



Original Article

Comparison of traditional vascular reconstruction with covered stent in the treatment of subclavian artery injury

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ABSTRACT

Purpose: To explore the significance of traditional vascular reconstruction and covered stent for limb salvage after subclavian artery injury.

Methods: Patients with subclavian artery injury admitted to Beijing Jishuitan Hospital from January 2010 to December 2018 were retrospectively analyzed. All the injuries have been confirmed by intraoperative exploration, computed tomography angiography or digital subtraction angiography. Complete or partial amputation injuries were excluded. Mild artery defect or partial intimal damage was treated by interventional implantation, while other patients received open surgeries, including direct suture of small defect less than 2 cm and transplantation with autologous vein or artificial blood when the defect was more than 2 cm. Patients were divided into open surgery group and stent implantation group based on the treatment they received. Patients were followed up at 2 weeks (first stage) and 6 months (second stage) after operation to investigate limb salvage. Student's *t*-test was used to compare the general data between two groups and Chi-square test to analyze the rate of limb salvage.

Results: Altogether 50 cases of subclavian artery injury were treated, including 36 cases of open surgery and 14 cases of stent implantation. Combination of nerve injury was observed in 27 cases (75.0%) in open surgery group and 12 cases (85.7%) in stent implantation group. Amputation developed in 3 cases with open surgery and 1 case with stent implantation. Consequently the rate of successful limb salvage was respectively 91.7% (33/36) and 92.9% (13/14), revealing no significant difference ($p > 0.05$).

Conclusion: Rapid reconstruction of blood circulation is crucial following subclavian artery injury, no matter what kinds of treatment strategies have been adopted. Interventional stent implantation can achieve a good effect for limb salvage.

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Introduction

The subclavian artery locates deep and is hard to be injured. Clavicle artery injury, once occurs, no matter blunt or punctured, often causes massive bleeding, sharp expansion of hematoma, and has a high mortality. The principle of arterial vascular injury treatment is early diagnosis, rapid hemostasis and vascular reconstruction. At present, the treatment methods are mainly traditional open surgery and stent implantation. The former is invasive, technique-demanding and combines many postoperative

complications, and thus has limited application. In recent years, endovascular interventional surgery has obtained widespread attention due to the advantages of minimally invasion, low risk, and simple operation.¹

The upper limb can get poor blood supply through collateral circulation after subclavian artery injury, but the amount is often insufficient. Consequently forearm of the affected limb may present with ischemia symptoms of lower temperature, decreased muscle strength, reduced muscle endurance, or even muscle necrosis, finger contracture, progressive fibrosis, etc. in severe cases, resulting in residual limb.

In this paper, patients with subclavian artery injury treated by either traditional vascular reconstruction or covered stent implantation were summarized to analyze the different therapeutic effects on limb salvage.

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Methods

Inclusion and exclusion criteria

Patients with traumatic subclavian artery injury admitted from January 2010 to December 2018 to Beijing Jishuitan Hospital were selected. Varying degrees of subclavian artery injuries have been confirmed by intraoperative exploration, computed tomography angiography or digital subtraction angiography, including complete/partial breakage, intimal injury and secondary thrombosis, false aneurysm formation, and so on. However, severe wounds like complete or partial amputation injuries were excluded.

Treatment

Patients were treated by either traditional surgical treatment or interventional stent implantation based on the injury condition. A stent was implanted when probe exploration showed not serious defect or partial intimal damage, otherwise traditional vascular reconstruction will be conducted, including direct suture for vessel defects less than 2 cm and transplantation when the defect is more than 2 cm with autologous vein or artificial blood vessel.

Traditional surgical vascular reconstruction

Make a transverse incision under the clavicle to cut the pectoralis major muscle and the pectoralis minor muscle, and then expose the subclavian artery, vein and brachial plexus nerve. If the injury locates in the deep surface of the clavicle or even deep inside the sternoclavicular joint, open the clavicle and free the sternoclavicular joint. Some patients may combine with clavicular fracture. With the help of the probe, find the injured arteries, veins and brachial plexus; free the proximal and distal ends, find the surrounding normal blood vessels and open them to remove the thrombus. After then check and remove the damaged vein or artery vessels.

If the defect is less than 2 cm, direct suture can be done, otherwise transplantation with autogenous great saphenous vein or artificial blood vessels needs to be done based on patients condition, i.e. status of autogenous saphenous vein, intraoperative blood pressure and heart rate stability, local injury and infection severity, etc.

Finally end-to-end anastomosis of the brachial plexus nerves is important. Under the following condition that anastomosis was not available; the nerve should be sutured, fixed and documented precisely for second stage transplantations: (1) the proximal or distal nerve cannot be found; (2) only the broken end of proximal or distal unilateral nerve is found; or (3) the defect is too large to be directly

sutured. According to the muscle tension of the forearm and upper arm, open incision and tension relaxation can be done or not.

Interventional stent implantation

Following successful puncture via the common femoral artery, coordinate the loach guide wire and angiographic catheter to enter the proximal end of the injured subclavian artery, find the injury site using angiography, pass the guide wire through the injury part and implant the Viabahn covered stent. Thereafter intraluminal isolation and balloon dilation was performed for hemorrhage control. A typical case is shown in Fig. 1. Angiography was re-conducted to ensure complete coverage of the injured artery and full patency.

Postoperative care

Postoperative care was routinely carried out, including (1) treatments of anticoagulation, vasodilation and detumescence; (2) monitoring of hemoglobin, white blood cells, neutrophils, platelets, liver and kidney functions, urine color and urine specific gravity; and (3) observation of radial and ulnar artery pulsation, skin temperature, capillary reaction, etc. After 10–14 days, if the wound is open to relieve tension, thorough debridement and skin grafting can be done. If necrosis unfortunately attacks the upper limb, forearm or finger, amputation should be arranged.

If the limb survived, patients who received simple arterial anastomosis or transplantation received oral aspirin (100 mg per day) while those who underwent both arterial and venous anastomosis or transplantation received oral Warfarin anticoagulation therapy, and the international standard ratio was adjusted to 1.8–2.5.

Follow-up

Limb salvage was checked at 2 weeks (first stage) and 6 months (second stage) after operation. Successful limb salvage was defined as a palpable radial and ulnar artery or confirmed patency of the subclavian artery by computed tomography angiography or digital subtraction angiography.

Statistical analysis

SPSS 17.0 software was used for data analysis. Measurement data were described as mean \pm standard deviation, and student's *t*-test was used for baseline data comparison between two groups. Classified data were described by percentage, and Chi-square test or Fisher exact probability method was used to compare the rate of limb amputation after different treatment methods. A *p* value less than 0.05 was considered statistically significant.

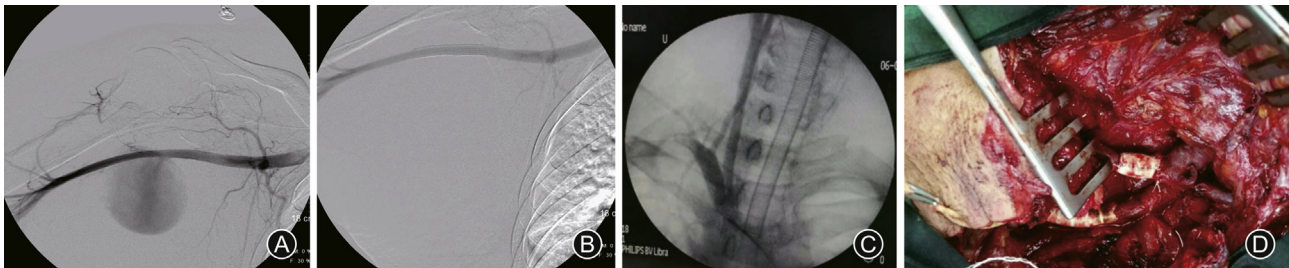


Fig. 1. (A) Giant pseudoaneurysm after fracture before intervention; (B) Viabahn stent completely blocks the breach after intervention; (C) Before open surgery, infraclavicular artery being deep in the sternoclavicular joint and distal vertebral artery, close to the aorta, which can be blocked with a balloon; (D) Subclavian arteriovenous graft reconstruction after open surgery.

Results

A total of 50 cases of subclavian artery injury were included in this study. Among them, 36 received conventional reconstruction (open surgery group) and 14 stent implantations (covered stent group). Comparison of the general data of two groups is shown in Table 1. Direct suture was conducted in 6 patient; all achieved limb salvage. The other 30 cases with a defect greater than 2 cm received autologous vein or artificial blood vessel transplantation, and limb salvage was succeeded in 27 cases. The rate of successful limb salvage in this group reached as high as 91.7%. For the stent group, 13 patients obtained limb salvage, and the limb salvage rate was (92.9%). Chi-square test showed no significant difference ($p=1$). Combination of nerve injury was observed in 27 cases (75.0%) in open surgery group and 12 cases (85.7%) in stent implantation group.

Discussion

The left subclavian artery arises from the aortic arch, and the right subclavian artery from the brachiocephalic artery behind the right sternoclavicular joint. The left and right subclavian arteries are arched upward in the neck, passing laterally through the front of the parietal pleura and behind the scalenus anterior, crossing the base of the neck to the lateral margin of the 1st rib and extending to the axillary artery.

Taking the scalenus muscle as a marker, the subclavian artery can be divided into 3 segments. The first one locates on the medial side of the anterior scalene muscle, passing the front of the parietal pleura and surrounded by the vagus nerve on the medial side and the phrenic nerve on the lateral side. The second segment locates behind the anterior scalene muscle, with its upper part abutting the brachial plexus and the lower part close to the parietal pleura. The third segment is between the lateral margin of the anterior scalene muscle and the lateral margin of the first costal muscle, inside the brachial plexus and behind the subclavian vein. Anatomical difference of the three segments of subclavian artery signifies diverse surgical procedures and difficulties. When injury occurs to the third segment, there is a large space for operation, which makes the surgery relatively easier. But the superficial layer of this part is often covered by the trunk of the brachial plexus, and the nerves need to be well noted and protected. If the injury locates on the second segment, opening the clavicle can increase the operation space. But if the injury involves the first segment (deep side of the sternoclavicular joint or proximal end), there will be very limited operation space and surgeons need to fully free the sternoclavicular joint or remove the proximal end of the sternoclavicular joint, or even split the sternum.

Early reconstruction of the blood flow is the first principle for arterial injury treatment. Limb ischemia following arterial injury for more than 6–8 h will lead to muscle ischemia necrosis and irreversible injury, and further limb amputation.^{2,3} Moreover, after injury of the subclavian artery, uncontrollable massive bleeding will occur, and most patients presented hemorrhagic shock at admission with a very dangerous condition. For supraclavicular artery injury, in addition to active anti-shock treatment, gauze

packing, bandaging and compression hemostasis at the supraclavicular socket and wound can be done. Moreover, no matter what the causes of injury and what the conditions of collateral circulation are, as long as there is a chance of one stage reconstruction, blood vessels should be repaired to restore blood supply. The results of this study also proved that the success rate of limb salvage was high, 91.7% for open surgery and 92.9% for stent implantation. And the difference is not significant regarding treatment methods ($p > 0.05$).

If the injury is caused by sharp instruments or low energy, and patient is generally stable, interventional treatment can be tried. But preparation of open surgery is also needed. If the guide wire fails to pass through the damaged artery or complications developed, conversion into open surgery must be done. If the injury is caused by high energy, or the general condition of the patient is poor, open surgery should be the first choice to control bleeding and rebuild blood supply.

After the recovery of blood flow (reperfusion) for tissue cells with a certain period of ischemia, the degree of tissue injury rapidly increases, which is called ischemia reperfusion injury. The underlying pathogenesis could be after reperfusion, abundant calcium flows into the ischemia cells and generates a large amount of oxygen free radicals, causing extensive tissue and cell damage.⁴

It is reported that in vascular repair, most patients need preventive fasciotomy, and the indications include ischemic sensorimotor loss, pharyngeal vein injury, delayed repair, and large-scale muscle ischemic edema during operation, etc.^{5–8} The preventive fasciotomy is superior to treatment incision in prognosis.^{9,10} Wall et al.¹¹ found that when the osteofascial compartment pressure is > 30 mmHg or perfusion pressure (diastolic pressure - osteofascial compartment pressure) < 30 mmHg, preventative fasciotomy is needed, which can reduce the amputation rate.¹² Fainzilber et al.¹³ reported that fasciotomy at the primary repair of blood vessels could reduce the amputation rate by 6 times. García et al.⁵ thought that when the preoperative ischemic time has exceeded 6 h or osteofascial compartment syndrome has present, the fascial compartment should be opened before arterial repair.

The severity of ischemia-reperfusion injury varies according to the ischemic time and the severity of ischemia. The collateral circulation of upper limbs can be established quickly with rich blood supply, and the degree of ischemia-reperfusion injury is mostly mild. But some collateral circulation is not well established and induces severe ischemia-reperfusion injury, which cause significant swelling of the distal limb and further exacerbate the ischemia, cascading an osteofascial compartment syndrome and necessitating open incision and tension relief.

The procedures of open incision and tension relief are different for forearm and shank. For the shank, full open of the deep fascia is enough for tension relief. However, forearm tension relief requires additional open of muscle space and well dissociation of each flexor tendon and muscle as well.

High energy subclavian artery injury often combines damage to the general subclavian vein and brachial plexus nerves.^{14,15}

Table 1

Comparison of general data of 50 cases with subclavian artery injury.

Group	Male gender	Age (years)	Nerve damage	Open injury	With fracture	Sharp instrument injury	Left upper limb
Open surgery ($n = 36$)	29 (80.6)	32.69 ± 15.93	27 (75.0)	14 (38.9)	12 (33.3)	19 (52.8)	18 (50.0)
Covered stent ($n = 14$)	13 (92.9)	44.21 ± 18.39	12 (85.7)	5 (35.7)	7 (50.0)	5 (35.7)	6 (42.9)
p values	0.525	0.049	0.659	0.836	0.276	0.278	0.65

Data are expressed as n (%) or mean ± standard deviation.

Simple arterial blood vessel reconstruction and vein ligation will result in severe swelling and skin blisters after limb surgery, which could not be resolved. Once the brachial plexus nerve is not reconstructed, the consequent long-term upper limb dysfunction and nerve atrophy will increase the operation difficulty of second stage nerve reconstruction. Krüger et al.¹⁶ have indicated that simple arterial reconstruction whereas venous ligation will reduce the limb blood supply by 50%. Therefore, if the patient's vital signs are stable during operation, reconstruction of the main vein is recommended at the first stage. If the patient's vital signs are not stable, compromise on venous ligation should be decided. Brachial plexus nerve should be reconstructed in the first stage as far as possible. If reconstruction is not manageable, local suture and fixation of the broken end must be done and the specific location should be carefully recorded for the second stage reconstruction.

There are many ways for subclavian artery reconstruction. (1) If the injury is not serious or the artery defect is no more than 2 cm,¹⁷ direct end-to-end suture will be good enough. (2) If the injury is serious or the defect is greater than 2 cm, bridging of blood vessels is required. Autologous blood vessel should be always the first choice of transplantation material. Under the condition of unsuitable autologous vein or unmatched diameter, artificial blood vessel can be used. But thorough debridement of necrotic tissue is mandatory. End-to-end anastomosis can be selected as the bridging method, which has been reported to have a higher rate of long-time patency than end-to-side anastomosis or side-to-side anastomosis.^{18,19} (3) For sharp instrument injury, pseudoaneurysm formation or low-energy artery injury, vascular injury is often manifested as intimal damage or pseudoaneurysm bleeding, but vascular patency still exists. Implantation of a covered stent across the injury part and endovascular exclusion can achieve a good effect, and this procedure is time-saving, which greatly shortens the blood vessel patency time and reduce complications following open surgery. In our study 13 cases received covered stent treatment and 12 achieved limb salvage.

Interventional treatment can be a good supplement for open surgery following subclavian artery, which has proved the beneficial effect, but this technique cannot be imported. Full preparation should be made before interventional stent treatment in case of any failure when open surgery can be shortly converted into. Interventional therapy has another advantage that a balloon can be reserved at the proximal end for temporary blocking and reducing the risk of massive intraoperative bleeding. In this study, the number of interventional stent implantation was relatively small, and the degree of arterial injury was lower than that of the open surgery group. As a result the long-term rate of patency and other outcome, such as crossing the joint, need further studies.

This paper has limitations. The injury degrees of subclavian artery of intervention group and open surgery group are different. Due to different trauma energy and injury mechanism. At the same time, interventional surgery could not clarify the subclavian vein injury, and thus combination with vein injury was not compared in this paper.

To sum up, major artery injury in limbs should be repaired to restore blood flow as soon as possible once found. Direct suture or transplantation with autologous great saphenous vein should be the first choice of treatment. Using covered stent to cover the injured segment can get satisfactory results, but the long-term effect needs further and longer studies.

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Ethical Statement

Informed consent has been obtained from all the patients or relatives. This study has been approved by the local ethical committee.

Declaration of Competing Interest

Authors declare no competing interest.

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