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Review Article

35-Years Single Center Experience in the Treatment of Civil and War Peripheral Vascular Trauma

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Abstract

At the beginning of the 20th century, Serbian surgeon Vojislav Subbotić published his experience in treating peripheral vascular injuries from the Balkan Wars (1912-1913). At the end of the 20th century, former Yugoslavia experienced civil war, being followed by NATO bombing of Serbia. Because of these unpleasant facts, an entire generation of vascular surgeons had the opportunity to treat a significant number of wartime vascular injuries. In addition, a significant number of civilian vascular injuries have been treated at Clinic for Vascular and Endovascular Surgery of the University Clinical Center of Serbia-Belgrade (Clinic) over the past few decades. In the absence of a national registry, the most reliable data related to vascular injuries in Serbia can be found in the database of that Clinic. The first part of this database contains 413 peripheral arterial injuries treated between 1992 and 2002. Of these injuries, 140 were war-related, while 273 were civilian. Between 2002 and 2020, an additional 222 civilian peripheral arterial injuries were included in this registry. Historically, the treatment of vascular trauma has gone through three phases of development. The first focused on saving the life of the injured person. The second also included limb salvage, and the third included salvage of a functional extremity.

The main goal of this article is to present what we have learned regarding the treatment of peripheral arterial injuries (strategy, diagnosis, vascular repair, complex injuries, late revascularization, early and long-term complications, pediatric vascular trauma).

Endovascular procedures improved significantly the treatment of peripheral vascular trauma. The main indications for endovascular treatment after peripheral vascular trauma include surgically inaccessible arterial lesions, hemostasis from medium to small arteries, early failures after open repair, as well as long-term complications after open repair. However, in majority of cases open surgery is a method of choice (hemodynamic instability; mid-to-small arteries lesions; distal residual thrombosis; arterial contusion; prolonged ischemia; complex injuries; associated venous injuries; failures after endovascular repair), especially referring to children and younger patients. For this reason young generations of vascular surgeons should be educated in open vascular surgery during endovascular era.

Keywords: Vascular Trauma; Peripheral; Treatment

Introduction

At the begening of the 20th century reconstructive procedures were used sporadically for the treatment of injured vessels. One of the first papers dedicated to repair of peripheral vascular injuries was published by Serbian surgeon Vojislav Soubbotich in 1913 [1]. During the Balkan wars, between 1912 and 1913, sixty false traumatic aneurysms and 17 traumatic arterio-venous fistulas were treated by himself and his coworkers. In about 40% of cases vascular reconstructions were performed. They included even 15 end-to-end anastomosis which was the incredible surgical step forward at that time [1]. More than three decades later in their series of 2471 arterial injuries from the Second World War DeBakey and Simeone reported only 81 repairs of injured vessels including 3 end-to-end anasthomosis [2]. Due to this it is not unexpected that one of world's leading vascular surgeons at the time Rudolph Matas spoke about Soubbotich with words filled with praise. He said: "Doctor Soubbotitch had made a most timely and valuable contribution to the surgery of the blood-vessels resulting from wound in war. The report shows that the Balkan conflict has been no exception to the rule, and that vascular injuries, especially arterial and arteriovenous aneurysms, have become a conspicuous feature of modern military surgery, and that this class of injuries must command the closest attention of the modern military surgeon. It is one of the notable features of this report that the suture (circular and lateral) has been utilized more often in the Balkan conflict than in any previous wars; and judging also by Dr. Soubbotitch's statistics, the success obtained by the surgeons of his staff in the Serbian Army Hospital at Belgrade far surpasses those obtained by military surgeons in previous wars, with the exception perhaps of the remarkably favourable results obtained by Kikuzi, with the intra-saccular ligation, in the Japanese Reserve Hospitals" [3]. Commenting on this, our contemporary Norman Rich said: "It is ironic that nearly 40 years passed before similar successful efforts were achieved during the latter part of the Korean conflict (1952 to 1953) [4]. Soubbotitch's results published in Lancet more than 100 years ago, were quoted 20 times including most recently published books and articles [5-7].

At the end of the 20th century, former Yugoslavia experienced civil war, being followed by NATO bombing of Serbia. Due to these unpleasant facts, whole generation of vascular surgeons had the opportunity to treat a significant number of war vascular injuries. In addition, a significant number of civil vascular injuries have been treated in our Clinic during the past few decades. The main aim of this article is to present a 35-years single center experience in the treatment of civil and war peripheral vascular trauma.

Strategy during management of peripheral vascular trauma

Through history, management of vascular trauma has passed through three phases of development: lifesaving, limb-saving and finally saving of functional limb [8]. It could be assumed that this order of main objectives is still adoptable in the modern approach to vascular injury. That is why primary bleeding control, rapid transportation of the injured, adequate diagnosis and timely vascular repair are necessary.

Primary bleeding control

The first step in successful management of peripheral vascular trauma is primary bleeding control. It directly saves the life of the injured person. However, if not performed adequately, primary bleeding control can additionally damage already injured vessels [8]. The way of initial approach to primary hemostasis significantly influences the extent and perspective of for coming vascular reconstruction. The application of tourniquet is recommended as last option in cases with uncontrolled bleeding from extremity vascular trauma when local compression is not sufficient [9]. Due to these medical personnel (doctors, nurses, etc.) must be trained to establish effective and proper primary bleeding control.

Vascular repair or primary amputation?

The first question that vascular surgeon has to answer before the treatment of peripheral vascular trauma even begin is whether there is a point in doing vascular repair [6-10]. According to same studies, indications for primary amputation in the cases of vascular trauma include: bone fracture with loss of continuity of more than 6cm in length; massive soft tissue damage and loss; prolonged limb ischemia; severe nerve destruction; major veins obstruction and associated small vessels injury [10-12]. Even though these indications are quite clear, the decision regarding primary amputation following vascular trauma is quite difficult, especially in young patients. Therefore, current clinical practice guidelines on the management of vascular trauma published by European Society for Vascular Surgery (European guidelines) recomend multidisciplinary decission making regarding primary amputation or revascularization in patinets with complex extremity vascular trauma [9].

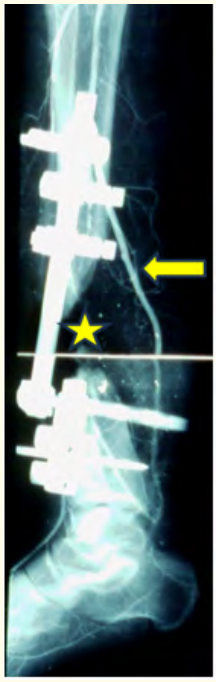

Figure 1: Angiography shows a patent bypass from the distal to the retromalleolar portion of the posterior tibial artery (yellow arrow) in a patient who sustained an explosive wound to the lower leg. The patient also had very complex fractures of the tibia and fibula with a large bone defect (yellow asterisk) and massive soft tissue damage and loss. Consequently, it was unlikely to expect functional recovery of the extremity. A few months later a secondary amputation was performed, but we assume the primary one was better option in this case [7].

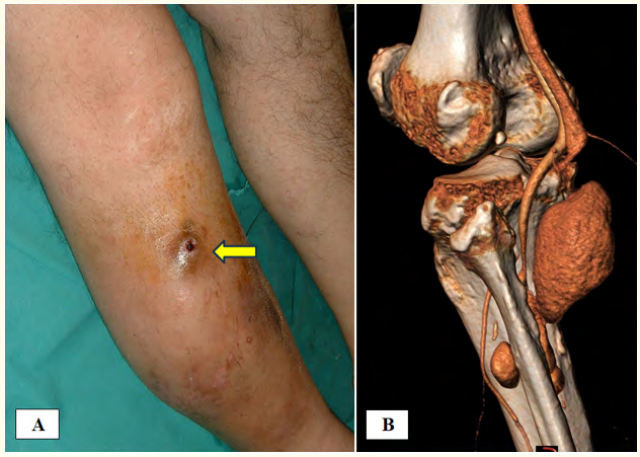

Figure 2: (A) Minor surface wound below the knee (yellow arrow). (B) MDCT angiography was identified a fistula between popliteal artery and vein [7].

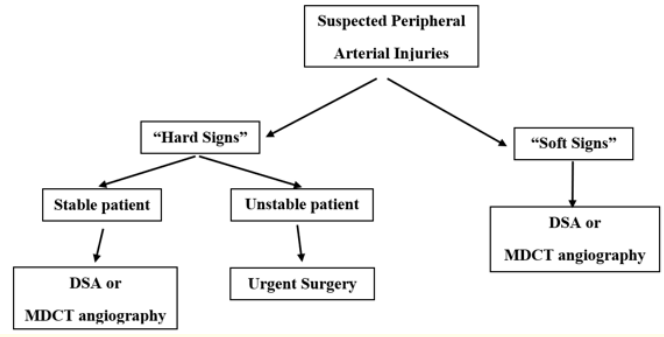

Figure a

Diagnosis

The diagnosis of peripheral arterial injury is not always simple. Namely, minor surface wounds can hide behind them serious vascular injury.

How to recognize periheral vascular injuries when so called "hard signs" (external arterial bleeding, acute limb ischemia, absent distal pulses, expanding hematoma, false aneurysm, and bruit/thrill over area of injury) are not present? [13]. We use a simple diagnostic algorithm regarding cases of suspected peripheral arterial injuries which is supported with the current European guidelines [5,7,9,12].

Firstly, additional diagnosis (DSA or MDCT angiography) is indicated in all cases with "soft" signs of vascular trauma (history of severe bleeding, diminished distal pulses, small nonexpanding hematoma, injury to anatomically related nerve, and anatomic proximity of wound to a major vessels) [5,7,9,14]. In addition, we also recommend DSA or MDCT angiography in all hemodynamically stable patients with "hard signs" of vascular injuries [5,7,12,14]. These procedures are essential in confirming or excluding the presence of arterial trauma. Additionally, they present location, extent and complexity of vascular trauma. DSA or MDCT angiography findings suggest also a surgical approach, as well as the type of vascular repair. Hemodynamically unstable patients with "hard signs" of vascular injuries require immediate surgical exploration without additional diagnosis [5,7,9,11,12].

Vascular repair

In relation to repairing injured artery, the following steps are important: the selection of repair procedure; the choice of vascular graft; the treatment of associated venous injuries; the presence of associated other complex injuries and finally, the treatment of prolonged limb ischemia [8].

The simplest methods of injured arterial repair are lateral suture or end-to-end anastomosis. However, they can be only performed in cases when defect between edges of injured artery is not too long [5,7]. Otherwise, short graft interposition or bypass procedure is indicated by using autologous saphenous vein [5,7,9]. Prosthetic grafts should be avoided due to the risk of secondary infection and poorer long-term patency [5,7].

Anastomotic stenosis, residual distal arterial thrombosis and inadequate treatment of arterial contusion are the most common failures following repair of injured peripheral artery [5,7,15]. Anastomotic stenosis is particulary common after repair of small arteries and when reconstruction is performed by inexperienced vascular surgeons. This complication can be avoided using so called "triangular technique" described by Alexis Carrel more than a century ago [16]. Meanwhile, the oblique end-to-end anastomosis was developed.

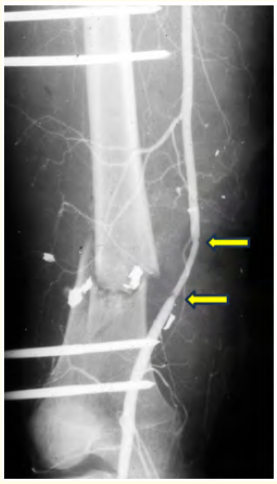

Figure 3: The injured superficial femoral artery was repaired with an autologous saphenous artery in a patient with an associated femoral fracture. Due to the absence of distal arterial pulses, control angiography was performed. The angiography showed significant stenosis (yellow arrows) at both proximal and distal anastomoses [7].

Residual distal thrombosis compromises adequately performed reconstruction of the injured artery. For this reason, exploration of the distal arteries with a Fogarty catheter prior to repair is mandatory [5,7,12,15]. In cases of arterial contusion, the abundant resection of the damaged artery should be performed prior to reconstruction. Inadequate arterial debridement is a common cause of arterial thrombosis during early postoperative period [5,7,12,15].

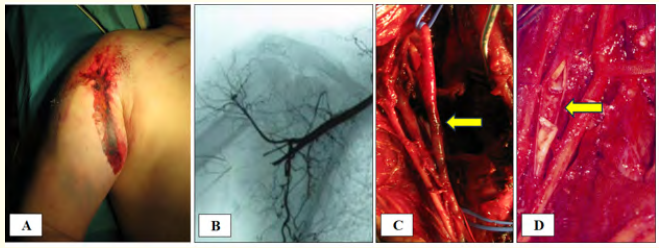

Figure 4: Blunt trauma to the shoulder followed by axillary artery contusion. (A) External aspect. (B) DSA shows an occlusion of the axillar artery. (C) Intraoperative finding shows contusion (yellow arrow) of the axillar artery. (D) After opening the contused arterial segment, intimal dissection is seen (yellow arrow) [7].

Vascular graft infection following repair of an injured peripheral artery is most serious early complication. It is usually accompanied by secondary bleeding and limb loss. The risk of vascular graft infection is increased by inadequate debridement of damaged tissue, as well as by anatomical arterial repair in the presence of contaminated wounds and in cases with massive damage and loss of soft tissue [5,7,11,15,17]. In such circumstances, we recommend an extra anatomic reconstruction [5,7,11,12,17]. In the begining of civil war in former Yugoslavia (1991-1995) we performed vascular repairs using standard anatomic vascular reconstructions. However, during the early postoperative period, we revealed that in cases with contaminated or infected wounds as well as in cases with massive skin destruction and soft tissue loss, anatomic reconstruction was significantly associated with secondary hemorrhage, usually resulting in major amputations [11,15,17]. We improved our early results by using extraanatomical procures [5,7,11,12,17]. Namely, after anatomical reconstruction of complicated popliteal artery injury the amputation rate was 34%, while after extraanatomical reconstruction it was 6% ($p < 0.01$) [17].

The treatment of associated venous injuries

Simultaneous repair of associated venous injuries improves patency of the already repaired artery, minimizes limb swelling and the development of compartment syndrome, as well as the development of long-term chronic venous insufficiency [5,7,12]. For these reasons repair of localized femoral, popliteal and subclavian venous injury should be considered over ligation in hemodynamically stable patients [5,7,9,11,12]. Repair of large and medium-sized veins require the usage of panel or spiral vein grafts, the fabrication of which requires additional preparation time [5,7,11,12].

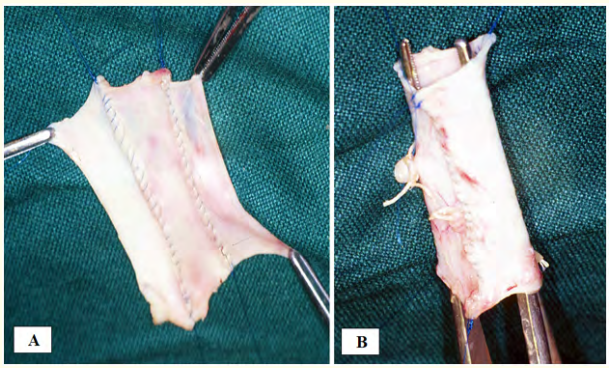

Figure 5: Panel graft. (A). Creation of a panel graft from an autologous saphenous vein. (B). Panel graft is created [7].

Late revascularization

The delayed or late revascularization after peripheral arterial injuries can be followed by many significant disorders. Those are compartment syndrome, muscle contracture, disabling efferent neuralgia, poor functionality of the limb and even major amputation [5,7]. Patients with untreated traumatic arteriovenous fistulas can even develop congestive heart failure [18,19].

When timely vascular repair is not feasible, the use of vascular shunt is recommended [9]. Its use should be considered in cases of prolonged limb ischemia, in polytraumatized patients and in patients with associated orthopedic injuries [5,7,11,12]. If compartment syndrome occurs, urgent fasciotomy is necessary to release all four-calf muscle compartments [9,18]. Fasciotomy is rarely indicated in the upper extremity.

Complex injuries

Complex injuries should be treated interdisciplinary by an experienced team consisting of vascular surgeons and other specialists [5,7,12]. A significant number of patients with injured peripheral vessels have also associated bone fractures. In such cases, the initially performed vascular reconstruction may be compromised by traction and secondary displacement of bone fragments during the orthopedic procedure [5,7,15,17]. Therefore, after proximal and distal bleeding control and shunt insertion, fixation of the bone fracture must precede vascular repair [5,7,11,12].

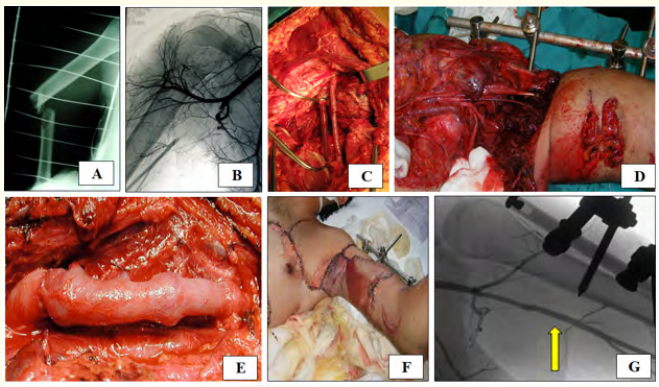

Figure 6: A humerus fracture with dislocation caused an injury to the axillary artery. (A) Radiography shows humerus fracture with dislocation. (B) DSA shows traumatic thrombosis of the contused axillary artery. (C) Step 1: Temporary bleeding control and temporary shunt insertion. (D) Step 2: Stabilization of a humerus fracture with external fixation. Massive damage to the skin and muscles is noticeable. (E) Step 3: Injured axillar artery is replaced with saphenous vein graft. (F) Step 4: Reconstruction of soft tissue defects using a vascularized muscle flap. (G) Control DSA shows patent saphenous vein graft (yellow arrow) [7].

Endovascular repair of injured vessels

Endovascular procedures that include embolization and repair have an important role in the treatment of peripheral arterial trauma. Endovascular embolization treatment is recommended for patients with bleeding from the injured hypogastric artery and its branches, as well as from injured side branches of the main arteries of the limbs [5,7,9].

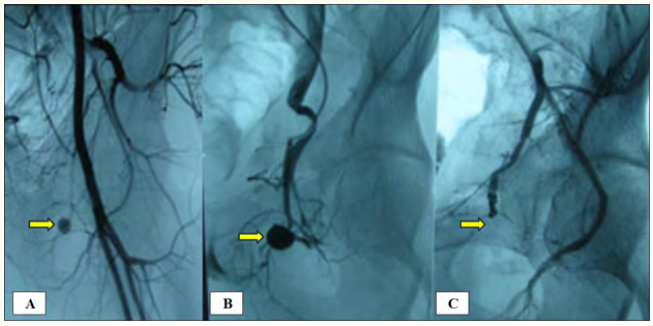

Figure 7: (A) DSA shows extravasation from the injured side branch of the deep femoral artery. (B, C) Phases of successful embolization [7].

Endovascular repair of injured peripheral arteries may be considered as an alternative to open repair when anterograde arterial flow must be preserved [9]. In this regard, endovascular repair is the method of choice for the treatment of surgically inaccessible arterial injuries, for some complex injuries, for failures after open repair, as well as for the treatment of late complications after open repair of injured artery [9,21,22].

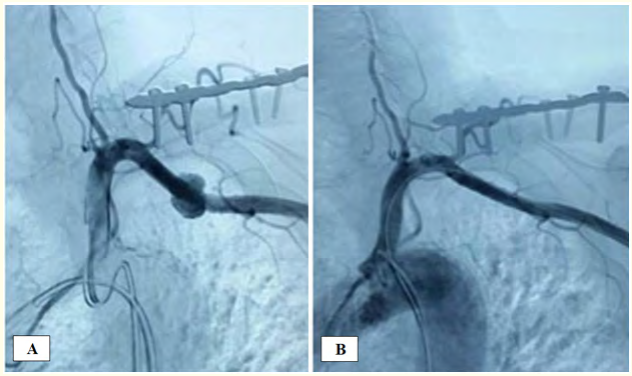

Figure 8: (A) DSA shows false traumatic aneurysm of the subclavian artery caused by clavicle fracture. (B). In this case, the clavicle makes surgical access to subclavian artery very difficult. Due to this endovascular repair (placement of covered stent graft) was successfully performed [7,23].

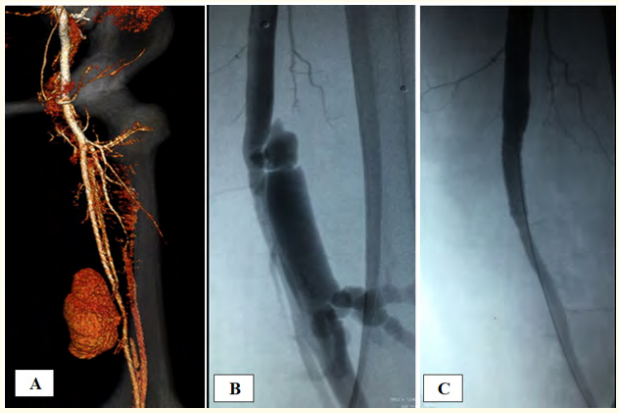

Figure 9: The diagnosis of this traumatic AVF is established 18 years after injury. (A) MDCT angiography. (B) DSA. Due to significant venous collaterals and regional venous hypertension, open surgery would be associated with significant bleeding, as well as with a higher risk of iatrogenic injury to surrounding structures. An endovascular repair with a covered stent was a better choice. (C) Control angiography shows patent stent graft in the superficial femoral artery with no signs of communication with the superficial femoral vein.

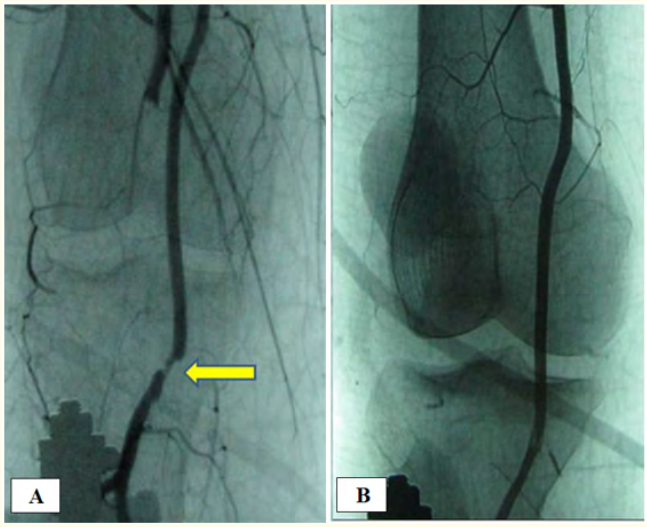

Figure 10: Anastomotic stenosis after open repair of injured popliteal artery. (A) DSA shows significant anastomotic stenosis (yellow arrow). (B) Control angiography after successful stenting [7].

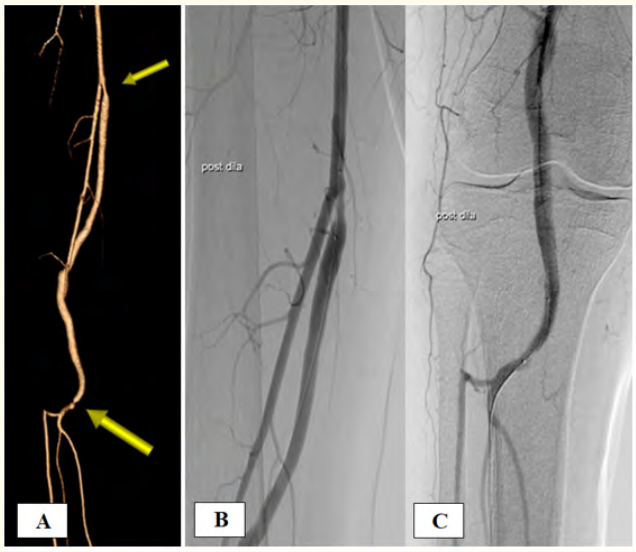

Figure 11: In childhood, this patient underwent a femoropopliteal bypass reconstruction with an autologous saphenous vein graft to treat an injured popliteal artery. Ten years later, the patient developed disabling claudication discomfort. (A) MDCT angiography revealed stenosis on both anastomoses (yellow arrows) caused by neointimal hyperplasia. (B) Control angiography confirmed successful PTA of both stenoses.

Strict contraindications to endovascular treatment of peripheral arterial injuries include hemodynamically instability, extensive vascular injuries, injuries without sufficient proximal or distal vascular fixation points, associated venous injury, as well as arterial transections [7,9].

Pediatric vascular trauma

Traumatic vascular injuries in children are relatively uncommon and account for only 0.3% to 1.4% of all civil pediatric injuries [24-26]. According to American experience from Afghanistan and Iraq wars, the incidence of war pediatric vascular injury is significantly higher, about 3.5% [27]. One of the most recently published largest studies is Swedish national registry with 222 cases collected between 1987 and 2013 [28]. An experience of our Clinic includes 16 cases of civil pediatric vascular injuries over 25-year period [29]. According to most recently published scoping review that included 39 studies extremity vascular trauma was reported to cause 0.6-4.4% of all pediatric trauma admission [30]. Penetrating mechanisms and upper limbs injuries being the most common. Primary repair followed with interposition graft and bypass graft were the most commonly reported procedures. Synthetic graft was less commonly used (incidence range 0.5-33%). The amputation was reported in 0 to 13% respectively.

Main characteristics of pediatric vascular trauma are arterial vasospasm, less developed collateral circulation and smaller total volume of blood with limited tolerance to hemorrhagic shock in comparison with adults [28,31]. Due to this, pediatric vascular injury requires more aggressive and earlier intervention. Several factors unique for children should be considered during repair of injured vessels. Firstly, dimeter of the injured vessels makes surgical correction more complex and increases complication rate [32-34]. Second, the circumferential running suture causes a "purse stringing" effect with further arterial growth [29,33]. For this reason, interrupted suture repair that allows vessel development is recommendable. Also, during repair of injured vessels in children, surgeons should think about a significant risk for growth and developmental complications including limb-length disparities, claudication, and decreased perfusion [34,35]. Finally, there are significant limitations for the use of synthetic or allografts due to long-term patency concerns [28,29,31]. On the other hand, vein graft dilatation should be expected over time. This is why some authors suggest reinforcement of the vein graft with synthetic mesh [25,32,34].

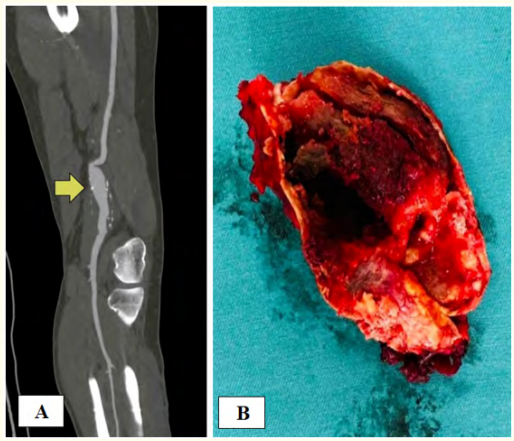

Figure 12: A saphenous vein graft aneurysm developed 12 years after repair of an injured popliteal artery during childhood. (A) MDCT angiography revealed aneurysmal degeneration of complete saphenous vein graft with parietal thrombus (yellow arrow). (B) The oppening of resected aneurysmatic sac showed parietal thrombosis.

Neointimal hyperplasia is potentially more frequent because of longer follow up after repair of injured vessels in children compared to adults [25,29,32,34] (Figure 11).

From our perspective, it seems reasonable to use endovascular techniques at least as a bridge in children with multiple associated injuries [9,29,32,34]. There are no clearly defined recommendations on who should operate vascular injuries in children: pediatric or vascular surgeons? Unfortunately, in most countries, including Serbia, pediatric surgeons do not have adequate education in vascular surgery during their specialization. At the same time vascular surgeons are not educated in pediatric surgery. Probably vascular and pediatric surgeons should collaborate [28,29,31].

War versus civil vascular trauma

According to the common opinion the management of vascular injuries is fundamentally different compared war and civil circumstances. However, in nowdays it is not necesserilly so. Besides natural disasters (earthquakes, etc.), traffic, industrial and agricultural trauma as well as increasing frequency of terrorist attacks, even sport injuries can be accompanied by severe damage of blood vessels [7,36].

An insignificant difference regarding the early outcome between war and peacetime vascular injuries was also presented in our study published in 2005 [11]. That study compared 273 civil and 140 war vascular injuries. According to univariante analysis, out of a total of 54 included variables, failed revascularization, associated nonvascular injuries, secondary surgery, explosive injury, war injury, arterial contusion, popliteal artery injury, and delayed treatment significantly increased the amputation rate after repair of injured peripheral arteries. However, multivariate logistic regression analysis of the previous eight variants showed that only failed revascularization, associated nonvascular injuries, and secondary surgery significantly increased the amputation rate.

Long-term complications after repair of peripheral vascular trauma

There are no many studies dedicated to long-term results after repair of peripheral arterial injuries. Two main long-term complications after open repair of injured peripheral arteries include true vein graft aneurysms and anastomotic stenosis due to neointimal hyperplasia (Figures 11 and 12). Long-term results after endovascular repair of injured peripheral arteries are not yet completely clear. Endograft migration, fracture and stenosis caused by neointimal hyperplasia are potential complications [37].

Conclusion

Endovascular procedures improved significantly the treatment of peripheral vascular trauma. The main indications for endovascular treatment after peripheral vascular trauma include surgically inaccessible arterial lesions, hemostasis from medium to small arteries, early failures after open repair, as well as long-term complications after open repair. However, in majority of cases open surgery is a method of choice (hemodynamic instability; mid-to-small arteries lesions; distal residual thrombosis; arterial contusion; prolonged ischemia; complex injuries; associated venous injuries; failures after endovascular repair), especially referring to children and younger patients. For this reason an education and training in open vascular surgery is still needed.

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