Eur J Trauma Emerg Surg (2012) 38:359–371
DOI 10.1007/s00068-012-0206-x

REVIEW ARTICLE

Femoral vessel injuries; high mortality and low morbidity injuries

G. Ruiz · A. J. Perez-Alonso · M. Ksycki · F. N. Mazzini · R. Gonzalo · E. Iglesias · A. Gigena · T. Vu · Juan A. Asensio-Gonzalez

Received: 15 May 2012 / Accepted: 16 June 2012 / Published online: 1 September 2012

Abstract Femoral vessel injuries are amongst the most common vascular injuries admited in busy trauma centers. The evolution of violence and the increase in penetrating trauma from the urban battlefields of city streets has raised the incidence of femoral vessel injuries, which account for approximately 70% of all peripheral vascular injuries. Despite the relatively low mortality associated with these injuries, there is a high level of technical complexity required for the performance of these repairs. Similarly, they incur low mortality but are associated with significantly high morbidity. Prompt diagnosis and treatment are the keys to successful outcomes with the main goals of managing ischemia time, restoring limb perfusion, accomplishing limb salvage and instituting rehabilitation as soon as possible.

Keywords Vascular injuries · Management of femoral vessel injuries · Morbidity and mortality · Anatomy

G. Ruiz · A. J. Perez-Alonso · M. Ksycki ·
F. N. Mazzini · R. Gonzalo · E. Iglesias · A. Gigena · T. Vu ·
J. A. Asensio-Gonzalez M.D. FACS FCCM FRCS (England)
Division of Trauma Surgery and Surgical Critical Care,
Dewitt Daughtry Family Department of Surgery, Ryder Trauma
Center, University of Miami Miller School of Medicine,
1800 NW 10 Avenue Suite T-247, Miami, FL 33136-1018, USA

Present Address:
J. A. Asensio-Gonzalez M.D. FACS FCCM FRCS
(England) (✉)
Westchester University Medical Center, New York Medical
College, Trauma Department of Surgery, 100 Woods Road
Taylor Pavilion, Suite E137, Valhalla, NY 10595, USA
e-mail: asensioj@wcmc.com

Introduction

Femoral vessel injuries are amongst the most common vascular injuries admitted in busy trauma centers. The evolution of violence and the increase in penetrating trauma from the urban battlefields of city streets have raised the incidence of femoral vessel injuries, which account for approximately 70 % of all peripheral vascular injuries. Despite the relatively low mortality associated with these injuries, there is a high level of technical complexity required for the performance of their repair. Similarly, these injuries incur low mortality but are associated with significantly high morbidity. Prompt diagnosis and treatment are the keys to achieve successful outcomes, along with the main goals of managing ischemia time, restoring limb perfusion, accomplishing limb salvage and instituting rehabilitation as soon as possible.

Anatomy

The femoral artery is a direct continuation of the external iliac artery, located in the femoral triangle, posterior to the inguinal ligament. Its most proximal portion, known as the common femoral artery, courses deep to the sartorius muscle together with the femoral vein contained within a fibrous sheath. The lateral compartment of the femoral sheath contains the femoral artery, the middle contains the femoral vein, and the most medial compartment is the femoral canal. After a short course, the common femoral artery—which can be palpated through the skin on the proximal aspect of the inner thigh midway between the anterior superior iliac spine and the symphysis pubis—divides into the deep (profunda femoris artery) and the superficial femoral artery. The profunda femoris artery traverses deep into the thigh muscles and is the main contributor of blood flow to this area. The superficial femoral artery traverses almost the entire length of the femur and ends at the opening of the adductor magnus (also known as Hunter's canal) where it becomes the popliteal artery. The main branches of the femoral artery are the pudendal artery, the superficial epigastric artery, the circumflex iliac artery and both the greater and lesser saphenous arteries.

The femoral vein is a continuation of the popliteal vein. It accompanies the femoral artery and receives drainage both from the profunda femoris vein and the greater saphenous vein, which pierce the femoral sheath on its anterior aspect before passing under the inguinal ligament to become the external iliac vein.

Incidence

Traumatic injury to the femoral vessels accounts for approximately 67 % of all vascular injuries in the military setting. Recently, the incidence of femoral vessel injury in the civilian arena has increased secondary to an increase in urban violence. Penetrating injuries are reported in approximately 88 % of these cases and are usually secondary to gunshot or stab wounds by knife or impalement. Less common are blunt injuries, which account for approximately 12 % of all cases.

The incidence of these types of injuries has varied during the major military conflicts of the past century and has increased slightly with each conflict. During World War I, Makin's (1919) classical textbook [1] detailed a 31 % incidence rate reported by British surgeons, whereas the incidence of femoral vessel injury reported by American surgeons was lower at 22 %. DeBakey and Simeone [2], reported a total of 517 femoral arterial injuries for an incidence rate of 21 % during World War II, with a very high amputation rate of 53 %. Hughes [3] reported a slightly higher incidence of 31 % for the Korean Conflict, while Rich [4] reported a 35 % incidence of femoral vessel injuries during the Vietnam Conflict.

Historical perspective and wartime experiences

The earliest documents reporting vascular injuries date from 1600 B.C. Egyptians were known to use styptics consisting of vegetable matter, lead sulfate and copper sulfate to control hemorrhage, as reported in the Ebers Papyrus [5]. In 1000 B.C., the Chinese were first to use tight bandaging to control bleeding in the affected limb as well as styptics for the control of hemorrhage.

However, the treatment of choice for vascular injuries throughout the Middle Ages consisted mainly of cautery. In 1497, Hieronymus Brunschwig, also known as Jerome of Brunswick [6], published his work on ligatures as treatment for injuries secondary to gunshot wounds. His work was further refined in 1552 by Ambroise Paré [7], who also promoted the use of ligatures to control hemorrhage. Paré [7] additionally recommended amputation above the line of demarcation to achieve better outcomes. However, Hallowell [8] was first to attempt a vascular reconstruction in 1759, when he repaired a brachial artery with a suture known as the Farrier's stitch or veterinarian's stitch.

Some 127 years would pass until vascular repair was again attempted. During the latter part of the nineteenth century, pioneers such as Jassinowsky and Postemski [9] promoted the concept of direct vascular repair. Israel [10], in 1883, described the first successful primary repair of a lacerated iliac artery, while John B. Murphy [11, 12] from Rush Medical College in Chicago completed the first successful end-to-end anastomosis of a femoral artery in 1897. This was later followed by the first autogenous reverse saphenous vein graft to repair a popliteal aneurysm in 1906 by Goyanes of Spain. Despite these advances made at the end of the nineteenth century, it would take almost three decades before vascular repairs were again systematically utilized.

World War I

During the first part of the World War I, vascular injuries were typically secondary to the low velocity projectiles used and thus limited in occurrence; however, the second half saw the introduction of high explosive artillery with improved, high velocity munitions. The change in the destructive power of ordnance contributed to an increase in mass casualties and a decrease in the number of wounded that could be evacuated. The time between injury and definitive surgical treatment drastically increased and vascular repair became impractical. Although the chance for immediate repair was lost, vascular repair was attempted to manage false aneurysms and arteriovenous (AV) fistulas on a delayed basis.

Limited attempts at repair of femoral vessel injuries were made during World War I. Makins [1] reported the British experience of femoral artery injuries consisting of 366 arterial injuries in 1,202 patients for an incidence of 31 %. American surgeons also reported 78 femoral injuries in 344 patients for an incidence of 22 %.

World War II

The years between World War I and II showed an uneven advance between the instruments of destruction and the advent of surgical interventions. DeBakey and Simeone [2] reported a total of 2,471 arterial injuries from the European theater of war; unfortunately, nearly all were treated with ligation resulting in a very high amputation rate of 49 %. In this study, DeBakey and Simeone reported only 81 attempts at repair, of which 78 were lateral suture repairs/arteriographies with only three end-to-end anastomoses performed. Of 2,471 cases of vascular injuries reported, 517 (21%) were femoral vessel injuries.

The main factors contributing to this low number of vascular repairs included delays in transport time, lack of training in vascular trauma for military surgeons, and relative lack of access to antibiotics; although penicillin and sulfa had been introduced during this conflict, they were available only in very limited supply. Other factors included the absence of appropriate suture material, and unavailability of vascular instruments. Interestingly enough, the first vascular clamp was created by Victor Satinsky precisely during World War II.

Korean conflict

Vascular surgery advanced in leaps and bounds during the Korean conflict thanks to several factors. Improvements in anesthesia, the advent of antibiotics and the development of blood transfusions greatly enhanced the success rate of vascular repairs. Perhaps the single greatest factor was the development of forward aid stations accompanied by rapid evacuation of the wounded by helicopter, which significantly improved transport of these patients. Similarly, surgeons such as Hughes, Jahnke, Spencer and Howard demonstrated an interest in developing techniques for vascular injury repair.

Several reviews from this time period showed primary vascular repair to be gaining wide acceptance. Jahnke and Seeley [13] reported 14 femoral artery injuries for an incidence of 19 %. Hughes subsequently reported 95 femoral vessel injuries out 304 patients for an incidence of 31 %. These are amongst the earliest series in the literature demonstrating a well defined approach to the management of vascular trauma.

Vietnam conflict

Practices during the Vietnam conflict built on the previous advances in evacuation and faster transport of the wounded. Thus, a higher number of surgeons trained in vascular surgical techniques allowed for improved outcomes and patients that could now be followed up with on a long term basis as the war ended. The Vietnam vascular registry created by Dr. Norman Rich and based at the Army Medical Center of Walter Reed allowed for long term follow-up and continued evaluation of all vascular injuries from the Vietnam conflict. The landmark report from Rich [4] in 1969 showed 351 femoral artery injuries out of a total 1,000 patients for an incidence of 35 %. Unfortunately, data on femoral venous injuries from this conflict is scarce, with ligation being the standard of care noted in the wartime literature.

Iraq and Afghanistan

The Iraq and Afghanistan campaigns that have spanned most of the last decade have seen significant improvements in the overall survival of combat casualties. Increases in survival rates can be attributed to the wide use of body armor which has dramatically decreased torso injuries, the widespread use of pre-hospital tourniquets, and the use of damage control techniques along with the rapid evacuation for definitive surgery to Landstuhl Regional Medical Center and subsequently to the continental United States (CONUS).

The injury patterns seen in these two conflicts are notably different than in other wars. Due to the widespread use of body armor, the number of torso injuries has decreased significantly, however there has been a great increase in head injuries and distal extremity vascular injuries. These changes in injury patterns resulted from the departure from regular warfare to counter-insurgency combat which involves ambush techniques and the utilization of anti-personnel devices such as improvised explosive devices (IED). The use of high explosives in these IEDs has resulted in a very large incidence of severe extremity injuries and in some cases, multiple amputations. There have also been a large number of vascular injuries.

Data collected from war registries [14, 15] have shown a general increase in the incidence of all types of vascular injuries, which has accounted for 4 to 9 % of the total combat casualties. When accounting for only extremity vascular injuries it appears that most of the injured vessels are located in the lower extremities with a reported incidence of 7 % for femoral arteries, 3 % for isolated femoral venous injuries and a combined incidence of femoral vessel injuries accounting for 7 % of all cases. The wide use of temporary vascular shunts as early restoration of vessel flow, fasciotomies, and external fixation of open fractures as methods of damage control in the field management of vascular injuries, along with the rapid transport to Landstuhl Regional Medical Center have resulted in large number of limbs salvaged (Senior author's personal experience) (See Table 1).

Mechanism of injury

Penetrating trauma remains the predominant cause for the majority of femoral vessel injuries. This was confirmed in the series by Cargile [17], who reported an 88 % incidence of penetrating injuries and a 12 % incidence of blunt trauma. In Feliciano's series [24], the incidence of penetrating trauma was 81 %, while Martin [16] reported that

Table 1 Military experience with femoral vessel injuries

Conflict	References	Total injuries	Femoral vessels	Incidence (%)
WWI	Makins [1]	1,191	366	30.5
WWII	DeBakey and Simeone [2]	2,471	517	20.9
Korea	Hughes [3]	304	95	31
Vietnam	Rich [4]	1,000	351	35
Iraq and Afghanistan	White [15]	1,570	268	17

104 of 105 femoral arterial injuries were from penetrating trauma. In Asensio's series [21], 86 % of the patients were admitted with penetrating injuries while 28 (14 %) sustained blunt injuries.

Civilian epidemiology

The incidence of femoral vessel injury is well documented in the civilian trauma literature. Feliciano [24] reported a series of 220 lower extremity vascular injuries, of which 142 were of the femoral artery, for an incidence of 65 %. Martin [16] reported 188 lower extremity injuries with 105 femoral artery injuries for an incidence of 56 %. Cargile [17] reported data from a Parkland Hospital study, consisting of 233 patients who sustained a total of 321 femoral vessel injuries over a 17-year period. In this study, he reported a total of 112 isolated femoral artery injuries (48 %), 36 isolated femoral vein injuries (15 %) and 85 combined injuries for an incidence of 36 %. Femoral venous injuries were infrequently reported in Martin's series [16], where out of 105 femoral vessel injuries only three were of the femoral vein.

Asensio [21] reported a series of 204 patients treated for 298 vessel injuries during a 10 year period, for an incidence of 26 % of all the vascular injuries reported for this period at his institution (see Table 2).

Clinical presentation

The clinical presentation of patients sustaining femoral vessel injuries ranges from severe (i.e., hemodynamic instability and cardiopulmonary arrest requiring emergency department thoracotomy (EDT), aortic cross-clamping and cardiopulmonary resuscitation), to patients that are hemodynamically stable (admitted with either the classical hard signs of vascular injury secondary to distal decreased flow and ischemia, or those that harbor soft signs of vascular injury).

Cargile [17] reported that 87 patients (37 %) who presented with a femoral vessel injury had systolic blood pressures <90 mmHg, while 35 patients (40 %) presented in profound shock.

In Degiannis (37), 19 patients with femoral vessel injuries arrived hypotensive with systolic blood pressures <90 mmHg, 37 of 81 patients (46 %) with isolated extremity injuries were hypotensive, and four patients arrived in cardiopulmonary arrest requiring EDT. In Asensio's series [21], 11 patients (5 %) arrived in cardiopulmonary arrest requiring EDT; 3 (27 %) of these patients ultimately survived.

Less commonly, the lacerated or transected femoral artery may retract and thrombose resulting in distal limb ischemia. Associated muscle and bone injuries are common with penetrating injuries, therefore meticulous care should be exercised when reducing long bone fractures. With large tissue defects resulting from penetrating injuries, actual hemorrhage may be present which requires prompt control with direct pressure or tourniquet application depending on the location of the injury. However, if the common femoral or very proximal superficial femoral artery is involved, the use of a tourniquet may not be feasible. In this instance, direct pressure on or above the injury with immediate proximal and distal surgical control is mandatory.

With blunt injuries, loss of blood flow is accompanied with ischemic pain, and sensory and/or motor loss depending on the associated structures involved. Hemorrhage from

Table 2 Incidence of femoral vessel injuries in lower extremity vascular injuries

Author(s)	Years	Total injuries in lower extremities	Femoral injuries			Incidence (%)
			Artery	Vein	Total	
Feliciano [24]	1988	352	142	93	235	66.7
Timberlake [26]	1990	322	–	116 (36 %)	–	
Bongard [20]	1990					
Martin [16]	1994	188	105	21	126	67
Clouse [14]	2007	220	74	37	111	50.4
White [15]	2011	94	44 (46.9 %)	–	44	

blunt injury is rare but may occur secondary to associated orthopedic injuries resulting in partial or complete laceration or transection of the vessel.

In Cargile's [17] series, 90 of 233 patients (40 %) presented with hard signs of vascular injury requiring immediate surgical intervention. Despite a significant number of these patients presenting with hard signs, preoperative angiography was performed in 106 patients. Degiannis (37) and associates relied more on clinical examination, noting that 70 % of their patients presented with an ischemic extremity.

In Asensio's series [21], the majority of patients presented with hard signs of vascular injury; 48 % of his patients presented with distal ischemia, 43 % presented with absent or diminished pulses, and 29 % presented with an expanding hematoma. In this series, the reliance on clinical examination alone for detection of femoral vessel injuries reduced the incidence of preoperative angiography to 15 %. Fewer patients presented with soft signs of vascular injury: peripheral nerve deficits accounted for 10 % and proximity injuries for 7 %.

Diagnosis

The need for diagnostic workup is limited in penetrating trauma but frequently can clarify a confusing clinical picture with blunt injuries. The bifurcation of the common and superficial femoral artery is superficial enough to allow clinical diagnosis by inspection and palpation. Penetrating injury with tissue destruction and active hemorrhage needs no diagnostic workup. Patients that have sustained blunt trauma or penetrating injury without active bleeding benefit from a thorough clinical exam initially. Changes in the clinical examination of the femoral, popliteal, posterior tibial or dorsalis pedis arteries and their respective pulses and alterations in the sensory and motor exam may indicate an injured vessel [18]. Tight or painful compartments and associated orthopedic injuries warrant further investigation. The first and easiest diagnostic test to perform is the ankle-brachial index (ABI) exam. This exam is performed by measuring the systolic blood pressure at the ankle, which is then divided by the brachial artery systolic pressure. A difference <0.9 is considered suspicious for the presence of vascular injury and warrants further imaging either with computed tomographic (CT) angiography or formal angiography [19] (see Table 3).

Table 3 Hard and soft signs of vascular injury at admission

Hard
Signs of distal ischemia
Absent or diminished pulses
Expanding hematoma
Palpable thrill
Pulsatile bleeding
Bruit
Soft
Capillary refill >3 s
Peripheral nerve deficit
Proximity injury
Moderate bleeding (limited)

Surgical management

Prior to admission to the operating room (OR) arrangements for blood to be immediately available are required. Every possible effort should be made to avoid hypothermia. Broad-spectrum antibiotics should be administered prior to the commencement of the procedure. In preparing the patient for surgery, the lower abdomen, both groins and both lower extremities should be prepared and draped for possible involvement.

Initial control of an exsanguinating vessel is obtained by direct compression, followed by obtaining proximal and distal control. This may be obtained by direct dissection down onto the common femoral artery though a longitudinal incision, overlying its course from the inguinal ligament distally to the area of injury [16]. More proximal control may be obtained by gaining control of the external iliac artery, either by performing an exploratory laparotomy with cross-clamping of the vessel in the pelvis or by transecting the inguinal ligament through a muscle-splitting, lower quadrant incision carried down to the retroperitoneum. With this approach, the vessels can be controlled without entry into the peritoneum [21]. The profunda femoris artery is exposed through the same incision employed to expose the common femoral artery. The superficial femoral artery is dissected proximally and posterolaterally to identify the origin of the profunda femoris artery.

With inflow controlled, a careful dissection along the anatomic path limits secondary injury to the artery and avoids secondary hemorrhage from neighboring vessels. Vascular clamps, silastic vessel loops and ocular magnification in the form of Loupes are essential tools necessary for obtaining definitive control of the injured vessel [21]. Meticulous dissection of the femoral vessels is of the utmost importance, especially for the femoral veins, as they tend to be delicate, have a propensity to bleed significantly and are easily injured iatrogenically. To obtain both proximal and distal control we recommend use of 30°, 45° or 60° angled DeBakey clamps for both the femoral arteries and veins. If venorrhaphy of the superficial femoral vein is feasible, the use of small, partial occlusion Cooley or Satinsky clamps is preferred (see Fig. 1). The profunda femoris artery should

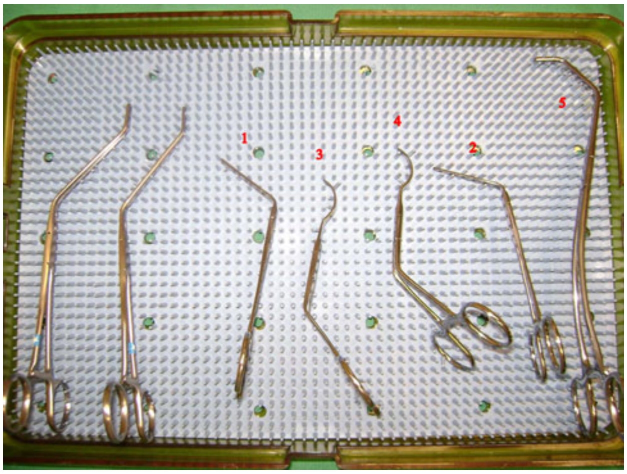

Fig. 1 One of Professor Asensio's vascular trays. Notice 60° angled DeBakey clamps (*1*, *2*), and profunda femoris clamps (*3*, *4*). Also notice Satinsky clamp (*5*)

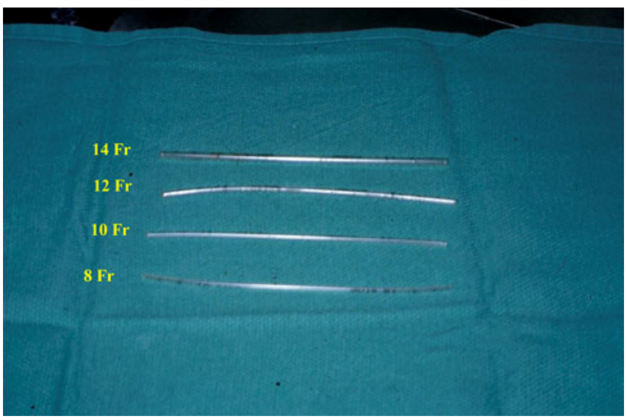

Fig. 2 Argyle shunts

be controlled with special profunda vascular clamps. Argyle shunts should always be available to temporarily restore perfusion to the common or superficial femoral arteries and as an adjunct to damage control (see Figs. 1, 2).

Primary repair

Arteriorrhaphy should be performed with 4–0 or 5–0 polypropylene monofilament sutures in either an interrupted or running fashion. Whichever method chosen, great care must be taken to avoid narrowing the artery and causing stenosis [19]. Fogarty catheters should be sized appropriately and used to clear the distal and proximal femoral artery of potential clots; this should be performed prior to completion of the repair or anastomosis. As with any injury, damaged or devitalized segments of the vessel must be debrided, even if this renders primary repair no longer a feasible option. End-to-end anastomosis is an option following proper debridement, as long as there is

Fig. 3 Anterior–posterior (AP) view of an open right femur fracture associated with a distal femoral arterial injury just above Hunter's canal. Note missile fragments within the wound (*arrows*)

Fig. 4 Lateral view of an open left femur fracture with associated femoral arterial and venous injury. Note comminuted bone fragments which often act as secondary missiles (*arrow*)

adequate length to perform the repair without any undue tension whatsoever (see Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22).

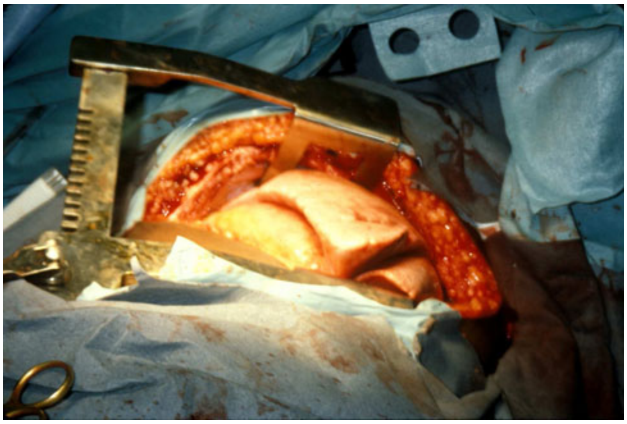

Fig. 5 Emergency department resuscitative thoracotomy with aortic cross clamping and open cardiopulmonary resuscitation required in a patient that sustained an exsanguinating combined gunshot wound to the right superficial femoral artery (SFA) and vein (SFV)

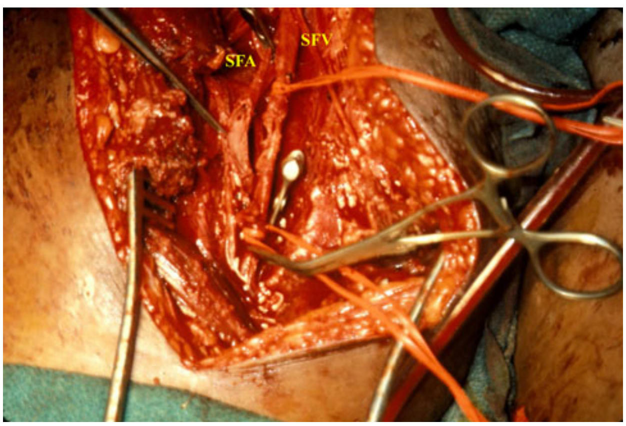

Fig. 6 After a successful emergency department thoracotomy the patient was transported to the operating room while digital control of the femoral vessels was applied along with simultaneous intravascular volume replacement with crystalloids, blood and blood products. Figure shows proximal and distal control of a right superficial femoral artery (SFA) and superficial femoral vein (SFV)

Grafts

Interposition grafts must be utilized when there has been significant vessel destruction and primary end-to-end anastomosis is thus not possible. PTFE is an excellent choice for a replacement conduit, as it is available in various sizes and has moderate resistance to infection in contaminated fields.

Autogenous reverse saphenous vein grafts have been traditionally advocated as the preferred conduit due to their long term patency and resistance to infection. Feliciano [24] reported on a prospective study of the use of PTFE and concluded that it had good long term patency. Asensio [21] reported for his series that the use of PTFE was associated with increased mortality only because it was employed on patients who had sustained greater injury severity, multiple

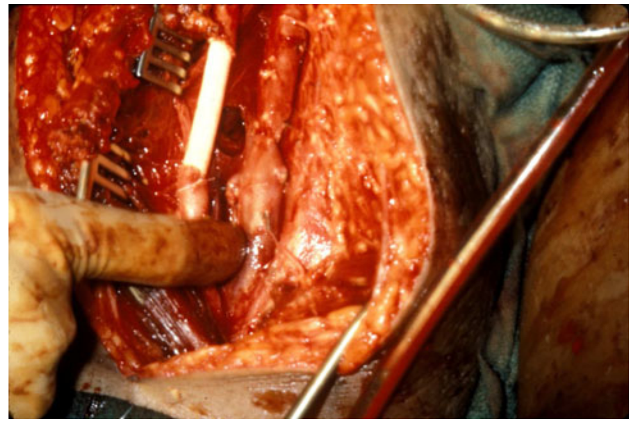

Fig. 7 Same patient showing placement of an 8-mm PTFE graft in the right superficial femoral artery (SFA) and a primary venorrhaphy of the superficial femoral vein (SFV). The patient required thigh and foreleg four-compartment fasciotomies which were initially covered with cadaveric xenografts and subsequently closed on the fifth postoperative day

Fig. 8 Patient after emergency department resuscitative thoracotomy

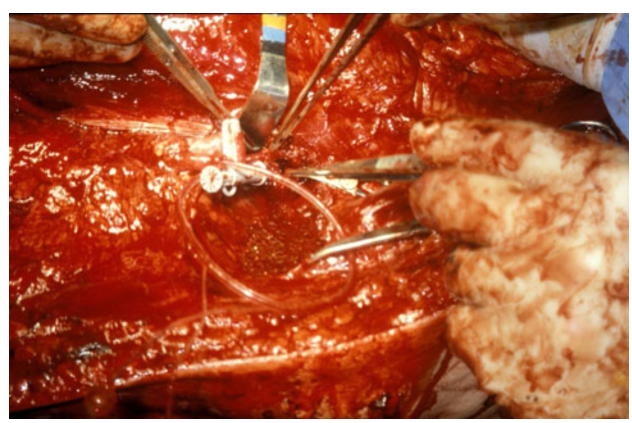

Fig. 9 Young man that sustained an exsanguinating gunshot wound secondary to a high velocity handgun missile which lacerated his right superficial femoral artery (SFA) and right superficial femoral vein (SFV). The patient was rapidly transported to the operating room, and a 10 Fr Argyle shunt placed to rapidly restore blood flow. The patient also sustained a comminuted right femur fracture

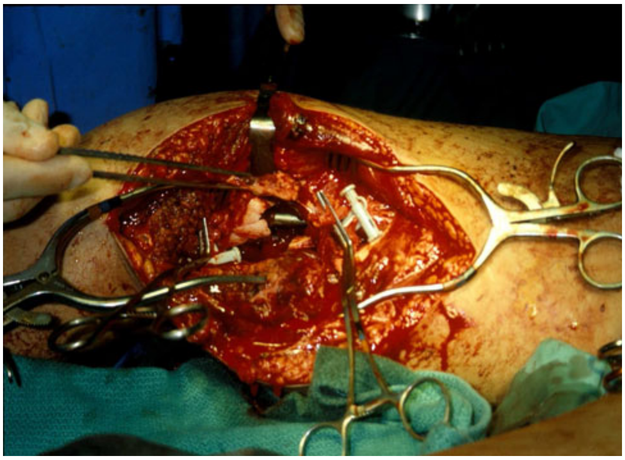

Fig. 10 The same patient after the shunt has been removed and the orthopedic surgeons have performed an open reduction and internal fixation (ORIF) with a reamed femoral rod. The Fogarty Bulldog clamps are controlling the SFV while the 45° and 60° angle DeBakey clamps are controlling the superficial femoral artery (SFA)

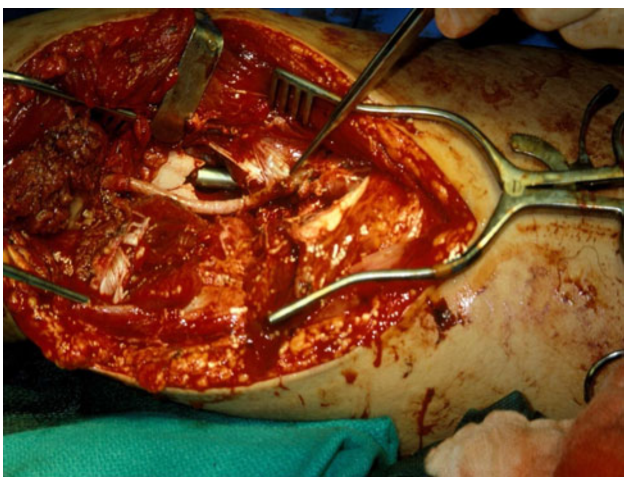

Fig. 11 The same patient after ligation of the superficial femoral vein. The patient has undergone an end-to-end superficial femoral artery interposition graft with an autogenous reverse saphenous vein graft. Note femoral rod bridging the open femoral fracture

associated injuries and presented in shock. He recommended its use in patients who presented with hypothermia, coagulopathy, acidosis and increased requirements of blood and blood products, given its availability and because it significantly decreases operative time.

The senior author of this manuscript has subsequently evolved towards the utilization of ringed PTFE grafts (see Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22).

Fasciotomies and Shunting

Patients sustaining extremity vascular injuries are at risk for the development of compartment syndromes depending on

Fig. 12 The same patient. Intraoperative arteriogram demonstrates excellent flow in the interposition graft. Notice the absence of interlocking screw in the distal femoral rod

Fig. 13 The same patient. Intraoperative completion arteriogram showing excellent blood flow in the interposition graft as well as in the tibioperoneal trunk and shank vessels. Note absence of interlocking screw in the distal femoral rod

the length of ischemia and associated tissue destruction. The consequences of missing the diagnosis are dire, with the patient often losing entire muscle compartments, if not the entire extremity. Even after successful revascularization, the systemic complications of the reperfusion syndrome, its effects on the kidney and its resulting electrolyte abnormalities and acidosis can result in significant morbidity [24]. The performance of fasciotomies on the revascularized limb allows for swelling and edema to occur without vascular compromise, thus ensuring limb salvage. Compartment fasciotomies should be performed via separate incisions (see Table 4). They should be complete fasciotomies. Thigh fasciotomies including lateral and medial incisions may also be necessary (see Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22).

Venous injuries

Injuries to the femoral vein are life threatening, though not to the extent of their arterial counterparts, and are usually

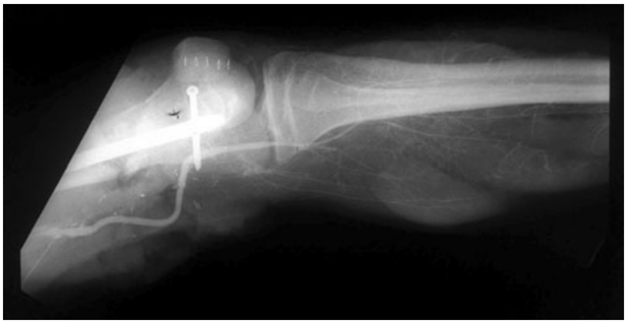

Fig. 14 The same patient after orthopedic surgeons placed interlocking screw. Notice a 90° angle on the graft after the extremity was properly aligned. This required a take-down of the original interposition graft

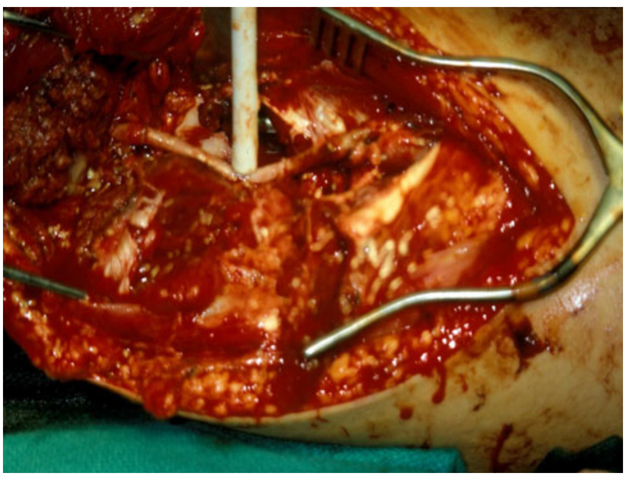

Fig. 15 Angled interposition graft redone. Figure depicts the use of the Doppler probe to detect triphasic flow signals on the actual graft

Fig. 16 Figure depicts the use of the Doppler probe to detect triphasic flow signals at the dorsalis pedis pulse after the graft was redone. Notice four-compartment fasciotomies at the foreleg

Fig. 17 Figure depicts the use of the Doppler probe to detect triphasic flow signals in the posterior tibialis pulse after the interposition graft was redone. Notice four-compartment fasciotomies of the foreleg

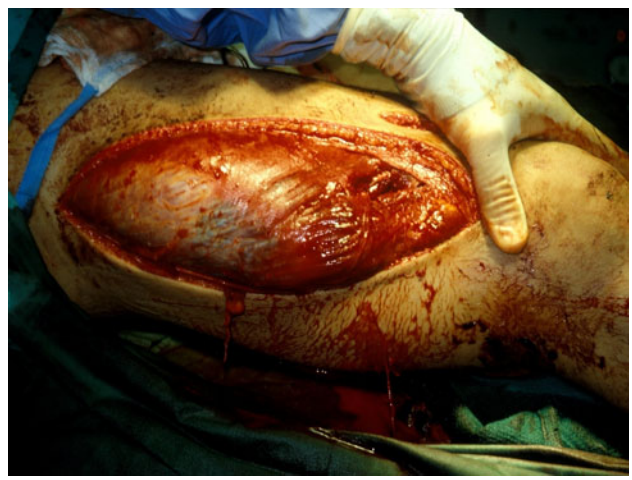

Fig. 18 The same patient who required both thigh and foreleg four-compartment fasciotomies covered with cadaveric xenografts

Fig. 19 The same patient after the correction of his 90°-angled graft. Intraoperative arteriogram shows flow in the popliteal, tibioperoneal trunk, and shank vessels; however, there is significant spasm

Fig. 20 The same patient with closed fasciotomies

Fig. 21 Figure depicts the same patient with primarily closed right foreleg fasciotomies and healed left anterolateral thoracotomy incision

Fig. 22 Depicts the same patient ambulating. Physical therapy is of the utmost importance in these patients

ligated in the face of associated massive arterial hemorrhage. Ligation, although a reasonable approach, is fraught withthe risk of developing significant complications that are prevalent with ligation of the major paths of venous return. Venous thrombosis places the patient at risk for clot propagation and potentially the development of pulmonary emboli requiring long term anticoagulation, if the patient survives. The development of venous insufficiency can be debilitating, and leads to disability and increased infectious complications throughout the postoperative course. The resulting lower extremity edema can be devastating for previously physically active patients [21]. Repair of the femoral vein is encouraged in appropriate situations when the patient's survival is not in question.

Several studies including Nypaver [25], Timberlake [26], Kerstein [27], and Zamir et al. [33] agree on major vein repair when feasible. This is also recommended by Asensio [21]. The surgical repair of venous injuries is dependent on several factors: limb salvage, patient safety and associated complications. It is noted that the presence of an associated venous injury in addition to an arterial injury greatly increases limb morbidity [28, 32]. If warranted, the vein should be repaired first, with simple lacerations repaired with a running technique. If debridement is necessary, a tension-free end-to-end anastomosis is also an option, although this is very rarely performed. If there is extensive damage and a more involved repair is required, especially when there has been extensive destruction of the venous system or for important veins such as the common femoral vein, a shunt can also be placed to temporarily re-establish outflow as a life-saving measure, and/or in anticipation of performing a vein–vein bypass [29–31, 34] (see Figs. 23, 24, 25, and 26).

Outcomes and mortality

The advances in diagnosis and techniques for injuries to the femoral artery have shown significant improvements in patient survivals that are close to 95 % as reported by Asensio [21], with a concomitant decrease in the amount of amputations and a general improvement on the functional outcomes. The morbidity has remained high, despite improvement in detection, operative techniques and follow-up. Asensio [21], in his study of 298 femoral injuries in the span of more than a decade, identified and

Table 4 Surgical management of femoral vessel injuries

Author		Total femoral injuries	Procedure							
			Lateral suture	Ligation	End-to-end	Autogenous	PTFE	Vein patch	Other	Amputation
Phifer [33]	Artery	25	7 (28 %)	–	8 (32 %)	9 (36 %)	1 (4 %)	–	–	
	Vein	25	14 (56 %)	6 (24 %)	2 (8 %)	2 (8 %)	1 (4 %)	–	–	
Feliciano [24]	Artery	142	10 (7 %)	21 (14.8 %)	40 (28.2 %)	–	59 (41.5 %)		6 (4.2 %)	6
	Vein	93	49 (52.7)	19 (20.4 %)	7 (7.5 %)	–	18 (19.3 %)		–	
Timberlake [26]	Artery	–	–	–	–	–	–		–	–
	Vein	116	45 (38.8 %)	71 (61.2 %)	–	–	–		–	–
Cargile [17]	Artery	190	34 (17.9 %)	2 (1 %)	81 (42.6 %)	66 (34.7 %)	1 (0.5 %)	6 (3.2 %)	–	11
	Vein	131	69 (52.7 %)	12 (9.2 %)	15 (11.4 %)	22 (16.8 %)	3 (2.3 %)	70 (7.6 %)	–	
Martin [16]	Artery	105	25 (23.8 %)	–	–	25 (23.8 %)	55 (52.4 %)	–	–	1
	Vein	21	10 (47 %)	6 (28.6 %)	–	1 (4.8 %)	4 (19 %)	–	–	
Asensio [21]	Artery	204	53 (26 %)	13 (6.4 %)	–	108 (52.9 %)	21 (10.3 %)	9 (4.4 %)	–	6
	Vein	94	41 (43.6 %)	49 (52.1 %)	–	4 (4.3 %)	–	–	–	
White [15]	Artery	44	8 (18.2 %)	7 (15.9 %)	–	23 (52.3 %)	–	6 (13.6 %)	–	–
	Vein	–	–	–	–	–	–	–	–	
Clouse [14]	Artery	74	14 (18.9 %)	9 (12.2 %)	–	46 (62.2 %)	4 (5.4 %)	–	1 (1.3 %)	–
	Vein	37	12 (32.4 %)	11 (29.7 %)	–	14 (37.9 %)	–	–	–	

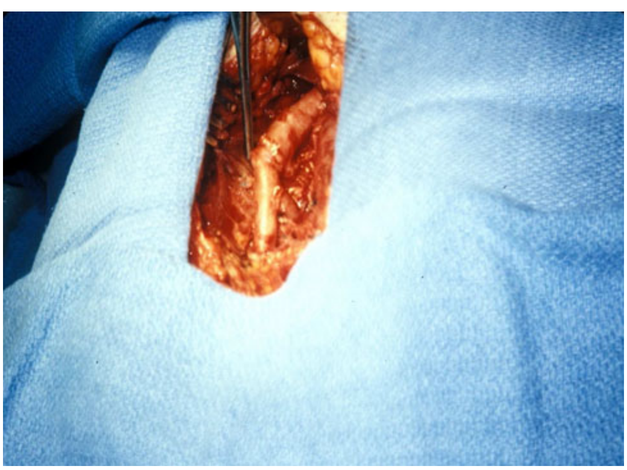

Fig. 23 Figure depicts a complex venorrhaphy of the right common femoral vein (CFV). The common femoral vein should always be repaired if at all possible. Ligation frequently results in significant complications and possibly limb loss

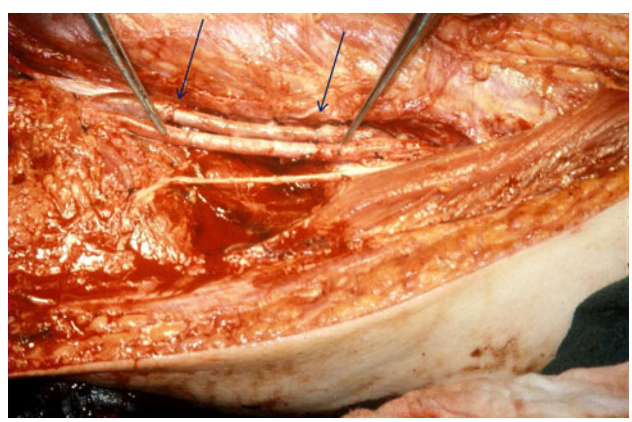

Fig. 24 Figure depicts a superficial femoral arterial injury interposition graft with an autogenous reverse saphenous vein graft being shown with Gerald forceps. *Arrows* also depict a superficial femoral vein interposition graft with non-reversed autogenous saphenous vein

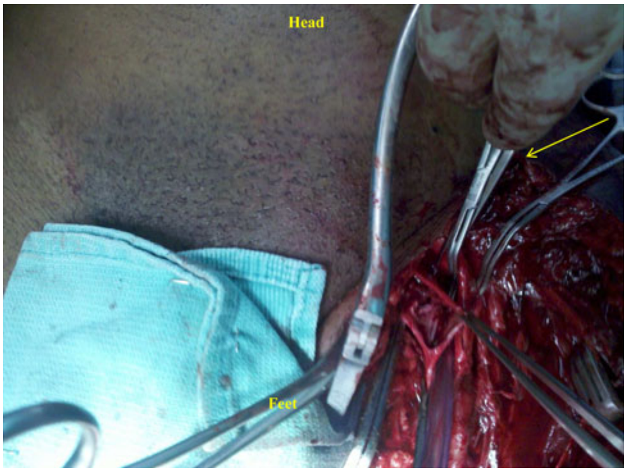

Fig. 25 Figure depicts a high velocity gunshot wound which caused combined arterial and venous injuries to the left common superficial and profunda femoris arteries and vein. *Arrows* show both the profunda femoris artery and vein controlled with profunda femoris clamps

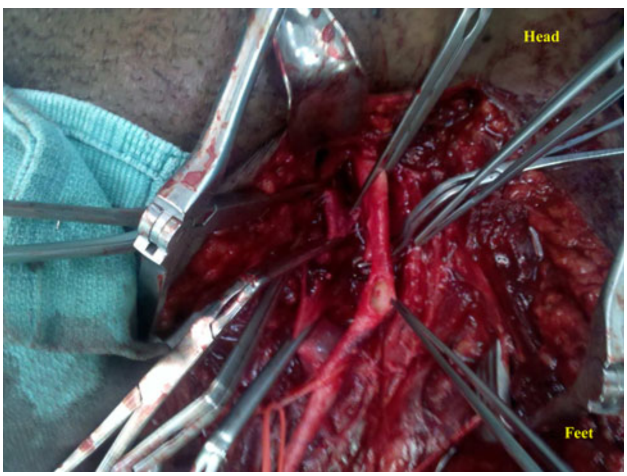

Fig. 26 Same patient showing the common femoral (CFA), superficial femoral (SFA) and profunda femoris (PFA) arteries controlled after massive exsanguinating hemorrhage. Similarly, the left common femoral vein (CFV) and superficial femoral vein (SFV) and profunda femoris vein (PFV) are also controlled. This patient arrived in profound shock with a systolic pressure of 60 and was rapidly transported to the operating room with digital control. He was acidotic, hypothermic and coagulopathic. Given his severely compromised hemodynamic status, we initially performed damage control, but were unable to shunt his common femoral vein (CFV), he thus required ligation of his common femoral (CFV), superficial femoral (SFV) and profunda femoris vein (PFV) as a life saving procedure. He also required an 8-mm ringed PTFE common femoral (CFA) to distal femoral (SFA) interposition graft just above the Hunter's canal. Unfortunately the profunda femoris artery (PFA) was severely damaged and could not be incorporated as a profundaplasty in the proximal common femoral artery (CFA) anastomosis. The patient required thigh and foreleg fasciotomies which were later closed. The patient survived and has resumed work as a senior officer in a counterterrorist team

statistically validated predictors of outcome. These include a GCS <8, the need for emergency intubation, as well as the need for Emergency Department Thoracotomy (EDT) and Injury Severity Score (ISS) >25 which are significant predictors of mortality. Hypotension, hypothermia and coagulopathy, as well as the use of PTFE or the presence of an associated abdominal injury or bony fracture are also associated with high mortality and wound sepsis [21]. No other maneuvers other than prompt detection, quick vascular control and sound surgical technique are likely to decrease the morbidity and mortality of femoral vessel injuries [22, 23].

Conclusions

Femoral vessel injuries are the most common peripheral vascular injuries encountered in both the civilian and military arenas. Throughout history they have evolved from rare and highly lethal to frequent with low mortality, but highly morbid injuries.

Clinical evaluation is often sufficient with penetrating injuries, however, blunt injures require a combined clinical and invasive approach to defining the area and type of injury. Advances in vascular grafts and surgical instruments has made the repair of these injures easier and faster, but the associated morbidities caused by prolonged ischemia and the complications resulting from ligation of the venous system are still significant. When suspected, rapid transport together with rapid surgical control of hemorrhage and restoration of flow remain the mainstay of femoral vessel injury management. When damage control is initiated, shunted vessels should be accompanied by fasciotomies of the associated lower extremity and adequate DVT prophylaxis. With prompt identification and rapid surgical intervention along with aggressive postoperative care, patients should be able to survive if every possible precaution is undertaken to minimize the high complication rates resulting from these injuries.

Conflict of interest None.

References

1. Makins GH. The Bradshaw lecture on gunshot injuries to the arteries: delivered before the Royal College of Surgeons of England. Br Med J. 1913;2(2764):1569–77.
2. DeBakey ME, Simeone F. Battle injuries of the arteries in WWII: an analysis of 2,471 cases. Ann Surg. 1946;123:534–79.
3. Hughes CW. Acute vascular trauma in Korean War casualties; an analysis of 180 cases. Surg Gynecol Obstet. 1954;99:91–100.
4. Rich NM. Vascular trauma in Vietnam. J Cardiovasc Surg (Torino). 1970;11(5):368–77.

5. Von Klein CH. The Medical Features of the Papyrus Ebers. J Am Med Assoc. 1905 Dec.
6. Tubbs RS, Bosmia AN. Hieronymus Brunshwig (c. 1450–1513): his life and contributions to surgery. Childs Nerv Syst. 2011; 28(4):629–32.
7. Kocher MS. Early limb salvage: open tibia fractures of Ambroise Paré (1510–1590) and Percivall Pott (1714–1789). World J Surg. 1997;21(1):116–22.
8. Rich NM, Mattox KL, Hirshberg A. Vascular trauma. 2nd ed. Philadelphia: Elsevier Saunders; 2004.
9. Rich NM. Vascular trauma historical notes. Perspect Vasc Surg Endovasc Ther. 2011;23(1):7–12.
10. Cohen SM. The surgical management of vascular trauma. Overseas Postgrad Med J. 1946;1(1):15–33.
11. Hufnagel CA. Acute vascular trauma. Fundamentals of management. Postgrad Med. 1966;39(1):81–92.
12. Bergentz SE, Bergqvist D, Ericsson BF. Vascular trauma: a review. Acta Chir Scand. 1983;149(1):1–10.
13. Jahnke EJ Jr. The surgery of acute vascular injuries; a report of 77 cases. Mil Surg. 1953;112(4):249–51.
14. Fox CJ, Patel B, Clouse WD. Update on wartime vascular injury. Perspect Vasc Surg Endovasc Ther. 2011;23(1):13–25. doi: 10.1177/1531003511400625.
15. White JM, Stannard A, Burkhardt GE, Eastridge BJ, Blackbourne LH, Rasmussen TE. The epidemiology of vascular injury in the wars in Iraq and Afghanistan. Ann Surg. 2011;253:1184–9.
16. Martin LC, McKenney MG, Sosa JL, Ginzburg E, Puente I, Sleeman D, et al. Management of lower extremity arterial trauma. J Trauma. 1994;37(4):591–8. (discussion 8–9).
17. Cargile JS, Hunt JL, Purdue GF. Acute trauma of the femoral artery and vein. J Trauma. 1992;32(3):364–70. (discussion 70–1).
18. Frykberg ER. Advances in the diagnosis and treatment of extremity vascular trauma. Surg Clin North Am. 1995;75(2):207–23.
19. Modrall JG, Weaver FA, Yellin AE. Diagnosis and management of penetrating vascular trauma and the injured extremity. Emerg Med Clin North Am. 1998;16(1):129–44.
20. Lee JT, Bongard FS. Iliac vessel injuries. Surg Clin North Am. 2002;82(1):21–48.
21. Asensio JA, Kuncir EJ, Garcia-Nunez LM, Petrone P. Femoral vessel injuries: analysis of factors predictive of outcomes. J Am Coll Surg. 2006;203(4):512–20.
22. Baker WE, Wassermann J. Unsuspected vascular trauma: blunt arterial injuries. Emerg Med Clin North Am. 2004;22(4):1081–98.
23. Carter SL, McKenzie JG, Hess DR Jr. Blunt trauma to the common femoral artery. J Trauma. 1981;21(2):178–9.
24. Feliciano DV, Herrskowite K, O'Gorman RB, et al. Management of vascular injuries in the lower extremities. J Trauma. 1988;25: 319–28.
25. Nypaver TJ, Schuler JJ, McDonnell P, Ellenby MI, Montalvo J, Baraniewski H, Piano G. Long-term results of venous reconstruction after vascular trauma in civilian practice. J Vasc Surg. 1992;16(5):762–8.
26. Timberlake GA, O'Connell RC, Kerstein MD. Venous injury: to repair or lígate, the dilemma. J Vasc Surg. 1986;4(6):553–8.
27. Timberlake GA, Kerstein MD. Venous injury: to repair or lígate, the dilemma revisited. Am Surg. 1995;61(2):139–45.
28. Adebo O. Limb salvage in peripheral vascular trauma. West Afr J Med. 1996;15(3):139–42.
29. Choudry R, Schmieder F, Blebea J, Goldberg A. Temporary femoral artery bifurcation shunting following penetrating trauma. J Vasc Surg. 2009;49(3):779–81.
30. Bhargava JS, Kumar R, Singh RB, Makkar A. Civilian vascular trauma: an experience of 54 cases. J Indian Med Assoc. 1996; 94(2):47–9.
31. Fisher MM. Trauma and peripheral vascular disease. Ind Med Surg. 1952;21(11):538–42.
32. Degiannis F, Levy RD, Velmahos GC, et al. Penetrating injuries to the femoral artery. Br J Surg. 1995;82:492–3.
33. Zamir A, Weaver FA, Rosenthal RE, et al. Combined skeletal and vascular injuries of the lower extremities. Am Surg. 1984;50: 189–97.
34. Field CK, Senkowsky J, Hollier LH, Kvamme P, Saroyan RM, Rice JC, et al. Fasciotomy in vascular trauma: is it too much, too often? Am Surg. 1994;60(6):409–11.