FIVE-YEAR RESULTS OF USING THE "FROZEN ELEPHANT TRUNK" TECHNIQUE FOR THORACIC AORTIC DISSECTION

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Analysed herein is efficacy of hybrid intervention according to the "frozen elephant trunk" procedure in the medium-term period of follow-up in patients operated on for aortic dissection.

During the period from 2012 to 2018, a total of 44 «frozen elephant trunk» procedures were carried out for Stanford type A and B thoracic aortic dissections. All interventions were performed in conditions of moderate hypothermic circulatory arrest (25–28 °C) with unilateral cerebral perfusion through the brachiocephalic trunk.

The mean diameter of the implanted stent grafts amounted to 27.7±2.8 mm (range 24-30 mm). The distal edge of the stent graft was located at the level below the Th9 in more than 65% of cases (range Th7-Th12). The stent grafts were fixed proximally at the levels Z0–Z3, predominantly in the Z3 zone (72.7%). Thirty-day mortality amounted to 6.8%, with in-hospital mortality of 15.9%. Five-year survival in acute and chronic type A aortic dissection (AD) amounted to 100 and 80%, respectively (p=0.175). In acute type B aortic dissection five-year survival amounted to 62.2%, being 25.0% for chronic AD (p=0.057). Freedom from reinterventions for acute and chronic type A aortic dissection amounted to 100 and 66.7%, respectively (p=0.286). Freedom from aortic reinterventions for acute and chronic type B aortic dissection amounted to 100% and 75%, respectively (p=0.123).

Reconstructive operations performed according to the «frozen elephant trunk» technique appear to be effective surgical treatment in patients with thoracic aortic dissection, yielding satisfactory clinical results during a medium-term follow-up period.

Key words: *aortic dissension, «frozen elephant trunk», E-Vita open plus, mid-term survival, reintervention.*

INTRODUCTION

Open reconstruction of proximal portions of the thoracic aorta (TA) with simultaneous implantation of a stent graft into the descending aorta, the so-called «frozen elephant trunk» procedure (FET), is becoming increasingly popular amongst patients with multisegment pathology of the TA. In aortic dissection (AD) this technique makes it possible to stabilize the true lumen and to close the entry/re-entry zones of the proximal portion of the descending aorta.

Early results of using the «frozen elephant trunk» technique demonstrated its high efficacy [1, 2]. However the contemporary literature pays insufficient attention to analytical assessment of the remote results after such hybrid interventions [3].

The purpose of the present study was to analyse mid-term efficacy of a hybrid intervention performed in patients with AD according to the «frozen elephant trunk» technique.

PATIENTS AND METHODS

Between March 2012 and February 2018, a total of 44 consecutive patients with Stanford type A and B aortic dissection were operated on by means of the «frozen elephant trunk» technique. The patient cohort consisted of 30 (68.2%) men and 14 (31.8%) women, mean age 54.5 years (range 51–63). The structure of aortic pathology in our patients is shown in Table 1.

Multislice computed tomography (MSCT) was used as the main method of examination of TA pathology. In emergency situations we assessed aortic pathology based on the findings of transthoracic and transoesophageal echocardiography.

Prosthetic repair of the TA was performed with access through a median sternotomy approach in conditions of moderate hypothermia (25–28° C). Cerebral protection at the stage of circulatory arrest was performed by means of unilateral perfusion through the brachiocephalic trunk according to the previously described technique [4].

In each case we used a hybrid stent graft E-vita open plus (Jotec, Germany) measuring from 24 to 30 mm in diameter and 150 mm in length. The size of the stent graft necessary for implantation was determined preoperatively by the findings of MSCT aortography. In acute AD while selecting the stent graft's size we were guided by the overall diameter of the descending aorta

Table 1

Characteristics of patients

Parameter	Total (n=44)	Type A aortic dissection		Type B aortic dissection	
		acute (n=10)	chronic (n=16)	acute (n=5)	chronic (n=13)
Age, years	54.5±11.1	53.7±11.7	52.4±11	52.3±11.1	52.9±11.1
Males, n (%)	30 (68.2%)	7 (70.0%)	8 (50.0%)	4 (80.0)	11 (84.6%)
Emergency intervention (within 24 hours after symptom onset)	13 (29.5%)	10 (100%)	0	3 (60.0%)	0
Prior interventions on the TA	3 (6.8%)	0	3 (18.8%)	0	0
CAD	10 (22.7%)	1 (14.3%)	4 (25.0%)	2 (40.0%)	3 (23.1%)
LV EF >40%	2 (4.5%)	0	2 (12.5)	0	0
Blood creatinine <150 g/l	5 (11.4%)	0	1 (6.3%)	3 (60.0%)	1 (7.7%)
COPD	3 (6.8%)	0	2 (12.5%)	0	1 (7.7%)
Diabetes mellitus	2 (4.5%)	0	0	0	2 (15.4%)
A history of AICC	3 (6.8%)	1 (14.3%)	1 (6.3%)	0	1 (7.7%)
Marfan syndrome	2 (4.5%)	0	2 (12.5%)	0	0

Note: CAD – coronary artery disease; LV EF – left-ventricular ejection fraction; COPD – chronic obstructive pulmonary disease; AICC – acute impairment of cerebral circulation.

at the level of the bifurcation of the pulmonary trunk. For the patients of this cohort it is necessary to select an adequate size of the stent graft, with no oversizing allowed. In chronic AD we measured the overall and true lumens of the descending aorta at the level of the bifurcation of the pulmonary trunk. In these cases the optimal size of the stent graft was determined by means of a compromise choice between the diameters of the overall and true lumen of the descending aorta. The stent graft's diameter is allowed to be slightly more (an oversizing not exceeding 10%) than that of the true lumen of the aorta. Implantation of the hybrid device was guided by transesophageal echocardiography. The stent graft was inserted into the descending portion to the maximal length of the aorta for its maximum stabilization.

The proximal portion of the stent graft was fixed by the blanket suture with monofilament thread 4/0 with the use of the «sandwich technique». In 32 (72.7%) cases, the distal aortic anastomosis was formed behind the subclavian artery and in 12 (27.3%) cases – proximal to this zone. «Proximalization» of the distal aortic anastomosis is determined by anatomical peculiarities hampering mobilization of the distal portion of the aortic arch, as well as by high risk of damaging various structures. This tactics makes it possible to reduce the duration of distal reconstruction of the aortic arch. Establishing the distal anastomosis was followed by traction of the vascular prosthesis from the stent graft and clamping thereof. An auxiliary arterial cannula was inserted into the graft beneath the clamping site and corporal artificial circulation at an estimated volumetric rate was re-established, to be followed by worming up of the patient. Along with it, we performed reconstruction of the aortic-arch vessels with the help of the island technique, debranching, or a combination thereof. Once this stage completed, bilateral cerebral perfusion was restored. Finally, we performed proximal reconstruction of the TA, as well as the necessary concomitant interventions on the aortic valve and coronary arteries (Table 2).

Throughout the whole operation, as well as during circulatory arrest, we evaluated the parameters of cerebral oximetry (Invos 5100 – Somanetics Corp., USA) / Foresight – Casmed, USA). Arterial pressure was controlled by means of direct measurement in both radial arteries. The target values of haematocrit at the stage of circulatory arrest were maintained at the level not less than 25%. Neither monitoring of pressure nor drainage of cerebrospinal fluid were performed.

All patients discharged from hospital underwent clinical examinations including MSCT aortography in a hospital or at the place of residence 6 and 12 months after surgery, then annually.

For objectivization of the level of thrombosis of the false lumen in AD we used the segmental scheme suggested by M. Shrestha, et al., wherein segment A is the distance from the distal aortic anastomosis to the level of the left auricle (in the postoperative patients it corresponded to the level of the implanted stent graft), segment B – from the level of the left auricle to the celiac trunk, and segment C – from the level of the diaphragm to the aortic bifurcation [3].

The data was statistically processed using the SPSS 17 software package for Windows (SPSS Inc., USA). The quantitative parameters obeying the normal law of distribution were expressed as the mean (M) and standard deviation (±SD); those not obeying the normal probability law of distribution were described with the help of the median (Me) and the interquartile range (Q25–Q75). The parameters characterising qualitative attributes were determined taking into account the absolute number (n) and relative value (%). Survival of and freedom from reinterventions in the operated patients were analysed by means of the Kaplan-Meier method, the curves were

Table 2

Intraoperative data

Parameter	Total (n=44)	Type A aortic dissection		Type B aortic dissection	
		acute (n=10)	chronic (n=16)	acute (n=5)	chronic (n=13)
Concomitant operations					
CABG	7 (15.9%)	0	1 (6.3%)	1 (20.0%)	2 (15.4%)
AVR	7 (15.9%)	1 (10.0%)	4 (25.0%)	0	0
Arch vessels reconstruction					
Island technique	21 (47.7%)	8 (80.0%)	6 (37.5%)	3 (60.0%)	4 (30.8%)
Debranching	13 (29.5%)	1 (10.0%)	7 (43.8%)	0	5 (38.5%)
Combination of the methods	10 (22.7%)	1 (10.0%)	3 (18.8%)	2 (40.0%)	4 (30.8%)
Characteristics of the implanted stent graft					
Stent graft size (range), mm	27.7±2.8 (22–40)	27.2±2.3 (24–30)	27.5±2.3 (24–30)	27.6±2.2 (24–30)	28.2±1.5 (24–30)
Level of distal aortic anastomosis:					
Z0	1 (2.3%)	0	1 (6.3%)	0	0
Z1	1 (2.3%)	0	0	0	1 (7.7%)
Z2	10 (22.7%)	0	5 (31.3%)	0	5 (38.5%)
Z3	32 (72.7%)	10 (100%)	10 (62.5%)	5 (100%)	7 (53.8%)
Zones of the lower edge:					
Th7	5 (11.4%)	0	1 (6.3%)	1 (20.0%)	3 (23.1%)
Th8	10 (22.7%)	0	2 (12.5%)	2 (40.0%)	6 (46.2%)
Th9	12 (27.3%)	7 (70.0%)	1 (6.3%)	2 (40.0%)	2 (15.4%)
Th10	9 (20.5%)	2 (20.0%)	5 (31.3%)	0	2 (15.4%)
Th11	6 (13.6%)	1 (10.0%)	5 (31.3%)	0	0
Th12	2 (4.5%)	0	2 (12.5%)	0	0

Note: CABG – coronary artery bypass grafting; AVR – aortic valve repair; Z0–Z3 – zones of formation of distal aortic anastomosis; Th7–Th12 – designation of the bodies of thoracic vertebrae.

Table 3

Temporal characteristics of hybrid interventions (min)

Parameter	Total (n=44)	Type A aortic dissection		Type B aortic dissection	
		acute (n=10)	chronic (n=16)	acute (n=5)	chronic (n=13)
Duration of the operation	421.1 [412; 427]	420 [409; 423]	465.6 [458; 471]	427.6 [412; 433]	413.1 [405; 415]
AC duration	217.6 [209; 221]	221.9 [214; 227]	230 [220; 232]	263.2 [253; 269]	199 [178; 203]
Cardiac arrest duration	144.8 [139; 148]	171.4 [167; 175]	168.3 [159; 172]	140 [137; 147]	121.8 [114; 124]
CA duration	43.1 [41; 46]	42 [41; 45]	41.7 [40; 44]	43.9 [41; 45]	44 [41; 46]
ACP duration	62.9 [59; 64]	62 [58; 63]	69.2 [65; 72]	58.4 [56; 64]	71.2 [66; 73]

Note: AC – artificial circulation; CA – circulatory arrest; ACP – antegrade cerebral perfusion.

compared using the log-rank test. Differences were regarded as statistically significant if p<0.05.

RESULTS

Table 3 shows the main temporal characteristics of the operations performed.

As can be seen from Table 4, in the early postoperative period the incidence of permanent neurological deficit of the brain amounted to 2.3%, with no episodes of ischaemic catastrophes on the part of the spinal cord. Neither were there cardiac complications revealed. Totally, the 30-day and in-hospital mortality amounted to 6.8 and 15.9%, respectively. The causes of death were as follows: rupture of the abdominal aorta (n=2), haemorrhagic shock (n=2), multiple organ failure (n=3).

Six (16.2%) of the 37 discharged patients died during the five-year follow-up period (mean 23±17 months). The lethality structure included: massive pulmonary thromboembolism (n=1), heart failure (n=3), stroke (n=1) and in one case the cause of death was not established. All deaths were not aorta-associated, with none of the deceased patients having had indications for repeat reconstructions of the proximal portions of the TA.

Thus, survival amongst the patients with acute and chronic type A aortic dissection amounted to 100 and 80%, respectively (p=0.175). For acute and chronic type B aortic dissection, the 5-year survival rate amounted to 62.2 and 25.0%, respectively (p=0.057) (Fig. 1).

Five-year results were followed up in 37 patients with AD (100% of patients discharged from hospital). After the operation, in 16 (43.2%) patients with aortic dissection extending distally to the level of the diaphragm, the false lumen was completely thrombosed all along the length.

Of 21 (56.8%) patients with dissection extending to the aortic bifurcation according to the MSCT findings in the middle-term period, complete thrombosis of the false lumen was determined: at the level of segment A – in 18 (85.7%), segment B – in 5 (23.8%), segment C – in 4 (19%) patients (Table 5).

Repeat elective intervention on distal portions of the aorta was performed in 3 of the 21 patients, thus

Table 4

Postoperative characteristics

Parameter	Total (n=44)	Type A aortic dissection		Type B aortic dissection	
		acute (n=10)	chronic (n=16)	acute (n=5)	chronic (n=13)
TIA	2 (4.5%)	0	0	1 (20.0%)	1 (7.7%)
Stroke	1 (2.3%)	0	0	0	1 (7.7%)
Spinal ischaemia	0	0	0	0	0
RRT	13 (29.5%)	1 (10.0%)	4 (25.0%)	3 (60.0%)	5 (38.5%)
Haemorrhage	2 (4.5%)	0	1 (6.3%)	1 (20.0%)	0
Prolonged mechanical ventilation (>48 hours)	31 (70.5%)	7 (70.0%)	10 (62.5%)	4 (80.0%)	10 (76.9%)
30-day mortality	3 (6.8%)	0	1 (6.3%)	1 (20.0%)	1 (7.7%)
In-hospital mortality	7 (15.9%)	0	2 (12.5%)	2 (40.0%)	3 (23.1%)

Note: TIA – transitory ischaemic attack; RRT – renal replacement therapy.

amounting to 14.3%. Two (66.7%) of them had chronic type B aortic dissection and one (33.3%) had chronic type B aortic dissection. The average interval till the second stage amounted to 8±3.5 months (range 6–12 months). All these patients endured additional implantation of a stent graft to the descending portion of the aorta to the level of the celiac trunk in order to elongate the «frozen elephant trunk».

Hence, freedom from reinterventions in patients with acute and chronic type A aortic dissection amounted to 100 and 66.7%, respectively (p=0,286). For acute and chronic type B aortic dissection freedom from reinterventions amounted to 100% and 75%, respectively (p=0.123) (Fig. 2).

DISCUSSION

The «frozen elephant trunk» technique targeted at maximally possible radical single-stage intervention expanded the range of cardiosurgical means and significantly simplified treatment of complicated cases of TA pathology. By now the main indication for using this procedure is not only AD but also TA aneurysms, however, this issue is still open [5–7].

Type A aortic dissection. Reconstruction of the proximal portion of the aorta with resection of the primary fenestration is a commonly accepted method of treatment of patients with acute type A aortic dissection, whereas the use of simultaneous reconstruction of distal portions of the TA remains controversial [8]. There is an opinion that carrying out limited proximal reconstruction of the aorta in this cohort of patients makes it possible to reduce mortality, since it is characterised by shorter duration of assisted circulation, circulatory arrest, and the operation as a whole, as well as lower volume of the transfusion load. However, a meta-analysis conducted by S.S. Poon, et al. revealed no advantages of limited replacement of the TA over extensive intervention in the early postoperative period [9]. Moreover, preservation of the false lumen in limited proximal reconstruction of the aorta correlates with its dilatation and unsatisfactory surgical outcomes, as well as the necessity of reinterventions in the remote period, amounting to 30%. At the same time, a combination of proximal reconstruction of the aorta with implantation of a stent graft into the descending portion ensures stabilization of a considerable segment of the true lumen. This promotes thrombosis of the false lumen all along the length of the stent graft in 86–94% of cases as early as in the immediate postoperative period with a tendency towards increased frequency of thrombosis in the remoteperiod [8, 10]. It should be mentioned that in chronic AD the false lumen is characterized by lower frequency of thrombosis as compared with that for acute dissection. The major cause of this is considered to be compaction of the dissected membrane, as well as the presence of multiple fenestrations distal to the level of the implanted stent graft. Nevertheless, D. Pacini et al. reported that at the in-hospital stage the frequency of false lumen

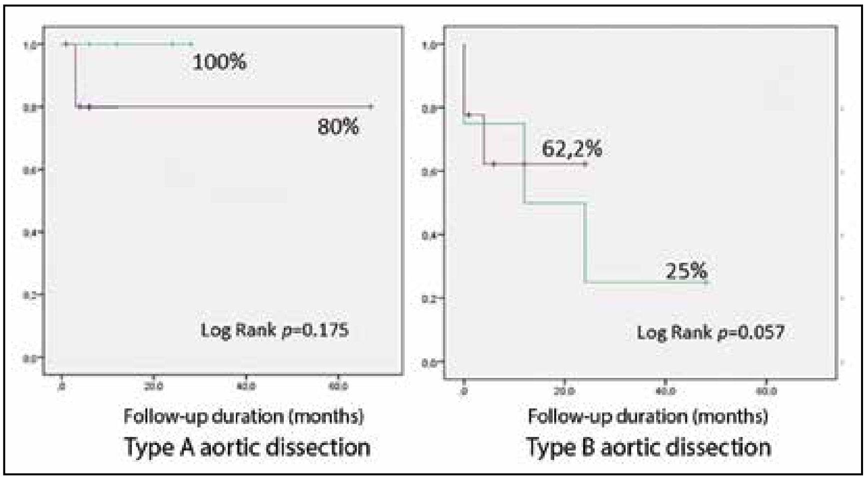

Figure 1. Kaplan-Meier survival curves in type A aortic dissection (left) and type B aortic dissection (right) in the mid-term follow-up period

Table 5

State of the false lumen in the middle term period in patients with aortic dissection below the diaphragm

Characteristic	Total (n=21)	Type A aortic dissection		Type B aortic dissection	
		acute (n=5)	Chronic (n=4)	acute (n=3)	chronic (n=9)
Segment A					
Complete thrombosis	18 (85.7%)	5 (100%)	4 (100%)	2 (66.7%)	7 (77.8%)
Partial thrombosis	3 (14.3%)	0	0	1 (33.3%)	2 (22.2%)
Patent	0	0	0	0	0
Segment B					
Complete thrombosis	5 (23.8%)	1 (20.0%)	2 (50.0%)	1 (33.3%)	1 (11.1%)
Partial thrombosis	13 (61.9%)	2 (40.0%)	2 (50.0%)	2 (66.7%)	7 (77.8%)
Patent	3 (14.3%)	2 (40.0%)	0	0	1 (11.1%)
Segment C					
Complete thrombosis	4 (19%)	1 (20.0%)	1 (25.0%)	1 (33.3%)	1 (11.1%)
Partial thrombosis	6 (28.6%)	0	2 (50.0%)	1 (33.3%)	3 (33.3%)
Patent	11 (52.4%)	4 (80.0%)	1 (25.0%)	1 (33.3%)	5 (55.6%)

thrombosis along the length the stent graft in chronic dissection amounted to 70% and in the middle-term period of follow up reached 92% [11].

According to the literature data, middle-term survival rate amongst patients with type A aortic dissection ranges from 74 to 78%, with the freedom from reinterventions amounting to 69–82%. Mention should be made that the frequency of repeat interventions in chronic dissection is expectedly higher (25%) than that in acute AD (11%). Today, prevailing in the structure of reinterventions performed are endovascular interventions as least traumatic, with the proportion of open operations not exceeding 10% [8, 11]. Similar tendencies regarding the requirements for the second stage, as well as the type of the intervention are traced in the present study.

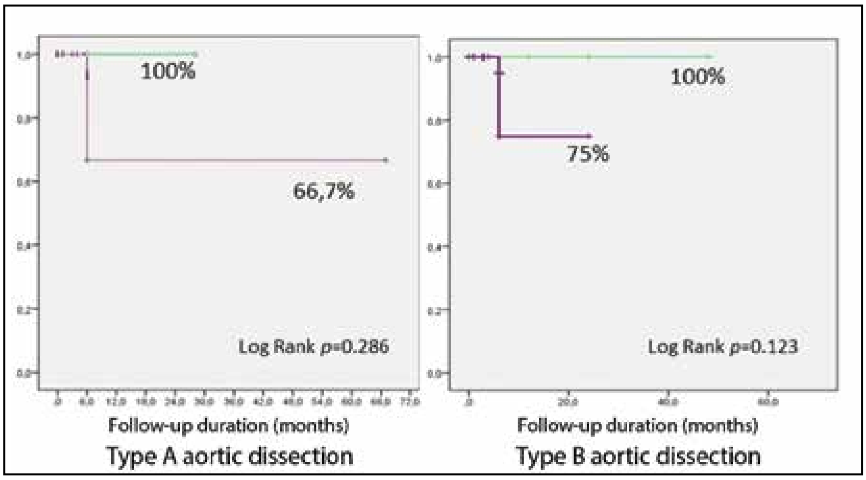

Figure 2. Kaplan-Meier freedom-from-reintervention curves in type A aortic dissection (left) and type B aortic dissection (right) in the mid-term follow-up period

Type B aortic dissection. Medicamentous therapy is currently the standard approach to treatment of patients with "stable" type B aortic dissection. Endovascular methods are used in complicated forms manifesting themselves by unrelieved pain syndrome, uncontrolled hypertension, as well as progression of dissection with high probability of rupture and malperfusion in visceral organs. Despite the improved technique of implantation, as well as stent grafts in a series of cases the procedure may be associated with high risk of complications. Therefore, no optimal invasive method of treatment has been determined yet [5, 6, 12].

While treating patients with type B aortic dissection preference should be given to the "frozen elephant trunk" technique for a series of reasons. The proximal suture fixation of a stent graft to the aorta in open implantation, as opposed to endovascular one, makes it possible to avoid proximal endoleak, protecting stent-graft migration and ensuring prevention of retrograde dissection which is accompanied by high mortality rate (up to 42%) [13, 14]. Moreover, in concomitant dilatation of the ascending portion and aortic arch, even borderline, it is appropriate to perform simultaneous hybrid reconstruction of the TA. Besides, in some cases it is necessary to carry out concomitant cardiosurgical operations requiring sternotomy (coronary artery bypass grafting, intervention on the aortic valve).

According to the literature data, middle-term survival of patients with type B aortic dissection after the "frozen elephant trunk" procedure amounts to 75%, with no significant difference between the acute and chronic forms of the disease (p=0.65). Also, implantation of a hybrid stent graft is accompanied by high frequency of thrombosis of the false lumen at its length (97–100%) which significantly exceeds the frequency of thrombosis in endovascular implantation of a stent graft (36–76%) [12, 15]. Low need for repeat interventions on the aorta also favourably distinguishes the hybrid technique from endovascular one. According to the findings published by G. Weiss et al, repeat intervention on distal portions of the aorta with the use of the "frozen elephant trunk" technique was required in only 8% of cases, with the freedom from reinterventions amounting to 79% [12]. At the same time, N.D. Andersen et al. reported higher requirements for repeat interventions in isolated endovascular approach (23%), with the reason for them being complications related to the aortic arch in 7% of cases and the cumulative freedom from reinterventions in such approach not exceeded 68% [16].

The "frozen elephant trunk" technique is undoubtedly a revolutionary solution in treatment of patients with TA pathology. Nevertheless, there are still unsolved problems related to this manipulation. One of them is believed to be postoperative spinal ischaemia, the most severe complication of hybrid intervention. Many studies were devoted to revealing risk factors for and prevention of this condition. Thus, K. Katayama, et al. revealed that along with diabetes mellitus, prior aortic reconstruction, pronounced atherosclerotic lesion of the aorta the development of ischaemic lesion of the spinal cord is significantly influenced by the distal position of the stent graft below the ninth thoracic vertebral level [17]. J. Flores, et al. reported that when distal landing zone at Th7 or a more distal point and history of abdominal aortic aneurysm repair were combined, this was the strongest significant independent predictor for spinal cord ischaemia [18]. Other authors, relying on the concept of collateral blood supply believe that high frequency of spinal cord ischaemia during the "frozen elephant trunk" procedure is largely due to simultaneous intraoperative impairment of blood supply in various basins of the collateral network, rather than to occlusion of the excessive intercostal arteries [7, 11, 12, 19]. Thus, provision of the major blood flow in the main basins (subclavian and iliac) makes it possible to safely position the distal end of the stent graft even at the level of Th10–Th12 with the purpose of maximum stabilization of the descending aorta [20].

Adhering to this point of view, the authors aimed to attain the maximal insertion the stent graft into the descending aorta. Thus, in more than 65% of patients the distal position of the stent graft was below the Th9 level which is regarded by a series of researches as a "critical" zone of implantation. However, in none of the cases there were signs of postoperative spinal ischaemia. In our opinion, this result is determined by carrying out comprehensive prevention of ischaemic lesion of the spinal cord, which included unilateral cerebral perfusion via the brachiocephalic trunk at a perfusion rate of 8–10 ml/min and perfusion pressure within a range of 60-80 mm Hg, moderate hypothermia (25–28 °C), as well as maintaining the haematocrit value not below 25% throughout the whole operation.

Our approach to implantation of a stent graft makes it possible to stabilize the descending aorta over a long length, thus favourably contributing to reduced requirements for reinterventions in the remote period. However, in a series of cases performing repeat intervention was dictated by the need to prevent probable negative remodelling of distal portions of the aorta. All patients underwent endovascular reinterventions not earlier than after 6 months. We believe that this time interval is sufficient for restructuring of blood supply of the spinal cord after the primary implantation of the stent graft to the descending portion. This makes it possible to ensure additional prevention of spinal cord ischaemia.

CONCLUSIONS

Reconstructive operations performed according to the "frozen elephant trunk" technique appear to be effective surgical treatment of patients with TA dissection, ensuring clinically satisfactory results in the medium-term period of follow-up.

Conflict of interest: none declared.

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