THORACIC AORTIC DISEASES SURGICAL MANAGEMENT UHL CARDIAC SURGERY POLICY

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*We are grateful to all consultant cardiac surgeons of the Cardiac Surgery Unit at Glenfield Hospital for their contribution.

SUMMARY

ABBREVIATIONS

ACT	Activated clotting time
CABG	Coronary artery bypass grafting
CVC	Central venous catheter line
ECMO	Extracorporeal membrane oxygenation
GERAADA	German Registry for Acute Type A Aortic Dissection
IABP	Intra-aortic balloon pump
IMH	Intramural hematoma
ITU	Intensive care unit
MDT	Multidisciplinary meeting
NIRS	Near-infrared spectroscopy
PAU	Penetrating aortic ulcer
SHO	Senior house officer
TAD	Thoracic aortic disease
TOE	Transoesophageal echocardiography
TEG	Thromboelastography

1. INTRODUCTION AND TO WHOM THE POLICY APPLIES TO

1.1. Scope of the Policy

This policy is intended to assist senior and junior cardiac surgeons in becoming more familiar with the surgical techniques employed in complex aortic surgery operations at University Hospitals of Leicester NHS Trusts (Glenfield Hospital).

1.2. Recipients

This policy applies to adult patients referred for surgical intervention for thoracic aortic diseases (TAD), including both aortic aneurysms and dissections. The policy applies to elective, urgent and emergent patients affected by TADs. The policy applies to isolated TAD surgery as well as TAD cases concomitant with planned cardiac operations.

1.3. Aim

This policy offers a guide for consultant cardiac surgeons and cardiac surgery registrars in dealing with patients affected by TADs. The techniques reported here are recommended in international guidelines, consensus and position papers [1-6].

1.4. Participants

The surgeons must closely liaise with cardiac anaesthetists, perfusionists, and theatre staff to apply the surgical techniques here reported. The policy is disseminated to cardiac anaesthetists, perfusionists and theatre staff.

1.5. Excluded Topics

Perioperative and postoperative patient management is not part of this policy.

1.6. Disease

The present policy refers to the below aortic diseases of the thoracic aorta:

Acute aortic syndromes
1. Type A acute aortic dissection
2. Intramural haematoma (IMH)
3. Penetrating aortic ulcer (PAU)
4. Type B dissection with retrograde arch/ascending extension (IMH)
5. Symptomatic aortic aneurysm with signs of impending rupture
Stable aortic diseases
1. (Redo) chronic type A aortic dissection
2. Symptomatic aortic aneurysm with no signs of impending rupture
3. Asymptomatic aortic aneurysm
4. (Aortic root abscess - native or prosthetic aortic valve)

1.7. Aortic Segment of Interest

The present policy pertains to the following aortic segments:

1. Aortic root
2. Ascending thoracic aorta
3. Aortic arch
4. Descending thoracic aorta (in combination with)

1.8. Related Guidelines

The related international guidelines and other relevant papers are those listed below:

1. ESC (European Society of Cardiology) 2014 [1].
2. AHA (American Heart Association) 2010 [2].
3. CSC (Canadian Cardiovascular Society) [3].
4. http://www.aorticsurgeryguidelines.com/

2. BACKGROUND AND RATIONALE FOR THE POLICY

2.1. Background

Admissions for thoracic aortic diseases (TAD) have increased worldwide [1-16]. In the face of this increasing problem, the optimal service configuration for managing patients affected by TAD has not been defined [1,2]. In Europe and the wider world, mortality for operated type A dissection ranges from 2.8% to 47.6% [5-15].

2.2. Effect of Hospital/Surgeon Volume on Outcomes

International guidelines recommend that affected patients benefit from high-volume surgical centres with focused multidisciplinary expertise in thoracic aortic surgery [1-3]. High-volume aortic centres have reported significantly lower mortality rates. Data from the literature have shown that patients affected by acute aortic syndrome and treated in high-volume centre had a 49% relative risk reduction in in-hospital mortality when compared with low-volume centres (Figure 1) [16]. Acute aortic syndromes surgically treated by high-volume surgeons had a 59% relative risk reduction in mortality (Figure 1) [16]. Similar data is also observed in patients affected by thoracic aortic aneurysm [17].

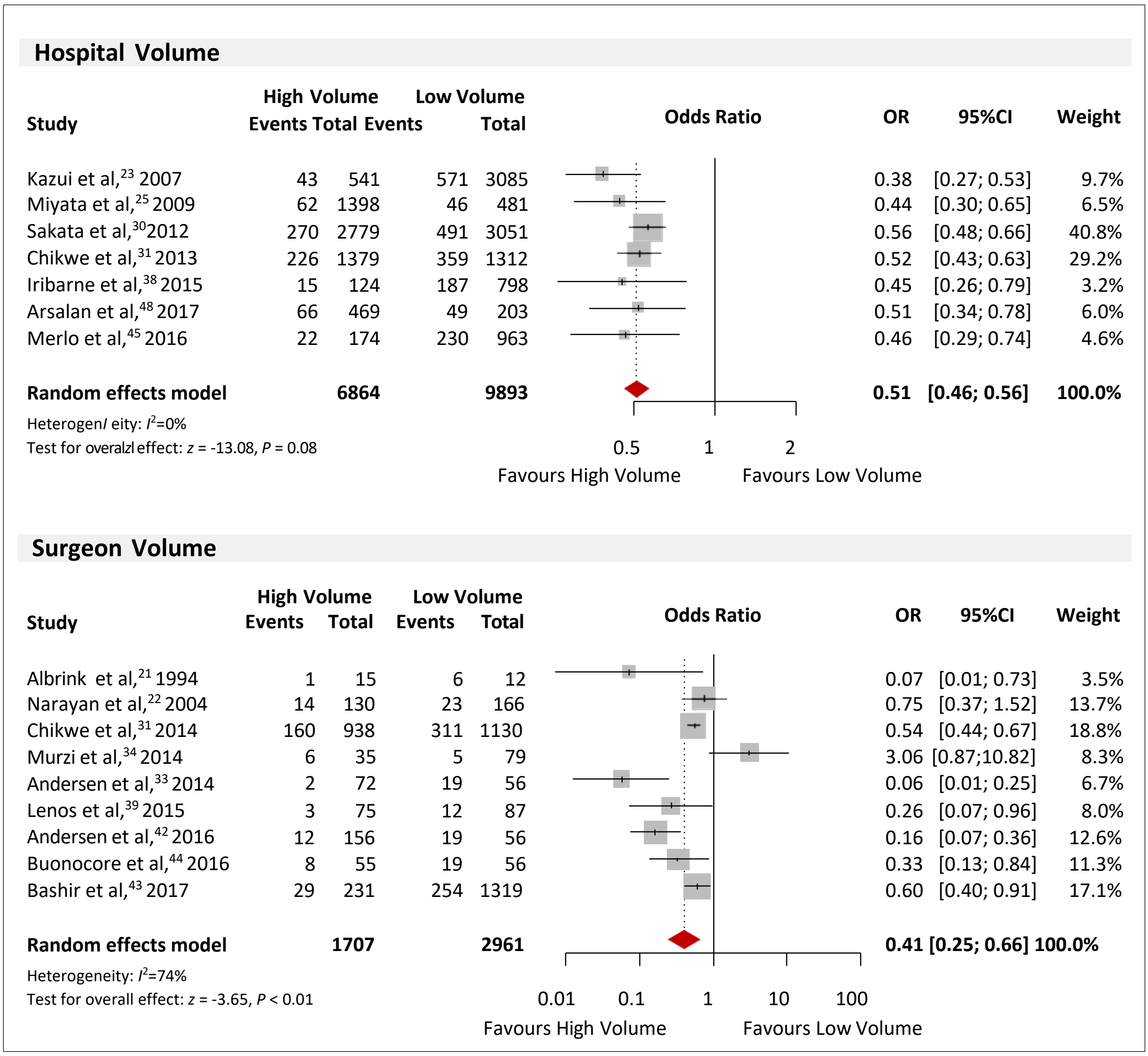


Figure 1. Forest plot with unadjusted risk estimates for in-hospital/30-day mortality in high-volume versus low-volume hospitals (upper panel) and in high-volume versus low-volume surgeons (lower panel). Abbreviations: CI, confidence interval; OR, odds ratio. Data derived from: Mariscalco et al. Aortic centres should represent the standard of care for acute aortic syndrome. Eur J Prev Cardiol. 2018;25(1_suppl):3-14 [16].

2.3. Multidisciplinary Aortic Programme

Existing evidence suggests that TAD patients treated in multidisciplinary specialised aortic centres demonstrate significantly improved outcomes and decreased mortality [15]. Centres that introduced a specific multidisciplinary aortic program have reported a 69% risk reduction in mortality in comparison with the prior patient management (Figure 2) [16,17]. Better survivals have also been observed in centres that introduced a dedicated on-call aortic team with a 63% risk reduction in mortality compared to the era with a mixed on-call rota (Figure 2) [16].

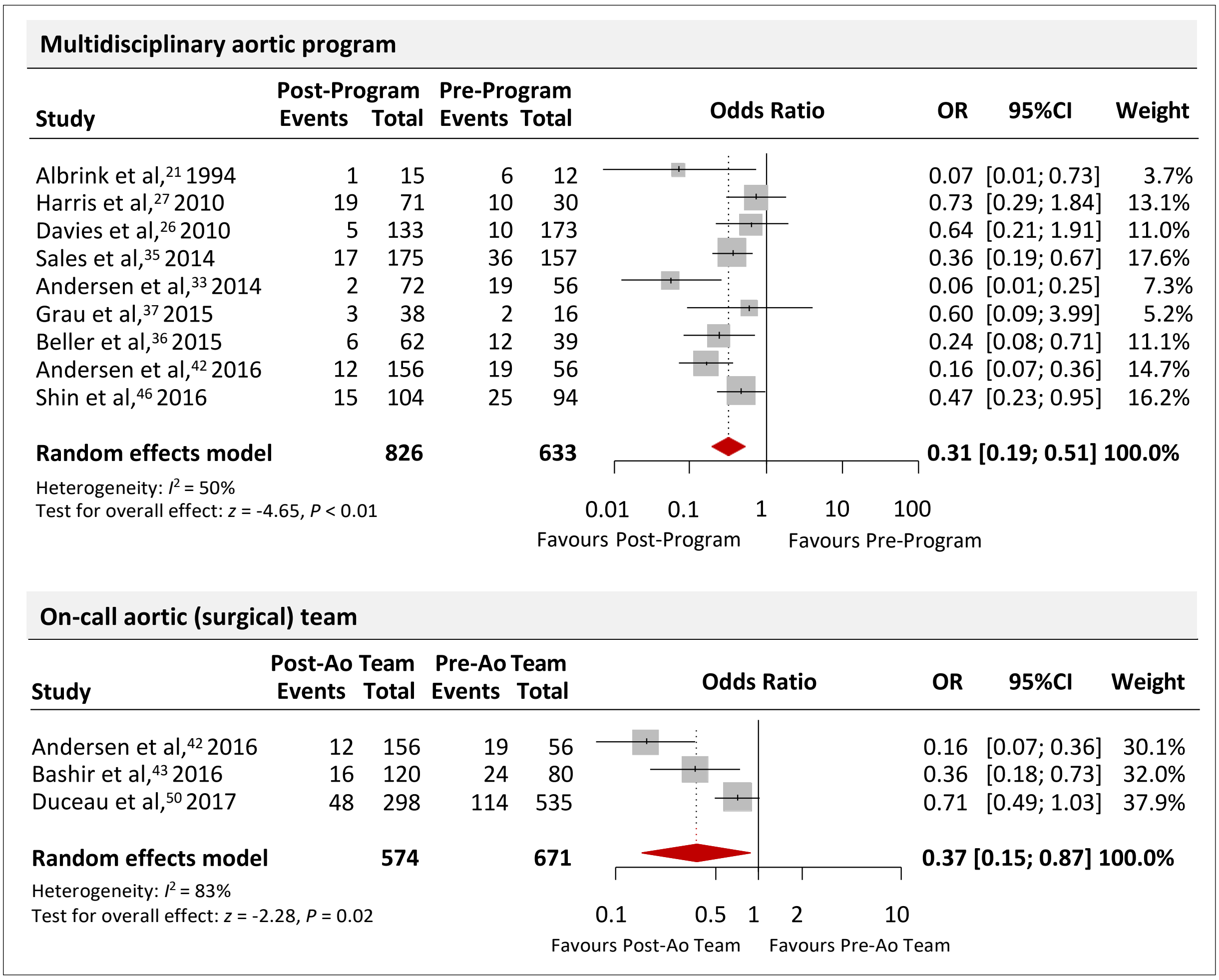


Figure 2. Forest plots with unadjusted risk estimates for in-hospital/30-day mortality in hospitals with dedicated multidisciplinary standardised care for acute aortic syndromes (before and after implementation, upper panel) and hospitals with a dedicated on-call aortic team (lower panel). Abbreviations: CI, confidence interval; OR, odds ratio. Data derived from: Mariscalco et al. Aortic centres should represent the standard of care for acute aortic syndrome. Eur J Prev Cardiol 2018;25(1_suppl):3-14 [16].

2.4. National Data from the United Kingdom

National UK data are consonant with the experiences registered in the US and Europe [14,17].

2.4.1. National variation in care

An analysis of Hospital Episode Statistics (HES) database has shown a significant regional variation in access to treatment, the organisation of clinical services, and mortality for patients affected by with TAD in England [17]. The analysis of the National Adult Cardiac Surgery Audit (NASCA) data has indicated wide regional variation in the volume and complexity of TAD cases undertaken in English cardiac centres. Centres undertaking higher volumes are more likely to treat more-complex disease and had lower risk-adjusted mortality [17].

2.4.2. National outcomes

Data from the National Institute for Cardiovascular Outcomes Research (NICOR) database, including 1550 type A acute aortic dissection, demonstrated that the mean annual volume of procedures per surgeon during the 6-year period (April 2007-March 2013) ranged from 1 to 6.6, with an overall in-hospital mortality rate of 18.3%. Surgeons with a mean annual volume <4 over the study period had significantly higher in-hospital mortality rates in comparison with surgeons with a mean annual volume ≥4 (19.3% vs 12.6%) [17].

2.4.3. Specialised aortic centres in the United Kingdom

In 2007, Liverpool Heart & Chest Hospital was the first institution in the UK to implement a thoracic aortic on-call dissection rota [18]. Analysis of Liverpool's data before and after the dissection rota implementation revealed that patients undergoing dissection repairs in the post-dissection rota period were less likely to suffer in-hospital mortality (11.7% vs 28.3%).

2.5. Local Experience and Results

Sixty-seven (n=67) type A acute aortic dissections were operated on at Glenfield hospital between January 2015 and December 2018, and 23% of patients were aged ≥75 years. Hospital mortality accounted for 17 cases (25.4%). The data analysis demonstrated that surgeon volume (aortic surgeons) was one of the most important factors related to hospital outcomes along with clinical status at presentation. Aortic surgeons (high-volume surgeon) had significantly lower hospital mortality that non-aortic surgeons (10.8% vs 56.7%) (Figure 3). The exclusion of patients with a critical preoperative status at presentation also resulted in a lower hospital mortality (16.7% vs 25.4%).

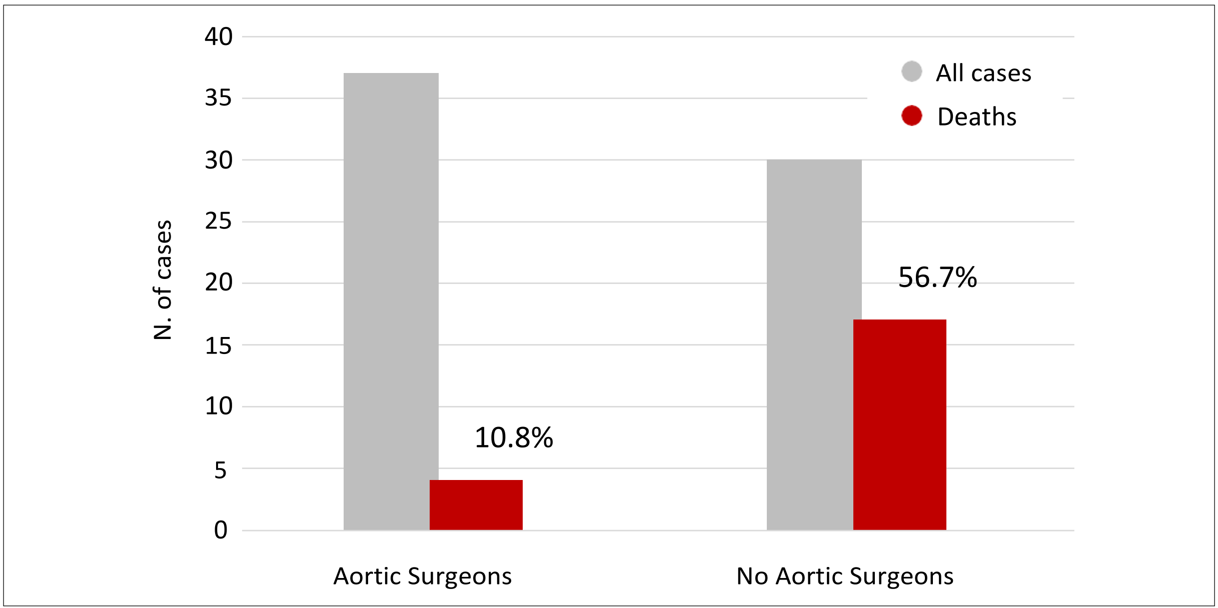


Figure 3. Data on hospital mortality for patients operated on type A acute aortic dissection at Glenfield Hospital between January 2015 and December 2018. Data are divided between aortic surgeons and non-aortic surgeons.

2.6. Definition/number of Aortic Surgeon for Glenfield

Taking into account the volume of elective aortic cases (70~80 cases/year) and of acute type A acute aortic dissections performed in the past recent years in Glenfield (Figure 3), a maximum number of two (or three) aortic surgeons is deemed necessary to warrant better postoperative outcomes. Whenever possible double consultant scrubbing is always recommended.

2.7. Rationale for the Policy

International, national and local data clearly suggest that a dedicated aortic team with standardised internal policies represents the standard of care for patients affected by TADs.

3. PREPARATION BEFORE THE ARRIVAL OF THE PATIENT

3.1. Patient Acceptance and Surgical Indications

3.1.1. Indications for surgery

Indications for surgery need to be compliant with national and international guidelines [1-5].

3.1.2. Elective patients

Patients affected by stable aortic conditions (i.e. aneurysms, redo aortic conditions and redo chronic type A/B dissection) follow the pathway of other elective patients scheduled for cardiac surgery. Direct assessment of the patient in the clinic is as per standard. Whenever indicated, a discussion in the aortic MDT is recommended, especially for high-risk patients and patients with a severe comorbidities profile. Equally, patients with borderline surgical indications should be discussed. The aortic MDT is arranged on a monthly basis and includes cardiac surgeons (consultants, clinical fellows, registrars and SHO), vascular surgeons, consultant cardiologists, and radiologists.

3.1.3. Urgent patients

Patients affected by symptomatic aortic aneurysms, sub-acute/chronic type A dissections (unclear onset of symptoms), stable penetrating aortic ulcers (PAU), type B dissections with retrograde extension and intramural haematoma (IMH) of the aortic arch/ascending aorta need to be considered as urgent cases. A discussion in an "*ad hoc*" aortic MDT is indicated in the presence of an intensivist/cardiac anaesthetist, vascular surgeon (in case a hybrid approach can be considered), and at least one of the senior aortic surgeons. Cases suitable for frozen elephant trunk (Thoraflex/Evita-Neo devices), combined surgical and hybrid repair (AMDS device), Lupiae technique, and off-pump aortic arch reconstruction need to be treated by the dedicated aortic team.

3.1.4. Emergent patients

Patients affected by type A acute aortic dissection and impending aneurysmal rupture of the ascending aorta, IMH/PAU with signs of increasing pericardial tamponade or haemothorax should be considered as emergent cases. In the case of type A acute aortic dissection, no delay is justified, and whenever possible, patients should be transferred directly to the theatre.

- Direct transfer to theatre with no delays should be adopted when the underlined diagnosis is evident or impending rupture is documented (i.e. cardiac tamponade).
- Blood typing and crossmatching should not delay the patient transfer to theatre as well as recent food ingestion.
- Patient referred/transferred overnight should be promptly operated on without waiting for the following morning.

An algorithm for the management of type A acute aortic dissection (or equivalent) is presented in section 3.3.

3.1.5. Complicated type A acute aortic dissections

The following conditions represent examples of complicated type A acute aortic dissections:

Conditions	Details
Resuscitation before surgery	
Previous cardiac surgery	
Intubation/ventilation at referral	
Catecholamines at referral	
Preoperative organ malperfusion	Coronary malperfusion Visceral malperfusion (renal and liver failure) Peripheral malperfusion
Preoperative neurological signs	Loss of consciousness, hemiparesis
Symptomatic cardiac tamponade	Impaired right ventricular function

In case of complicated type A acute aortic dissections, the preoperative GERAADA Score [19] can be utilised to predict the risk of patient mortality and to guide the appropriate decision-making (to offer or reject surgery). The GERAADA score is an easy, useful and accurate tool for predicting 30-day mortality in patients affected by type A acute aortic dissection, and its Web application based on the final model can be found at https://www.dgthg.de/de/GERAADA_Score. In case of a predicted mortality ≥ 18% (the UK mean mortality for surgical repairs of type A acute aortic dissections for the years 2017-2020 is 17.7% [20]), a discussion with another senior aortic surgeon, a consultant intensivist and cardiac anaesthetist should be sought.

Alternatively, the Penn score [21] can be considered to guide patient decision-making.

Penn classification	Criteria
Penn class A	Absence of malperfusion (class B) or circulatory collapse (class C)
Penn class B	Branch-vessel malperfusion:
	• Stroke
	• Paraplegia
	• New-onset lower extremity weakness or paralysis
	• Upper or lower extremity pulse deficits
	• Need for vascular surgery to restore blood flow to the extremities
	• Acute kidney injury (serum creatinine > 2 times baseline, glomerular filtration rate reduction by more than 50%, urine output less than 0.5 mg/kg/h in the first 12 h, or new need for renal replacement therapy)
	• Mesenteric ischemia (malperfusion to the celiac trunk, superior mesenteric artery, or inferior mesenteric artery with either radiographic evidence or clinical findings of an acute abdomen; need for emergency bowel resection; or acute gastrointestinal bleeding owing to ischemic colitis)
Penn class C	Circulatory collapse:
	• Newly reduced left ventricular ejection fraction <50%
	• New right ventricular dysfunction
	• Pericardial tamponade
	• Acute coronary ischemia
	• Myocardial infarction
	• Need for intra-aortic balloon pump
	• Need for venoarterial extracorporeal membrane oxygenation
Penn class B + C	• Meeting at least 1 criterion for malperfusion (class B) and circulatory collapse (class C)

In case of a Penn score class C or class B+C, a discussion with another senior aortic surgeon and an intensivist should be sought. In addition, the Penn score can be utilised to anticipate postoperative complications with relevant repercussion to the patient recovery.

3.1.6. Summary of indications

Aortic condition	Intervention	Clinic	Aortic MDT
TAAAD	Emergency	-	(Penn score)
Diseases with signs of imminent rupture*	Emergency	-	√ (ad hoc)
Type B with retrograde IMH extension	Urgent	-	√ (ad hoc)
IMH	Urgent	-	√ (ad hoc)
PAU	Urgent	-	√ (ad hoc)
Chronic TAAD	Urgent	-	√ (ad hoc)
Destructive aortic valve/root endocarditis	Urgent	-	√ (ad hoc)
Symptomatic aneurysm	Elective	√	√
Redo chronic TAAD	Elective	√	√
Redo aortic cases	Elective	√	√
Aortic cases with concomitant surgeries	Elective	√	√

*Signs of increasing pericardial collection, pericardial tamponade, haemothorax, peripheral malperfusion/ischemia.
Abbreviations: IMH, intramural hematoma; MDT, multidisciplinary team; PAU, penetrating aortic ulcer; TAAD, type A aortic dissection; TAAAD, type A acute aortic dissection.

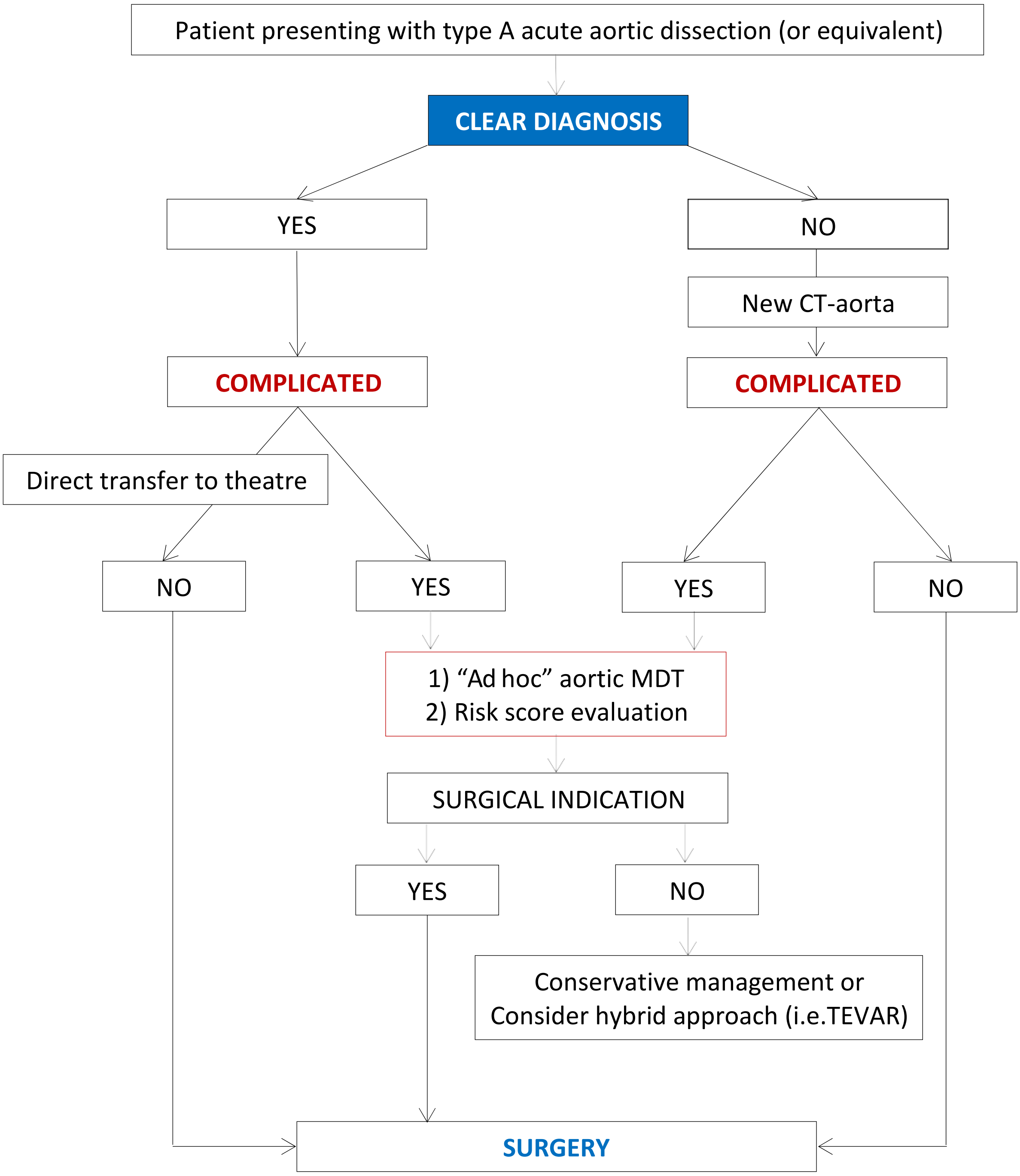
3.2. Pre-operative Investigations

Required (diagnostic) imaging follows recommendations of recognised international guidelines [1,2]. In the case of elective patients, all the required diagnostic tests need to be requested through the standard pathways**.** In case of emergent/urgent patients, especially those referred by DGHs, the on-call registrar needs to ensure that all diagnostic exams are promptly transferred and available into the PACS system for immediate evaluation.

3.2.1. Quality of pre-operative imaging

The imaging needs to be promptly reviewed by the consultant surgeon or consultant radiologist before the patient is transferred to theatre and anaesthetised. This will ensure that the quality of imaging, especially CT-aorta from DGHs (and not ECG gated), is of sufficient quality to exclude an incorrect diagnosis, especially in case of acute aortic dissection/rupture.

3.3. Algorithm for the Management of Type A Acute Aortic Dissection



4. PATIENTS ADMITTED TO THEATRE

4.1. Standard Requirements

4.1.1. Elective and urgent cases

Elective and urgent cases with reference to blood requirements and informed consent follow a standard routine.

4.1.2. Emergent cases

In case of emergent cases, the on-call cardiac registrar needs to ensure that crossmatch with appropriate blood typing and crossmatching as well as informed consent are immediately obtained. Timing of referral and transfer from DGHs should be obtained to plan the most appropriate admission pathway (i.e. direct transfer to theatre, CCU/ITU for further evaluation and discussion).

4.2. Briefing

Briefing (in theatre) needs to be promptly performed and all theatre staff, including the cardiac anaesthetist and the perfusionist, need to be informed regarding the patient aortic condition and surgical technique (reported in this policy) that will be adopted.

4.3. Patient Preparation

4.3.1. Operation limited to the ascending aorta/root

The surgical field is prepared according to standard CABG practice with prepped groins (for femoral exposure) and legs. This will allow: 1) emergent harvesting of veins in case a “rescue” bypass is required; 2) insertion of IABP; 3) institution of peripheral ECMO support.
External defibrillators are applied as per standard.

4.3.2. Operation with the involvement of the aortic arch/descending aorta

The surgical field is prepared as per standard CABG operation accompanied by the full exposure of both axillary artery areas. This will allow the cannulation of axillary arteries if needed before sternotomy or during the operation. External defibrillator pads are applied as per standard.

4.3.3. REDOs with the involvement of the aortic arch/descending aorta

The surgical field is prepared as per standard CABG operation, but the full exposure of both axillary arteries needs to be secured. However, the left neck needs to be prepped as well to allow surgical access for a possible left carotid-subclavian bypass. External defibrillators pads are applied as per standard.

4.4. Anaesthetic Requirements

Local standard protocols (including TOE and coagulopathy management) applied. Additional requirements are presented below.

4.4.1. Arterial monitoring

Standard aortic procedures limited to the ascending aorta/root require the monitoring of one radial and one femoral artery. Operations with possible/planned involvement of aortic arch surgery/descending aorta require the simultaneous monitoring of three arterial lines (two radials and one femoral). This allows constant monitoring of the upper and lower parts of the body's combined perfusion, especially in the case of aortic dissections and circulatory arrest.

4.4.2. Right central venous access

CVC needs to be inserted in the right jugular vein. This will allow: 1) the mobilisation of the innominate vein when the full exposure of the brachiocephalic vessels is required; 2) the infusion of fluid/blood in case of redo case with laceration of the innominate vein during re-sternotomy.

4.4.3. NIRS (near-infrared spectroscopy)

NIRS monitoring is recommended in all cases of surgery involving the thoracic aorta.

4.4.4. Additional consideration

In case of operations requiring circulatory arrest, it is recommended the following:

1) the head should be packed in ice at least 10 min before circulatory arrest.
2) Tazocin (4.5 g) is administered one hour before circulatory arrest institution [22].

Operation	Surgical field - prepping				Arterial lines	NIRS
	Groin	Leg	Axillary	Left neck		
Aortic root	√	√	-	-	Rad+Fem	√
Aortic root/ascending aorta	√	√	-	-	Rad+Fem	√
Aortic arch	√	√	√	√ (redo)	Rad+Rad+Fem	√
Aortic arch/descending aorta	√	√	√	√ (redo)	Rad+Rad+Fem	√
(Frozen elephant trunk)	√	√	√	√	Rad+Rad+Fem	√

5. SURGICAL MANAGEMENT

5.1. Sternotomy

5.1.1. Root surgery and ascending aorta with no circulatory arrest

Standard median sternotomy or mini-sternotomy incisions are recommended.

5.1.2. Operation with planned circulatory arrest

Median sternotomy with a T-shape skin incision is recommended to allow the full exposure of all brachiocephalic vessels. This incision will also allow a subsequent tracheostomy if necessary.

5.2. Cannulation for Cardiopulmonary Bypass

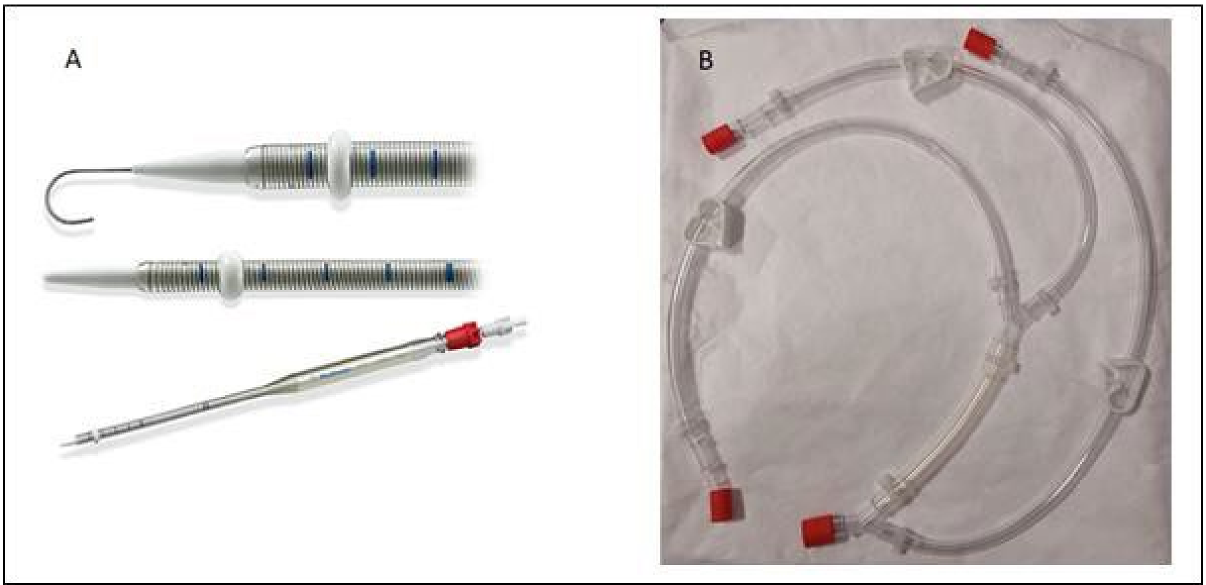


Figure 4. Panel A: EOPA cannula with guide wires for Seldinger technique cannulation. Panel B: arterial circuit in use at Glenfield Hospital with three arterial inflow.

5.2.1. Cannulation: first-time sternotomy

Arterial cannulation of peripheral vessels, including axillary, innominate and femoral arteries, should be accomplished using an 8 mm interposition Dacron graft (side-to-side). This will allow bidirectional perfusion, avoiding prolonged ischemia of the arm or leg. In the case of a salvage scenario, direct cannulation with EOPA cannula with Seldinger technique should be considered (Figure 4A). Regarding venous cannulation, right atrial cannulation with a dual-stage cannula is preferable (or bicaval cannulation if a mitral procedure is deemed necessary). Specific surgical scenarios are detailed below.

5.2.1.1. Root surgery and ascending aorta with no circulatory arrest

The arterial cannulation is as per standard and included the direct cannulation of the distal ascending aorta or the aortic arch. In case of cannulation of the mid/distal aortic arch, the EOPA cannula with Seldinger kit is recommended (Figure 4A).

5.2.1.2. Operation with planned circulatory arrest

The right axillary or the innominate artery with the interposition of side-to-end 8 mm Dacron graft should be considered as the arterial inflow of choice. This will allow antegrade body perfusion, especially in type A acute aortic dissection.

In addition, the use of the arterial circuit split into 3 inflow lines is recommended (Figure 4B).

This will allow:

1) Brain perfusion through antegrade or retrograde perfusion irrespective of the selected technique.
2) Switch of the arterial return from a peripheral artery (i.e. axillary or femoral artery) to the central one (side branch of bifurcated strait Dacron graft, central side branch of the Lupiae or Thoraflex prostheses).
3) Simultaneous perfusion of upper and distal body parts in case of peripheral/central malperfusion through axillary and femoral arteries.

5.2.2. Cannulation: REDO operations

Exposure of the groin, with direct cannulation of the femoral artery before sternotomy or with the insertion of guidewires for possible subsequent directed cannulation should be considered. This applies when adhesions between the sternum and cardiac structures are evident from preoperative CT-aorta with possible “iatrogenic” risks of acute malperfusion.

In case of a planned high-risk redo aortic arch repair/replacement with expected prolonged circulatory arrest, a “T” graft configuration into a left carotid-subclavian bypass is recommended (Figure 5). This approach has been internally validated, and support from the consultant vascular surgeons is recommended.

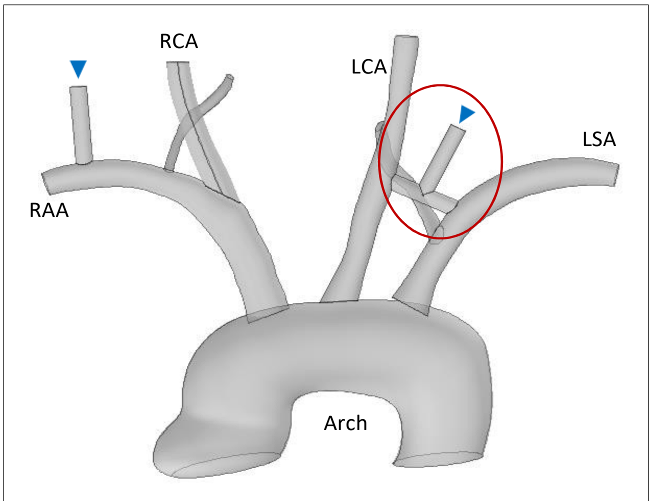


Figure 5. Arterial cannulation strategy in case of redo operations with expected circulatory arrest and adhesions between the sternum and the aorta. The right axillary artery with an 8 mm Dacron graft is cannulated, constituting the first arterial inflow (blue arrow). A second arterial inflow is created by an 8 mm Dacron graft side-to-end anastomosed to a left carotid-axillary bypass (inflow-blue arrow). The use of the arterial circuit with three arterial lines is recommended. Abbreviations: RAA: right axillary artery; RCA: right carotid artery; LCA: left carotid artery; LSA: left subclavian artery. Figure adapted from: Mariscalco et al. Computational fluid dynamics of a novel perfusion strategy during hybrid thoracic aortic repair. J Card Surg. 2020 Mar;35(3):626-633 [23].

This configuration offers the following advantages:

1) body perfusion in case of injury of vessels during re-sternotomy;
2) reduced dissection of the left subclavian artery in arch reconstruction (Lupiae and Thoraflex procedures);
3) easy obliteration/occlusion of the left subclavian artery;
4) brain protection with preservation of the vertebral system perfusion (spinal cord).

Once the cardiac structures have been identified, right atrial cannulation with a dual-stage cannula is recommended as per standard or bicaval cannulation if a mitral procedure is deemed necessary.

5.3. Cardioplegia Delivery

5.3.1. Root surgery and ascending aorta with no circulatory arrest

Cardioplegia instillation follows standard delivery routes (antegrade and/or retrograde). Retrograde cardioplegia instillation is always recommended, especially in case of suspected dissection of the coronary ostia.

5.3.2. Operation with planned with circulatory arrest

Retrograde cardioplegia (along with the antegrade) route delivery is recommended in order to achieve the safest myocardial protection possible. This is of utmost importance in type A acute aortic dissection when dissection of the coronary ostia is suspected or when selective antegrade cannulation represents a risk for ostia trauma with possible iatrogenic dissection. Retrograde cardioplegia delivery is strongly recommended during circulatory arrest when minimising the length of the circulatory arrest is the main operative goal.

5.4. Brain Perfusion (Circulatory Arrest)

5.4.1. Antegrade brain perfusion

Antegrade brain perfusion is the technique of preference when all brachiocephalic vessels have been identified and snared. Bilateral brain perfusion is the technique of preference. Unilateral antegrade perfusion should be only adopted when bilateral perfusion is not feasible (difficult exposure of the left carotid or left axillary artery, presence of dissection in one of the brachiocephalic vessels). Depending on the initial cardiopulmonary bypass institution modality, two strategies for brain perfusion can be achieved: by the use of Kazui's cannulas or preliminary direct cannulation of the axillary arteries through an 8 mm Dacron graft (Figure 6). Transection of the left subclavian artery and direct cannulation through an 8 mm Dacron graft can also be considered. The use of the arterial circuit with three inflow lines is mandatory. Snaring of the brachiocephalic vessels need to be achieved before the institution of the circulatory arrest.

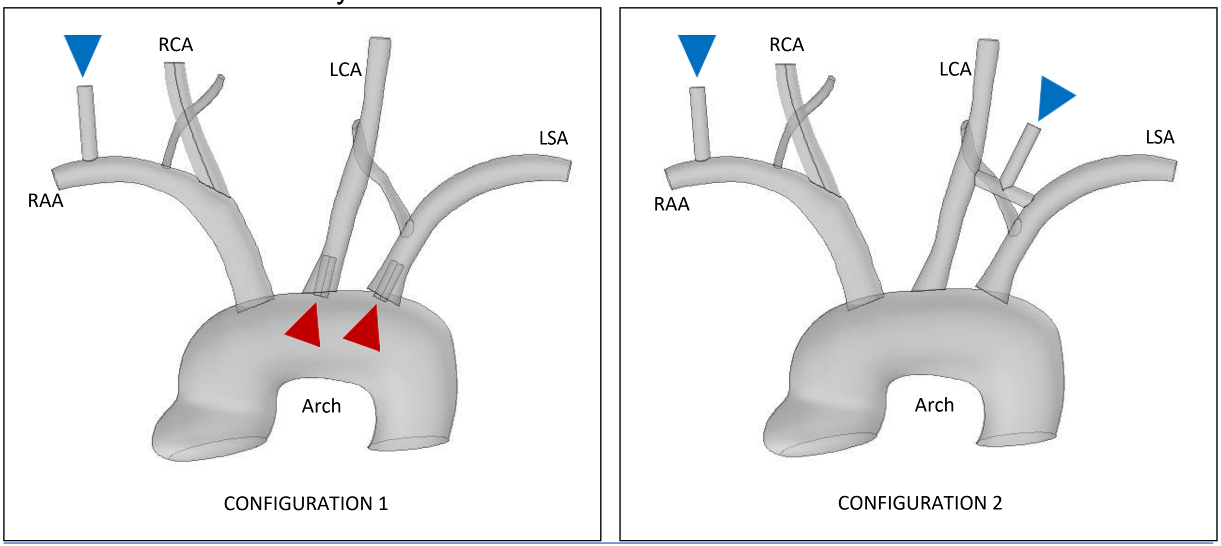


Figure 6. Antegrade cerebral perfusion strategies. **Configuration 1**: the right axillary artery is cannulated through an 8 mm Dacron for the institution of the cardiopulmonary bypass and warrant the antegrade perfusion of the brain via the right carotid artery (blue arrows). The insertion of one or two Kazui's cannulas (red arrows) in the left carotid and/or left axillary artery warrants the antegrade perfusion of the left brain. **Configuration 2**: Brain perfusion is warranted by the simultaneous perfusion of the right axillary artery and the left carotid-subclavian bypass (blue arrows). The use of the arterial circuit with three arterial lines is recommended. Abbreviations: RAA: right axillary artery; RCA: right carotid artery; LCA: left carotid artery; LSA: left subclavian artery. Figure adapted from: Mariscalco et al. Computational fluid dynamics of a novel perfusion strategy during hybrid thoracic aortic repair. J Card Surg. 2020 Mar;35(3):626-633 [23].

During antegrade perfusion, the nasopharyngeal temperature should be maintained between 21-26˚C based on the surgeon's preference and confidence. The perfusate flow should be maintained between 8-12 ml/Kg/min in order to achieve a target radial pressure of 40-50 mmHg and NIRS signals within basal ranges.

5.4.2. Retrograde brain perfusion

Retrograde brain perfusion is another standardised technique for brain protection. This technique implies the retrograde perfusion of the brain through the superior vena cava. A Pacifico's venous cannula (16-18 French) or a manually inflated Kazui's cannula are connected through one of the available arterial inflows of the trifurcated cardiopulmonary bypass circuit or the cardioplegia roller pump (Figure 4). The superior vena cava is snared. During retrograde perfusion, the nasopharyngeal temperature should be maintained between 18-21˚C, and a superior vena cava pressure of 15-25 mmHg needs to be achieved.

The retrograde brain perfusion should be considered in case of:

1) Dissection of the brachiocephalic vessels.
2) Hostile anatomy of the aortic arch (i.e. obese and short patients).
3) Suspected brain air embolism.

5.5. Distal Body Perfusion (Circulatory Arrest)

Distal body perfusion should be considered in case of prolonged circulatory arrests. Perfusion of the distal body can be achieved through the insertion of a Pruitt cannula/Foley catheter into the descending aorta. This cannula is connected through an arterial inflow of the trifurcated cardiopulmonary bypass circuit or the cardioplegia roller pump. The flow of perfusion should warrant a target femoral pressure of 30±10 mmHg.

5.6. Open Distal Anastomosis Without Brain Perfusion (DHCA)

An open distal anastomosis without the aid of antegrade or retrograde cerebral perfusion can be achieved in the case of a straightforward distal anastomosis, especially in the case of an aortic aneurysm with favourable anatomy. In this scenario, a nasopharyngeal temperature should be kept between 23˚C and 25˚C, based on the surgeon's experience and confidence.

5.7. Clamp-on Technique

This technique can be considered in case of old and frail patients (i.e. ≥80 years-old patients with comorbidities) with tear located in the ascending aorta and no sign of malperfusion. Mild to moderate hypothermia is recommended.

Technique	T (˚C)	Route	Pressure
Antegrade	21-25 (˚C)	Brachiocephalic vessels	Rad (40-50 mmHg)
Retrograde	18-21 (˚C)	SVC	SVC (15-25 mmHg)
DHCA	23-26 (˚C)	-	-
Clamp-on	32-36 (˚C)	Ascending aorta	Rad (50-60 mmHg)

6. SURGICAL TECHNIQUES IN DISSECTION SCENARIOS

6.1. Suture Lines
Suture lines can be reinforced with Teflon strips in the presence of fragile aortic tissues. In type A acute aortic dissection, internal and external Teflon strips ("sandwich technique") are recommended to reinforce the native aortic wall suture line, avoiding bleeding and subsequent pseudoaneurysm formation. This should be accomplished before securing the graft to the native aortic dissected segments.

6.2. Aortic Root Repair
In case of type A acute aortic dissection, the aortic root can be repaired with the aid of glue between the aortic wall layers. The "sandwich technique" with Teflon strips is recommended to reinforce the aortic wall, avoiding bleeding and subsequent pseudoaneurysm formation (Figure 7A). Valve sparing operation and modified Bentall procedures should be considered when appropriate.

6.3. Direct Tear Repair
In case of type A acute aortic dissection with a tear visualised in the aortic arch, with no possibility of its excision, the repair of the tear can be achieved by a running suture with pledgets at both ends of the suture line (Figure 7B).

6.4. Suture Line Integrity
The integrity of the suture lines at the level of the proximal aorta/aortic root and coronary ostia can be obtained with a direct infusion of cardioplegia into the Dacron graft. The Dacron graft is then pressurised with a target pressure between 150 and 200 mmHg. This is recommended before the removal of the aortic cross-clamp or reinstitution of the body perfusion.

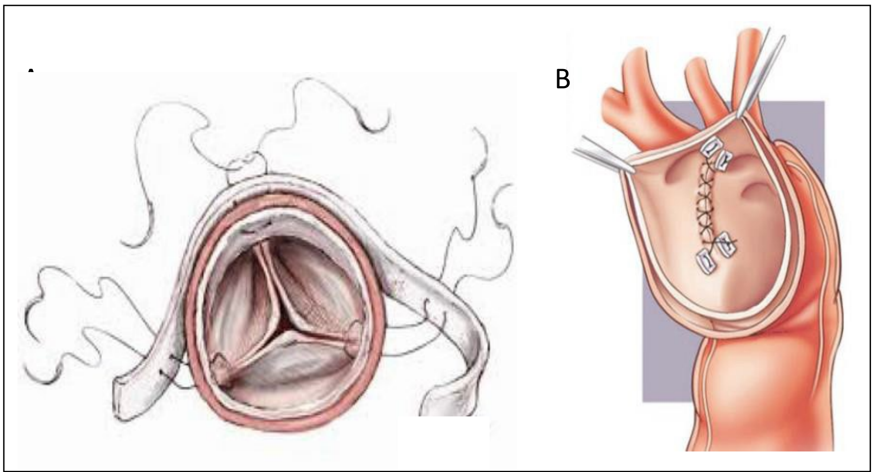


Figure 7. Panel A: "sandwich technique" with internal and external Teflon strips to reinforce the native dissected aortic root wall. Panel B: direct repair of the dissection tear located into the aortic arch. Figures adapted from Okita Y, et al. Surgical techniques of total arch replacement using selective antegrade cerebral perfusion. Ann Cardiothorac Surg 2013;2:222-8 [24]; and Cleveland Clinic Center for Medical Art & Photography 2015. All Rights Reserved).

6.5. Technique for Lupiae and FET (Thoraflex) Surgery
Once the ascending aortic aneurysm/dissection is excised, the circulatory arrest is achieved. The brachiocephalic vessels are clamped and disconnected (or surgically obliterated) from the native aortic arch. The aortic arch is usually open longitudinally, generally between the innominate artery and left carotid artery (zone 1). The distal anastomosis is then performed between the native aortic arch and the Thoraflex collar or the Lupiae graft (distal site). After the distal aortic arch reconstruction, the sidearm of the Thoraflex or Lupiae grafts is connected to the arterial line of the cardiopulmonary bypass, and body perfusion is re-established. Once the cross-clamp is removed, reimplantation of the brachiocephalic vessels is realised on beating heart and during the rewarming phase.

7. MEDIASTINAL PACKING

7.1. Bleeding Management

Bleeding management, as well as correction of coagulopathy, follows standard anaesthetic protocols. When no evident surgical bleeding from suture lines is present at the end of the procedure, the control of coagulopathy relies on protamine sulphate administration and blood product use, guided by both TEG and ACT results. Topic application of sealants can also be considered (i.e. Coseal/Floseal and Tachosil).

7.2. Massive Coagulopathy and Intractable Bleeding

Massive coagulopathy and intractable bleeding are well-described perioperative complications following complex aortic surgery, especially acute aortic dissection and aortic reoperations. In cases of intractable and uncontrollable coagulopathy, packing with multiple swabs around the site of bleeding (aortic suture lines) should be considered [25]. A precise count of the swabs needs to be reported to the scrub nurse and documented in the patient notes. The median sternotomy can be closed either by skin sutures only or partial sternal closure (2/3 stainless steel wires) plus the skin or left open and covered by a Steri-drape dressing. In case of severe myocardial dysfunction, it is recommended leaving the chest open. The mediastinal drainage tubes are placed on the standard 10-20 mm Hg suction. Specific attention to signs of pericardial tamponade needs to be made in the first hours following surgery. ITU staff needs to be promptly informed at patient arrival on ITU.

7.3. Removal of Packing

Removal of packing is generally recommended when complete control of bleeding is reached. Evidence suggests that this can be obtained within 24 to 36 hrs [25] from the mediastinal packing. Therefore, the removal of packing and definitive closure of the sternum can be safely achieved. It is recommended that packing removal and the sternal closure is performed in theatre, warranting a completely safe and sterile environment. After removing swabs from the mediastinum, massive irrigation with saline is done, and a re-evaluation of all of the suture lines and other possible bleeding points is done.

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