Chapter

Methods of Reconstruction for Distal Aortic Dissection

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Abstract

The modern approach to the correction of aortic dissection involves the most complete reconstruction of the entire pathologically altered segment of the vessel, which is often impossible due to the vastness of the lesion and the associated severity of surgery. Reduction of intraoperative trauma can improve survival in the immediate postoperative period, and the completeness of reconstruction to reduce the number of complications and relapses in the long term. In this chapter, the methods of reconstruction of the aorta in case of distal dissection from a conventional open surgery to endovascular techniques, or usage of their combination for minimization of surgical trauma, are reviewed.

Keywords: aortic dissection, hemodynamic, surgical approach, aortic surgery, EVAR, hybrid

1. Introduction

Aortic dissection is defined as the penetration of blood masses between the inner and middle layers of the aortic wall, with the formation of a rupture of the inner layer of the aortic wall, intima. In this case, a flap is formed that divides the aortic lumen into true and false [1, 2].

The aortic wall consists of three layers: the inner tunica intima, the middle tunica media, and the outer tunic of adventitia. Despite the fact that different components and special types of cells form each of these layers, they all represent a single structure that can withstand high variable loads. The inner layer, tunica intima, has a thickness of 130 microns. Its first shell is the endothelium, a single-row layer of cells that directly contact the blood. Endothelial cells are oriented in accordance with the direction of blood flow [3]. The endothelium prevents thrombosis, has selective permeability to liquids and nutrients, participates in maintaining vascular tone, regulates blood pressure, has immunomodulatory and barrier functions, and plays an important role in regulating vasculoangiogenesis and remodeling the cardiovascular system [4]. A thin subendothelial shell, consisting of a small number of collagen-synthesizing fibroblasts and collagen fibers, attaches to the endothelium. The processes of endothelial cells connect the intima with the middle layer.

Tunica media is the thickest and most durable layer of the aortic wall that converts the pulsating blood flow, so it is most susceptible to variable loads. The average thickness of the media is up to 1.2 mm. Elastic plates separated by thin layers of connective tissue, collagen fibers, and smooth muscle cells form the structure of the media tunic. Elastic and collagen fibers make up 20–30% of the total volume of the aortic wall separately, and smooth muscle cells make up 5% [5]. Elastic plates are concentrically arranged fenestrated membranes (lamellae), the fibers of which are intertwined. The media tunic has 45–60 elastic plates covering 1/3–3/4 of the circumference of the aortic diameter. As a rule, these are oppositely twisted, cross-linked spiral structures arranged in a staggered order, which are held together by interlamellar connecting fibers. A network of fine collagen fibers surrounds both lamellar and connective elastic fibers. In addition, the elastic plates are supported by muscle fibers connected through points of contact with the mucoid membrane of the elastic plates. Interstitium contains colloidal mixtures of proteoglycans. The outermost elastic lamellar plates separate the aortic media from the thin adventitial layer [6, 7].

The adventitia tunic consists of loose connective tissue with a small number of elastic fibers, muscle cells, and macrophages. Through it from the outside, the vessels that feed the wall of the aorta vasa vasorum and nerve endings pass. Vasa vasorum, originated from the network of vessels located in adventitia, penetrate the outer third of the media and branch between the outer and middle layers, penetrating no deeper than the inner third of the media of the aorta. Thus, the outer third of the aorta receives nutrition through the vasa vasorum, while the inner layers are fed by diffusion from its lumen, which will support the structure of the aortic flow [8] (**Figure 1**).

Despite a long history of studying the pathogenesis of aortic dissection, it is still not clear enough. When studying the morphology of the aortic wall in patients with dissection, changes in the middle tunic of the media were most often detected. Gsell (1928) described damage to smooth muscle fibers during aortic dissection, Erdheim (1929) described damage to elastic fibers, and Cellina (1931) described a combination of these processes [6]. Currently, the media damage is, described as damage and loss of smooth muscle fibers, destruction and fragmentation of elastic plates, and filling of the resulting voids with proteoglycans [9] (**Figures 2** and **3**).

Such changes may occur in patients with inherited syndromes accompanied by connective tissue dysplasia, such as Marfan, Loeys-Dietz, Ehlers-Danlos, Turner, and others, or in their absence.

The same changes along with atherosclerosis are found in the aortic wall in elderly patients and with increased variable loads, in particular with arterial hypertension. It is, believed that due to the loss of elastic properties of the aortic wall, the vasa vasorum network is traumatized, which leads to the formation of lacunae

Figure 1.
Aortic sections from a normal subject. Panel is oriented with the intima at the top and the adventitia at the bottom; hematoxylin and eosin (H&E) staining.

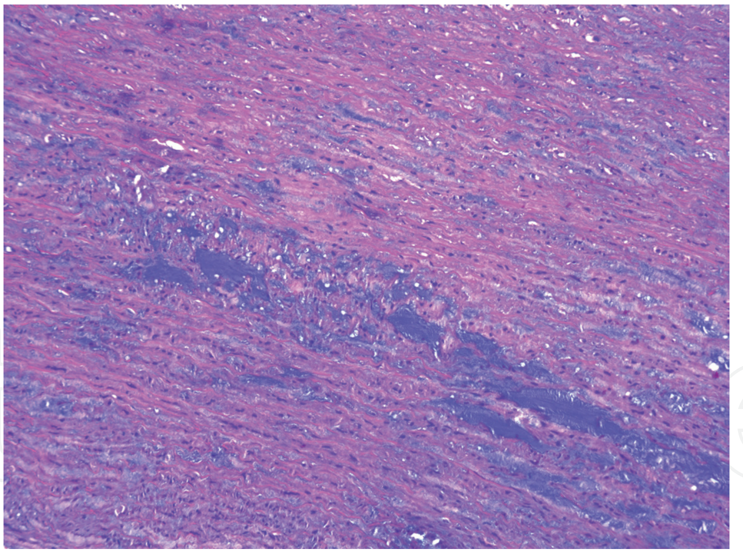

Figure 2.
Aortic sections from a patient with aortic dissection. Fragmentation of elastic fibers, loss of smooth muscle cells, and accumulation of proteoglycans (stained blue) in the medial layer.

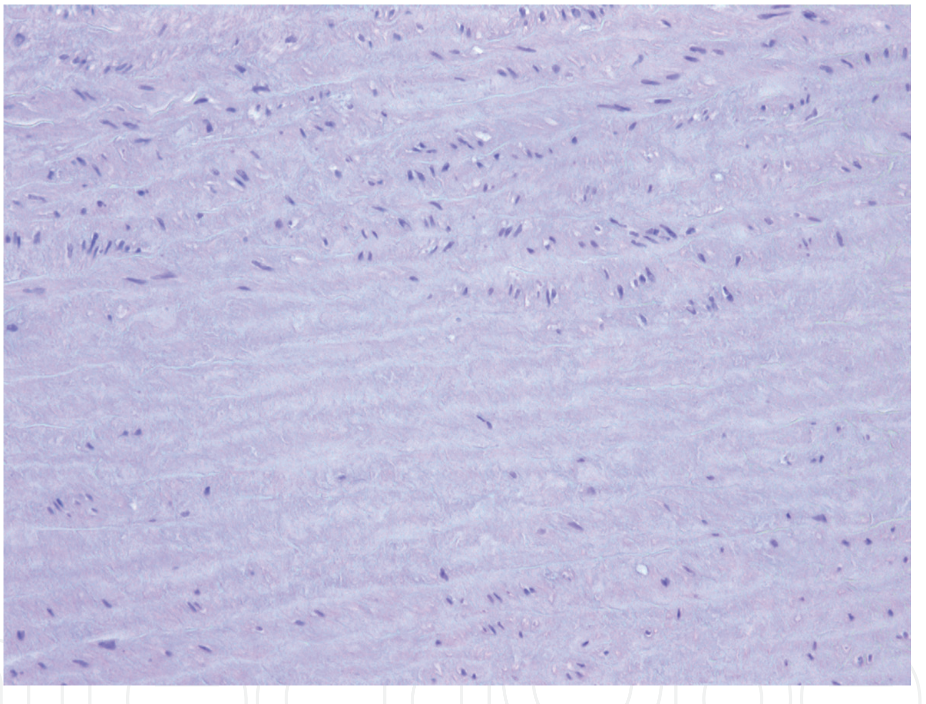

Figure 3.
Necrosis of the aortic media tunic, chaotic arrangement of smooth muscle and elastic fibers.

filled with blood, and subsequently an intramural hematoma. The beginning of the stratification is the rupture of the intima due to the impact of the peak load [6, 7] (**Figures 4** and **5**). However, this concept does not explain the mechanism of dissection in acute trauma in young patients with noncompromised aortic wall. In all likelihood, with excessive loads or due to degenerative changes within it, the aortic wall ceases to function as a whole and is divided into separate fragments with different mechanical properties (**Figure 6**).

The exact number of cases of distal aortic dissection is very difficult to determine, since this disease refers to various conditions due to different causes. It is important to divide the distal dissection into primary and secondary. Primary dissection is a firstly appeared dissection, and secondary distal dissection can be called the presence of active false lumen of the descending aorta, after correction of the proximal dissection.

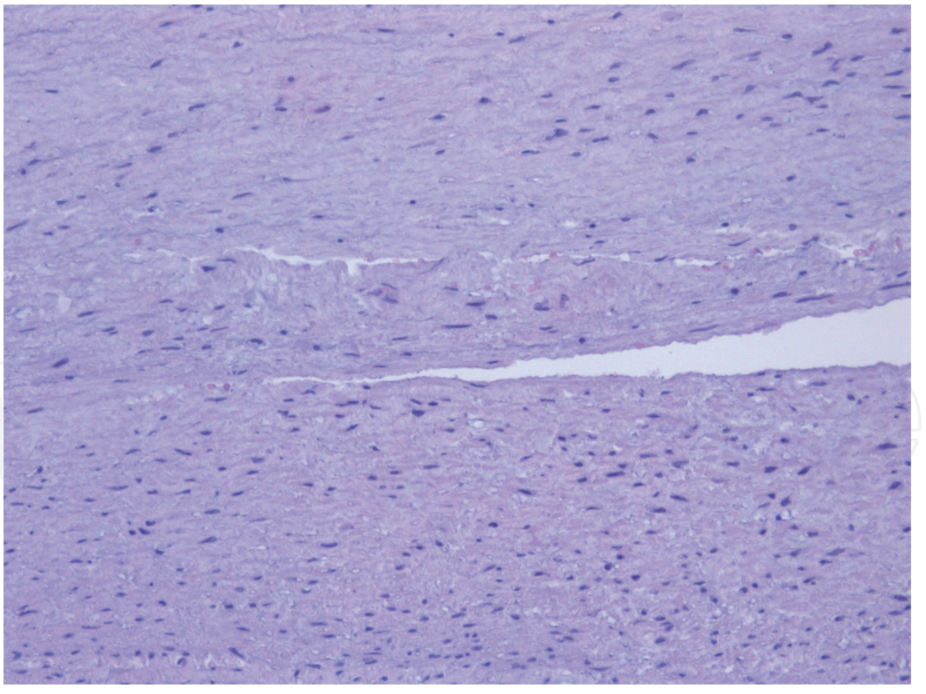

Figure 4.
Dissection in the middle layer of the aorta, tunic media. On the left are the nuclei of single erythrocytes.

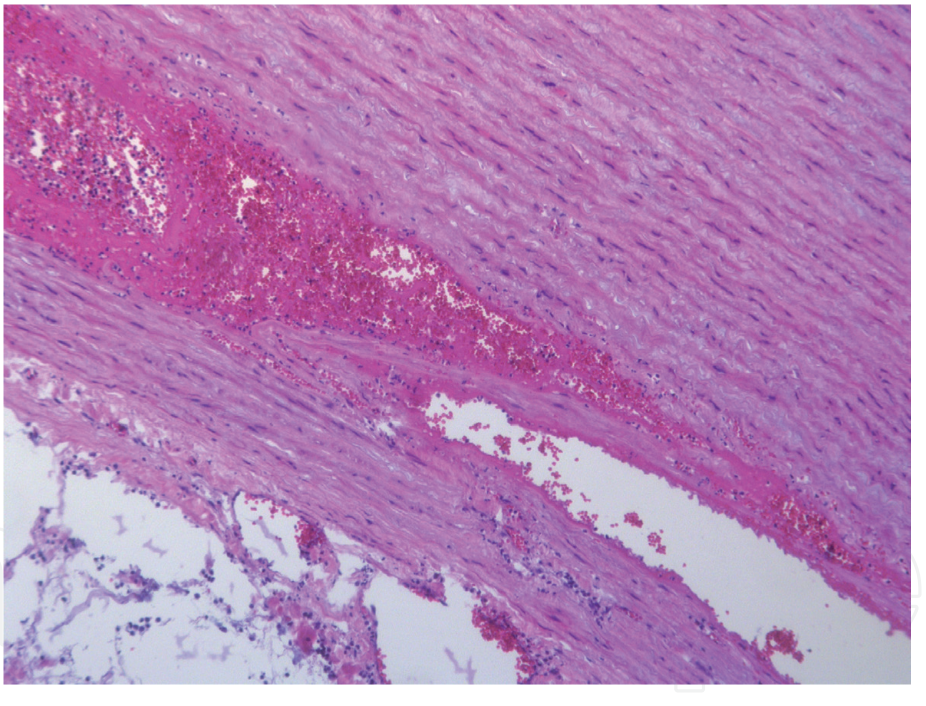

Figure 5.
Extensive acute aortic dissection. Areas of tearing are localized in the distal third of the media tunic closer to the adventitia. A large number of red blood cells are observed inside the false lumen.

Primary dissection may be associated with dysplasia of connective tissue due to congenital genetic syndromes such as Marfan, Loeys-Dietz, Ehlers-Danlos, Turner, and others. Connective tissue dysplasia in distal dissection can also occur without the presence of hereditary syndromes. Distal dissection occurs in patients without connective tissue dysplasia, for example, after trauma.

Recently, acute aortic syndrome has been isolated, which, in addition to aortic dissection, includes a penetrating ulcer and an intramural hematoma; these conditions are predictors of dissection and require exactly the same approach as the dissection itself.

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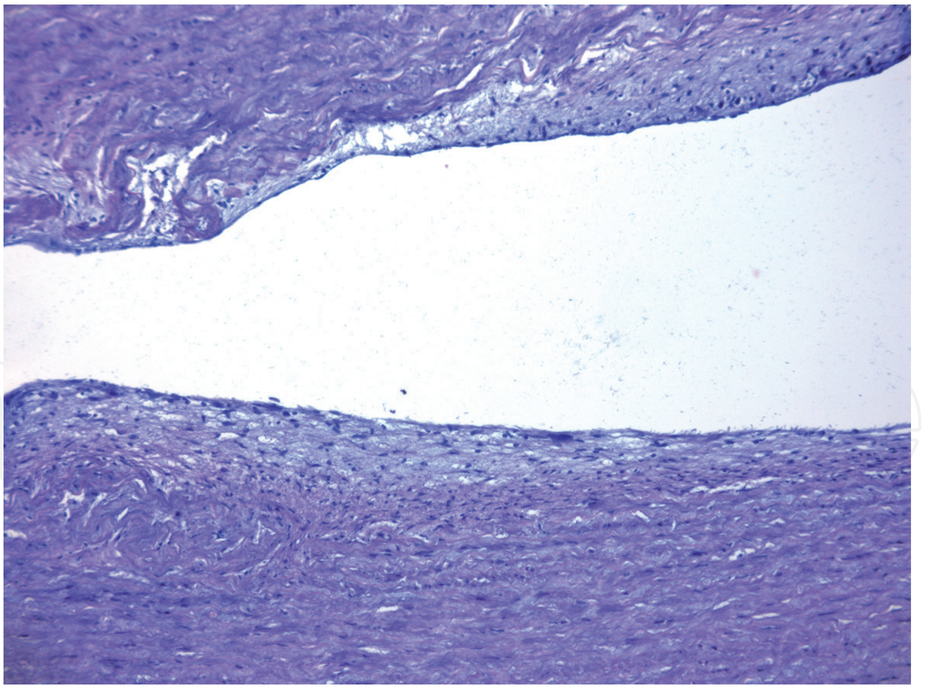

Figure 6.
Chronic aortic dissection. The formation of a pseudo-intima is observed along the edges of the false lumen.

Distal dissection or aortic dissection of type B most often affects male patients and has an incidence between 2.9 and 4.0 per 100,000 people per year [10]. The number of cases of distal dissection is increasing, with improved diagnostic capabilities and an aging population being put forward as reasons. A recent prospective analysis of 30,412 middle-aged men and women over a 20-year follow-up period showed the incidence of acute aortic dissection in 15 patients per 100,000 population per year [11]. The number of penetrating aortic ulcers has also increased. In symptomatic patients considered as candidates for invasive intervention, the prevalence of penetrating ulcer is from 2.3 to 7.6%, while in 90% of patients, the lesion is localized in the descending thoracic aorta [12]. The prevalence of intramural hematoma is from 5 to 20% of patients with acute aortic syndrome;, in 60% of cases, the descending thoracic aorta is involved in the process [13]. Blunt aortic trauma occurs in less than 1% of all road accidents. However, it is the second most common cause of death among trauma patients and accounts for 16% of all traumatic deaths [14]. Rupture of an aneurysm of the descending thoracic aorta occurs in 5 persons per 100,000 population per year. The average age of patients in this cohort is 70 years for men and 72 years for women [15]. Mortality in aneurysms and aortic dissection has recently increased from 2.49 per 100,000 to 2.78 per 100,000 of the population per year from 1990 to 2010, with a predominance of males [16].

Most clinical classifications of aortic dissection, including the first and most common, proposed by DeBakey, are based on the identification of the localization of the initial rupture of intima, since most of this largely depends on the severity of the patient's condition, further treatment tactics, and prognosis of his life. According to DeBakey, the aortic dissection is divided into three types: type I—primary rupture of intima is localized in the ascending aorta, and the dissection extends below the source of the left subclavian artery; type II—primary rupture of intima is localized in the ascending aorta, and the dissection extends no further than the source of the brachycephalic trunk; and type III—primary rupture of intima is localized below the source of the left subclavian artery and extends to the distal aorta, up to its bifurcation [17]. Subsequently, types I and II were combined into one type A, and type III was separated into type B, and this classification was called Standford [18].

Some authors began to call the type A dissection (types I and II by DeBakey) proximal, and type B (type III by DeBakey) distal, since apparently these terms most fully reflect the essence of pathological processes occurring inside the aorta [19, 20]. For forms where the dissection is limited to the aortic arch or extends retrograde from the descending aorta to the arch and ends before the ascending aorta, the term "non A non B" is proposed [21, 22].

Currently, new classifications that are more modern are proposed, in particular DISSECT classification, which considers six key parameters: duration of the disease, localization of intimal rupture, size of the stratified aorta, length of the affected area of the aorta, clinical complications of stratification, and the presence of false lumen thrombosis [23]. In the surgical treatment of distal dissection (type III DeBakey) within 30 days mortality surgery ranges from 10 to 24%, while at carrying out of conservative therapy, this index varies within 10%. Therefore, the distal dissection (type III DeBakey) is adopted a conservative wait-and-see tactic. Long-term results demonstrate the need for intervention in 20% of patients treated conservatively within 3 years from the beginning symptoms of the dissection [24].

The strategy and tactics of treatment of distal widespread aortic dissection are still the subject of discussion [25]. A majority of authors agree that invasive intervention is indicated by increasing the diameter of the aorta to 5.5 cm, with the combined diameter of the true and false lumen to 4.5 cm, or with complicated forms of dissection [22]. Complicated forms of aortic dissection type B are considered to be a rapid increase in the diameter of the aorta; rupture of the aorta and/or hypotension or shock; ischemia of internal organs, kidneys or lower limbs; paraplegia/paraparesis; periaortic hematoma; re-emerged or untreatable pain syndrome; and refractory to drug therapy hypertension. At the same time, with conservative treatment of complicated forms of distal aortic dissection, mortality is about 50% [26–29].

Consequently, most interventions in distal aortic dissection are carried out for emergency indications. Methods of reconstruction in distal aortic dissection can be divided into traditional open, video-assisted, X-ray endovascular, and hybrid.

2. Methods

Methods of reconstruction of distal aortic dissection: 1. thrombosis of false lumen by foreign bodies; 2. the creation of an artificial distal fenestration; 3. extraanatomical bypass surgery; 4. prosthetics between the two clamps; 5. prosthetics between the two clamps with the use of an extraanatomical bypass shunt; 6. prosthetics between the two clamps with the use of methods of extracorporal blood circulation; 7. prosthesis without the use of clamps by circulatory arrest; 8. endoprosthetics (stent grafts); 9. stenting; and 10. hybrid methods in the form of a combination of these techniques using different types of access.

Initially, the reconstruction of the descending aorta during dissection was carried out in nonradical ways, such as initiation of thrombosis of the false lumen by means of foreign elements or reduction of the diameter of the aorta outside by suture or exoprosthesis. In the future, methods of simple clamping of the aorta and its replacement were performed. Frozen arterial homografts and then synthetic vascular prostheses were used [30].

Despite such disadvantages as limiting the time of anastomosis not more than 30 min and the formation of tissue hypertension, in the areas above and below the imposition of clamps, the supporters of this method think because there is no need for systemic heparinization of the patient and the use of perfusion support. All these significantly reduce blood loss and surgery time [31]. In the early stages of surgery for rupture of the descending part of the thoracic aorta, the technique of bypass grafting was also used: ascending aorta—abdominal aorta. At the same time, a homograft was used as a shunt. However, this technique was not ideal due to the technical complexity of the shunt, its bulkiness, and insufficient reliability [32].

In 1955, based on the work of DeBakey et al., the first experience of reconstructive interventions on thoracic aorta with dissection in 6 patients was published [33]. In 1965, they analyzed 10-year results of treatment of thoracic aortic dissection, including T III. Two surgical techniques were described. Earlier, it was the formation of artificial distal fenestration in the thoracic aorta and reconstruction of the true lumen below its level. The authors themselves recognize this technique does not correspond to the concept of restoring integrity and normal function of the aorta, but rather palliative. Another technique was the imposition of the left-femoral bypass, the intersection of the aorta between the two clips superimposed directly at the ostium of the left subclavian artery and near the diaphragmatic opening, and the restoration of the integrity of the true lumen of the aorta and its replacement with a synthetic vascular prosthesis. At the same time, according to the authors, in the case of spreading the dissection proximal to the left subclavian artery, it could be sacrificed by ligation, or reimplanting its origin into a vascular prosthesis [34].

The use of cardiopulmonary bypass increased the safe time for anastomosis, but did not solve the problems associated with the imposition of clamps on the aorta, since in most patients with distal aortic dissection, the inlet of the false canal is located directly at the origin of the left carotid artery. In addition, the clamp applied at the level of the diaphragm to the aorta makes it difficult to form a qualitative distal anastomosis, and damage to the altered tissues of the aorta can cause its insolvency. Moreover, the problem of residual dissection below the diaphragm level remains unsolved.

DeBakey et al. in 1966 established the principles of the surgical technique of treatment of aortic dissection, including excision of the dissected intimal flaps, overlapping the proximal enter in false lumen and reconstruction of the aorta by the implantation of synthetic tubular prosthesis. Based on this, techniques for reconstruction of distal aortic dissection were further developed [35].

In 1974, Stanley Crawford reported on his experience with thoracoabdominal aneurysms and dissections. In earlier observations, the implantation of a synthetic Dacron graft was undertaken as an extraanatomical shunt with subsequent overlapping of the aortic lumen and serial reimplantation of the aortic branches by vascular prostheses in the wall of the aortic graft. In later cases, the vascular graft was placed inside the aneurysm with reimplantation of the origin of visceral vessels directly into the wall of the graft [36].

Currently, this technique is the basis for the open correction of extensive thoracoabdominal aortic dissection. However, the technical details of the operation are controversial.

1. Method of extracorporeal blood circulation:

    a. left-femoral bypass with or without oxygenation (left atrium eyelet or pulmonary vein-femoral artery);

    b. full bypass femoral artery—femoral vein.

2. Ways of protection of internal organs: normothermic perfusion with the perfusion of visceral vessels; hypothermia; and total circulatory arrest without the use of clamps on the aorta.

3. Method of implantation of vertebral arteries in the prosthesis for the prevention of spinal complications.

4. Method of implantation of the visceral branches.

There are various options to use this technology. In particular, in the conditions of left-femoral bypass and normothermal perfusion, the procedure is performed from thoracophrenolumbotomy access in stages. In the beginning, the clamping of a proximal segment of the aorta is done, the formation of a proximal anastomosis with a vascular graft to the descending thoracic aorta is carried out, and the mobilization of the thoracic aorta is produced. The clamp on the distal portion of the aorta is placed, producing distal anastomosis, dissecting aneurysm, and lumbar arteries are stitched, producing temporary occlusion of the visceral arteries with balloons catheters. Produce perfusion of the renal arteries to protect against ischemia; the intercostal arteries are implanted to the prosthetic aorta at the site Th8-L1 to restore adequate blood supply to the spinal cord, and renal arteries and visceral branches are implanted [37].

Further improvement of this technique was carried out by sewing visceral branches into the vascular prosthesis of the aorta on separate islands or using an aortic vascular prosthesis originally made with branches for the implantation of visceral arteries [38, 39]. The difference between the methods lies in the fact that the implantation of the origin of the vessels on a single island reduces the time of the procedure, but there is a risk of relapse in the long term, as in the bloodstream there are large areas of altered aortic tissue with untreated arterial origins. When using the technique of Coselli, the origins of the visceral vessels are filed separately to those already present in the aortic graft that prevents recurrence of the aneurysm, but does not allow avoiding the complications associated with the tension and kinking of the vessels and extends the duration of the procedure.

To prevent these complications, a modified technique of visceral arteries reimplantation was proposed. Its essence lies in the fact that used graft with four prestitched lateral branches. After applying the proximal and distal anastomoses, each lateral branch is wrapped around the main graft, forming a slightly curved loop around it. The opening of each visceral artery is sutured to the lateral branch. This method prevents bending of the lateral branches and allows for hemostasis with a good overview of all suture lines [40]. Estrera et al. describe a modification of the classical technique used by them in the correction of chronic complicated aortic dissection type B. The procedure is performed by bypass of the left ventricle on the scheme of the lower left pulmonary vein—distal aorta, through a vascular prosthesis attached to the aortic prosthesis. Is drainage of the cerebrospinal fluid, and neuromonitoring. After clamping the distal portion of the aorta and forming a wedge-shaped hole in the membrane between the true and false lumens, a distal anastomosis is formed to adequately supply them with blood. Then the clamp is shifted higher on the aortic prosthesis and the vascular prosthesis starts blood flow to the distal aorta, and then the aorta is clamped at the level of the left subclavian artery. The aorta is incised, intercostal arteries or clipped or made their temporary occlusion using a Fogarty catheter. A reversed elephant trunk is formed, then a proximal anastomosis is made. If necessary, intercostal arteries are drained into the vascular prosthesis on a single site, and prestitched to the aortic prosthesis with both ends. According to the authors of their more than 20 years of experience, it is shown that when using this technique, hospital mortality is 8.3%. Persistent neurological disorders occur in 1.3%, strokes 2.9%, the need for dialysis in 6%. 5-, 10-, 15-, and 20-year survival rates are 72%, 60%, 45%, and 39%, respectively [41].

At the same time, the technique of complete shutdown of the descending aorta from the systemic circulation using the methods of deep hypothermia without applying clamps to it has not lost its relevance [42]. According to some authors, this technique has significant advantages since it allows you to do without applying a clamp to the proximal portion of the descending thoracic aorta, as close as possible to impose anastomoses to the origin of the left subclavian artery and the aperture of the diaphragm, as well as in the case of retrograde dissection, if necessary, move to the distal portion of the aortic arch. The advantages of the technique include a bloodless surgical field, the return of a large amount of blood to the contour of the apparatus and hypothermic protection of the central nervous system, heart, and visceral organs. In addition, there is no need to use the drainage of cerebrospinal fluid, monitoring of evoked potentials, separate perfusion of renal and visceral arteries, and the insertion of epidural catheter [43].

Its main drawback is the need to protect the brain and spinal cord, as well as internal organs from hypoxia and a limited time of safe duration of circulatory arrest, no more than 90 min at a body temperature of 18°C [44]. The cooling phase of the patient takes quite a long time since the decrease in body temperature should be uniform, complete, and prolonged [45]. The time to reach the optimum temperature can take from 30 to 50 min [46]. The method of warming the patient should also be done slowly and in compliance with a number of different conditions. In conditions of complicated distal aortic dissection, the technique of circulatory arrest with deep hypothermia may not always be effective enough.

The influence of different approaches to revascularization of intercostal and lumbar arteries during reconstructive interventions on the distal aorta on the prevention of paraplegia has not been studied enough. One hundred consecutively operated patients were performed open reconstruction of the distal lesions of the aorta with a consistent overlap of the segmental arteries. Early mortality was 6%. The average length of stay in the intensive care unit was 2.5 days, and the average length of stay in the hospital was 10.0 days. On average, 8.0 ± 2.6 pairs of segmental arteries were closed, with an average of 4.5 ± 2.1 covered segment pairs being in the area between T7 and L1, where is the artery of Adamkewicz. Postoperative paraplegia occurred in 2 patients. The authors conclude that the overlap without reimplantation of 15 pairs of intercostal and lumbar arteries during the reconstruction of the distal aorta is safe, and is accompanied by a moderate number of paraplegia in the early and late postoperative period [47].

Radical surgery shows good immediate and long-term results in patients with hereditary connective tissue syndrome. In particular, in patients with Marfan syndrome, total replacement of the entire thoracoabdominal aorta and reconstruction of all visceral branches are recommended to avoid relapses in the long term, even if dilation in some segments is not expressed. In a study by Omura et al., a series of observations was reported in 20 patients with Marfan syndrome who underwent total replacement of the thoracoabdominal aorta for a dissecting aneurysm. All patients during the surgical intervention were performed cerebrospinal fluid drainage, distal perfusion of the aorta and selective perfusion of the internal organs. Deep hypothermia was used in 13 patients.

In the 30-day postoperative period, no fatal outcomes were observed. The average follow-up period was 54 months. One patient died of interstitial pneumonia 38 months after surgery. The survival rate for 8 years was 91.2 ± 9.0%. Two patients required additional interventions on the aorta. Actuarial index of freedom from operations on the aorta for 8 years was 83.9% ± 10.5%; no patient needed a rethoracotomy. During follow-up, neither false nor asymptomatic aneurysms by computed tomography (CT) were noted [48].

Even though the results of surgical treatment of distal aortic dissection have improved over the last decade, they are still not optimal, and hospital mortality is 25–50% [49, 50]. Complications associated with the open method of surgical intervention are the following: spinal cord ischemia (6.8%), cerebral circulation disorders (9%), abdominal ischemia or intestinal infarction (4.9%), and acute renal failure (19%) [51, 52].

The widespread use of open radical operations is limited by the severity of the patient's condition, the presence of concomitant diseases, and its physiological reserve. A significant disadvantage of this technology is a very low possibility of its replication. Such operations with a low level of mortality can be carried out only in specialized aortic centers with 20–30 years of experience in such operations and close-knit teams of highly qualified specialists. In conditions of acute complicated DeBakey type III dissection, this is not always possible and requires simpler and no less reliable solutions.

The need for their search and the beginning of the era of percutaneous transcatheter interventions on the coronary arteries prompted researchers to create a vascular prosthesis that could be placed inside the lumen of the aorta to block the entrance opening of the false canal and isolate its wall without performing extensive surgical access. In 1988, Volodos reported on the first percutaneous endoprosthesis of the thoracic aorta with a self-fixing synthetic prosthesis for a large posttraumatic aneurysm [53].

With significant advantages due to the reduction of intraoperative trauma and no need to protect the brain and spinal cord, as well as internal organs, the methods of transcatheter reconstruction of the distal aortic dissection initially had a number of limitations and did not immediately gain a leading position in the treatment of complicated distal aortic dissection [54].

Stent graphs are ideal for implantation in straight areas of the aorta, where there are no large hemodynamic values of arterial trunks; such in the reconstruction of the distal dissection can only be a portion of the descending thoracic aorta, from the ostium of the left common carotid artery and ending with the level of renal arteries. Despite the fact that during the period from the left subclavian artery to the renal from the descending aorta does not depart large arterial branches, overlapping its area for more than 20 cm at this level can lead to the development of pronounced spinal disorders [55–57]. The wall of the aorta is constantly shrinking, conducting a pulse wave, and violation of its elastic properties during dissection creates a tendency to irreversible dilation of the aorta and its thinning up to rupture [58].

To prevent spontaneous dislocation of the stent graft, two proximal landing zones of at least 1.5 cm and a distal zone of at least 2 cm in length are required [59].

For successful fixation of the stent graft in the landing zones, it is necessary to overestimate the pressure on the aortic wall in the places of fixation, which is achieved by increasing its landing size by 2–3 mm or more. In this regard, one of the most dangerous complications associated with the implantation of a stent graft is the retrograde progression of the dissection [60, 61].

In addition, the number of complications included caudal migration of the prosthesis under the influence of the pulse wave; the collapse of a stent graft; and lack of precision of its positioning, because this process performed distantly is not under direct visual, and under angiographic control, which may lead to the implantation of stent graft in the false lumen of the aorta [62].

Specific complications of implantation of stent graft also considered para prosthesis leakage (endoleaks) [55–57]. Endoleak type Ia is a frequent complication in the reconstruction of TEVAR for distal aortic dissection and is caused by inadequate sealing of the endograft's in the proximal area [63]. This endoleak that occurred immediately after TEVAR for acute dissection of type B may indicate the unstable condition of the aorta [64].

In most cases, proximal intimal fenestration in distal dissection is located near the ostium of the left subclavian artery, due to the formation of reverse blood flow in the aorta in this area [58]. Thus, in 20–30% of cases, stent graft implantation requires closure of the left subclavian artery ostium [65]. Intentional overlapping of the left subclavian artery of the stent graft leads to a statistically significant increase in the risk of stroke [66] and the frequency of spinal cord ischemia [67]. In this regard, current recommendations include revascularization of the left subclavian artery (LSA) [65]. In one retrospective comparative study, there was a statistically significant increase in the number of strokes and upper limb ischemia in patients who did not undergo revascularization of LSA in comparison with patients who underwent revascularization of LSA by reimplantation of its ostium or bypass surgery [68].

In order to reduce the aggressiveness of the intervention and increase the landing zone, the endovascular technique of parallel stent grafts is used, that is, implantation of a separate stent graft into the left subclavian artery, its placement parallel to the main stent graft, and removal of its orifice beyond the proximal landing zone of the main stent graft, the so-called chimney or snorkel technique [69]. Chimney is the method of choice in patients with complex aortic arch anatomy to extend the proximal landing zone and provide perfusion of the aortic arch branches [70]. This technique can be used in patients with aberrant right subclavian artery in the case of acute type B aortic dissection [71]. In addition, this endovascular technique can be used for revascularization of all branches of the aortic arch [72].

The technique of chimneys has a number of limitations, such as entanglement and bending of branches, but the most significant of them is the aggravation of the danger of the formation of endoleaks of type I, due to the loose fit of the main stent graft to the wall of the aorta in the landing zone [73].

To solve these problems for the purpose of endo prosthesis of the aortic arch, a number of commercially available endografts with preattached branches are produced; endoprostheses have a wide size range and do not need individual manufacture. Despite the shown good results in relation to the early postoperative mortality, the number of strokes, and the frequency of repeated interventions in patients with increased surgical risk, this procedure requires detailed preliminary calculations, is difficult to perform, and is more suitable for patients with residual dissection after reconstruction of the proximal aorta for type A dissection [74, 75].

The procedure of implantation of scalloped or fenestered stent grafts is less complicated; stent-graft with a half-opening on the edge or opening for the mouths of brachiocephalic vessels well adheres to the altered aortic wall, is easier to manufacture, and is more accessible than branched stent graft. However, fenestrated stent grafts are more prone to dislocation and show the worst results for the number of strokes and 30-day mortality [76].

All of the above techniques are also successfully used for revascularization of visceral branches. In addition, they have the same advantages and disadvantages as in the application of the aortic arch, as fenestrated stent grafts and the periscope technique, are well suited for the treatment of patients with complex anatomy in the region of the visceral branches of the aorta [77]. Technology chimney and periscopes are also used for the relief of endoleaks type I after EVAR prior to increase in the proximal and distal landing zones for endografts [78] . However, according to some authors, the application of chimney technology for revascularization of the visceral branches of the aorta in the late postoperative period increases the risk of violations of the patency of visceral implants and development of endoleaks [79].

Recently, for the revascularization of the visceral and iliac arteries, the sandwich technique has become widespread, which is a later modification of the chimney or periscope technique and is used to stop extended aortic lesions. In this case, the origin of the visceral branches prostheses is opened into the lumen of another stent graft, implanted on top of the first and overlapping it in a certain area. The feature of this technique is that there is a greater risk of developing "gutter" endoleaks, aorta overlap for a much longer distance, visceral arteries requires stent graft greater length. Nevertheless, this technique gives good results both in the near and in the long term and is not accompanied by a high frequency of spinal complications [80, 81].

According to a meta-analysis of the results of repeated open interventions after TEVAR in the aortic dissection, which consisted of 2029 cases in the TEVAR 2403 cases of aortic dissection, with an average follow-up period of 34 months, the most common reasons for reintervention was endoleak type I (35.2%), redo dissection (14.4%), and perfusion of the false lumen (9.3%) [82].

In another study of 2531 patients who had TEVAR performed for acute complicated aortic dissection type B, mortality within 30 days after the intervention was noted in 7.3% of cases; in comparison with the 2347 patients treated with conservative treatment for acute uncomplicated aortic dissection type B, where the mortality rate was 2.4%. In the group of 1276 patients where open surgery was performed, the mortality rate was 19%. Patients who were performed TEVAR had more favorable results in relation to remodeling of the aorta and survival associated with lesions of the aorta than patients treated with medical therapy [83].

Given the presence of a large number of endoleaks after TEVAR, it is suggested that this technique is not quite suitable for the treatment of aortic dissection since most patients do not have a suitable anatomy [84].

However, one study showed that TEVAR is safe to perform in chronic distal aortic dissection, but there are limitations due to the complex anatomy of the dissection. Unfavorable factors are the departure of less than two vessels from the true lumen of the aorta, the large diameter of the aorta before surgery and the location of the primary rupture at a greater curvature [85].

In addition, infrequent (0.4%) but quite a formidable complication is infection of stent grafts, developing mainly in weakened patients with immunosuppression. In this case, open intervention with complete excision of the infected material and extraanatomic revascularization or revascularization in situ is required [86].

In order to avoid many of these complications, the use of a bare metal balloon expandable stent was proposed for decompression of the false aortic lumen [87–89].

The stent can be opened to the required diameter, but not more than 4.5 cm, which is one of the significant limitations. It can also be used on any part of the aorta, since the opening of the stent cells has an area of at least 1 cm^2, which allows for unhindered perfusion of the branches of the aorta in any zone. The main disadvantage of the bare metal stent is that it does not completely cover the perfusion along the false lumen, since, as a rule, when dissection, there are a large number of small gaps along the false channel. However, in conservative treatment of type B dissection, there is also a valid false channel, and patients do without surgery for years. During implantation of the stent, the main task is the stabilization of the lumen of the aorta due to the redirection of the main mass of blood in the true lumen rather than achieving a perfect angiographic effect. The principal negative points are also considered that the bare metal stent is balloon expandable and this can lead to the progression of the dissection [90].

Nevertheless, if certain techniques are followed, such as controlled hypotension and gradual slow opening of the balloon, it is possible to achieve adequate stent adherence to the aortic wall even at the level of the aortic arch and brachiocephalic branches. The high degree of replication of the technique and the absence and versatility of bare metal stents are undeniable advantages. The combination of stenting with implantation of stent graft also gives good results in the implantation of the stent in the area of origin of the artery of Adamkewicz Th8-L1, as well as visceral and brachiocephalic branches. As a monomethod, the implantation of a bare metal stent gives good results in posttraumatic aortic dissection [91–93].

There is another more common technique of false lumen decompression, which is an endovascular balloon fenestration of the false lumen of the aorta in the distal region and a stent implantation in visceral branches. This technique improves patient outcomes in the long term, especially in relation to be aortospecifically complications [94].

As hybrid interventions for aortic dissection, two methods are described in the literature; one of them is the implantation of combined prostheses where a vascular prosthesis with preprepared one or several branches for implantation of brachiocephalic arteries is made together with a stent graft, which is implanted in the upper and middle portion of the descending aorta. This method is called "frozen elephant trunk" by analogy with the two-stage operation proposed by Borst in 1982. The technique is used in patients with proximal dissection passing to the descending thoracic aorta in order to reduce Borst procedure to one stage [95].

Another hybrid technique is debranching or a technique of open switching the branches of the aorta with subsequent implantation of a stent graft. This technique is widely used to increase the landing zone for stent graft, both in the area of the aortic arch and visceral branches [96, 97]. The advantages are less intraoperative trauma and no need for circulatory arrest, brain perfusion, and spinal cord protection. The disadvantages include the availability of open access and the interval between stages, which are not always acceptable with urgent intervention about the progression of distal dissection. In addition, a large number of complications at the stage of vascular switching accompany the technique of visceral debranching [98].

In the literature, for some reason, little attention is paid to the description of methods of prosthetics of the descending thoracic aorta and simultaneous implantation of bare metal stents in the visceral zone or on the contrary in the region of large spinal branches, in particular the Adamkewicz artery, under video or X-ray control with extensive distal aortic dissection. This technique significantly reduces operating access, limiting it to a thoracotomy, thus allowing for simultaneous intervention, for example, revascularization of the myocardium provides a good quality of anastomosis of the aorta, and significantly it reduces the time of circulatory arrest and at the same time provides good permeability of all visceral branches [99].

According to the 17-year follow-up of the International Registry of Acute Aortic Dissection (IRAD), most patients are treated conservatively; however, in recent years, the frequency of this treatment has decreased from 75 to 57%. The number of endovascular interventions performed has increased from 7 to 31%, the frequency of open surgical operations has decreased from 17 to 8%, and hybrid techniques were widely introduced (5%) [100].

3. Conclusion

Thus, it can be stated that transcatheter methods of treatment are first-line methods with complicated distal aortic dissection and suitable for this anatomy of the dissection. In case of impossibility of performance, transcatheter intervention should consider the implementation of an open or hybrid repair. Conservative management of patients is preferable in uncomplicated distal dissection. Improving knowledge in the field of brain and spinal cord physiology, as well as transcatheter and hybrid techniques, will allow safe interventions in stable patients with type B dissection to improve their survival and quality of life. Further progress in the treatment of distal aortic dissection depends not on the juxtaposition of different reconstructive techniques, but on their carefully thought-out choice and combination.

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