ENDOVASCULAR REPAIR OF THE AORTIC ARCH

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Objective. The study was aimed at assessing the in-hospital results of aortic arch endoprosthetic repair using different variants of endovascular supraaortic debranching.

Patients and methods. The analysis included 27 patients subjected within the framework of aortic arch endoprosthetic repair to various types of supraaortic endobranching, including the technique of parallel prostheses and implantation of fenestrated stent grafts. We analysed the clinical and morphological status of patients prior to operation, peculiarities of the intervention (type of debranching and Ishimaru's classification zones in which the reconstruction was performed) and in-hospital results of treatment.

Results. The patients' mean age amounted to 66 years. The main nosology (70%) was an aortic aneurysm. Nearly in 30% of cases, the operation was performed emergently for acute aortic syndrome. The main causes of refusal from the traditional prosthetic repair included chronic kidney disease (22.5%), chronic obstructive pulmonary disease (11%), acute cerebral ischaemia within the previous 6 months (15%). The technical success rate of the operation was achieved in 100% of cases. The average duration of the intervention amounted to 226 min, with the mean blood loss equalling 355 ml. The majority of reconstructions were performed in zones 1 and 2 according to Ishimaru (59 and 33%, respectively), in 2 (7%) patients prosthetic repair was performed in zone 0. The total number of the aortic branches involved into reconstruction amounted to 45. Intervention-related complications included 3 (11%) cases of acute cerebral circulation impairment, 2 (7.4%) aortic branch occlusions, and 1 (3.7%) type II endoleak. The in-hospital and 30-day mortality rates amounted to 3.7 and 7.4%, respectively.

Conclusions. Aortic arch endoprosthetic repair using supraaortic endobranching is considered to be an effective alternative method of treatment for patients with various pathology of the aortic arch and contraindications to traditional prosthetic repair involving artificial blood circulation.

Key words: *aortic arch endovascular repair, supraaortic debranching, fenestrated stent graft, parallel grafting technique, ultrasound duplex scanning.*

INTRODUCTION

Since the first implantation of an aortic stent graft by Nikolay Volodos in 1987 when many specialists were skeptical about this method there has occurred a revolution in the attitude of the world medical community to endovascular aortic repair [1]. In the modern clinical practice endoprosthetic repair is considered as a generally accepted method of treatment of various-localization aortic pathology. In reconstruction of the descending thoracic aorta, endoprosthetic repair becomes a method of choice for many elective and majority of emergency cases [2]. In pathology of the aortic arch, the «gold standard» remains traditional prosthetic repair using artificial circulation, which is associated with significant mortality and stroke incidence, often being a cause of refusal in operative treatment [3–8]. Recent trends are toward increased interest in endovascular and hybrid methods of correction of aneurysm of the aortic arch and is branches [9]. The hybrid technique includes a combination of stent-graft implantation and surgical debranching. A total endovascular approach envisages endobranching with the use of the method of various-modification parallel grafts («chimney», «periscope», «sandwich») or implantation of fenestrated or branched endografts. We present our experience with aortic arch endovascular repair using various techniques of endodebranching.

PATIENTS AND METHODS

At the Department of Cardiovascular Surgery of the National Medical Research Center of Cardiology of the RF Ministry of Public Health, more than 170 operations of thoracic aorta endoprosthetic repair were performed. Of these, about 50 consisted in prosthetic repair of the aortic arch in its segments, performed using various types of aortic arch debranching.

Selected for the analysis were 27 patients with various types of endovascular debranching,

including the «chimney» parallel graft technique and endoprosthetic aortic repair with a fenestrated stent graft. All patients gave their written informed consent for participation in the study according to the Declaration of Helsinki. We analysed the preoperative clinical and morphological status. All patients within the framework of preparation for the operation underwent contrast-enhanced multislice computed tomography (MSCT). Based on the obtained findings we assessed the aortic anatomy followed by making a decision as for the zone of proximal fixation of the aortic graft and the type of supraaortic debranching. Besides, the protocol of preoperative examination included ultrasound Doppler scanning of aortic arch branches for further intraoperative assessment of blood flow parameters in dynamics after debranching. Also studied were intraoperative parameters (duration of surgery, blood loss, etc.) and in-hospital results of treatment such as incidence of various complications, length of hospital stay, etc. Efficacy of debranching was evaluated based on the clinical picture, postoperative MSCT findings and in part of patients – also ultrasound duplex scanning (USDS) of aortic branches.

RESULTS

The patients' mean age amounted to 66 years. The main nosology for which the patients were operated on was an aortic arch aneurysm. In one third of cases there was acute aortic syndrome. 11% of patients suffered from chronic obstructive pulmonary disease of severe or utterly severe course. One patient had end-stage chronic kidney disease requiring programmed haemodialysis. In 15%, a cause of refusal from open operative treatment with assisted circulation was a history of acute cerebral ischaemia (ACI) endured within the previous 6 months. Table 1 shows the main characteristics of patients included into analysis.

The main intraoperative parameters are shown in Table 2. In one third of cases, operative intervention was performed emergently for acute aortic syndrome (acute rupture, aortic dissection and in 1 case multiple symptomatic penetrating ulcers with formation of intramural haematomas of the aortic arch). The technical success was achieved in all patients. The average duration of the intervention amounted to 226 min, average blood loss – 355 ml. In 2 cases of acute aortic rupture with moderate and large haemothorax with pulmonary collapse, the second stage on day 2 after aortic reconstruction we performed thoracotomy with sanitation of the haematoma and drainage of the pleural cavity. Most often endoprosthetic repair was performed in zone 1 according to Ishimaru classification in a combination with one or other type of debranching of the left common carotid and left subclavian arteries [10]. The spectrum of the methods of supraaortic debranching and prostheses used depending on the zone of proximal fixation of the aortic stent graft is shown in Table 3.

Table 1

Clinical and functional profile of patients

Characteristic	N=27
Age, years	66±16
Male/female gender	9 (33.3%)/18 (66.7%)
Body mass index, kg/m^2	28±5
Aortic arch aneurysm	19 (70%)
Aortic dissection: · type A · type B	 1 (4%) 7 (26%)
Acute aortic syndrome (emergency operation) · acute aortic rupture · acute dissection	 3 (11%) 5 (18,5%)
CAD	11 (41%)
Chronic obstructive pulmonary disease	3 (11%)
Chronic kidney disease: · stage III–IV · stage V	 5 (18,5%) 1 (4%)
ACI within previous 6 months	4 (15%)
A history of prior heart surgery	1 (4%)

Note: CAD – coronary artery disease; ACCI – acute cerebral ischaemia

Table 2

Intraoperative parameters

Characteristic	N=27
Emergency surgery	8 (30%)
Technical success	100%
Proximal zone according to Ishimaru: · 0 · 1 · 2	 2 (7,4%) 16 (59,3%) 9 (33,3%)
Surgery duration, min.	226±101
Blood loss, ml	355±265
Contrast volume, ml	200±86
Aortic endograft: · Valiant · Gore · Alpha · Ancura	 3 (11%) 3 (11%) 8 (30%) 13 (48%)

Depending on the objective data and ultrasound parameters of blood flow in the reconstruction-involved vessels (peak systolic and end-diastolic flow velocity, as well as type of blood flow based on the analysis of the envelope curve of the Doppler spectrum, some of these parameters are shown in Table 4) in 7 of 15 fenestrations additionally were implanted stent grafts with transition to the proximal segment of the respective supraaortic branch. It was caused by the presence of objective signs of obstruction in the proximal segment of the vessel (the appearance of high difference in blood pressure between the left and right arms, significant increase in blood velocity and negative change of the Doppler

Table 3

Varieties of aortic arch debranching performed (total number of shunted aortic branches = 45)

Characteristic	Peripheral endograft	N=45
«Chimney» of the left common carotid artery	Advanta (13), Lifestream (1), BeGraft (1)	15
«Chimney» of the left subclavian artery	Advanta (3), Lifestream (1)	4
Fenestration in the area of the left common carotid artery ostium	Lifestream (1), BeGraft (2), without endoprosthetic repair (1)	4
Fenestration in the area of the left subclavian artery ostium	Lifestream (1), BeGraft (2), without endoprosthetic repair (6)	9
Fenestration in the area of the brachiocephalic trunk ostium	Lifestream (1), without endoprosthetic repair (1)	2
Left carotid-to-subclavian artery bypass grafting	Without endoprosthetic repair	11

spectrum envelope shape) and in 8 cases the fenestra was not stented. In 3 (11%) cases revascularization of the left subclavian artery was not performed.

The main results and complications of operative treatment are shown in Table 5.

The average length of stay in ICU and average length of postoperative in-hospital stay amounted to 1.2 and 8.2 days, respectively. Analysing complications revealed 3 cases of ACI: 1 extensive ischaemic stroke requiring transfer to a specialized hospital, an episode of transient loss of visual field and ischaemic stroke in the basin of the right middle cerebral artery with the development of left-sided hemiparesis and anosognosia.

As for renal complications, there were no cases of contrast-induced nephropathy. Probably, this is related to using intraoperative vascular navigation with low doses of the contrast media injected,

Table 4

Parameters of ultrasound Doppler scanning of vessels before and after implantation of a fenestrated endograft

Target artery	Without endoprosthetic repair (n=8)		With endoprosthetic repair (n=7)	
	USDS before	USDS after	USDS before	USDS after
BCT (n=2)	–	–	PSV 90 cm/s Main blood flow	PSV 87 cm/s Main blood flow
	PSV 101 cm/s Main blood flow	PSV 90 cm/s Main blood flow	–	–
Left CCA (n=4)	PSV 98 cm/s Main blood flow	PSV 107 cm/s Main blood flow	–	–
	–	–	PSV 168 cm/s Main blood flow	PSV 134 cm/s Main blood flow
	–	–	PSV 114 cm/s Main blood flow	PSV 95 cm/s Main blood flow
	–	–	PSV 62 cm/s Main blood flow	PSV 63 cm/s Main blood flow
Left SCA (n=9)	PSV 98 cm/s Main blood flow	PSV 103 cm/s Main blood flow	–	–
	PSV 103 cm/s Main blood flow	PSV 97 cm/s Main blood flow	–	–
	–	–	PSV 120 cm/s Main blood flow	PSV 150 cm/s Main blood flow
	PSV 115 cm/s Main blood flow	PSV 126 cm/s Main blood flow	–	–
	–	–	PSV 218 cm/s Main blood flow	PSV 127 cm/s Main blood flow
	PSV 119 cm/s Main blood flow	PSV 139 cm/s Main blood flow	–	–
	PSV 98 cm/s Main blood flow	PSV 129 cm/s Main blood flow	–	–
	PSV 98 cm/s Main blood flow	PSV 129 cm/s Main blood flow	–	–
	–	–	PSV 115 cm/s Main blood flow	PSV 114 cm/s Main blood flow

Note: USDS – ultrasound duplex scanning; BCT – brachiocephalic trunk; CCA – common carotid artery; SCA – subclavian artery.

Table 5

Immediate results and complications of surgical treatment

Characteristic	N=27
Number of days in ICU	1,2±0,6
Length of postoperative hospital stay (days)	8,2±4,5
Complications: · ACI · In-hospital mortality · 30-day mortality · CIN · Occlusion of aortic arch branch · Type II endoleak	 3 (11%) 1 (3,7%) 2 (7,4%) 0 2 (7,4%) 1 (3,7%)

Note: ICU – intensive care unit; ACCI – acute cerebral ischaemia; AIS – acute ischaemic stroke; CIN – contrast-induced nephropathy.

despite the scope of intervention and the presence in nearly a quarter of patients of severe impairments of renal filtration function.

Amongst complications, there was one type II endoleak diagnosed at MSCT prior to discharge, which completely regressed on control examination after 3 months.

The in-hospital mortality rate (3.7%) was influenced by a case of pneumonia with severe respiratory insufficiency in a patient with aortic rupture and total haemothorax. Yet another woman died of massive ischaemic stroke at a neurological hospital. Hence, 30-day mortality amounted to 7.4%.

Patency of the aortic branches involved into reconstruction, over the entire period of follow up (mean duration 2.2 years) amounted to 93%. In the remote period there were 2 cases of aortic branch occlusion: symptom-free closure of the carotid-subclavian shunt detected on MSCT 2 years after the intervention and left carotid artery chimney stent graft occlusion for which thromboectomy was performed, with a good angiographic and clinical effect.

DISCUSSION

Despite active implementation of endovascular techniques into clinical practice, the «golden standard» of treatment of patients with thoracic aorta pathology remains traditional surgical treatment using artificial circulation. Using surgical and perfusiological methods aimed at protecting the brain, decreasing blood loss and preventing multiple organ insufficiency failure in elective patients makes it possible to minimize the incidence of life-threatening complications and perioperative mortality [11]. At the same time, the results of surgical treatment for acute aortic arch pathology have still been associated with a relatively high level of perioperative mortality [12]. Aortic arch endoprosthetic repair has advantages from the point of view of safety and often is the only method of treatment in patients of extremely high intraoperative risk of traditional prosthetic repair of the aortic arch in the setting of artificial circulation. A large meta-analysis including 1021 patients demonstrated that at this state of the art of surgery as a rule is performed endoprosthetic repair of aortic arch in its distal segments (zone 1–3). Researchers came to recognize that in intervention on these zones endovascular methods of debranching are preferable whereas in prosthetic repair in zone 0 more often preferred is classical operation of vascular switching [13]. Probably this is related to the results of the same study having demonstrated clear-cut advantages for early mortality in patients with endobranching compared with shunting operations, who were subjected to endobranching in zones 1–3. Yet another finding during this meta-analysis was the fact that endobranching is more often performed in patients with aneurysms than dissections unlike traditional methods of vascular switching similarly frequently used in dissection and aneurysms. The spectrum of our patients differs from these data: in the overwhelming majority underwent endovascular debranching of the left CCA and subclavian artery and the patients were more often operated on for an aneurysm. Probably, low incidence of endoprosthetic repair in zone 0 was determined by unavailability of branched and fenestrated at manufacture endografts, since all such devices are still at the stage of studies and not yet been widely used in clinical practice.

Russian surgical practice also continues accumulating own experience with endoprosthetic repair of various segments of aortic arch as a stage of hybrid interventions. Thus, S.A. Abugov and coauthors reported the results of aortic endoprosthetic repair in 96 patients with a hospital mortality of 3.1%, and in 42 (43.8%) patients the intervention was performed on the aortic arch, however for debranching the authors used a surgical approach [14]. We have found no reports of clinical application of total endovascular debranching of aortic arch in the Russian literature.

In 2019, we began to apply the method of endoprosthetic repair of the aortic arch using a fenestrated stent graft with intraoperative formation of fenestrations. The fenestra is formed either on table after partial expansion of the prosthesis followed by reverse loading into the system of delivery, or in situ with application of a special balloon catheter with a puncture needle (Fig. 1).

One of the main moments in prosthetic repair of the aortic arch with fenestrated devices is the problem of additional stenting or endoprosthetic repair of branches through the fenestra. There is an opinion that during cardiac cycle the proximal segment of the aorta possesses higher motility. With time it by itself may lead to dislocation of the fenestra relative to the ostium of the vessel and became a cause of endoleak and/or ischaemia, especially of aortic aneurysm when

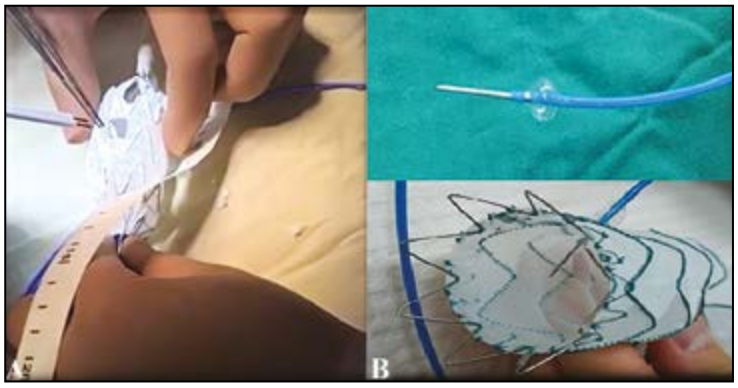

Fig. 1. Example of forming fenestrations: A – *on table*; B – *in situ*

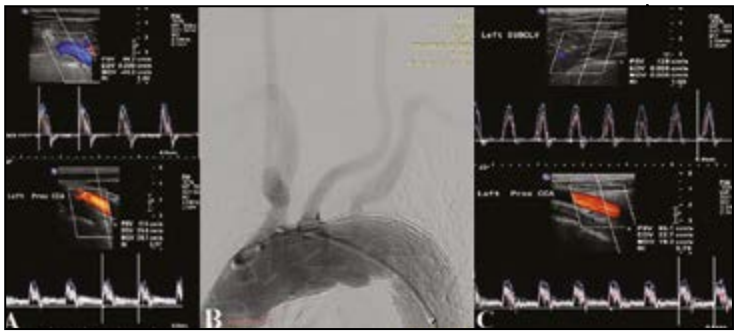

Fig. 2. Example of aortic arch endoprosthetic repair using fenestrated stent graft in zone 1: A – Doppler parameters of blood flow in the left subclavian (above) and left carotid arteries (below) prior to endoprosthetic repair; B – intraoperative angiogram after endoprosthetic repair, with a stent graft implanted into the fenestra of the left carotid artery, the fenestra of the left subclavian artery was not stented, C – Doppler parameters of blood flow in the left subclavian (above) and left carotid artery (below) after endoprosthetic repair.

the prosthesis is adhered to the native wall not all along the line but only at portions of distal and proximal neck. However, this theory supposes studying long-term prognoses and is not confirmed by pervious results [15]. Yet another cause of dislocation of the fenestra may be growth of an aneurysmal sac, induced by various types of endoleaks, including remote ones [16]. According to the data of the previously mentioned meta-analysis additional stenting of the fenestra on the one hand decreases the risk of aneurismal growth, frequency of the development of secondary endoleaks and ischaemic complications and on the other, anchoring of the aortal stent graft in distal segments of the ascending aorta may be associated with higher risk of type A retrograde dissection [13]. Therefore, the problem of choosing between two approaches in endoprosthetic repair of the aortic arch with fenestrated devices remains disputable.

In our practice, during interventions in zones 0 and 1 we nearly always performed endoprosthetic repair of the brachiocephalic trunk and left carotid artery, excluding singular cases. As for fenestration in the area of the left subclavian artery, in case of the origin of the branch from the aneurysm endoprosthetic repair should always be performed. In other anatomical variants when the ostium originates from the aneurismal neck, as well as in cases of aortic dissection the decision on additional stenting of the subclavian artery was made intraoperativley according to the objective data, i.e. given the picture of selective angiography through the fenestra the difference in arterial pressure on the arms, parameters of ultrasound Doppler scanning of the subclavian artery. Fig. 2 shows a clinical example of a patient with an aortic isthmus aneurysm subjected to endoprosthetic repair in zone 1 with fenestration below the carotid and subclavian arteries. Into the carotid artery was implanted a stent graft, and it was decide to abstain from stenting of the subclavian artery, since the results of USDS demonstrated no signs of significant circulatory impairment.

It should be mentioned that individual making of fenestrated stent grafts based on MSCT data considerably increases their cost and terms of waiting for the device thus making impossible their use in emergency situations. Operations with manual modification of the endograft are considered to be an off-label procedure and may be performed either in emergency situations or within the framework of a research study by experts possessing large experience in aortic endoprosthetic repair, and the first interventions should obligatorily be performed with participation of clinical specialists of the stent graft manufacturing company.

CONCLUSIONS

Aortic arch endoprosthetic repair using supraaortic endobranching is an effective and alternative method of treatment of patients with pathology of the thoracic artery who for some reason cannot be candidates for traditional prosthetic repair using assisted circulation. In accordance with the obtained results, this method is a promising technique requiring further study and improvement.

Conflict of interest: none declared.

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