interest None.

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