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Reimplantation Valve Sparing Procedure in Type A Aortic Dissection: A Predictive Factor of Mortality and Morbidity?

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1. Introduction

The aim of surgical interventions in type A aortic dissections (TAAD) is to manage the potentially fatal complications associated with it. These are: intra-pericardial rupture and tamponade, malperfusion phenomena (coronary, neurological, visceral) and acute aortic valve regurgitation. Despite excellent results from individual surgeons and expert centres, operative outcomes for TAAD have remained static with mortality rates from large databases that perhaps better reflect “real-world” practice still around 15 to 30% [Ergin et al, 1996, Fann et al, 1991, Hagl et al, 2003, Kouchoukos et al, 1991, Mazzucotelli et al, 1993, Nienaber et al, 2003a, 2003b, von Segesser et al, 1996].

Since the past decade, the reimplantation aortic valve sparing technique (David I) has been proposed as an alternative to supra commissural replacements or to modified Bentall-deBono procedures for repair of TAAD, based upon the principle of totally resecting the aortic root, but leaving in place a macroscopically intact aortic valve [Kallenbach et al, 2004]. Since the sinuses are very frequently involved in the dissection, in opposition to the aortic leaflets, this technique seems to be very appealing. Yet, in most of the cardiac centres, reimplantation valve sparing techniques are done by experienced surgeons, most often in elective ascending aortic aneurysms. These same surgeons are not those who deal routinely with aortic dissections, and it can be easily understandable that young assistants set as a gold standard in aortic dissection surgery a living patient better than an intellectually satisfying surgery.

For all these reasons, we have carried in our department a prospective study over a 5 years period to evaluate whether a reimplantation valve sparing technique could be associated with an increased perioperative morbidity or mortality when done routinely. The aims of this study were multiple: to proof efficacy and feasibility, to confirm long term reliability of the technique, and to demystify this approach still considered for too many surgeons as a technical challenge.

2. Patients

2.1 Preoperative data

Between February 2005 and April 2010, 51 consecutive patients (40 male/11 female) who underwent surgery for TAAD were analyzed prospectively. Mean age was 65±11 years. Mean logistic Euroscore was 23.3±15.3. Past medical history was marked by severe pulmonary disease in 8 patients, multivascular disease in 5, clopidogrel/anti K vitamin treatment in 4, cerebral stroke in 6, alcohol addiction in 1, and pulmonary Rendu-Ossler disease in 1. Cardiovascular risk factors were severe arterial hypertension (88%) and smoking (27%). None of the patients had previous cardiac surgery.

Diagnosis of type A aortic dissection, defined as involvement of the ascending aorta regardless to the distal extension of the lesions, was assessed by echocardiography, and confirmed in 46 cases by CT-scan. All of the diagnoses were done in external hospitals before transfer to our institution. All the patients had tricuspid aortic valve. Preoperative morphologic and hemodynamic data are represented in table 1. In two cases, the patients presented with a preoperative collapse needing intubation, inotropic support and fluid venous filling. Two other patients had an aortic rupture at the onset of the surgery. Eleven patients had one or more preoperative malperfusion syndromes (limbs 8, cerebral 4, digestive 4 and coronary 5). A 38-year-old woman had a complete coronary artery network dissection in association with the TAAD. Among these patients, 45 underwent a reimplantation valve sparing technique, 2 a modified Bentall-DeBono and 4 a supra commissural replacement.

Imaging assessement		n	%
	TEE	51	100
	CT-scan	46	90.2
Anatomical findings			
	Aortic insufficiency >2/4	9	17.6
	Ascending aortic diameter >50mm	22	43.1
Hemodynamic status			
	Shock (alone)	4	7.8
	Malperfusion (alone)	11	21.6
	Both	7	13.7

Table 1. Preoperative data TEE: transesophageal echocardiography.

2.2 Surgical technique in case of reimplantation valve sparing technique

All the procedures were performed under general anaesthesia, standard tracheal intubation and transesophageal echocardiography (TEE) monitoring. Two catheters were inserted into the right radial and the left femoral arteries for continuous blood pressure monitoring. Bispectral index was used for cerebral monitoring. After exposition of the heart and the great vessels, venous cannulation was done into the right atrium using a double stage cannula. In twelve cases, arterial cannulation was performed into the right femoral artery before sternotomy. For 38 patients, the arterial cannulation was made directly in the concavity of the aorta, at the junction between the ascending segment and the arch. In one, canulation of the brachiocephalic trunck was performed. After the cardiopulmonary bypass

(CPB) was started, we began general cooling to reach a rectal temperature of 30°C if an arch replacement was planned. The aortic root was dissected free from the pulmonary artery, the right ventricle and the left atrium. After cross clamping, the aorta was opened transversally and cold crystalloid cardioplegia (Celsior®, Imtix Sangstat, Wien, Austria) was infused directly into the coronary ostia and repeated when necessary. The coronary ostia were dissected, leaving two coronary buttons of approximately 1cm diameter, as well as the sinuses, up to a remnant of 3 to 4mm. The tops of the aortic commissures were suspended with one U-stitch of 4-0 polypropylene each. The diameter of the aortic annulus was assessed using a Hegar dilator to determine the size of the Dacron™ tube. Six threads of 2-0 coated polyester fibre were passed in a U-fashion underneath the aortic annulus from inside to outside in a horizontal way. These threads secured a Valsalva shaped Dacron™ Tube (Gelweave Valsalva graft, Vascutek, Ann Harbor, Mi) to the aortic annulus. The tops of the aortic commissures were then attached inside the tube. The aorta remnant layers forming three cuffs were reimplanted into the tube using three 4-0 polypropylene running sutures, without glue. The coaptation of the three cusps was then examined carefully to determine any residual leakage. In this case, additional leaflet plasty was performed by the mean of free margin running suture using CV-7 PTFe.

	With arch replacement (n=36)	Without arch replacement (n=15)	*p*
Age (years)	65±2	64±4	0.73
Cross clamping (min)	109±5	86±8	*0.01*
CPB (min)	136±6	138±24	0.91
Lowest temperature (°C)	29.1±0.5	34.7±0.5	*<0.0001*

Table 2. Comparative data between patients with or without arch replacement

At that moment, rectal temperature usually reached 30°C. In case of aortic arch replacement, a brief circulatory arrest was performed and the aortic arch was resected, totally or partially, in order to remove as much arch tissue as possible. Two manually inflatable retrograde cardioplegia cannulas (Medtronic™, Minneapolis, Mn) mounted on a Y-shaped injection line were inserted into the lumen of the brachiocephalic trunk and the left carotid artery to provide continuous cerebral antegrade perfusion at a temperature of 30°C and a flow rate of 1.2 to 1.6l/min (10 to 15ml/kg). The adequate perfusion was determined regarding to the right arterial radial pressure and to the lateral pressure line on the left carotid artery cannula. Another Dacron™ prosthesis was anastomosed to the aortic isthmus with a 4/0 polypropylene running suture, after instillation of fibrin glue (Tissucol®, Baxter™, Maurepas, France) between the two layers of the descending aorta. An aortic cuff, including the three cerebral trunks, was anastomosed on the top side of the graft. At the end of the suture, the cerebral perfusion cannulas were removed, and a new cannulation was performed directly into the arch tube through a small incision and secured using a snare. The CPB was started slowly in order to de-air the tube before clamping and re warming.
The two coronary buttons (left then right) were anastomosed on the lateral side of the Valsalva tube at the level of the skirt-like segment. Finally, the two Dacron™ tubes (ascending aorta and arch) were anastomosed end-to-end with a 3-0 polypropylene running suture. For the patients without arch replacement, the ascending tube was directly anastomosed underneath the arterial brachiocephelic trunk. The aorta was declamped after

de-airing, and the CPB was weaned in a standard manner. Two temporary epicardial pacing wires were placed on the right ventricle. Pericardial drainage was made using two Ch16 redon catheters with high depression (-700mmHg) [Farhat et al, 2003].

2.3 Follow-up

Postoperative follow-up was done by the surgeon at the hospital, after 1, 6, 12 months and every year. A transthoracic echocardiography (TTE) and a CT-scan were done before each outcome visit. Aortic regurgitation was assessed semi quantitatively between 0 and IV/IV. Thrombosis of the false lumen of the descending aorta was noted as well. Clinically, general dyspnoea was calculated using the New York Heart Association classification (NYHA).

3. Results

3.1 Operative data

We didn't note any intraoperative mortality. Mean cross clamping, cerebral perfusion and CPB times were respectively 102±31, 24±10 and 137±58min. Mean low temperature was 30.7±3.8°C. There was a significant difference in cross clamping times and lowest temperatures between patients with or without arch replacement, but surprisingly not in CPB times (table 2).

	Alive, n=43	Dead, n=8	*p* value
	N=43	N=8	
Age (mean standard deviation)	63 (11)	72 (13)	0.12
Type 1 DeBakey Dissection (%)	32 (74%)	7 (88%)	0.66
Hypertension	38 (88%)	7 (88%)	1
Preoperative malperfusion	14 (33%)	4 (50%)	0.43
Preoperative shoc	8 (19%)	3 (38%)	0.35
Preoperative AI>2	18 (42%)	2 (25%)	0.46
Aorta diameter > 50 mm	19 (44%)	3 (38%)	1
Arch repair	30 (70%)	6 (75%)	1

Table 3. Comparative data between alive and dead patient in the perioperative period AI: aortic insufficiency.

The overall cooling time was less than 20 minutes. The surgical sequence that we used allowed us in each case to reach the ideal temperature at aortic declamping. In two cases, the aortic cannulation was directly made into the false lumen. At the aortic cross clamping, the radial pressure dropped dramatically attesting of the hypoperfusion of the true lumen. A brief CPB arrest was performed in a Trendelenburg position. The aortic clamp was released, and a surgical fenestration of the intimal flap was made in the aortic arch. The CPB was restarted after recalmping the aorta re-establishing a homogenous perfusion within the two lumen. Among all patients, 36 had an arch replacement, including one elephant trunk distal suture.

Five patients had associated coronary artery bypasses during surgery, four for coronary occlusions and one for coronary dissections. Another patient had an extracorporeal life support (ECLS) at the end of the surgical procedure because of biventricular failure (preoperative left main coronary trunk dissection).

3.2 Early postoperative course

3.2.1 Postoperative mortality

Eight patients died in the early postoperative period (15.7%). One patient died on postoperative day (POD) 8 during a tracheal aspiration. No diagnostic autopsy was performed. Two patients presenting with a preoperative coma died respectively on POD 3 and 4. Two patients died from myocardial infarction respectively on POD 1 and 13. One patient died on POD 56 due to severe pneumopathy. One patient died on POD 27 from multiple organ failure. The last patient died one day from discharge without clear reason (non contributive autopsy). There was no statistical difference in between alive and dead patients regarding age, distal extension of the dissection, preoperative hypertension, preoperative malperfusion or shock, preoperative severe aortic insufficiency, aortic diameter or arch repair (table 3).

With malperfusion (4 death)	Survival 78% (95%CI : 61-100)
Without malperfusion (4 death)	Survival 87% (95%CI : 76-100)
Log-rank	*p*=0.36
With preoperative shock (3 death)	Survival 73% (95%CI : 51-100)
Without preoperative shock (5 death)	Survival 87% (95%CI : 77-99)
Log-rank	*p*=0.23

Table 4. Survival in patients with or without preoperative malperfusion

Moreover, postoperative survival was not affected by preoperative malperfusion (OR=2.07 [0.45-9.52] *p*=0.35), shock (OR=2.63 [0.52-13.32] *p*=0.24, table 4) or age (OR=2.21 [0.96-5.05] *p*=0.06). To refine the analysis of preoperative risk factors for postoperative mortality, we have defined as severity factor patients presenting with malperfusion, shock or both. In this case, there was no difference in between patients with (5 death) or without (3 death) severity criteria regarding mortality (OR=2.55 [0.54-12.08] *p*=0.24). After analysing the population of patients over 70 years old, the results were also comparable (OR=5.54 [0.63-48.44] *p*=0.12).

		Value
Total transfusion		
	RBC	4.4±5.1
	FFP	3.6±3.6
	Platelets	0.6±0.8
Aortic insufficiency		
	Grade 0	43
	Grade 1	2

Table 5. Early postoperative data.

Regarding anatomical findings, preoperative aortic insufficiency >2/4 (2 *vs* 6 deaths, OR=0.46 [0.08-2.56] p=0.38) was not related to increased mortality, neither was an aortic diameter >50mm (3 *vs* 5 deaths, OR=0.76 [0.16-3.58] p=0.72). Patients with a preoperative AI>2/4 had better survival comparably to others but without reaching statistically significant difference (90% *vs* 80%, *p*=0.32), as well as patients with an aortic diameter >50mm (86% *vs* 82%, *p*=0.72) when compared with patients with aortic diameter <=50mm.
Finally, survival in case of reimplantation technique (7 deaths) was comparable to other approaches (1 death, respectively 84% *vs* 83%, *p*=0.94, OR=0.92 [0.09-9.13])

3.2.2 Postoperative morbidity

Eleven patients (21.6%) underwent revision for bleeding. Four were previously treated with clopidogrel, and one was under ECLS. No surgical causes were noted on reintervention. Eight patients (15.7%) had postoperative neurological deficit, completely regressive within 24 hours. Cerebral CT-scan didn't show ischemic signs. One patient with preoperative leg malperfusion presented with postoperative mesenteric ischemia needing surgical abdominal aortic fenestration on POD 1. One patient had on POD 7 an implantation of a descending aortic covered stent graft (Talent™, Medtronic) for a pre-existing penetrating aortic ulcer (PAU) located 10 cm above the celiac trunk. This procedure was done under epidural analgesia because of severe COPD.

Mean troponin I level at 24 hours was 15±20µg/l. Mean bleeding at 24 hours was 846±825ml. Mean intubation and ICU times were respectively 9.2±17.2 and 10.7±14.2 days. Yet, twelve patients with severe preoperative comorbidities (malperfusion, alcohol addiction, pulmonary Rendu-Ossler disease, preoperative shock) had prolonged ventilations (range from 14 to 48 days). Other postoperative data are represented in table 5.

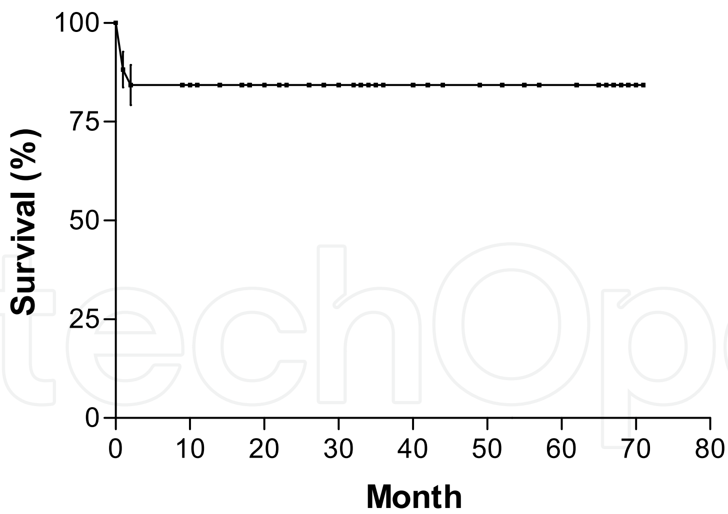
ICU stay was analyzed regarding preoperative risk factors. Malperfusion (13.9 days if malperfusion *vs* 9.0 if not, p=0.33) or preoperative shock (7.14 if shock *vs* 11.7 if not, p=0.13) were not found to be predictive factors of prolonged ICU stay. Analyzing the postoperative neurological deficit, neither arch repair (8/36 *vs* 0/15, p=0.08) nor direct aortic canulation (6/38 *vs* 2/13, p=1) were found to be risk factors.

3.3 Late postoperative course

Mean follow up was of 34±25 months and was completed in all cases. Actuarial survival rate at 1 year was 84.3% (figure 1). We didn't have any reintervention on the aorta during the follow up period. 42 patients presented in NYHA I class while 1 was in NYHA II (COPD). TTE control didn't show any aortic insufficiency greater then grade I. CT-scan control showed neither false aneurysm on the proximal or distal anastomosis, nor malperfusion syndrome. In 6 cases, CT-scan showed a complete thrombosis of the descending aortic false lumen. For all patients, we could note the Valsalva shaped aspect of the aortic root (figure 2) with a non modified geometry of the cusps coaptation.

4. Discussion

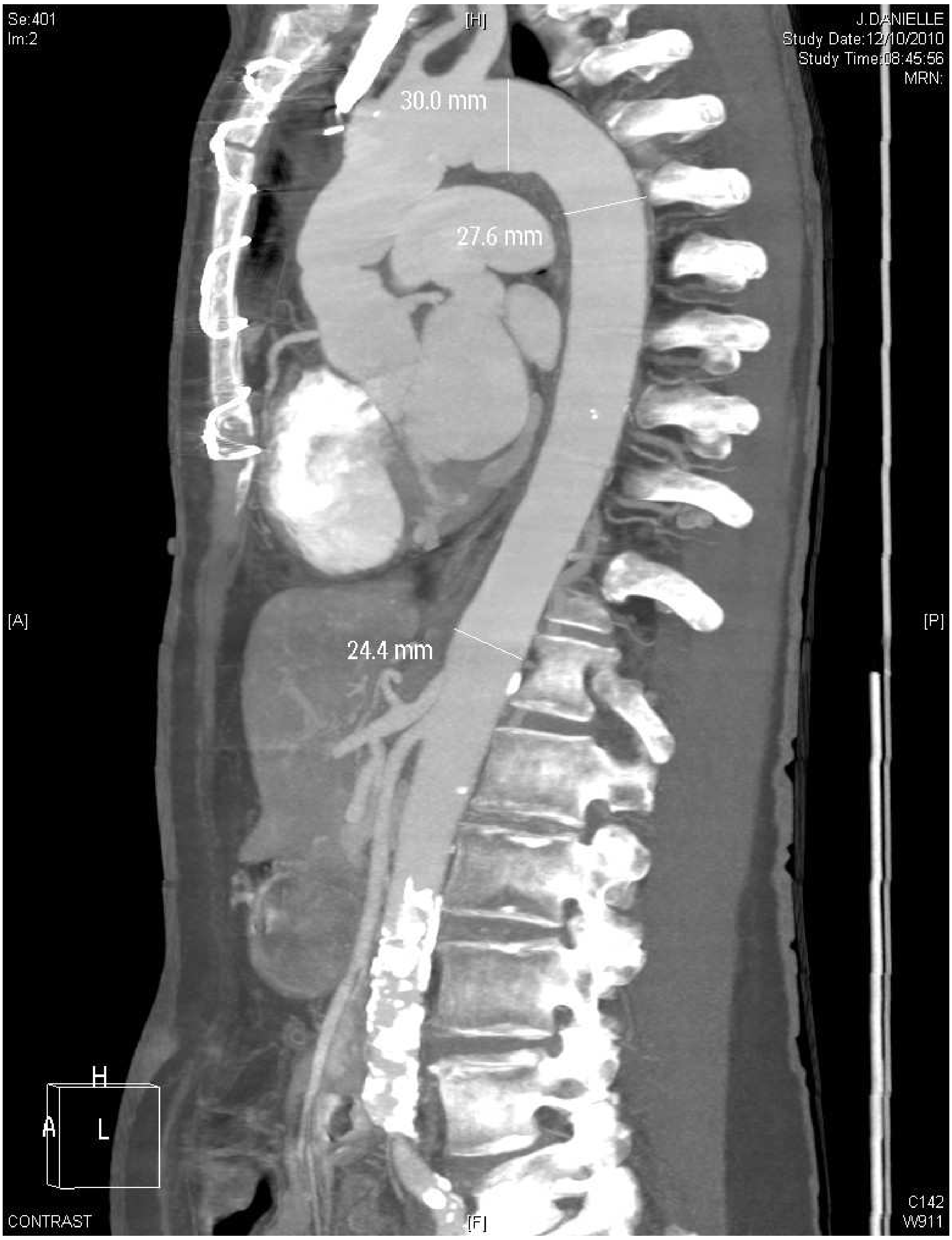
The surgical approach of type A aortic dissection remains questionable for many reasons. First, this pathology represents one of the major life-threatening emergency situations in cardiovascular diseases, due to the risk of aortic rupture into the pericardium, and to the consequences of malperfusion (cerebral, digestive, limbs) that can higher morbidity or mortality even if the surgical management of the ascending aorta itself is optimal [Nienaber et al, 2003a]. Second, type A aortic dissection presents the very bad habit of being a "mid-night pleasure"! Thus, a big majority of the surgeons tend to privilege a fast and easy technique. Third, the absence of dilatation of the aortic root is very often present, and in this case, total aortic root replacement (regardless to valve preservation or not) is difficult to justify because of a potentially higher surgical risk. Finally, and in many institutions, reimplantation techniques in scheduled patients are reserved for confirmed surgeons. Unfortunately, all of the surgeons who deal with type A aortic dissection in the middle of the night are not always used to this approach.



Time (months)	14	26	36	67
Patients at risk (n)	38	30	22	10

Fig. 1. Actuarial survival curve for patients with type A aortic dissection treated by reimplantation valve sparing technique according to David in association or not with arch replacement. Early mortality is included.

Supracommissural tube graft replacement in conjunction with reconstruction of the sinuses with glue is the easiest way to treat type A aortic dissection [Fann et al, 1991, Kouchoukos et al, 1991, Mazzucotelli et al, 1993]. This technique allows in almost 90% of the patients the restoring of the geometry of the aortic sinuses and subsequently the valve competence which is failing in many cases. If this surgical treatment brings entire satisfaction in immediate postoperative course, the long term outcome remains controversial. Supracommissural replacement has been proven by some authors inasmuch as the freedom for reoperation for aortic valve dysfunction was elevated after 10 years of follow-up (up to 91%) [Casselman et al, 2000, Driever et al, 2004]. Yet, others underscore that the progression of the disease, regardless to a pre-existing aortic aneurysm, could lead to aortic insufficiency by the absence of coaptation between the three leaflets. Simon *et al* found that 29% of the patients with supracommissural tube graft for type A aortic dissection developed a sinus of Valsalva aneurysm within 44±22 months after surgery [Simon et al, 1994]. Three reasons are often evoked as an explanation: first, the supracommissural replacement of the aorta leads to increased shear stress in the sinuses because of the absence of elasticity of the Dacron™, especially during diastole, thereby transferring the diastolic pressure to the only sinuses [Simon et al, 1999]. Second, a long aortic root remnant has by itself a dilatation risk due to cystic medial necrosis that is diffusely present in the aortic structure and which is the primary reason for aortic dissection [Marsalese et al, 1990]. Third, the use of gelatine-resorcinol-formaldehyde has been incriminated in a higher incidence of false aneurysms or re-dissections, particularly in the proximal part of the aorta [Kirsch et al, 2002]. For all these reasons, some authors have strongly recommended total aortic root replacement by a composite graft, subsequently to eliminate the entire diseased aortic root [Ergin et al, 1996, Hagl et al, 2003]. Yet, solving a problem was to create another one: biological tubes lead to valve failure, and mechanical ones to lifetime anticoagulation. Thus, the valve preserving techniques (remodelling/reimplantation) have gained more interest these past years in type A aortic dissection treatment along with their development in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(a)

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Fig. 2a. and 2b. CT-scan showing transverse (a) and sagittal (b) views of the aorta and aortic leaflets. The sinuses' diameter is 20 to 25% larger than the annulus diameter. The three leaflets are well identified and coaptation can be assessed

elective cases, such as aortic root aneurysms. Kallenbach *et al* have reported that the aortic valve preservation techniques can be performed with favourable functional results regardless to the underlying aortic lesion (type A aortic dissection or aneurysm) [Kallenbach et al, 2004]. Yet, Leyh *et al*, from the same team, noted a higher failure rate in aortic root remodelling, in patients with type A aortic dissection, comparatively to a reimplantation technique [Leyh et al, 2002]. These results can be easily understandable: the remodelling is based upon the suture of a Dacron™ tube, which is previously three folded, directly to the 3 to 4mm remnants of the sinuses of Valsalva. This suture is made on a diseased tissue, without any protection against further dilatation of the aortic annulus.
Our prospective series was carried on to find out whether a near systematic performance of a reimplantation technique is accompanied with a higher mortality or morbidity risk. Post operative death proportion in our series is comparable to what we can find all along the literature. Yet, many points are remarkable in this series. In opposition to what previously

described in the literature, preoperative malperfusion, shock or age of the patients were not found to be risk factors of perioperative mortality. Arch replacement, as well as direct aortic cannulation, didn't emphasize the postoperative risk of stroke.

Different points are to be discussed in our global strategy. First, we did direct aortic cannulation into the dissected aorta for 38 patients. This technique was first described by Lijoi *et al*, who performed two cases of aortic replacement in type A aortic dissection, with direct aortic cannulation and deep hypothermia [Lijoi et al, 1998]. Minatoya *et al* reported a series of 14 patients with direct aortic cannulation, without rupture or peroperative malperfusion [Minatoya et al, 2003]. The difference with the Lijoi description is that the arch replacement is performed under mild (28°C) hypothermia and antegrade cerebral perfusion, like reported in our series. Beside the aortic rupture risk, the elective perfusion of the false lumen is the other pitfall of this technique. This problem can only be tracked down at cross clamping, when the proximal intimal aortic tear is excluded and doesn't anymore constitute an entry site for the perfusion of the true lumen. This complication can be suspected easily while the right radial pressure drops (along with a preservation of the pressure in the femoral artery), witnessing of a malperfusion of the arterial brachiocephalic trunk. Minatoya *et al* have also reported this complication. We propose a simple fenestration of the intima in the arch, that is to recreate a downstream re-entry site and to perfuse adequately the true lumen. The second point of our technique is the arch replacement under mild hypothermia with selective antegrade cerebral perfusion. Minatoya *et al* have recently reported the absence of difference upon neurological outcome with antegrade cerebral perfusion, comparatively between three groups with a body temperature of 20, 24 and 28°C [Minatoya et al, 2005]. Karck *et al* performed prolonged circulatory arrest times (up to 62±14min) in combined aortic arch and descending aortic replacement, using a 28°C antegrade cerebral perfusion, without major cerebral complications [Karck et al, 2005]. This technique brings the advantage of shortening the CPB time, reducing the platelets dysfunction and subsequently the postoperative bleeding. Regarding the postoperative neurological events, direct aortic canulation and arch replacement were not found to be risk factors when considered alone. The third point of our approach is the use of a Gelweave Valsalva™ prosthesis for the root replacement. This tube was designed to reproduce the anatomic and physiologic features of the normal aortic root. The root of the tube, shaped as a skirt, has vertical crimps, allowing it to expand transversally along with the cardiac systole and diastole, contrarily to the body of the tube, which has horizontal crimps. In a normal aortic root, the sinuses of Valsalva create eddy currents, first described by DaVinci, with a major importance in the aortic leaflets motion: on valve opening, they prevent the cusps' edges from impacting the aortic wall, and they participate to the initiation of the aortic valve closure [Hopkins et al, 2003, Kunzelman et al, 1994, Leyh et al, 2003]. One of the suggested reasons for mid term failure of the reimplantation technique is the use of a straight Dacron™ tube without any stretching structure allowing the transversal expansion during systole. The consequence is repetitive impaction of the cusps' free edges on the tube's walls, leading to a progressive fibrotic retraction of the cusps with subsequent coaptation default. We believe that the Valsalva shaped tube prevents from this evolution by recreating the anatomy and the haemodynamic of a normal aortic root. Along with the progression of the series, we noticed during echographic control that the Valsalva segment was far from the free edge of the cusps during systole.

Follow up was done for 34±25 months and was completed in all cases. We didn't observe any evolution towards aortic insufficiency in any patient, and previous aortic aneurysm didn't constitute a risk factor for aortic repair failure [Leyh et al, 2003]. None of the patients had anticoagulant treatment. Mean aortic gradients and effective permeability index were acceptable, without difference between the postoperative period and follow-up. CT-scan reconstructions allowed a perfect visualization of the aortic root, showing the shape of the Valsalva skirt. In 9 patients, we noted a thrombosis of the false lumen. The persistence of perfusion in the other patients is probably related to the re-entry sites situated distally on the descending and abdominal segments. One patient presented an evolution to dilatation of the descending aorta, without reaching surgical criteria.

5. Conclusion

Based upon our experience in the management of type A aortic dissection, the reimplantation valve sparing technique could be performed systematically without emphasizing perioperative risk. Our results during follow-up, along with other results published by many authors, seem to be encouraging, and push up to keep on performing this technique routinely in type A aortic dissection. Preoperative malperfusion or shock shouldn't push the surgeon to counter indicate the patients to undergo surgery. We also think that the use of a Valsalva tube grandly contributes to these mid term good results.

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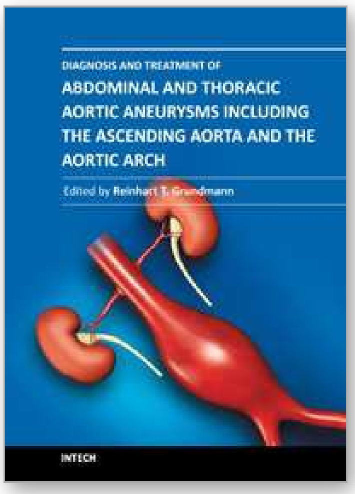

Diagnosis and Treatment of Abdominal and Thoracic Aortic Aneurysms Including the Ascending Aorta and the Aortic Arch
Edited by Prof. Reinhart Grundmann

ISBN 978-953-307-524-2
Hard cover, 208 pages
Publisher InTech
Published online 22, June, 2011
Published in print edition June, 2011

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.