TRAUMATIC INJURIES TO SUBCLAVIAN ARTERIES TREATED WITH STENTGRAFT IMPLANTATION

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The aim of the study was to present the experience of our centre in endovascular treatment for subclavian artery injuries.

Material and methods. In the years 2000-2005, seven patients (five men and two women, aged 28 to 69 years) with traumatic injuries to their subclavian arteries were treated in the Department of General and Vascular Surgery and Department of Radiology. Four patients were diagnosed with post-traumatic aneurysms including one iatrogenic aneurysm following fixation of a fractured clavicle; one patient experienced post-traumatic injury to subclavian artery; one with iatrogenic perforation of subclavian artery with bleeding into pleural cavity; and the last one with another iatrogenic injury resulting from attempts to place a central access line following surgical restoration of patency within subclavian and axillary arteries. All patients underwent endovascular treatment with the use of self-expanding peripheral stentgrafts (Wallgraft, Boston Scientific, USA).

Results. The procedure of stentgraft implantation was successfully performed in all seven patients. In the patient with iatrogenic injury to the subclavian artery, blood extravasation around the stent was observed the next day, which required the stent to be additionally expanded with a balloon catheter. No complications during or immediately after the procedure were detected in any patient. The patient with iatrogenic injury to the subclavian artery following clavicle fracture suffered from thrombosis within the brachial artery during the third week after the procedure.

Conclusions. Endovascular treatment of subclavian artery injuries with the use of peripheral stentgrafts is an efficient method that is associated with low complication rates and should be the method of choice in the treatment of subclavian artery injuries.

Key words: Subclavian artery injuries, subclavian artery aneurysm, covered stent, stentgraft

Traumatic injuries to the subclavian and axillary arteries are very rare and comprise 1-2% of all arterial injuries (1). Due to the relatively high mortality, patients with subclavian artery injuries are difficult to manage surgically. The mortality during repair procedures of the subclavian artery injury may be as high as 33%, especially in patients with cardiovascular conditions (1). It is of particular importance in the management of patients with iatrogenic injuries, e.g. resulting from an attempt to place pacemaker electrodes or central venous access lines.

In many patients undergoing such procedures, open surgery is too risky due to their poor general condition (2). The problem of subclavian artery injuries will increase due to the increasing number of iatrogenic injuries related to the more and more common use of central access lines (3).

The recent development of endovascular techniques has significantly improved prognosis on the treatment of patients with subclavian artery injuries relative to classic surgical procedures.
The purpose of this work is to present the experience of our centre in endovascular treatment for subclavian artery injuries.

MATERIAL AND METHODS

In the years 2000-2005 seven patients, five men and two women, aged 28 to 69 years (mean age 45.7) with traumatic subclavian arteries injuries were treated in the Department of General and Vascular Surgery and Department of Radiology. Four patients were diagnosed with post-traumatic pseudoaneurysms (fig. 1a,b) including one iatrogenic aneurysm following fixation of a fractured clavicle (fig. 2a,b); one patient was found with post-traumatic bleeding from damaged subclavian artery; one with iatrogenic perforation of subclavian artery with bleeding into pleural cavity following several attempts to place a central access line (fig. 3a,b); and the last one with another iatrogenic injury following surgical restoration of patency within subclavian and axillary arteries.

In four patients, the left subclavian artery was involved and the right was involved in three patients. In two iatrogenic subclavian artery injuries, the diagnosis was determined within the first day. In the case of iatrogenic perforation of the subclavian artery, the diagnosis was made on the second day. In the remaining four patients with pseudoaneurysms, the diagnosis was determined within 2-18 months. Three patients required emergency endovascular procedures, while the four patients with pseudoaneurysms underwent elective procedures.

Each patient underwent diagnostic examinations including Doppler sonography and digital subtraction arteriogram (DSA) of the aortic arch and upper extremities. Sonographic and Doppler sonographic examinations were performed with the use of the Siemens Sonoline Elegra apparatus with a 5-9 MHz linear head. DSA examination was performed by puncturing the femoral artery (Seldinger technique) and introducing a Balt 5F pigtail catheter into the ascending aorta. Then, the selected subclavian artery was ballooned with the use of 0.35 hydrophilic guidewire (Terumo or Roadrunner, Cook) and 5F selective catheter (mostly Headhunter I or II, Balton).

The stentgraft implantation procedures were performed with femoral access in six cases while one female patient underwent the procedure using brachial access. All patients underwent endovascular treatment with self-expanding peripheral stentgrafts (Wallgraft, Boston Scientific, USA). Diameters of the applied stentgrafts were matched to the size of the arteries treated and ranged from 7 to 10 mm following the principle that stent diameter should exceed vessel diameter by 1-2 mm. In six patients, the stent was implanted just outside the branching of the vertebral artery, whereas in one patient, the branching was covered with the stent (tab. 1). In one patient, endovascular treatment was preceded with thrombectomy of upper extremity arteries (in this case the procedure was performed from brachial access), and in another with local fibrinolysis. Postoperatively, six patients underwent follow-up sonographic examinations within 6-12 months.

Fig. 1a. Pseudoaneurysm of left subclavian artery caused by a screw used for fixation of fractured clavicle

Fig. 1b. Picture of left subclavian artery after implantation of a covered stent and exclusion of a pseudoaneurysm from the circulation
Traumatic injuries to subclavian arteries treated with stentgraft implantation

Table 1. Subclavian artery injuries and method of their repair in the group of treated patients

<table>
<thead>
<tr>
<th>No.</th>
<th>Age</th>
<th>Sex</th>
<th>Type of lesion</th>
<th>Stentgraft diameter [mm]</th>
<th>Stent-graft localization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>M</td>
<td>pseudoaneurysm</td>
<td>8</td>
<td>outside vertebral</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>M</td>
<td>pseudoaneurysm</td>
<td>8</td>
<td>outside vertebral</td>
</tr>
<tr>
<td>3</td>
<td>51</td>
<td>F</td>
<td>iatrogenic injury (restoration of patency)</td>
<td>7</td>
<td>vertebral artery occluded</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>M</td>
<td>pseudoaneurysm</td>
<td>9</td>
<td>outside vertebral</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>F</td>
<td>pseudoaneurysm</td>
<td>10</td>
<td>outside vertebral</td>
</tr>
<tr>
<td>6</td>
<td>34</td>
<td>M</td>
<td>iatrogenic injury (after clavicle fracture)</td>
<td>9</td>
<td>outside vertebral</td>
</tr>
<tr>
<td>7</td>
<td>69</td>
<td>M</td>
<td>iatrogenic injury (central line)</td>
<td>8</td>
<td>outside vertebral</td>
</tr>
</tbody>
</table>

RESULTS

The procedure of stentgraft implantation was successfully performed in all seven patients. None of the patients died within the perioperative period and none experienced intraoperative complications. In six patients, the stent-graft was implanted distally to the branching of vertebral artery, occluding branchings of the thyrocervical and costocervical trunks.
(tab. 1). No ischaemia within tissues supplied with the above-mentioned vessels were observed after the procedure. No symptoms of CNS ischaemia were observed in the patient with occluded branches of the vertebral artery either. Doppler sonography revealed a lack of blood flow within the vertebral artery with occluded branching, whereas blood flow in the contralateral vertebral artery and basilar artery was regular. In one of the patients with iatrogenic injury to the subclavian artery, blood extravasation around the stent was observed the next day. The process of expanding the stent with the use of balloon angioplasty eliminated the leak. In a patient admitted with symptoms of arterial thrombosis of the upper left extremity and subclavian aneurysm, following successful local intra-arterial fibrinolysis (LIF) and stentgraft implantation, thrombosis of the brachial artery re-occurred within the third week after the procedure. A second attempt at local thrombolysis and thrombectomy failed, whereas control DSA examination revealed non-significant displacement of the prosthesis, with no signs of blood leak. A thoracic sympathectomy was performed to improve blood supply to the upper left extremity. The patient was discharged with no pain symptoms and improved blood supply of the upper left extremity. Patency of the stentgraft in the subclavian artery and closure of the injury site were determined postoperatively in all seven patients.

Follow-up sonographic examinations was performed in six patients within 6-12 months postoperatively and revealed unobstructed flow through the subclavian artery with no signs of blood leak. One female patient with an implanted stentgraft died because of complications resulting from implantation of bifurcation prosthesis due to Leriche’s syndrome. She was not followed.

**DISCUSSION**

Subclavian artery injuries pose a significant therapeutic problem due to limited possibilities of safe and rapid repair. The most common cause of injury to the subclavian artery is external, blunt or penetrating trauma during road traffic accidents or iatrogenic damage - as a complication of surgical fracture management or a failed attempt at subclavian vein cannulation to place pacemaker electrodes or gain central line access (3). Some subclavian artery injuries remain undiagnosed resulting in patient death due to hypovolemic shock or the formation of pseudoaneurysms. Some patients require emergency repair due to active bleeding into the pleural cavity and/or mediastinum. In cases of pseudoaneurysm formation, there is a high risk of thromboembolic complications or nerve plexus compression, which pose a significant hazard for functions of the upper extremity (4).

Classical surgical access to the subclavian artery in traumatic patients, due to the need for rapid hemostasis, is associated with high risk complications related to additional damage to vessels (mostly veins), nerves (phrenic nerve, brachial plexus, sympathetic trunk), lungs and thoracic duct (4, 5). The preferred access is a sternotomy or thoracotomy allowing maximal exposure of anatomic structures and poses an additional complication risk in patients of poor general condition (4, 5). Conservative therapeutic methods for arterial bleeding, such as compression, are inefficient in the case of subclavian artery due to anatomic positioning (4, 6).

The introduction of endovascular methods for the treatment of vascular conditions into clinical practice enables the application of minimally invasive techniques in the repair of subclavian artery injuries with the use of covered stents (7). Initially, this method had few advocates because of the rigid stentgrafts used, which were easy to bend or displace (8, 9). Currently manufactured stentgrafts are perfectly suitable for the repair of peripheral arteries, due to their shape, memory capabilities and high flexibility (10, 11). However, there is still a risk of remote complications caused by tissue reactions around the graft and development of embolism. Due to the variable diameter of the treated artery, displacement of the stent may occur (as in one of the cases presented), which is associated with arterial thrombosis. The application of grafts with diameters exceeding that of the vessel by 10% should ensure firm endovascular prosthesis fixation, while keeping placement correction and additional stent expansion (sealing) with a balloon catheter possible. Intimal hypertrophy in the place of graft fixation may result in stent occlusion, which occurs even in 17% of patients subjected to the intervention according to some authors (12).
One of the most important factors ensuring success in the repair of subclavian artery injuries is the availability of modern methods of imaging diagnostics, angiography, CT, MRI and Doppler sonography, as well as an appropriately equipped vascular laboratory (13). Appropriate equipment and experienced staff are necessary for proper stentgraft implantation in cases of emergency.

The presented cases make it evident that the combination of open vascular surgery methods with endovascular techniques is necessary. Two-stage management consisting of surgical thrombectomy of the upper extremity arteries or intra-arterial thrombolysis and implantation of a covered stent decreases the scope of surgical intervention and associated risk. It also completely eliminates the risks associated with general anaesthesia as well as with the opening of large arterial vessels.

The implantation of covered stents following iatrogenic arterial injuries as a result of failed attempts at large venous vessel cannulation (which occurs from 0.02% to 9% of punctures) makes it possible to avoid unnecessary open intervention (14). It is of particular benefit in patients with heart or circulatory failure.

It is recommended that the centre performing endovascular procedures be equipped with at least several covered stents of various diameter and length, which enables the operator to apply the described treatment method without the necessity of ordering size-matched stents from the manufacturer. This is of particular importance in cases of management of active bleeding. For elective repair of pseudoaneurysms, ordering a graft “dedicated” to a particular patient is a better solution.

If an attempt to exclude a pseudoaneurysm from circulation fails, embolization of the aneurysmal cavity may also be applied. It is an auxiliary procedure with good immediate effects, but it is not recommended as a first line treatment (15). The possibility of rapid and minimally invasive repair of vascular injury in anatomically complex areas is an advantage of covered stent placement and has been confirmed by several authors in other centres (5, 7, 8, 9, 15, 16, 17).

CONCLUSIONS

1. In our opinion, the implantation of covered stents should be the treatment of choice in subclavian artery injuries.
2. The application of covered stents makes it possible to avoid complications related to repair of subclavian artery injury, such as damage to the phrenic nerve, brachial plexus and subclavian vein.
3. Irrespective of the remote effect, implantation of a covered stent in the subclavian artery provides significant immediate benefits. It enables stabilisation of the patient’s condition in cases of haemorrhage and ensures the exclusion of permanent aneurysms or makes it possible to further plan reconstructive procedures.

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**COMMENTARY**

Technological progress made during the past years, including the introduction of intravascular surgical instruments, and increasing experience in the field has enabled physicians the ability to debride damaged arteries.

For example, the experience gained after performing numerous procedures on lower limb arteries has enabled the use of this minimally invasive technique. This is especially important when considering the need for intravascular treatment of patients after subclavian artery injuries. The first stent implantation in a patient with subclavian artery injury was performed by Becker in 1991.

The Authors of the study have presented treatment results for seven such patients. Four patients were diagnosed with false aneurysms, while the remaining three were diagnosed with arterial wall injuries that occurred during the initial two days following trauma.

Intravascular treatment is of limited significance for penetrating injuries, which are accompanied by disruption or depletion of the arterial wall. Rarely can one perform “emergency” intravascular arterial debridement on these vessels.

It is worth mentioning that an effective transient method of closing the damaged artery consists in the introduction of a balloon catheter, followed by its inflation at the site of the perforated or ruptured vessel. The above-men-

tioned method is often used in case of iatrogenic arterial injuries, which occur during diagnostic examinations and intravascular procedures.

When deciding to the intravascularly debride the injured subclavian artery, one should bear in mind the possibility of failure. The presence of a vascular surgeon, nearby placement of proper instruments which enable rapid opening of the thorax, and control of bleeding might save the patients’ life.

Surgically reconstructing the continuity of the subclavian artery or attempts to restore normal blood flow may fail; these situations may require minimally invasive treatment. The Authors of the study successfully implanted a stentgraft in such a patient.

One should note that suspicion of subclavian artery injuries, even during hemodynamic stability, should spur the use of rapid imaging diagnostics such as ultrasonography and computer tomography angiography. Should abnormalities suggest arterial injury, the patient should undergo aortic arch arteriography with simultaneous attempts to intravascularly treat the injured vessel.

The damaged subclavian arteries were treated with auto-expandable Wallgraft stentgrafts formed from braided steel wires covered with polyester. In similar cases, auto-expandable nitinol Viabahn stentgrafts were used, as well as
Steel intravascular prostheses (Jomed) covered by PTFE installed on the balloon catheter. The implantation of the latter enables their precise fixation, which is especially important for proximal subclavian artery or brachiocephalic trunk injuries.

Decisions concerning the method and time of arterial correction should be individualized. For example, the method which is chosen depends on the mechanism of trauma, the patients’ general condition, and experience of the operating team.

Intravascular treatment of an injured artery might only be considered in hemodynamically stable patients. The Authors of the study successfully treated such patients, and I would like to congratulate them on their good results. In addition, I am waiting patiently for further interesting cases which serve as evidence to the constant progress being made in vascular surgery.

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