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Combined Surgical and Endovascular Approach for the Treatment of Complex Thoracic Aortic Pathologies

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1. Introduction

Extensive pathologies of the aorta are a major challenge in terms of its surgical treatment. In principle, complex pathologies of the aorta are divided into type A aortic dissection according to the Stanford classification, and aneurysmatic changes involving the aortic arch.
The first successful operations in the ascending aorta and the aortic arch were described by Denton Cooley, Michael DeBakey and Stanley Crawford (DeBakey et al. 1955, Cooley et al. 1956, Cooley et al. 1955). Several advancements made since this time have led to improvements in the surgical treatment of the ascending aorta (Bentall &De Bono 1968, Starr et al. 1963, David & Feindel 1992, Yacoub et al. 1998).
Surgical procedures focused on dissections of the proximal portion of the descending aorta and the distal aortic arch have received increasing attention in the last few years and been subjected to several modifications. Especially the development of interventional radiological endovascular techniques that reduce the invasive nature of surgery as well as complication rates led to rapid advancements.
In the following, a combined surgical and endovascular procedure for the treatment of complex aortic diseases will be presented. It is advancement on the methods used thus far. The development and performance of the method and results obtained by its application in patients at the Department of Cardiovascular Surgery, Hietzing Hospital -Vienna, as well as with reference to the European register will be summarised.

2. Background

Type A aortic dissection and aneurysms in the ascending aorta involving the aortic arch and the descending aorta are diseases that pose a major challenge for the surgeon. The classical approach of two-step surgery involves, as the first step, replacement of the ascending aorta and the aortic arch through a median sternotomy, which is then concluded after an interval of a few weeks by performing the second step. The latter consisted of replacement of the descending aorta through a left-lateral thoracotomy and connection with the vascular prosthesis inserted at the first session.
However, this procedure is associated with a high risk of morbidity and mortality; the cumulative risk may be as high as 20%. A further important aspect is the waiting period of

several weeks between the two surgical steps, which is associated with a mortality risk of 10% due to rupture. Restrictions for this laborious procedure are the patient's age and comorbidities. In fact, up to 30% of the patients do not live long enough to undergo the second step of the procedure (Kouchoukos, 2001). The aim of the method presented here is to render this complex treatment procedure simpler and safer.

Based on Borst's (Borst et al. 1983) description, the first part of the classical approach is named the "*elephant trunk*" operation and was developed further because of the setbacks reported after its application. The combination of open surgery and implantation of a stent graft opened new perspectives in the treatment of extensive changes in this sensitive portion of the aorta (Fleck et al. 2002, Mizuno et al. 2002, Jazayeri et al. 2003, Karck et al. 2005).

This combination of surgery and a stent-assisted procedure, which is partly performed simultaneously, may avoid or simplify further interventions. Besides, the occurrence of type I endoleaks can be avoided by this approach. A type I endoleak in cases of implanted endoprostheses is defined as a leak at the proximal docking site.

The results of this modified and combined surgical procedure have been analysed in the studies published thus far. In patients who underwent aortic dissection, the behaviour of the false lumen during the postoperative observation period was also analysed.

3. Material and methods

3.1 Patients

3.1.1 Primary analysis

Between August 2005 and December 2006, the first seven patients were treated at the Department of Cardiovascular Surgery, Hietzing Hospital Vienna (5 were men and 2 were women). Five patients had an aortic dissection; two of these were acute type A dissections and two were extensive complex chronic aneurysms of the aorta. The patients' median age was 62 years (Gorlitzer et al. 2007).

Thirty-one patients were treated with this combined method in our department until December 2010. After primary analysis all consecutive patients were included into the international E-vita Open Register.

3.1.2 E-vita open register

One hundred and twenty-eight patients were included in the international E-vita Open Register (IEOR) between January 2005 and March 2009. Five European centres (Hietzing Hospital Vienna, Western Germany Heart Centre Essen, University of Bologna, Na Homolce Hospital in Prague, and the University of Barcelona) participated in this multicentre trial (Tsagakis et al. 2011). Fifty-five of them had been operated on for an acute type A dissection, 51 for a chronic dissection, and 22 because of extensive aneurysms. Of these, nine patients had a Marfan syndrome (Tsagakis et al. 2010).

3.1.3 Follow-up: transformation of the false lumen

Our own series of patients were evaluated between August 2005 and February 2009 as regards transformation of the false lumen after treatment of aortic dissection. The mean observation period was 43 months. A control CT-angiography was performed immediately post-surgery, after 3, 6, and 12 months, and thereafter at yearly intervals. In all, 14 type A dissections were followed. The combined surgical and interventional procedure had been used in all 14 patients (Gorlitzer et al., 2010).

Ninety-three patients were followed in the course of the IEOR investigation: 49 after acute dissection and 44 after chronic dissection (Tsagakis et al., 2010).

3.2 Hybrid stent graft

Replacement of the ascending aorta, the aortic arch, and the proximal portion of the descending aorta can be performed by the use of the E-vita open prosthesis in a single-stage operation. This recently developed prosthesis consists of a 70-mm-long woven "classical" Dacron portion which is directly connected to a polytetrafluoroethylene-covered stent prosthesis via Z-shaped nitinol rings. (Figure 1) The rings are not connected to each other. Thus, two things are ensured: optimal flexibility of the stent graft, and ideal adaptation to the course of the proximal descending aorta (Gorlitzer et al., 2007). Self-expandable stents measuring 13 cm in length and 32mm, 34 mm or 36 mm in diameter were used. A spiral CT angiography of the thoracic aorta was performed preoperatively to assess the extent of the aneurysm and /or dissection and to determine the appropriate size of the stent graft in each case.

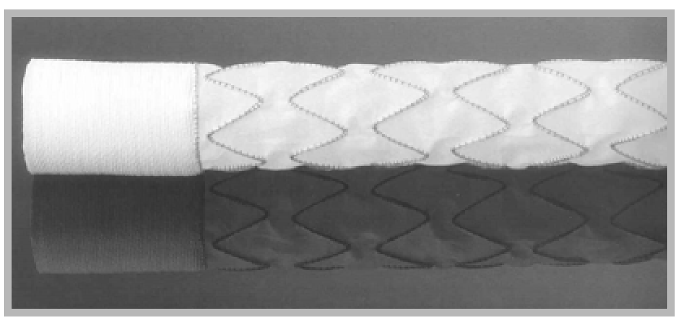


Fig. 1. E vita open graft

3.3 Surgical technique

For cerebral protection and extracorporeal circulation we use a classical heart-lung machine with alternative arterial cannulation via the axillary artery, moderate hypothermic circulatory arrest, and selective antegrade bilateral cerebral perfusion. The arterial cannula is introduced via a short 8-mm Dacron prosthesis, which is anastomosed to the right axillary artery. This permits the surgeon to subsequently perform a safe sternotomy on the one hand, and a means of achieving antegrade cerebral perfusion during circulatory arrest on the other (Strauch et al. 2005, Shimazaki et al. 2004, Numata et al. 2003, Okita et al. 2001).(Figure 2)

After median sternotomy, a venous two-step cannula is placed in the right atrium and the patient is cooled to 25°C at the heart-lung machine in order to achieve moderate hypothermia (Minatoya et al. 2008, Pacini et al. 2007). In contrast to deep hypothermia, moderate cooling offers the advantages of a lower risk of haemorrhage, shorter operating times, and a lower likelihood of inflammatory signs secondary to haemostasis (Kamiya et al. 2007).

During the cooling phase, the left ventricle has to be vented via the right upper pulmonary vein or the apex of the heart. Once the core temperature of 25° C has been achieved, the ascending aorta and the concave portion of the aortic arch are resected in a state of circulatory arrest. Selective antegrade cerebral perfusion with 10 ml/kg/min cold blood is achieved via a catheter in the left carotid artery and the cannula in the right axillary artery after clamping the brachiocephalic artery (Mazzola et al. 2002). Oxygen saturation is measured by infrared spectroscopy during cerebral perfusion (Harrer et al. 2010).

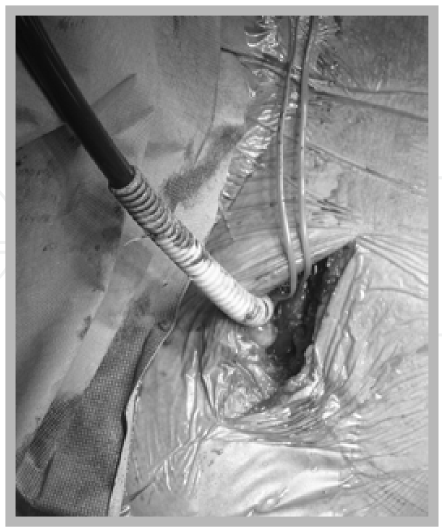


Fig. 2. Arterial cannulation of axillary artery

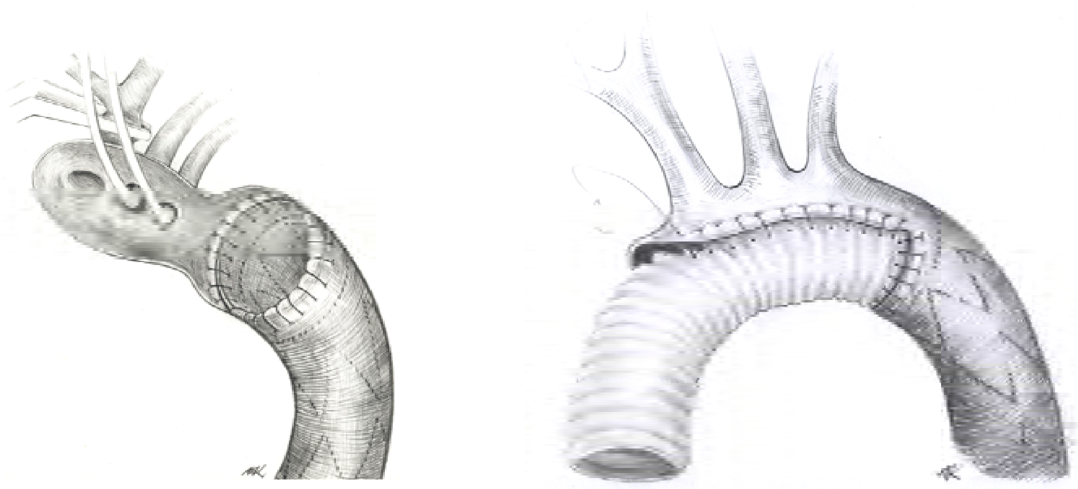
In cases of aortic dissection, the true lumen is identified by insertion of a stiff transfemoral guidewire which can be placed prior to commencement of the operation.
The E-vita open stent graft is introduced into the descending aorta via the open aortic arch, and is then adapted. The point of orientation for placement of the stent is the site of origin of the subclavian artery. (Figure 3)

Fig. 3. Insertion if combined stentgraft

The proximal part of the stent lies one centimetre distal to this point of origin. To avoid potential endoleaks - as initial experience in the use of this procedure showed - the integrated Dacron prosthesis is pulled out slightly and fixed to the proximal descending aorta by the use of sutures supported with Teflon strips. (Figure 4)

Fig. 4. Replacement the ascending aorta and hemiarch with a separate prosthesis

Two methods were used for replacement of the aortic arch: complete aortic arch replacement with reinsertion of the supra-aortic branches (Di Eusanio et al. 2004), or reconstruction of the aortic arch with preservation of the convex portion by way of "*light arch replacement*" (Gorlitzer et al. 2007). When using the latter approach, the supra-aortic branches are not isolated and need not be reimplanted individually. (Figure 5)



a b

Fig. 5. Replacement of the aortic arch with preservation of its convexity

The ascending aorta and the concave portion of the aortic arch are replaced with an additional coated Dacron prosthesis, and anastomosed to the reconstructed descending aorta. Additionally - if necessary - this access may be used to replace the aortic valve or create aortocoronary bypasses.

4. Results

4.1 Results of hospital hietzing

In our own series, implantations of the antegrade stent in the descending aorta as well as replacement of the ascending aorta and the aortic arch were successfully achieved in all patients. All patients survived the intervention. The duration of time on the heart-lung machine (HLM) was 197±29.9 minutes, that of hypothermic circulatory arrest 60±15.5 minutes, and aortic clamping 88±33.2 minutes. Implantation of the stent in the descending aorta took 10 minutes (range, 8 to 12 minutes). The duration of stay at the intensive care unit was 6.8 days (range, 2 to 21 days) while the overall hospital stay had a duration of 20 days (range, 8 to 35 days).

One patient had a transient neurological deficit postoperatively. Another patient had to be drained on the 11th postoperative day because of a pericardial effusion.

In one patient with a Marfan syndrome, thoraco-abdominal replacement of the aorta had to be performed five months later. At this operation, a direct proximal anastomosis to the stent graft could be performed. In a further patient, the stent had to be lengthened into the distal descending aorta. These operations involved no complications and did not require circulatory arrest (Gorlitzer et al. 2007).

4.2 Results of international E-vita open registry

In the course of the investigation of the International E-vita Open Registry (IEOR), 106 patients with acute (n=55) and chronic (n=51) aortic dissection were evaluated (see Table 1). The duration of time on the HLM, aortic clamping and hypothermic circulatory arrest were 242±64, 144±44 and 75±23 minutes, respectively.

Clinical status preoperatively of Aortic dissections

Aortic disease *no (%)*	Overall (n=106)	Acute AD-IEOR (n=55)	Chronic AD-IEOR (n=51)
Emergency < 24h	49 (46)	47 (86)	2 (4)
Inotropics preoperatively	23 (22)	21 (38)	2 (4)
Cardiac tamponade	13 (12)	13 (24)	0
Intubated prior to admission	14 (13)	12 (22)	2 (4)
Malperfusion			
Cardiac	9 (9)	9 (16)	0
Cerebral	13 (12)	13 (24)	0
Spinal cord	4 (4)	4 (7)	0
Visceral	7 (7)	7 (13)	0
Renal	9 (9)	8 (15)	1 (2)
Peripheral	9 (9)	8 (15)	1 (2)
Aortic valve regurgitation	57 (54)	37 (67)	20 (39)

AD= Aortic dissection; IEOR= International E-vita Open Registry

Table 1. Clinical status of patients of the International E-vita Open Register

The techniques of reconstruction of the aortic arch and associated procedures, such as replacement of the aortic valve and the mitral valve or aortocoronary bypass, are summarised in Table 2. Stent implantation was successful in 99% of cases. In one case the distal end of the stent was in the false lumen.

Intraoperative variables (mean±SD; no (%)			
Aortic disease	Overall (n=106)	Acute AD-IEOR (n=55)	Chronic AD-IEOR (n=51)
Cannulation site (n)			
Axillary artery	70 (66)	34 (62)	36 (71)
Proximal aorta	22 (21)	17 (31)	5 (10)
Femoral artery	1 (1)	1 (2)	0
Previous prosthesis	11 (10)	1 (2)	10 (20)
Others	2 (2)	2 (4)	0
Intraoperative values (min)			
CPB-time	242±64	239±59	246±70
Cross-clamp Time	144±44	139±40	150±47
SACP time	75±23	67±19	83±24
HCA-time	8±6	9±7	7±6
Antegrade stent grafting (n)			
Stent-graft size (mm)	29±5	28±4	30±5
Oversizing > 10%	17 (16)	10 (18)	7 (14)
Use of guidewire	71 (67)	30 (55)	41 (80)
Arch replacement			
Total	95 (90)	48 (87)	47 (92)
Subtotal	11 (10)	7 (13)	4 (8)
Supra-aortic vessels (n)			
Island	67 (63)	42 (76)	25 (49)
Separate	39 (37)	13 (24)	26 (51)
Ascending aorta replacement			
E-vita open prosthesis	9 (9)	3 (5)	6 (12)
Other prosthesis	82 (77)	51 (93)	31 (61)
Aortic valve intervention			
Bentall	14 (13)	6 (11)	8 (16)
Isolated valve replacement	10 (9)	3 (5)	7 (14)
Resuspension	20 (19)	20 (36)	0
Repair	5 (5)	5 (9)	0
Mitral valve repair	2 (2)	0	2 (4)
CABG	17 (16)	12 (22)	5 (10)

AD= Aortic dissection; IEOR= International E-vita Open Registry; CPB= cardiopulmonary bypass;

SACP= selective antegrade cerebral perfusion; CABG= coronary artery bypass grafting

Table 2. Intraoperative variables of the International E-vita Open Register

The median duration of stay at the intensive care unit was 6 days while that of the entire hospital stay was 21 days.
Mortality rates were 11% /6/55) for acute dissection and 14% (7/51) for chronic dissection; p=0.77. Of these, one patient died due to rupture of the abdominal aorta. Other causes of death were heart failure (n=3), visceral malperfusion (n=2), haemorrhage (n=2), sepsis (n=2), cerebrovascular accident (n=1) and lung failure (n=2). The incidence of postoperative cerebrovascular accident was 5%. Damage to the spinal cord occurred in three patients (3%). Of these, one had paraplegia and two had paraparesis (see Table 3).

Aortic disease, *no (%)*	Overall (n=106)	Acute AD (n=55)	Chronic AD (n=51)	p-value
In-hospital mortality	13 (12)	6 (11)	7 (14)	0.77
Intubation time 72 h	36 (34)	22 (40)	14 (28)	0.21
Re-exploration	20 (19)	11 (20)	9 (18)	0.80
LOS	9 (9)	6 (11)	2 (6)	0.49
Visceral ischemia	4 (4)	3 (5)	1 (2)	0.61
Stroke	5 (5)	4 (7)	1 (2)	0.36
Spinal cord injury	3 (3)	0	3 (6)	0.10

AD= Aortic dissection; LOS= low output syndrome

Table 3. Postoperative results of the Evita open Registry

Eleven patients (10%) had to undergo a second intervention in the aorta during their hospital stay: 10 stent elongations (acute dissection 4/55, 7% vs. chronic dissection 6/51, 12%; p= 0.52). Open replacement of the descending aorta was performed in one patient.
Ten patients (11%) died in the observation period of 20±11 months. As regards overall survival after 36 months, no significant difference was registered between acute and chronic dissections (79% vs. 87%; p=0.69) (Figure 6).

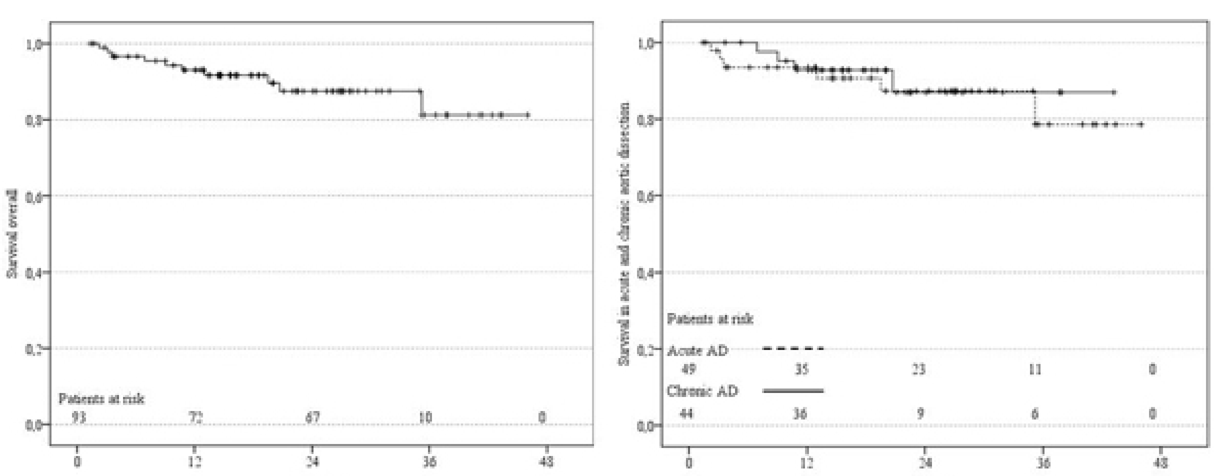


Fig. 6. Survival rates after the hybrid operation (left: all patients; right: after acute and chronic aortic dissection)

An additional intervention in the aorta could be avoided in 91% of patients after 12 months, and in 87% after 36 months (Figure 7) (Tsagakis et al. 2011).

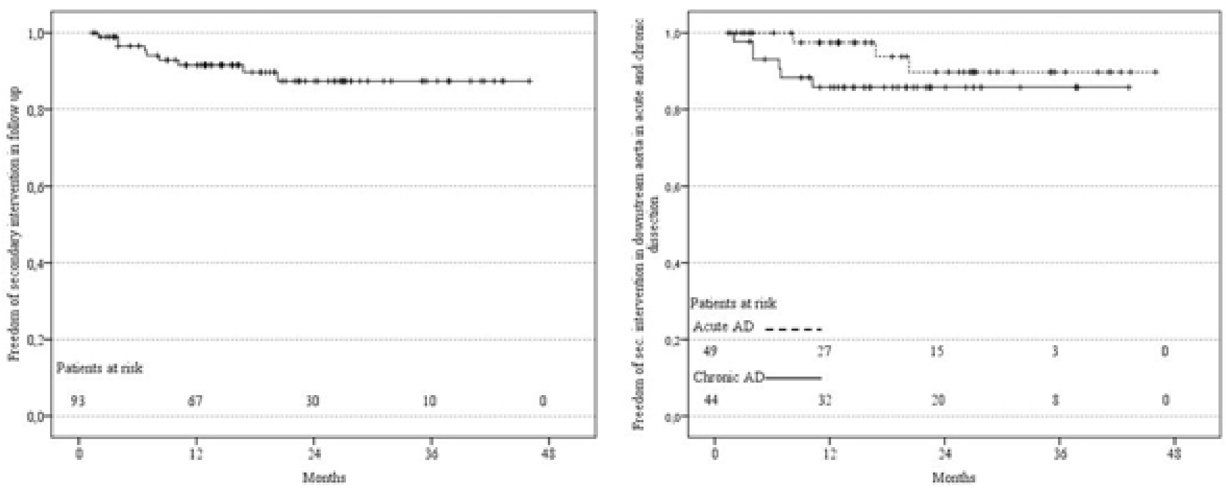


Fig. 7. Avoidance of additional surgery in the aorta (left: all patients; right: after acute and chronic aortic dissection)

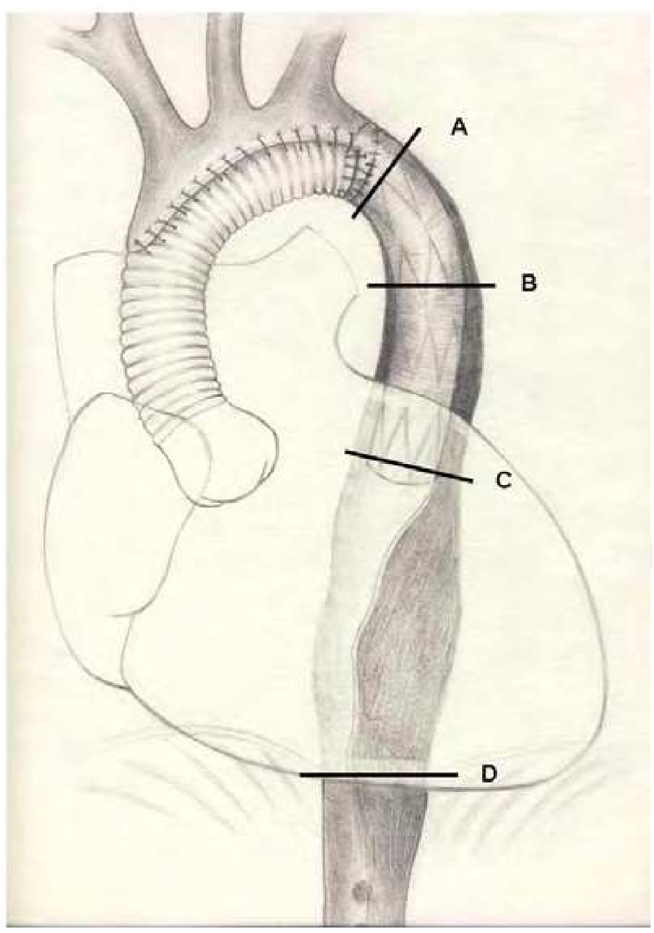


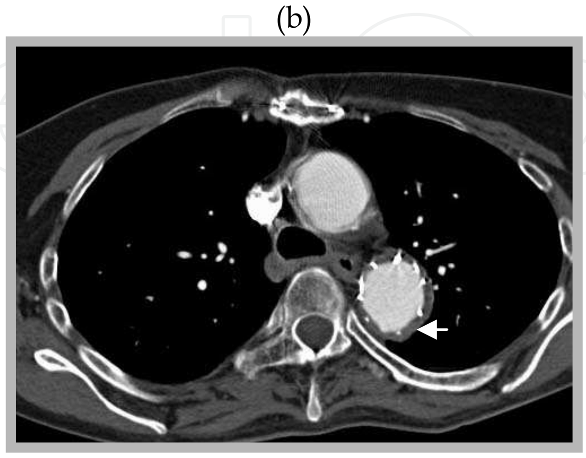
Fig. 8. The points measured in the aorta: A= Point of origin of the left subclavian artery, B= Pulmonary arteries, C= End of the stent, D= Diaphragm

4.3 Fate of the false lumen

In our own series of patients, the false lumen thrombosed completely at the level of the stent graft within two weeks in 86% of patients, while complete thrombosis at the level of the stent graft was observed after three months in all patients. The diameter of the aorta was measured at four points: the point of origin of the left subclavian artery, the level of the pulmonary artery, the end of the stent, and in the region of the diaphragm (Figure 8).

(a)

(b)



(c)

Fig. 9. CT scans preoperatively (a), 10 days (b) and 6 months postoperatively (c) (false lumen marked with arrow)

A significant reduction in the overall diameter of the aorta was observed at the level of the subclavian artery (3.9±0.45 cm vs. 3.6±0.39 cm; p=0.011), and a significant reduction in the diameter of the false lumen was noted in all portions of the stent graft.
No significant changes were observed in the untreated part of the aorta at the diaphragm (Gorlitzer et al 2010).
These observations concur with those of the IEOR, according to which 93% of patients developed a complete thrombosis in the region of the stent (Tsagakis et al. 2011). (Figure 9).

5. Conclusion

The treatment of complex aortic diseases by the use of the combined surgical and endovascular procedure is of a single-step operation which can be performed safely and is associated with a low rate of complications. Preservation of the convexity of the aortic arch (so-called *light arch replacement*) permits shorter, more visible suture line and reduces the duration of circulatory arrest.
Thrombosis of the false lumen in the region of the stent graft causes re-structuring of the descending aorta in its proximal portion. Our results are confirmed by those of the multicenter trial of the International E-vita Open Register.
Subsequent operations can be avoided or markedly reduced by this method without increasing the risk for the patient.

6. Acknowledgment

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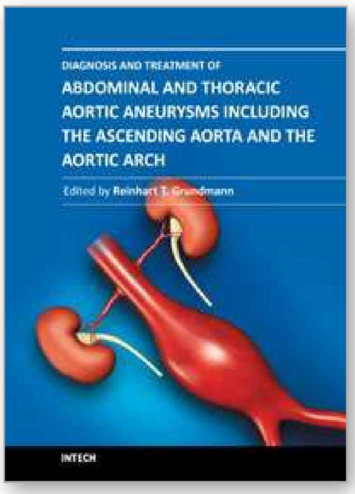

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This book considers diagnosis and treatment of abdominal and thoracic aortic aneurysms. It addresses vascular and cardiothoracic surgeons and interventional radiologists, but also anyone engaged in vascular medicine. The book focuses amongst other things on operations in the ascending aorta and the aortic arch. Surgical procedures in this area have received increasing attention in the last few years and have been subjected to several modifications. Especially the development of interventional radiological endovascular techniques that reduce the invasive nature of surgery as well as complication rates led to rapid advancements. Thoracoabdominal aortic aneurysm (TAAA) repair still remains a challenging operation since it necessitates extended exposure of the aorta and reimplantation of the vital aortic branches. Among possible postoperative complications, spinal cord injury (SCI) seems one of the most formidable morbidities. Strategies for TAAA repair and the best and most reasonable approach to prevent SCI after TAAA repair are presented.