



Redo proximal thoracic aortic surgery: challenges and controversies

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Abstract

Reoperations on the proximal thoracic aorta represent a challenge. The mortality rate is at least three times higher than it is for the initial surgery and the complications after such procedures occur with disappointingly high frequency, leading to substantial morbidity and delayed recovery. This article aims to present the early and the late outcomes of these kinds of operations, to identify the causes for failure of the primary surgery, to underline the critical points during the perioperative management of those patients and finally to emphasize on the rapid evolution and advent of techniques over the last few years.

Keywords Reoperation · Aorta · Proximal · Aortic surgery

Abbreviations

AV	Aortic valve
CVG	Composite valve graft
AI	Aortic insufficiency
LV	Left ventricle
EF	Ejection fraction
AVR	Aortic valve replacement
HCA	Hypothermic circulatory arrest
COR	Class of recommendation
LOE	Level of evidence
NYHA	New York Heart Association
CPB	Cardiopulmonary bypass
CT	Computed tomography
MRI	Magnetic resonance imaging
TEE	Transesophageal echocardiogram
TTE	Transthoracic echocardiogram
TEVAR	Thoracic endovascular aortic repair

Introduction

Over the past two decades, important advancement in the perioperative management of patients undergoing surgical intervention on the aortic root or ascending aorta, even in the setting of an acute Type A aortic dissection, had substantially reduced the mortality risk and improved the long-term outcomes [1, 2]. Despite this, patients undergoing redo thoracic aortic surgery still have higher operative risk, which was reported from previous studies to range from 6 to 16.4% [3–18] (Table 1).

Although the incidence of complications requiring reoperation appears to have decreased, the total number of patients at risk for the development of complications that may require reoperation has increased. The aetiology as one would appreciate is multifactorial. First of all, the routine use of imaging in the evaluation of patients with known aortic disease has identified abnormalities in asymptomatic or minimally symptomatic patients that may require reoperation. Second, the more frequent use of aortic allografts and pulmonary autografts as well as the increased use of valve-sparing operations have increased the incidence of reoperation. Finally, the aging of patients who are undergoing cardiac surgical procedures has resulted in an increase in the number of patients who will develop degenerative diseases of the aorta and will be thus candidates for redo surgery.

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Table 1 Early and late outcomes of redo proximal thoracic aortic surgery

Study author	Number of patients (<i>n</i>)	Early mortality (%)	Late survival
Sveto et al. [3]	156	11.5	86.4 ± 2.7% at 1 year, 72.6 ± 4.3% at 5 years, and 58.4 ± 7.8% at 10 years
Di Eusano et al. [4]	174	12.6	81.6% at 1 year, 74.2% at 5 years, and 44.55% at 10 years
Di Bartolomeo et al. [5]	224	12.1	95.6% at 1 year, 90.2% at 5 years, and 81.5% at 10 years
Stephens et al. [6]	134	6.6	89% at 1 year, 83% at 5 years, and 62% at 10 years
Estera et al. [7]	104	13.5	83% at 1 year, 80% at 5 years, and 62% at 10 years
Dougenis et al. [8]	81	8.6	89% at 1 year, 81% at 5 years, and 69% at 10 years
Keeling et al. [9]	122	11.5	85.9 and at 1 year, 81.6% at 3 years, and 74.2% at 10 years
Silva et al. [10]	58	12.1	77.9 ± 1.11% at 1 year, 75.3 ± 0.11% at 3 years
Dossche et al. [11]	56	5.4	91.2% at 1 year, 84.0% at 5 years, and 76.4% 10 years
David et al. [12]	165	7	68% ± 6% at 8 years
Czemy et al. [13]	60	13	83% at 1 year, and 68% at 5 years
Chong et al. [14]	66	4.5	81.5 ± 5.1% at 1 year, and 76.4% ± 5.4% at 5 years
Malvindi et al. [15]	104	7.7	92% at 1 year, 82% at 5 years, and 58% at 10 years
Mookheok et al. [16]	86	1.2	89% at 8 years
Pacini et al. [17]	73	16.4	93.8% at 1 year, 77.75 at 5 years, and 37% at 10 years
Want et al. [18]	269	16.4	65.5% ± 3.6% at 10 years, and 28.7 ± 4.3% at 20 years

Historical overview

Proximal aortic surgery involving replacement with prosthetic material was first described by DeBakey and Cooley in 1953 [19]. Wheat and colleagues, in 1964, were the first to report a successful replacement of the entire ascending aorta and aortic valve (AV) [20]. Later, in 1968, Bentall and colleagues described a technique that involved the use of a composite tubular graft containing a valve to replace the aortic root [21]. Although Bentall procedure revolutionized aortic root repair, with sufficient patient-observation years, it became clear that excessive tension on the coronary arteries could cause them to pull away from the graft, promoting aneurysm formation in the wrapped aortic dissection. Pseudoaneurysm and frank dehiscence of the coronary arteries, requiring reoperations, were also reported by numerous surgeons. In 1981, Cabrol and colleagues modified this technique through interposition of a short, small diameter graft between the coronary arteries and the ascending aorta replacement graft [22]. However, the Cabrol procedure was also associated with coronary artery pseudoaneurysm formation. In 1991, Kouchoukos and colleagues described an open button technique of coronary artery reattachment during composite valve graft (CVG) insertion [23]. This technique reduced the incidence of coronary artery pseudoaneurysm, and became soon the dominant mode of coronary artery reattachment.

Milestones in the surgery of proximal aorta are considered two more types of operation: Ross procedure and the valve-sparing root operations. In Ross procedure, which

was proposed in 1962 and first performed in 1967, the aortic root is replaced with the patient's own native pulmonary root and a cryopreserved allograft to establish continuity between right ventricle and pulmonary artery and this has the advantage of freedom from anticoagulation [24]. Ross procedure remains the first choice of treatment in infants and children, but its use in adults remains controversial. The increased number of failed pulmonary autografts considered its "Achilles tendon". On the other hand, valve sparing root operations pioneered by David and Feindel [25] and Yacoub et al. [26], provide patients the option of preserving the native valve and are associated with excellent early and midterm outcomes; however, observational studies reveal that some of the patients need to undergo reoperation mainly due to severe aortic insufficiency (AI).

Finally, it is worth to mention that performance of extended aortic reconstructions would be unlikely without the introduction by Griep et al. [27] of the hypothermic circulatory arrest (HCA) which changed completely the nature and the extent of procedures on the aorta allowing increased cerebral protection during ascending aorta and aortic arch procedures with subsequent lowered neurological morbidity.

Natural history and guidelines

At his first Aortic Symposium in New York in 1986, Dr Randall Griep emphasized the dearth of information on the natural history of thoracic aortic aneurysms. As late as 1995, Elefteriades [28] challenging to define the behaviour

of aortic aneurysms, reported that the aneurysmal thoracic aorta grows on average at 0.10 cm per year. The descending aorta, it was reported, grows faster than the ascending aorta at 0.19 vs 0.07 cm per year, respectively. Also, it was proved that the larger the aorta, the faster it grows. However, the most crucial finding in this study was the determination of a cut-off of 6.0 cm for the ascending aorta and 7.0 cm for the descending aorta, above which the patient faces the following yearly rates of developing adverse events: rupture (3.6%), dissection (3.7%), death (10.8%), rupture, dissection, or death (14.1%).

According to the most recent 2010 ACCF/AHA [29] guidelines for the management of patients with thoracic aortic disease, operation should be recommended: in asymptomatic patients for whom the ascending aorta or aortic sinus diameter is 5.5 cm or greater, in patients with a growth rate of more than 0.5 cm/year in an aorta that is less than 5.5 cm and in patients undergoing aortic valve repair or replacement and who have an ascending aorta or aortic root of greater than 4.5 cm (COR: I, LOE:C). Patients with Marfan syndrome or other genetically mediated disorders (vascular Ehlers-Danlos syndrome, Turner syndrome, bicuspid aortic valve or familial thoracic aortic aneurysm and dissection) should undergo elective operation at smaller diameters (4.0–5.0 cm depending on the condition) to avoid acute dissection or rupture (COR: I, LOE:C).

Indications for reoperation

Indications for redo surgery can be classified into three major categories: aortic, infective, and valvular (namely dysfunction of prosthetic valve or repaired native valve) (Table 2). The most common indication is reported to be an aortic root-ascending aorta aneurysm in a patient with previous aortic valve replacement (AVR). Dossche et al. reported

[11] that most reoperations in patients with primary cardiac surgery for Type A aortic dissection, are required for progressive aortic root dilatation or distal aortic dilatation, and for false aneurysm formation. On the contrary, in patients with degenerative aneurysm and annuloaortic ectasia, operation for false aneurysm formation, and prosthetic valve related problems (endocarditis, thromboembolic events, valve degeneration) are predominant causes of reoperation.

The failure of the pulmonary autograft following a Ross procedure presents to be an important cause of redo aortic surgery. During early exploration of this procedure, it was thought that autograft longevity will be better than that of any available prosthesis and whenever reoperation required, it will be simple and limited mainly to right ventricle-pulmonary artery conduit change. Stulak et al. [30] in a study that included 56 patients, who underwent Ross procedure, reported 144 reoperations and revealed that the most common indications were: isolated autograft (neoaortic) regurgitation (20%), isolated pulmonary conduit regurgitation/stenosis (16%), combined autograft regurgitation/dilatation (14%) and combined autograft regurgitation and pulmonary conduit regurgitation/stenosis (11%). He concluded that “a broad spectrum of reoperations may be required after the Ross procedure” and that the “patients and family members considering the procedure should be informed of the potential for associated morbidity should reoperation be necessary”.

David et al. [31] reporting the late outcomes of Ross procedure in a cohort of 212 patients revealed that 20 (9.4%) of patients required reoperation in a follow-up period of 15 years. At the same time, they found that the freedom from reoperation on the pulmonary autograft was 92%, the freedom from reoperation in the pulmonary valve was 97%, and the freedom from any cardiac operation was 85%. The freedom of dysfunction (presence of moderate or severe pulmonary insufficiency and or peak systolic gradient ≥ 40 mmHg) of the pulmonary homograft was found to be 70.8% at 15 years. They reported that preoperative AI, aortic annulus ≥ 15 mm/m², mismatch in annulus diameters between aortic and pulmonary artery and male sex, are considered risk factors for failure of the pulmonary autograft. Elkins et al. [32] reported that freedom from pulmonary autograft failure is 74% at 16 years and was similar for children and young adults. All the above should not be a reason for the surgeons to abandon the Ross procedure or to discourage patients from having it. The Ross procedure remains an important part of the surgical armamentarium to treat congenital aortic valve disease in children and young adults, but we need more information on late outcomes of this operation.

Similarly, failure of valve-sparing root operations seems to be an increased indication for redo aortic surgery, such operations have been performed now for over two decades.

Table 2 Indications for redo proximal thoracic aortic surgery

Aortic	Degenerative aneurysm
	Acute Type A dissection
	False aneurysm
	Chronic dissection
	Fusiform aneurysm due to medial degenerative disease (mainly in patients with Marfan's syndrome)
	Aneurysm persisting or occurring after brachiocephalic bypass
Infective	Infection of either the native valve or prosthesis
	Infection of the vascular graft
Valvular	Bioprosthetic structural valve dysfunction and degeneration
	Paravalvular leak
	Pulmonary autograft failure
	Failure of valve-sparing root replacement procedures
	Mechanical valve non-structural dysfunction

Tirone David presented the late outcomes of 374 patients, reporting that overall freedom from reoperation in the AV at 10, 15 and 20 years is 97.1, 94.2 and 94.2%, respectively [33].

In the same study, David emphasized the importance of careful selection of the patients undergoing these types of procedures. Older patients (> 50 years) with aortic root aneurysm and normal aortic annulus can be safely treated with the remodelling operation as long as their annulus is normal. That means that even mild dilatation of the annulus can result in mismatch between areas of the cusps and the aortic valve orifice area. On the other hand, younger patients with inherited aortic root aneurysms such as in Marfan syndrome, Loyes-Dietz syndrome, familial syndrome, and an incompetent bicuspid aortic valve, frequently have associated annuloaortic ectasia or develop dilatation of the aortic annulus years after the remodelling of the aortic root and have an increased risk of AI. It was also reported that the main causes of early failure of aortic valve sparing operations are probably technical errors [34] and lack of recognition of cusp prolapse. Additionally, the main cause of late failure was found to be probably the degeneration of the aortic cusps, but more information is needed to confirm this observation.

Infections of the vascular grafts appear to be an indication for redo aortic surgery requiring challenging management. The two main questions that the surgeon faces in these cases are: do I need to remove the graft and what should I use to replace it with? Although antibiotics are a critical component of treatment, among the many patients described in reports of ascending aortic graft infection, only a handful have been successfully treated with antibiotics alone [35, 36]. Also, the literature on surgical treatment of this complication fails to provide even the lowest level of evidence (Level C, consensus expert opinion) on which to base a concrete recommendation. Therefore, redo surgery remains the first choice of treatment for this subgroup.

Early and late outcomes from redo proximal aortic surgery

Early mortality rates of reoperations on the ascending aorta and the aortic root ranges from 6.0 to 16.4% [3–18] (Table 1). This variation is related to the different underlying diseases requiring reoperation, the types of reoperation and the operative techniques used, and the time interval in which the operations were performed. Various parameters have also been proposed as predictors of early death, including: New York Heart Association functional status (NYHA) III/IV, age ≥ 75 years, female sex, chronic pulmonary disease, preoperative renal failure requiring postoperative dialysis, underlying coronary artery disease requiring unexpected

bypass surgery, perioperative myocardial infarct, urgent operation, prolonged cardiopulmonary bypass (CPB), need for intra-aortic balloon pump (IABP) support. Dougenis et al. [8] reported that only NYHA III/IV and prolonged duration of cardiopulmonary bypass are independent predictors of increased 30-day mortality, while Dossche et al. [11] reported that there is no influence of type of reintervention on early mortality, but they identified active endocarditis or vascular graft infection as the only independent risk factor for hospital mortality. Leontyev et al. [37] underlined the importance of reduced ejection fraction (EF < 30%) and preoperative neurologic dysfunction as the most important predictors of early mortality.

Most of the series present acceptable late outcomes of the redo aortic surgery (Table 1). Comparing the current data and those that Crawford et al. [38] reported in 1985, when they presented an estimated 1- and 2-year survival rate of 70 and 60%, respectively, it is obvious that the mortality has been improved remarkably over the last 2–3 decades. Di Bartolomeo et al. [4] recognised the age and prolonged CPB as independent risk factors for late mortality, while Dougenis et al. [8] reported that reoperation for false aneurysm and presence of coexisting coronary artery disease requiring bypass surgery are the two more significant predictors for late mortality. Also, Silva et al. [10] revealed that the repeat operation affects the mid-term survival in patients undergoing proximal aortic surgery.

In 2012, data of 45,984 patients who underwent proximal aortic replacement were published by William et al. [39]. Risk factors were analysed and a parsimonious multivariable logistic regression model was constructed to predict risks of mortality and major morbidity. While operative mortality was 3.4% for elective and 15.4% for non-elective cases, emergency surgery was found to be the strongest predictor of mortality. Among elective patients, end-stage renal disease, reoperative status, severe lung disease, and concomitant procedures were highlighted as the most important factors that affect the operative outcomes. Arch involvement was associated with increased risk of mortality and major morbidity; however, root involvement was not. Adverse outcomes appeared more common after supracoronary ascending (with or without arch) replacement, despite being technically less challenging than root replacement, likely secondary to older age and greater comorbidities of these patients. This model is probably the most powerful predictive system ever created for proximal aortic surgery.

Using for first time a large contemporaneous European cardiac surgery database (8641 patients who underwent proximal aortic operation), Bashir et al. [40] developed and validated two risk prediction models for postoperative mortality after surgical procedure on the proximal aorta. One of them was created to be used in non-elective patients and the other in elective procedure. In the elective group, previous

cardiac operation was the most important predictor of post-operative mortality. Other risk factors included age, LV dysfunction, surgery on the aortic arch, triple vessel disease and concomitant coronary surgery, neurologic disease, aortic disease other than aneurysm, pulmonary disease, preoperative non-sinus rhythm, female sex and NYHA functional status \geq III/IV. For non-elective patients, salvage priority was the most important predictor. Previous cardiac operation was also strong predictor, followed by emergency priority, concomitant coronary surgery, age, preoperative non-sinus rhythm, cardiogenic shock, creatinine \geq 200 mmol/L, preoperative ventilation and peripheral vascular disease.

How to ameliorate the outcomes?

Improvement of the outcomes comes through two steps: (a) “early re-operation” according to the most recent guidelines that mentioned earlier accompanied with the appropriate perioperative management which eliminates the already increased mortality and morbidity risk for these procedures and (b) further technological evolution which will provide grafts with longer durability and at the same time will introduce techniques that will convert the complex redo operations on the proximal thoracic aorta to less invasive endovascular procedures.

Critical steps on the perioperative strategy of patients undergoing proximal aortic surgery

The adequate and accurate preoperative evaluation of the patient who are considered as candidate for redo aortic surgery is the first goal that needs to be achieved preoperatively. Multislice computed tomography (CT) angiography is mandatory in all redo cases, primarily in those cases with a previous coronary bypass. The status of the femoral vessels and lower limb arteries needs to be checked by Doppler examination. Intra-operative transesophageal echocardiogram (TEE) is also essential and shares useful information, as it allows: easier positioning of the venous drainage cannulae in the right atrium in the case of peripheral cannulation, evaluation of the collapse of the cardiac chambers after institution of peripheral CPB, continuous monitoring of contractile status and distension of the ventricles and facilitation in the de-airing phase.

The most crucial question that needs to be answered in a redo aortic case is if extracorporeal circulation (ECC) is required before the re-sternotomy or not. Dobell and Jain published a mortality rate of 47% among 30 patients with aortic sternal re-entry injury with catastrophic haemorrhage [41]. Luciani et al. [42] reported that the conditions

in which the reoperation should be performed with peripheral cannulation and ongoing CPB before re-sternotomy are: close adhesions between the sternum and the anterior cardiac surface; ascending aorta or bypass grafts (based on the CT scan); and patients with functional tricuspid regurgitation, haemodynamic /electric instability, previous mediastinitis, or depressed ejection fraction (EF < 25%). Di Bartholomeo et al. [5] highlighted that in patients with aortic aneurysm in close contact with the sternum or with aorta-to-sternum distance of < 10 mm, pre-sternotomy application of CPB is necessary.

Selection of cannulation site is the second crucial point that needs to be clarified and has dramatically changed during the last 10 years. The employment of the femoral artery, as Di Bartolomeo et al. reported [4], has decreased from the 93.1% of earlier years to 12.5% over the past 5 years, in favour of central cannulation sites, such as the ascending aorta, aortic arch, aortic prosthesis, and right axillary or innominate arteries. Interestingly, there is lack of gold standard evidence from randomized controlled trials comparing central cannulation and peripheral cannulation. The majority of the evidence on the subject is from observational cohort studies reporting conflicting results. On the meta-analysis reported by Benedetto et al. [43], in a total of 4476 was found that central cannulation is associated with a protective effect on in-hospital mortality and permanent neurologic deficit when compared to peripheral. Additionally, a trend towards an increased benefit in terms of reduced in-hospital mortality was observed when the right axillary artery was only used for central cannulation and this seems to be attributed to antegrade cerebral perfusion, which avoids complete arrest or reduces its duration to a minimum.

Considering that major cause of early death following reoperation in proximal aortic surgery is myocardial failure [44], great attention should be paid on the perfect intraoperative myocardial protection and therefore the appropriate delivery of cardioplegia as well as in the perfect attachment of the coronary ostia to the material that is used to replace the aortic root. Antegrade cardioplegia infusion through the ascending aorta should be avoided in patients with aortic valve/prosthesis insufficiency and in the presence of proximal leaks from dehiscent suture lines. Retrograde or percutaneous infusion of cardioplegia through the coronary sinus may represent a valid alternative. Also, if difficulties in delivering cardioplegia are anticipated with all routes, a lower core temperature will provide extra time for myocardial protection to address the complex situation more effectively. Finally, in patients in whom the ascending aorta cannot be controlled and clamped rapidly, transapical venting of the LV through a small left thoracotomy should be considered.

Long-term durability of aortic Dacron graft: is it a myth?

After 50 years since the initial implantation of Dacron grafts and despite their general good performance, dilatation or aneurysm, para-anastomotic pseudoaneurysm, and mechanical failure are still considered issues in the follow-up of these patients often requiring additional surgery. Several early studies revealed that a common pathogenic mechanism underlying the failure of these conduits was represented by the mismatch between the actual biomechanical properties of the grafts and those of the native vascular tissue. Inability of mimicking the electromechanical characteristics of the native arterial tissue, and the consequent lack of adequate compliance of the grafts, leads to dilatation with subsequent flow anomalies and is able to trigger a perpetuating circle of vascular wall alterations causing detrimental reflexes both locally and systematically [45]. A study from Takami et al. [46] demonstrated a 26% diameter increase, measured immediately after implantation, compared to the package size, a successive dilatation of 10.5% versus the diameter at discharge, and an increase of 3.23% per year over a 5-year follow-up period. Furthermore, insertion of systematic material into the arterial system was also shown to reflect in endothelial dysfunction and thrombosis [47].

Additionally, some other studies pointed out that the presence of an inextensible segment within the vascular tree, especially at the level of the ascending aorta, could also determine local suture overstress, leading to several prostheses—related complications, but more importantly, could ultimately exert retrograde deleterious effects on valve competence and cardiac function. The optimal function of AV following an aortic root replacement is not primarily determined by the presence and the geometry of Valsalva sinuses, but is also deeply affected by the neo-root compliance.

The ideal long-term solution would be to replace the native aorta with biological tissues such as xenografts / allografts or biometric prostheses obtained using engineering approaches.

Evolution of redo proximal thoracic aortic surgery: what the future holds?

Direct surgical treatment of extensive aneurysms that involve the ascending, arch and descending segments of the aorta still remains challenging. Although conventional procedures have been improved, these approaches are still associated with considerable mortality and morbidity,

raising the need for a less invasive management. On this spirit, thoracic endovascular aortic repair (TEVAR), which was developed during recent years, has changed the paradigm of the treatment in pathologies affecting the descending aorta. It would not be excessive to say that TEVAR is now the first-line therapy for patients with complicated acute type B dissections, descending thoracic aneurysms, and thoracic transections. With the success of TEVAR, new applications have been sought for this technology. One area of potential interest is the ascending aorta. However, before this technique applied in the proximal thoracic aorta, the management of its special anatomical and pathophysiological features is prerequisite.

First of all, navigation of an endograft through the iliofemoral segment, the often-tortuous thoracic aorta, and the aortic arch is often difficult and problematic. Secondly, the delivery of the endograft requires the body of the endograft and its associated delivery system need to be positioned in the LV, with the attachment risk of valve disruption and ventricular perforation. Thirdly, there is need to use a delivery system that accommodates deployment into curved anatomy. Fourthly, the proximal and distal landing zones in the ascending aorta are fraught with potential complications. The proximal landing zone, for example, will be necessarily close to the aortic valve and coronary arteries, whereas the distal zone will be in proximity to the innominate ostium. Finally, the fragility of the ascending aorta may pose difficulties, with the potential of retrograde type A dissection.

Considering the above special characteristics of the proximal aorta, Watanabe et al. [48], described a two-stage procedure using a branched proximal elephant trunk technique with implantation of stent grafts to the ascending aorta. In the first stage of this procedure, a “double-barrel tube graft” is inserted into the ascending aorta and fixed to the sinotubular junction under short-duration CPB in normothermia. In the next stage, after debranching of the left common carotid artery and left subclavian artery, stent grafts are deployed from the double-barrel tube graft to the descending aorta and the brachiocephalic artery to exclude the aneurysms. Although, more data regarding this procedure are required, it could be an attractive treatment option for extensive aortic aneurysms.

The first case of type A dissection treated with a customized stent-graft was reported back in 2008 [49]. Since then, other authors have published their experience with endovascular treatment of the ascending aorta. A great variety of indications, techniques, and materials is noted. Early results as reported in a limited number of patients up to now (< 150 worldwide) seem to be promising. Initial success rates are commonly > 95% and 30-day mortality rate are approximately 8% [50]. Potential serious complications include stroke due to catheter and wire manipulations in the aortic arch, ventricular trauma and aortic valve insufficiency

following imprecise proximal stent-graft deployment. Long-term results are scarce. Recently, Roselli et al. [51] published mid-term data on a total of 22 patients underwent ascending TEVAR for acute Type A dissection, intramural haematoma, pseudoaneurysm, chronic dissection or aorta-cardiac fistula. They reported three deaths (13.6%) and they found that actual survival at 30 days, 1 year, and 5 years was 86, 80, and 75% respectively. Further long-term outcomes are required.

The “hybrid” aortic arch is another goal which remains to be achieved and will definitely change the management of complicated surgical cases of the aortic arch, like in redo cases, especially in patients with a severe comorbid status. The arch hybrid concept entails reimplantation or bypass of all aortic arch vessels, and TEVAR implantation landing proximally in “zone 0” (ascending aorta-origin innominate), which is either suitable for use as a landing zone natively or has been replaced with a Dacron graft to construct an artificial landing zone. In a systematic review [52] of hybrid arch operations in 1886 patients, pooled mortality was 10.8%, with 15.1% mortality in diseases that extend to the ascending aorta. Pooled stroke risk was 7%, with a pooled spinal cord ischaemia rate of 7%, with no difference seen with respect to the extent of proximal ascending aorta involvement. Further follow up will attest the validity of this technique in aortic arch surgery.

Moving further from the hybrid arch repair which requires open surgical approaches, such as debranching for revascularization of cervical approaches, there is an intense competition to develop techniques and devices that will convert the whole approach to less invasive. More detailed, the introduction of new devices among types with similar characteristics (e.g., branched devices), the improvement of the delivery systems, and the development of supplement devices with auxiliary functions (e.g., gels for fixation) [53], will make at some point the dream of the total hybrid replacement of the aorta come true.

Follow-up in patients with previous surgery on the proximal thoracic aorta: what is the evidence?

It is true, that this subgroup of patients with previous surgery on the proximal thoracic aorta requires lifelong follow up. However, the frequency of this remains controversial. Current guidelines from the ACCF/AHA [29] on the diagnosis and management of thoracic aortic surgery disease contain recommendations for surveillance of various aortic pathologies after repair. However, the recommendations are Class IIa and based on Level C evidence, and the authors note that, “the frequency of surveillance is not clear as there are no data to accurately dictate surveillance

intervals”. For patients who have undergone repair of Type A dissection, current guidelines recommend imaging by CT or MRI at 1, 3, 6 and 12 months after dissection and then annually. No recommendations are provided regarding the duration of surveillance beyond 1 year. Halstead et al. [54] examined distal reoperations among 179 consecutive Type A dissection repairs and reported that in this surgical subgroup, distal operations are more prevalent (8.9%) than proximal reinterventions (2.8%) and also that the median interval was 2.0 years, with an observed hazard that began to decline at 3 years. Thus the current guidelines would seem more frequent than necessary, and a more liberal approach to annual screening beyond post-operative years 3 or 4 would likewise seem reasonable, assuming continued stable findings on prior studies.

Recommendations for imaging surveillance after a proximal aortic operation for aneurysm are less well defined. Current guidelines [29] recommend only transthoracic echocardiogram (TTE) before discharge and yearly for aortic root repair and aortic valve plus ascending aorta replacement. Strauch et al. [55], analysed 2281 anastomoses among 1475 patients and found that only 24 patients (2.3%) required reoperation for suture-line disruptions after graft-to-aorta anastomosis. Therefore, the recommended isolated TTE would not be effective as this test would not capture the most common indication for intervention.

The Duke University developed an evidence-based surveillance algorithm [56] for patients with previous aortic surgery which has the potential for significant reductions in health cost and lifetime radiation exposure. According to this, among patients with a DeBakey type I dissection, connective tissue disorder, or vasculitis/aortitis, at each surveillance time point there is a CT angiography (CTA) of the chest, abdomen, and pelvis plus TTE, or cardiac MRI/aortic magnetic resonance angiography. The initial scan is 3 months postoperatively followed by a second round in 6 months if any segment of aorta is > 4 cm or otherwise regularly in 9–12 months and then annually. After 5 years the follow up scan extended to 18 months and then to 24 months. Among patients with a DeBakey type II dissection, degenerative (atherosclerotic) aneurysm, or bicuspid AV, there is an initial scan of the chest, abdomen, and pelvis, but subsequent scans are limited to the chest if no abdominal pathology is present. With regard to surveillance interval, the initial postoperative surveillance in proximal aneurysm patients occurs between 6 and 9 months, then 18 months later and then every 2 years thereafter if imaging shows the repair is stable. This less aggressive protocol reflects the lower early rate of reinterventions in this group and the decreased likelihood of re-intervention beyond 3 to 4 years.

Conclusion

Re-operative surgery on the proximal thoracic aorta is being performed increasingly and represents a formidable challenge for the cardiovascular surgeon. Important advances in the perioperative management of those patients have significantly reduced the reported mortality and morbidity of these operations. The two major goals that remain are: an adequate primary surgery which eliminates the need for reoperation at the level of prevention and appropriate surgical strategy during the redo surgery accompanied by further evolution of the technology at the level of treatment which will convert these complex procedures to safer operations.

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