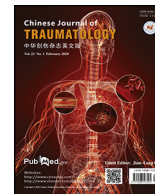




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Original Article

Literature review of peripheral vascular trauma: Is the era of intervention coming?

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ABSTRACT

Traumatic peripheral vascular injury is a significant cause of disability and death either in civilian environments or on the battlefield. Penetrating trauma and blunt trauma are the most common forms of vascular injuries. Besides, iatrogenic arterial injury (IAI) is another pattern of vascular trauma. The management of peripheral vascular injuries has been improved in different environments and wars. There are different types of vascular injuries, such as vasospasm, contusion, intimal flaps, intimal disruption or hematoma, external compression, laceration, transection and focal wall defects, etc. The main clinical manifestations of vascular injuries are shock following massive hemorrhage and limb necrosis due to tissue and organ ischemia. Ultrasound, computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are most valuable for assessment of peripheral vascular injuries. Angiography remains the gold standard for diagnosing vascular trauma. Immediate hemorrhage control and rapid restoration of blood flow are the primary goals of vascular trauma treatment. There are many operative treatment methods for vascular injuries, such as vascular suture or ligation, vascular wall repair and vascular reconstruction with blood vessel prostheses or vascular grafts. Embolization, balloon dilation and covered stent implantation are the main endovascular techniques. Surgical operation is still the primary treatment for vascular injuries. Endovascular treatment is a promising alternative, proved to be safe and effective, and preferred selection for patients. In summary, rapid diagnosis and timely surgical intervention remain the mainstays of the treatment. However, many issues need to be resolved by further studies.

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Epidemiology

Traumatic vascular injury is one of the common emergency diseases. The damage mechanism is related to the environment and time background. With the change of time background, the treatment of vascular injury is also changing. In short, the treatment of vascular injury is from simple to complex, from invasive to noninvasive, from simple to diverse. Nowadays, advanced medical equipment provide benefits to the patients with vascular injury. Meanwhile, traditional treatments are still playing an important role. It remains to be seen which treatment method will become the mainstream.

Traumatic vascular injury is an emergency in surgery, mainly characterized by damage to veins and arteries. Hemorrhage (commonly from truncal vascular injuries) and

ischemia (typical of peripheral arterial injuries) are the main clinical manifestations of vascular injury. If vascular trauma has not been treated in time, it may cause disability or even death, especially for limb vascular injury. There are many difficulties in diagnosis and treatment of vascular injuries, which have brought many challenges to the surgeons since the 20th century.

Trauma is a major cause of death. According to statistics of the National Coronial Information System and the Victorian State Trauma Registry, there were 11, 246 trauma deaths in Australia, of which 71% were out-of-hospital deaths. The main causes of injury were transport events (32%) and hangings (24%).¹ There were 40, 680 cases of adolescent (aged 16–24 years old) trauma over a 10-year period (2008–2017) in England. Road traffic collisions continue (50.3%) to be a major cause of trauma for adolescents.² Vascular trauma accounts for 3% of all traumatic injuries.³ The incidence rate of abdominal aortic injury is only 0.1% in all trauma admissions. The incidence rate of thoracic aortic injury is about 5 times of abdominal aortic injury.⁴ The literature reported that 20.1% of vascular traumas are located in the chest. Of these patients, 71%

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died before arrival at hospitals due to damage to the major vessels.^{5,6} For example, aortic trauma caused by gunshot remains one of the most challenging vascular injuries and the mortality rate is nearly 87.5%.⁷ Femoral vessel is one of the most common traumatic vascular structures, accounting for nearly 70% of all arterial injuries.⁸ Popliteal arterial injuries comprise 19% of all extremity arterial injuries among civilian populations.⁹ Vascular injury may lead to severe complications, so early diagnosis and timely treatment are critical.

Management

Vascular trauma can be divided into a limited number of types, mainly determined by the mechanism of injury. Penetrating trauma and blunt trauma are the most common forms of vascular injury. Types of vascular injury including vasospasm, contusion, intimal flaps, intimal disruption or hematoma, external compression, laceration, transection and focal wall defects with pseudoaneurysm or hemorrhage, etc.¹⁰ These penetrating injuries are most frequently associated with a gun or knife. Shotgun injuries are obvious because of severe tissue damage. Penetrating trauma usually results in lacerations or transection of the vessel without contusion.¹¹ A completely transected artery often retract and spasm with subsequent thrombosis. An incompletely transected blood vessel may be more prone to massive bleeding than a completely transected one. Penetrating vascular injury is common but also a serious problem in emergency medicine. The extent of a projectile injury depends on velocity, mass, and characteristics.¹²

Blunt trauma can lead to damage of the vascular wall, from small intimal flaps to severe transmural damage with thrombosis or extravasation. In patients with blunt trauma, the shearing or compressive forces can lead to contusion, tearing, and dissection of the blood vessel. Although blunt vascular injury is uncommon in patients with multiple trauma, it can cause substantial morbidity and mortality.¹³ Furthermore, blunt trauma is associated with a high risk of major soft tissue loss and concomitant fractures.¹⁴

The management of vascular injuries has evolved in recent decades. Vascular trauma occurred in civilian environments and on the battlefield was fundamentally different. Blunt trauma is the leading cause of injury in civilians, while the combat trauma is often caused by blast or gunshot.¹⁵ However, blunt trauma, as a result of road traffic accidents and motor vehicle collisions, is prevalent in the civilian population.^{9,16} Recently, the mechanism of vascular injuries has been changing because of an increase in urban violence.^{17,18} The increasing violence is leading to more and more penetrating vascular injuries.¹⁹

Iatrogenic arterial injury (IAI) is another pattern of vascular trauma. It was defined as an injury sustained to an artery during an operation or percutaneous intervention. It comprises up to 33% of the current vascular trauma in the civilian patients. Surgical techniques and interventional techniques are sophisticated and widely employed. The occurrence of IAI is increasingly frequent, so various catheter-based therapies have emerged.^{20,21} In community hospitals, the vast majority of the arterial injuries caused by community vascular and general surgeons are iatrogenic. About 50% of the IAIs need vascular surgical techniques for treatment or complication prevention.²²

Diagnosis

Clinical manifestation

Hemorrhage, tissue or organ ischemia caused by vascular injuries are the main clinical manifestations of vascular trauma. The

clinical manifestation of vascular injury is related to the injury mechanism. Damage to the large vessels, such as the brachiocephalic trunk artery, can lead to massive bleeding, which is clinically manifested as hypotension and shock. In general, visual inspection is sufficient to diagnose vascular injury. Nevertheless, diagnosing vascular injury is a challenge if the significant source of external bleeding cannot be found. Physical examination can confirm whether there is a blood vessel injury, and then determine whether surgery is needed. It is very important to determine vascular injury in lower extremities. The signs and symptoms of vascular injury in limbs can be described with “hard” or “soft”, distinguished by whether the intervene provided in time. Hard signs including arterial bleeding, loss of pulse, expanding hematoma, bruit or thrill, and signs of ischemia. The classic 6P syndrome is defined as paresthesia, pulselessness, paralysis, pain, pallor, and poikilothermia, which can be used to diagnose damage to arteries in lower limbs. Soft signs including the history of prehospital blood loss, diminished pulse, moderate hematoma, proximity to a large vessel or bony injury, and ipsilateral neurologic deficit. Hard signs indicate the need for surgical intervention. Soft signs require further diagnostic imaging to confirm.²³ If the injury involves some lower extremity blood vessels, negative clinical manifestations do not rule out vascular trauma. For example, if the fibular artery is damaged, the blood supply to the calf may be normal due to the blood flow compensation of the tibial artery.²⁴

Auxiliary examination

The ankle-brachial index (ABI) is the ratio of ankle blood pressure to brachial blood pressure. It has great value in identifying limb ischemia. ABI can indicate the presence of vascular injury quickly. A normal ABI is greater than 0.90. An ABI of greater than 0.90 has a high sensitivity to exclude vascular injury in lower limbs.²⁵ However, if the ABI is less than 0.90, both ultrasound and angiography are necessary for further investigation.²⁶

Ultrasound, especially color Doppler ultrasound, is a non-invasive, repeatable, and safe method to reveal pathologic changes in vessels, such as arterial thromboses, pseudoaneurysm, and arteriovenous fistulae. Duplex ultrasound is a cheap and non-invasive method to evaluate vascular injury. However, duplex ultrasound also has some disadvantages, such as operator dependency, inaccessibility of some areas and so on. It is not sensitive enough to rule out penetrating trauma.^{27,28} The study of Tisherman²⁹ showed that ultrasonic examination has an accuracy rate of 98% in diagnosis of vascular injury. However, ultrasound diagnosis is subjective, and there is a certain false-negative rate.²⁹ Computed tomography angiography (CTA) or magnetic resonance angiography (MRA) is also a non-invasive methods for diagnosing peripheral vascular injury. It uses the post-processing software to process the blood vessel images. CTA or MRA can identify the location of damaged vessels, contrast agent extravasation, vascular rupture and thrombosis, and has the characteristics of short inspection time and small radiation. In recent years, CTA has been proved quite accurate in diagnosing peripheral vascular injury.

Angiography is considered as the “gold standard” for diagnosing vascular injury. The location and extent of vascular injury can be identified by angiography. However, arterial angiography is an invasive examination and requires specialized equipment. Angiography, with high sensitivity and low morbidity, allows rapid evaluation of vascular injury.³⁰ As an auxiliary diagnostic method, angiography is greatly significant to diagnose arterial injury in the emergency department.

Treatment

Immediate bleeding control and rapid restoration of blood flow is the primary goal of treating vascular injury. Delay in diagnosis and treatment can be fatal for that a massive bleeding may cause shock. Ischaemic tissue damage to distal end of limb leads to high rate of amputation in patients.¹⁶ Severe ischemia of the lower limbs can lead to necrosis, dysfunction, and even amputation. The ischemic time that muscles and nerves can tolerate is only 6–8 h.³¹ If blood flow cannot be restored in time, amputation may be required. Therefore, surgical intervention should be given immediately to achieve functional recovery and limb salvage.

When dealing with vascular injury, minor vascular damage such as intramural or subintimal hematomas, small intimal flaps or pseudoaneurysms, and spasm may have minimal effect on distal arterial flow. Retrospective studies have shown that these minimal injuries can also be cured by non-surgical treatment.³² There are many operative treatment methods for vascular injuries, such as vascular suture or ligation, blood vessel prostheses, and grafts by polytetrafluoroethylene or greater saphenous vein. Embolization, balloon dilation and stent implantation are the main endovascular techniques. The goal of surgical repair is to control hemorrhage and restore distal arterial flow. There are several surgical repair methods such as primary repair, interposition graft and temporary shunt placement. Vascular wall repair may be accompanied by vascular anastomosis, grafting, and prosthesis placement.

Control hemorrhage and save lives

Vascular ligation

Arterial ligation was the primary treatment for vascular injuries before the Korean War. The first vascular repair was attributed to Hallowell in 1759.^{33,34} The incidence of arterial injuries among battlefield casualties was 0.07% in previous wars and 0.4% in the World War I. In World War II, it was less than 1%.³⁵ Because of the far distance, the soldiers sustained blood vessel damage on the battlefield could not reach the hospital for surgery in time. Most of the battle wounds were infected, while antibiotics were not widely used. What is worse, the damages of regional tissue or organ caused by vascular injuries are often life-threatening. For these reasons, ligation is more suitable for the majority of vascular injuries than other procedures. Besides, there are also surgical procedures such as suture repair and graft (vein, plastic, or glass).³⁶ DeBakey and Simeone³⁵ analyzed 2471 arterial injury cases. Of these people, ligation were performed in 1639, resulted in an amputation rate of 49%. Amputation after arterial injury was conducted for any of the two reasons: gangrene or infection. Suture repair was performed in 81, and the amputation rate was 36%. Vein grafts or prosthetic tubes were used in 54, and the result was the worst: the amputation rate reached as high as 56%.³⁵ Lovric et al.³⁷ reported that the amputation rate after ligation was 51.4% during the Korean War. The amputation rate of popliteal and femoral artery ligation was as high as 70%. Arterial ligation has been very rare in recent years.

The management of venous injury is one of the most controversial issues in vascular surgery. Ligation was the mainstay for venous trauma treatment during World War I and World War II. Vein ligation has little effect on muscle ischemia and successful arterial repair in certain trauma patients.³⁸ However, ligation of major veins may cause venous hypertension, extremity phlegmasia, etc. Surgical repair of a vein injury and the end-to-end venous anastomosis have been successfully performed for more than 100 years.³⁹ Nevertheless, repair of venous injuries may also result in vein thrombosis and fatal pulmonary emboli. Anyway, surgeons tend to ligate the distal veins of damaged extremities, and a larger

vein damage may require surgical repair. Ligation of injured veins remains the most common surgical treatment in the past half-century. Venous repair is common in civilian environment and the battlefield; however, overall surgical treatment strategies have unchanged since the Vietnam War.⁴⁰

Embolization or balloon dilation

Embolization is a new type of interventional technique. Common embolic agents are fibrin sealant, gelatin and coils. Embolization can be used for traumatic chest and abdominal artery bleeding such as internal iliac artery bleeding. Retrospective analysis confirmed that embolotherapy offers an effective and safe alternative to conventional surgical operation of traumatic vascular injuries.⁴¹ The mortality rate of brachiocephalic artery injury is very high. It is reported that 71% of patients die before arrival at the hospital.⁴² Once the injury was confirmed, the patient must immediately receive surgical treatment. Balloon dilation can control bleeding quickly and correct shock. When the interventional treatment cannot be performed smoothly, open surgery should be immediately adopted to save the live of patient.⁴³ The European guideline on management of major bleeding and coagulopathy following trauma recommends the patients with significant intrathoracic, intra-abdominal or retroperitoneal bleeding and haemodynamic instability to undergo urgent intervention.⁴⁴ Endovascular treatment is a feasible and effective method with short operative time and less trauma.

Vascular reconstruction and blood flow restoration

Vascular grafts

The graft is the optimum treatment for vascular injuries. These vascular grafts include autogenous veins and artificial vessels. Autogenous blood vessel and artificial blood vessel, which one is better? This is controversial. Lau et al.⁴⁵ reported that the early limb salvage rate was higher with an autogenous vein than an artificial graft. But until now, no significant relation was found between cumulative graft patency and limb salvage rate. It is suggested that artificial grafts can be used for first aid when autogenous vein vessel was unavailable. Grafts have certain disadvantages. Some venous grafts are short or small in diameter and may not match the long or thick target vessel. Moreover, the acquisition of venous grafts can prolong the operation time and increase wounding. Artificial vascular grafts are very expensive and have poor histocompatibility. Application of blood vessel prosthesis is also a good choice for vascular trauma treatment. The first blood vessel prosthesis was applied in 1952. On this basis, the amputation rate dropped from 51.4% to 13.0%.⁴⁶

Temporary vascular pathways

In addition to vascular grafts, temporary intravascular shunt (TIVS) can also be used for temporary vascular reconstruction. TIVS techniques developed rapidly in the 20th century. Temporary shunting techniques for arterial injury were reported in 1971.⁴⁷ During wartime, battlefield injuries may occur in remote areas. For patients with severe vascular injury, TIVS may be required because of extended travel. TIVS was often used in patients with open extremity fractures and concurrent arterial injury accompanied with extensive soft tissue injury. Patients with these limb injuries need to restore perfusion during complex vascular reconstruction and damage control.⁴⁸ According to the Balad Vascular Registry in Iraq, for the patients with extremity vascular injuries, shunt incidence rate ranged from 17% to 24%. It was about 53% according to the Navy and Marine Corps Combat Trauma Registry in Afghanistan.^{49,50} However, the incidence of shunt use is lower in civilian vascular trauma, ranging from 3% to 9%.^{51,52}

Compared with ligation, the shunt has proven its superiority. The vascular injury amputation rate dropped to 8% in the Vietnam War because of the application of shunts. Its amputation rate was lower than in World War II.⁵¹ The recent multicenter study reported that shunts were used for vascular injuries with 213 TIVS. The elevated mortality rate was 20.4% among shunted injuries in the study. The reason was that truncal artery injury accounts for 25% of the study population. The amputation rate was 3.5%. The cause of amputation was soft tissue injuries and graft complications rather than shunt use.⁵² With damage control, TIVS treatment of extremity vascular injury did not lead to worse outcomes in wartime. Amputation is related to venous ligation, associated fracture, and injury mechanism. Further studies to define any possible benefits of TIVS are needed.⁵³

Endovascular techniques

Endovascular treatment is a promising alternative to treat vascular injury. Research showed that endovascular treatment of vascular injuries was feasible and effective.⁵⁴ Endovascular techniques have been widely used in a variety of indications, especially the treatment of vascular trauma in recent years. However, the published experience remains limited. The reports of endovascular treatment of vascular trauma is limited to case reports in the literature. Dake et al.⁵⁵ reported that endovascular treatment is safe in highly selected patients with traumatic aortic aneurysms in 1994. The blunt rupture of the aortic aneurysm caused by blunt injury is fatal, and most patients dead immediately.⁵⁶ Despite reports of successful delayed repair, the patients were still at high risk of rupture. Semba et al.⁵⁷ confirmed that stent graft repair was a feasible and effective treatment method for the rupture of thoracic aorta in 1997. The widespread used devices for the treatment of vascular injury are various types of covered stents. There are several types of vascular injuries, such as pseudoaneurysm, arteriovenous fistula, occlusion, perforation, and dissection.⁵⁸ White et al.⁵⁹ reported that the wall graft endoprosthesis for the treatment of vascular injury offers an alternative to open surgical repair. There are considerable patency and less morbidity and mortality. The literature indicated that the incidence and severity of endovascular treatment complications are less than those of open surgical repair.⁵⁹ The meta-analysis also suggested that endovascular treatment for aortic artery injury is an alternative to open surgical repair. Moreover, there is a lower incidence of perioperative mortality and spinal cord ischemia.⁶⁰ Although endovascular treatment has its advantages, it is currently only suitable for some selected patients. Further randomized controlled trials are needed to provide optimal evidence on this issue.

Conclusion

Peripheral vascular injury is a surgical emergency. Delayed diagnosis and treatment can lead to amputation and even death. Management of vascular trauma has dramatically evolved in the past century. Immediate hemorrhage control and rapid restoration of blood flow is the primary goals of treating vascular injury. The treatment of vascular trauma has learn lessons from the wars in different periods across the world. Successful treatment and management of vascular traumas require a precise understanding of the pathophysiology of vascular injury. The purpose of surgical care is to restore perfusion. Ischaemic time should be taken into consideration. Irreversible damage to nerves and muscles is correlated with disability and amputation. Although open surgical repair has always been the gold standard for treating vascular trauma, the application of endovascular techniques is becoming more remarkable for selected indications. Rapid diagnosis and timely surgical

intervention remain the mainstay of treatment. However, many issues remain to be resolved by further experience and study.

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Ethical Statement

Ethics approval was obtained from the ethics committee of Beijing jishuitan hospital.

Declaration of Competing Interest

The authors have no conflicts of interest to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cjtee.2019.11.003>.

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