Review Article on Cardiac Surgery

Thoracoabdominal aortic aneurysm surgery: a different perspective on stent grafts failure

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Abstract: Endovascular repair of the descending and thoracoabdominal aortic aneurysm (TAAA), which is generally considered to be associated with lower morbidity and mortality than conventional open repair, appeals to both patients and clinicians. However, commonly this concept has been under continual evaluation and issues with long-term durability, disease progression and repair failure, including endoleak with all its types and not to forget aneurysm expansion, catastrophe of aortic rupture, and stent-graft infection are handing like ringing bells after every endovascular approach. In this literature review, we will review the current evidence of graft failure and delineate the actual and proposed theorems regarding the cause of failure of endovascular graft failure.

Keywords: Aorta; aortic aneurysm; stent graft; failed stenting; graft failure

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Introduction

In 1956, Dr. Michael DeBakey warned of the "grave significance" of thoracoabdominal aortic aneurysms (TAAA) with major visceral branch involvement (1). Since then, a boom of innovation and major progress in technical, clinical skills, perioperative and post-operative care and intraoperative monitoring changed the face of thoracoabdominal aortic repair. This paved the way for open surgical repair to be generalized and allowed many centres to achieve acceptable morbidity and mortality outcomes (2,3). The development and rapid phase evolutionary endovascular surgery allowed the surge of this technique over the moribund and unrealistic costly open repair. Endovascular approach became the main choice for treatment and management of thoracic and TAAA in many centres worldwide and amongst centres with high volume and acceptable results achieved through open techniques experience and concentration of expertise. The learning curve in the endovascular management of TAAA began and the utilisation of novel stent graft technology based on a custom-made branch design surged allowing endovascular surgery to mandate its existence as top and prime choice among the armamentarium for TAAA intervention. However, sceptics of endovascular approach consistently argue that the age of endovascular intervention will see its demise and device technology is bound to failure.

The challenges

Although no raw data exist so far on operative strategies discussion in many centres and amongst discussants in a multidisciplinary team approach, an endovascular surgeon opinion is always thought for and an agreed plan which patient- specific and tailored approach mandates and executed. This discussion takes into account the type of endograft used, its anatomical position and length as portrayed over reconstructed imaging, and the patient's overall operative risk are all variables that are openly debated in a multidisciplinary huddle.

It's of course and without discussion, the endovascular approach precludes the use of cardiopulmonary bypass, left heart bypass, and surely deep or moderate hypothermic circulatory arrest. It also avoids aortic manipulation and cannulation reducing further and hypothetically speaking the risk of neurologic insults and stroke. However, endovascular approaches have their own limitations and foremost among which is the need for re-intervention, as reported complications rates can be as high as 30% (4,5). Surely, late complications requiring re-intervention are much less frequent, and their rates according to current published literature varies with reports of 6–12% (6,7). The most serious complications include endoleaks, infection, graft migration and rupture (8,9). There is also the debate of reintervention or conversion on previously endovascular aortic repair and the necessity to remove all stent grafts remains controversial. Some authorities advocate removal of all stent-graft material to eliminate the risks of late stent-graft complications.

Due to these potential problems inherent to endovascular intervention, lifelong surveillance is currently recommended using different imaging methods (10,11). The focus is to highlight and detect endoleaks and any failure of the structural integrity of the endograft (12,13). It's unbearable to omit the cost-benefit of such intervention modality and to accurately postulate its monetary implications, the logistics of follow-up arrangements and consistent exposure to radiation.

Do we need to intervene?

From the utilitarianism perspective, our moral obligation is to pursue the action, intervention or policy that would maximize utility in the specific context in which such an option is being considered. Hence, considering the effect and controversy of the ultimate benefit on patient's outcome, the main question remains is how useful is our clinical decision making and at what expense and to what good? Literature data is scarce, and no therapeutic algorithm and clinical decision-making validity has ever been established. In an era of precision healthcare provision and with public scrutiny unfolding, the focus would be on determining those patients that may benefit from any intervention or treatment highlighting the qualitative and quantitative characteristics of open surgery versus endovascular modalities steered toward the correct pathology and involving patient related outcome measures and impact on quality of life *per se*. *Table 1* is summary of the key studies outlining their findings from their experience with requirement for open surgical intervention.

The culprit of failure as seen from basic science perspective

Many factors have pointed to systemic inflammatory responses (SIR) as a cause of graft failure and rejection. Some authors suggest that manipulation of the aneurysm may activate white blood cells and lead to release of various cytokines, while others speculate that injury to the endothelium may cause protein C activation and subsequent coagulopathy (16,17). However, it remains elusive whether or not this is the culprit of graft failure. Experimental study showed that iodide-containing contrast agent that is used during EVAR for vessel visualization induced neutrophil granulocyte degranulation (18).

Aneurysm thrombus may also potentiate the inflammatory response. Norgren and Swartbol proposed that an inflammatory response mainly involving TNF-α release from cell activation arising from intra-aneurysmal device manipulation (19). Gabriel *et al.* (20) suggested and elaborated on the hypothesis a mural thrombus of an aortic aneurysm contains high amounts of IL-6 and that manipulations with endovascular instruments inside the mural thrombus might release IL-6. This is not surprising, since aortic manipulation is a common habit in our hands and the amount of pre-existing mural thrombus within the aneurysm sac which we normally dispose of was not found to have any association with the development an inflammatory response in any study reviewed (17-19). However, Kakisis and his colleagues reported their findings on 87 patients after endovascular intervention stating that the volume of a new onset thrombus was associated with the development of the inflammatory response (21).

It would necessary to ameliorate this concern if further studies in open repair were compared to endovascular on similar material. Yet, what we came to learn is that endograft material is not without concerns. Voûte *et al.* in a later study showed that the implantation of stent grafts based on polyester was independently associated with a stronger inflammatory response (22).

Table 1 Summary of key studies

Author	Country	Type	N	Technique	Outcome
Melissano *et al.* (7) 2016	Italy	Retrospective	65	TEVAR: redo procedures. 30 underwent late open conversion	Majority of indications for open repair were distal aortic disease (30%), infection or fistula of stent-graft (33.3%), dissection (20%) and endoleak (10%). Perioperative mortality was 16.6%, and higher in infection group
Szeto *et al.* (6) 2013	USA	Retrospective	680	TEVAR	Total of 80 re-interventions were required in 73 patients Endograft failure reintervention rate due to endoleaks was 11.7% among the entire cohort. Stent graft likely fail when there is non-aneurysmal disease or aortic infection, with high complication and mortality rates
LeMaire *et al.* (9) 2012	USA	Retrospective	35	OR after TEVAR	69% of repairs were elective. Survival at 3 years was 64%±11%. Infected devices had difficult postoperative experiences, with higher rates of complications, longer length of stay and higher mortality rates
Ehrlich *et al.* (14) 2008	Austria	Retrospective	457	TEVAR	30-day mortality was 7.9%. A rate of 3.8% required later open repair, median at 14 months. This was mainly precipitated by endoleaks. Indications for OR were: previous cardiac surgical history ($P=0.01$), larger diameter of aorta ($P=0.01$), Marfan syndrome ($P<0.01$), early type 1 endoleak ($P=0.03$) and >1 stent graft ($P=0.016$)
Spiliotopoulos *et al.* (2) 2018	USA	Retrospective	67	OR post TEVAR in 67% and post EVAR in 33% of the cohort	Median interval from initial endovascular repair until OR was 18 months. The most common cause was enlarging aneurysm (n=56), follow by infection (n=11) and fistula (n=8). Over follow-up of 35.8 months, 19 late deaths occurred. 5-year survival was 60%±8%
Patel *et al.* (3) 2014	USA	Retrospective	420	TEVAR	20 patients did not survive 30 days (4.8%). Endoleak occurred in 32.9%. Over 10 years, freedom from reintervention, including further surgery, was 63.2%. 15-year survival was 32.3%
Roselli *et al.* (15) 2014	USA	Prospective	50	OR after TEVAR	Indications for type I endoleaks (n=19), dissection (n=9), chronic dissection (n=16) and graft infection (n=6). Median 3-year survival was 67%

TEVAR, thoracic endovascular aortic repair; OR, open repair.

To convert or not to convert: from endograft to open grafting?

The indications for thoracic and thoracoabdominal aortic endovascular intervention and repair including the limited zones of the thoracic aortic aneurysms sounds promising and enduring. Acute and chronic expanding type B dissection, traumatic aortic rupture, and penetrating aortic ulcer are among the agreeable areas for endovascular intervention, however, to reveal a solid number of stent graft procedures insertion, failure and exact number of annual thoracic stent graft procedures is unknown due to lacking mandatory registries. Staying on this note, voluntary registries like the European Collaborators on Stent/Graft Techniques for Aortic Aneurysm Repair (EUROSTAR) registry or the United Kingdom Thoracic Endograft Registry are certainly the largest compendium of collected thoracic procedures (5,14).

However, those endeavours represent part of the entire commercial driven implantation market, product design and engineering. Sales figures of commercially available thoracic stent grafts show 1,000 implantation procedures annually worldwide. There is rather more provision and openness that can easily discriminate outcomes between endovascular intervention on type IV TAAA and thoracic endovascular aortic repair (TEVAR).

Serious complications include primary or secondary type I endoleak, retrograde type A dissection, stent collapse,

Table 2 Indications for intervention and conversion

Factor	Intervention or conversion	Indication
Initial insult	Intervention	Acute and chronic expanding type B dissection, traumatic aortic rupture, and penetrating aortic ulcer
Anatomical criteria	Intervention	Aortic aneurysm proximal neck size 18–32 mm diameter, and longer than 10 mm
		Neck angulation less than 45–60 degrees
		Common iliac artery diameter 8–22 mm
		External iliac artery diameter over 7 mm
Severe complications	Conversion	Endoleak: primary or secondary type I
		Retrograde type A dissection
		Stent collapse
		Rupture
		Graft infection and impending aorto-enteric or aorto-bronchial fistula for abdominal and thoracic aneurysms, respectively

and rupture with subsequent death (9,15,23,24). Notably, published series involving stent grafting of TAAs have shown that endoleaks occur in up to 29% of patients and about 40% of these are life threatening type I endoleaks with unchanged pressurized aneurysm sack (14,25). The risk of retrograde type A dissection after TEVAR is approximately 6.8%, with a procedure-related mortality of 40% (26). However, most of the occurring complications can be managed by means of additional endovascular interventions.

The criterion for conversion is bluntly concentrated on group of patients in whom endovascular techniques in the initial setting or perhaps on its repeat setting remain unfeasible. The feasibility is down to the fact that landing zones are inappropriate and device extension would be deemed not possible. The most frequent causes of immediate type I endoleak include angulation of the proximal or distal neck, the presence of mural thrombus or calcifications or faulty endograft dimensions. The delayed type I endoleaks can be caused by proximal or distal landing-zone enlargement. It's those patients that would benefit from open procedure to avoid further complications.

The other entity for conversion although this is too debatable is graft infection and impending aorto-enteric or aorto-bronchial fistula for abdominal and thoracic aneurysms, respectively, abdominal abscess, groin fistula and septic embolization (2,3,27).

Treatment options for endograft infection include conservative therapy initially (antibiotics, CT-guided drainage) and surgical removal of the prosthesis (followed by extra-anatomical bypass or *in situ* prosthetic reconstruction).

Careful patient selection and understanding of the anatomy and potential hazards are all amongst the pearl of successful outcomes. Stenosed or angulated aorta/iliac arteries and stenosed aortic bifurcation (<20 mm) are potentially a jeopardy which might increase predilection of stent-graft kink, late graft thrombosis and occlusion due to kinking of the graft or restricted outflow (28). For patients with severely diseased or angulated arteries, open repair should be procedure of choice to avert risks of pseudoaneurysm and increasing risk of rupture (29-31). In cases when open surgery cannot be performed, intra-operative adjuncts (iliac artery angioplasty, use of aorto-mono-iliac endograft systems with femoro-femoral bypass) can be proposed (32,33). Balloon inflation or placement of balloon-expandable stents can help re-model the kinked endovascular prosthesis and serve as exit strategy for endovascular enthusiasts. *Table 2* is the summary of the indications for intervention.

Conclusions

Endovascular treatment of thoracic aortic diseases constitutes a complex procedure, and associated pitfalls are not uncommon. Patient tailored strategy in a multidisciplinary meeting and related clinical decision making remain a question of quality index. Neither the total number of annually performed endovascular procedures nor conversion rates to open surgery is known, but it is highly probable that the number of procedures and conversions will increase in the future. Failure of TEVAR comprises a new aortic pathology for open skilled surgeon to deal with and consider.

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