Chapter

Surgical Management of Aortic Dissection with Aortic Arch Involvement

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Abstract

The extent of aortic resection for aortic dissection is still debated. Although the resection and replacement of the aortic tract involved by the intimal tear remains the gold standard treatment, the fate and the evolution of the distal false lumen are hardly predictable. In recent years, several techniques and devices have been introduced to reduce the patency of the false lumen with consequent improvement of the positive remodeling of the true lumen, allowing the surgeon to perform a surgical strategy that is the most patient-tailored possible. This chapter aims to discuss hybrid strategies and new devices with related surgical techniques, with a brief literature review, to suggest a management protocol fitting each clinical and anatomical scenario.

Keywords: aortic dissection, hybrid approach, cerebral perfusion, malperfusion syndrome, aortic arch, false lumen fate

1. Introduction

Acute aortic dissection is a life-threatening condition that can represent a challenging situation for cardiac surgeons all around the world [1, 2]. Diagnosis, surgical treatment, and management of possible complications related to aortic dissection have always been the key points of this pathology. Above all, surgical treatment and management of aortic arch dissection represent the most challenging situation [3]. In this chapter, we propose a review of the recent literature on surgical treatment of the aortic arch. We described our experience with aortic arch dissection and evaluated a possible diagnostic and surgical protocol to use for the treatment of this disease.

1.1 Epidemiology and classification

Epidemiological data upon aortic dissection is not well defined. The majority of studies published are based on small populations or autoptic data [4]. For this reason, the true incidence of aortic dissection is not yet known [5, 6]. Looking at the International Registry of Aortic Dissection (IRAD), we can assume that the mean age of patients presenting with type A acute aortic dissection is 62 +/− 14.6 years with a significant difference between men and women (two-thirds of patients were men), a proportion that did not change over 17 years [7]. If we want to focus our attention on the aortic arch, described as the anatomical region identified between Ishimaru's zones 0–2 [8, 9], few studies have been published.

Historically, aortic dissections have always been classified upon two different classification systems: The DeBakey classification and The Stanford classification. DeBakey and his colleagues identified four different types of aortic dissections. Both types I and II originate from the ascending aorta, with Type II remaining confined to the ascending tract, while Type I extends into the arch and distal aorta. Type III dissections originate after the left subclavian artery, in the descending aorta, and run toward the diaphragm for type IIIA and type IIIB extending below it in the abdominal tract [10]. The Stanford classification made by Daily and colleagues classifies aortic dissections regardless of the anatomical location of the intimal tear. The focus is represented by the involvement of the ascending tract. If the ascending aorta is affected, we are talking about type A dissection. All other dissections, where the ascending tract of the aorta is not affected, as type B. This classification system has been most widely used due to its role in clinical decision-making process. Usually, type A dissections are treated in emergency with surgical procedures on ascending aorta. On the other hand, type B dissections usually need medical treatment focused on stabilization of the pathology and surgery is confined on treatment in case of emerging complications on the dissected tract of aorta [11, 12]. In both of previous classification (Stanford and De Bakey), the presence of an intimal flap engaging both the aortic arch and the descending aorta, without intimal disruption of the ascending aorta, has not been considered (**Figures 1** and **2**) [8].

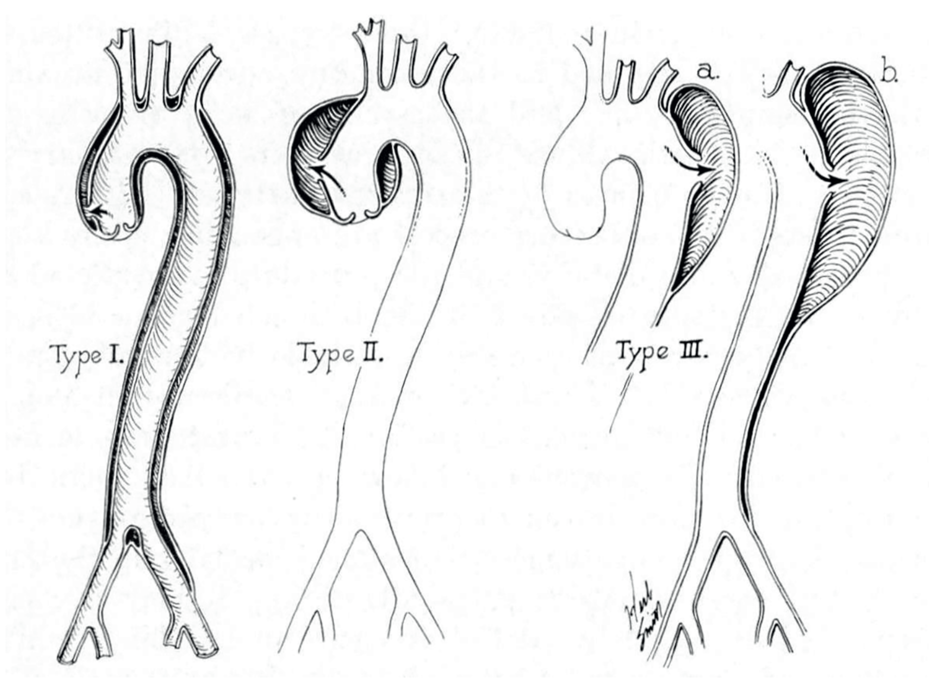

Figure 1.
De Bakey classification system.

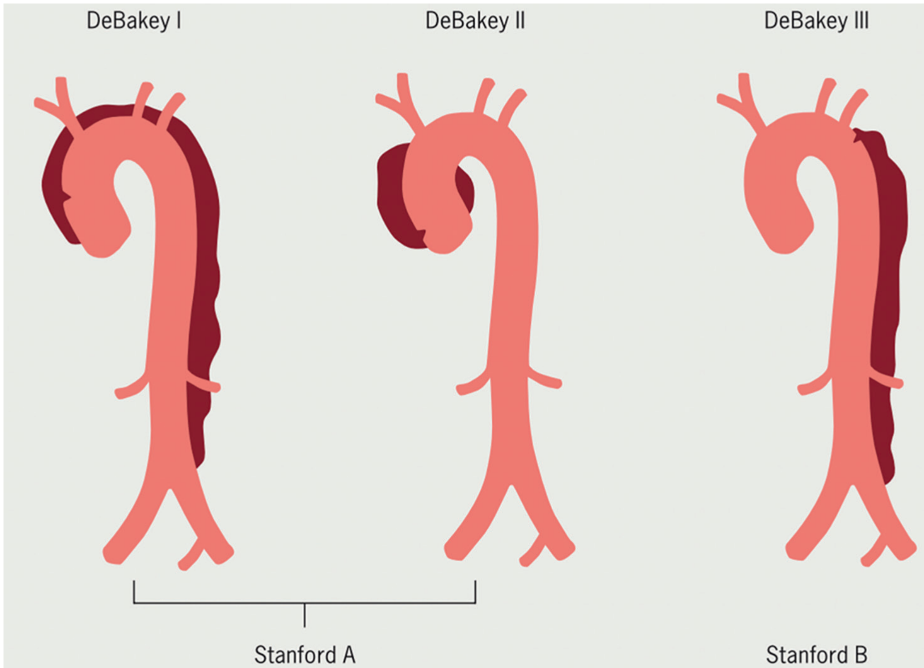

Figure 2.
Stanford classification system.

Recent literature and the most recent guidelines on the aorta tried to surpass these two systems and evaluate new ways to classify aortic dissection on a more clinical-based system [8]. Recently, the TEM (Tear, Entry, Malperfusion) classification, proposed by Sievers and colleagues, has been published. It differentiates from other classification systems by adding non-A non-B aortic dissection, first introduced by Von Segesser et al. [13] (**Figure 3**). Non-A Non-B dissections, which represent 10% of all acute aortic dissections [14], are defined as dissections with entry tear located in the descending aorta with retrograde progression into the aortic arch [13]. The location of the primary entry tear (E), which has a direct correlation with early clinical outcomes [2], and malperfusion (M) is a key point that needs to be considered in the decision-making process [15]. Different studies described that the location of entry intimal tear has a direct correlation with early surgical outcomes [14]. TEM classification has proved to be useful in clinical and surgical decision-making processes, giving additional anatomical information of the dissected tract, and focusing on organ malperfusion. These characteristics of the TEM classification system should help to decide the best surgical management of the patient and permit a correct prediction of early and late clinical outcomes. Because TEM clearly defines non-A non-B as a main category, it helps make quick clinical decisions in patients with acute dissections [15, 16]. There is currently no consensus regarding the best management of acute or subacute non-A non-B aortic dissection. In acute aortic dissection, isolated diseases of the aortic arch of any kind in adults are infrequent, as isolated surgical replacement [8]. Furthermore, if the surgical treatment of the dissected ascending aorta has been mostly standardized, the correct surgical management of the aortic arch, needed in 13–32% of ATAAD patients due to primary entry tear in Ishimaru's zones 1–2, is often center-related [17].

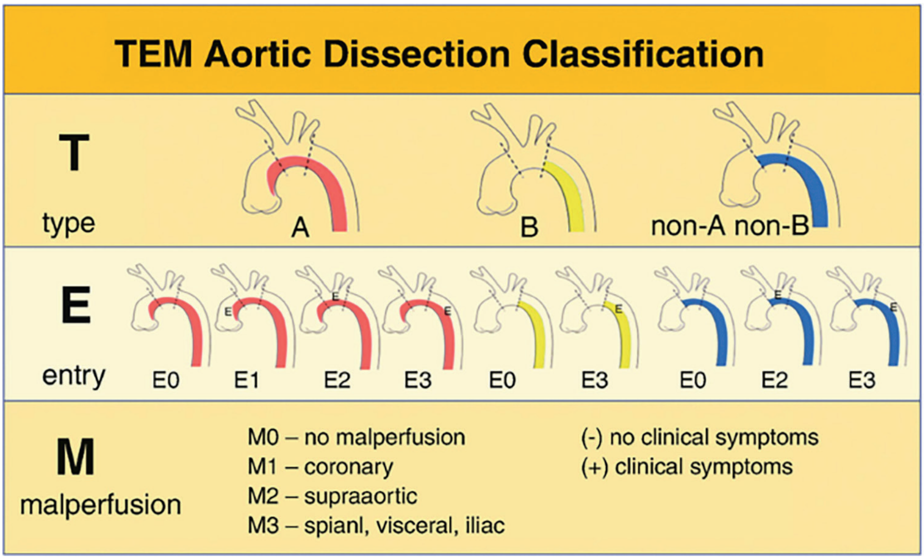

Figure 3.
TEM classification of acute aortic dissection [16].

1.2 Cerebral perfusion

Talking about aortic arch surgical treatment, a discussion about cerebral perfusion is needed. Different possibilities and techniques for cerebral protection have been proposed since the introduction of aortic arch procedures [17]. Surgical replacement of the aortic arch has become a surgical possibility, thanks to the implementation of hypothermia during circulatory arrest. The reduction of oxygen demand and metabolic activity guaranteed by lower body temperatures allows surgeon to temporarily stop circulation [14].

Referring to hypothermic circulatory arrest, the most recent EACTS guidelines on surgical treatment of the aorta redefined the correct terminology of hypothermic circulatory arrest. As it stands today, we must talk about (as reported in **Figure 4**):

- Deep hypothermia for temperature below 20°C
- Low-moderate hypothermia for temperature between 20.1 and 24°C
- High-moderate hypothermia for temperature between 24.1 and 28°C
- Mild hypothermia for temperature above 28°C [8]

Deep hypothermia permits a longer period of safe circulatory arrest, proved to be around 30 minutes, if compared to higher temperatures. In response to this longer safe period, several studies have shown that DHCA is correlated to a greater inflammatory response, greater risk of neurological damage, and higher mortality rates [18]. The first successful series of aortic arch surgical procedures using deep hypothermic circulatory arrest (DHCA) was reported in 1975 by Griepp et al. [19]. Since then, improvements and modifications have been made worldwide, ranging from Kazui [20], Bachet [21], and colleagues, who first introduced antegrade

TABLE 6 Writing Committee 2023 Consensus on Hypothermia Classification in Aortic Surgery	
Category	**Core Temperature (Rectal/Bladder)**
Deep hypothermia	≤20°C
Low-moderate hypothermia	20.1-24°C
High-moderate hypothermia	24.1-28°C
Mild hypothermia	>28°C

Figure 4.
Definition of correct nomenclature for hypothermic circulatory arrest made by EACTS guidelines [8].

cerebral perfusion during the period of circulatory arrest, to the use of more moderate levels of hypothermia used nowadays. As it stands today, an optimal and consistent approach worldwide is still missing [20, 21]. For example, in 2017, the Society of Thoracic Surgeons reported that DHCA used to be the most common technique for circulatory arrest [22]. Nowadays, the general trend is moving, especially in Europe, toward the association of cerebral protection and warmer temperature of circulatory arrest [22]. Several studies and meta-analyses demonstrated the superiority of these surgical techniques in terms of lower early mortality and lower adverse events (**Figures 5**–7) [18, 22, 23].

1.2.1 Retrograde cerebral perfusion (RCP) and anterograde cerebral perfusion (ACP)

Retrograde cerebral perfusion, first introduced for treating air cerebral embolism, used to be the first technique that was implemented to guarantee correct cerebral protection in association with DHCA [23]. Established by cannulation of the superior vena cava (SVC), without manipulation of supra-aortic vessels, RCP guarantees cerebral perfusion through the vein system [25]. Clinical and animal trials suggested that RCP provides a small percentage of cerebral flow (10–30%) compared to baseline flow characteristics [26]. During the years, numerous concerns about RCP arose from the literature in association with the diffusion of selective anterograde perfusion.

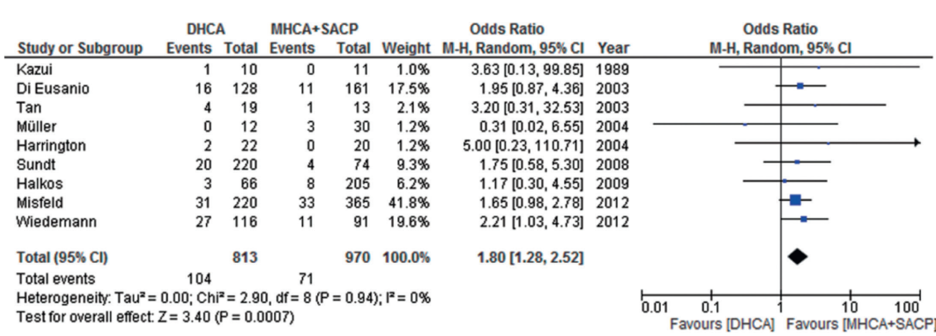

Figure 5.
Incidence comparison of postoperative stroke events during aortic arch replacement using deep hypothermic circulatory arrest alone (DHCA) or with moderate hypothermic circulatory arrest with selective antegrade cerebral protection (MHCA + SACP) made by Tian et al. [23].

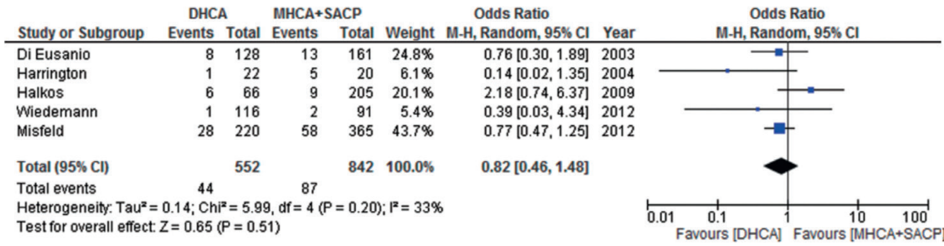

Figure 6.
Incidence comparison of postoperative temporary neurological deficit between deep hypothermic circulatory arrest alone (DHCA) and moderate hypothermic circulatory arrest with antegrade cerebral protection (MHCA+ACP) made by Tian et al. [23].

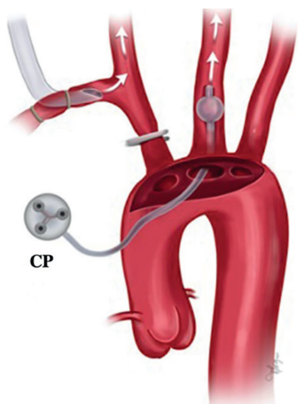

Figure 7.
Illustration of anterograde cerebral perfusion with direct cannulation of left common carotid artery as first described by Kazui et al. [24].

Several animal studies supposed that, during RCP, oxygen perfusion is not guaranteed through the cerebral parenchyma, assuming the inefficacy of this perfusion technique [27]. On the other hand, several studies with animal models challenged these concerns, defending the utility of RCP [27]. A recent meta-analysis conducted by Takagi et al. including a total of 15,365 reported no statistically significant differences in the postoperative incidence of stroke (17 studies enrolling a total of 9421 patients) and mortality (16 studies including a total of 14,452 patients). Contemporarily, a reduction in temporary neurological dysfunction (TND) was found during ACP [28].

Today, anterograde cerebral protection is the most common way of cerebral perfusion during surgical treatment on the aortic arch. Ghoreishi et al., analyzing the STS database including more than 7000 cases of Type A acute dissection, described how 71% of patients were treated using cerebral perfusion. Of these, two-thirds were ACP [28]. Several studies identified a satisfactory safe time of circulatory arrest of 80 minutes using anterograde cerebral perfusion [24].

Anterograde cerebral perfusion may be performed in different ways (unilateral cerebral perfusion and bilateral cerebral perfusion) based on the anatomical structure of the patient and possible involvement of the supra-aortic vessels by the aortic dissection. An important analysis of the eventual presence of an incomplete circle of Willis should be made based on preoperative CT to evaluate the possible necessity of direct cannulation of the left subclavian artery. Several studies found no significant differences in terms of early clinical outcomes depending on the cannulation site [29]. Ghoreishi et al. reported that, on the other hand, axillary cannulation was associated with a lower incidence of stroke, whereas femoral cannulation significantly increased the risk of stroke regardless of the cerebral perfusion strategy or the degree of hypothermia [28]. Aortic surgery centers have adopted different cerebral perfusion strategies to optimize operative results and minimize adverse neurologic outcomes [30]. Recently, the issue of using unilateral (u-ACP) or bilateral (b-ACP) ACP has been one of the most important concerns [31]. Similar results have been reported regarding mortality, stroke, TND, and renal failure rates between the two types of ACP in proximal aortic arch replacement [31]. Still debated is the effectiveness of u-ACP in total arch replacement, with b-ACP permitting longer circulatory arrest periods in safe conditions, as reported by Zierer and colleagues [32]. On the other hand, several studies found no statistical differences between unilateral and bilateral ACP upon organ perfusion [33].

2. The arch problem

Open surgery for aortic arch replacement is a challenging procedure and requires a great surgeon's experience to be performed. Moreover, aortic arch surgery is characterized by a higher operative risk with a higher rate of systemic and cerebrovascular complications, increasing early mortality. It is well known that the gold standard for the treatment of type A aortic dissection is the resection and replacement of the aortic tract with the intimal tear. Although the most frequent localization of the primary entry tear is within the ascending aorta, finding it in the distal aorta and the aortic arch is not so infrequent. When this happens, resection and replacement of the aorta must be extended to the portion where the intimal tear is located. Despite that, controversies exist about the management of the dissected aortic arch, wherever the intimal tear is located. Some authors suggest a more conservative approach, such as hemiarch replacement, to reduce procedure complexity, postoperative complications, and mortality [34]. This option improves early outcomes in terms of perioperative morbidity and mortality but does not assure similar long-term results. For this reason, other surgeons prefer a more invasive and aggressive management (e.g. total arch replacement with or without Frozen Elephant Trunk technique), regardless of the intimal tear location, to obtain a more complete result, accepting the increased procedural complexity and postoperative mortality [3].

However, some authors demonstrated similar short- and long-term outcomes of both aggressive and conservative approaches for selected patients, suggesting a more aggressive approach to treat complex arch lesions like arch aneurysms >4 cm or aortic dissection with an intimal tear at the arch unable to be excluded by hemiarch replacement [35]. It is reasonable to claim that such results are not simply reproducible because, as previously discussed, some procedures require to be performed by expert surgeons in high-volume centers to provide early and late outcomes comparable to less aggressive strategies. [36]

Whatever the strategy of choice, the aim of the surgical procedure is to save the patient's life and to achieve a regression of the dissecting process with a less invasive approach and a more complete as possible treatment of the aortic dissection, to give the patient a durable result. For this reason, although the primary strategy is to replace the aortic tract with the intimal tear, the extension of the aortic replacement is often based on institutional experience or the preferences of the surgeon.

3. Malperfusion syndrome

Acute type A aortic dissection can clinically manifest, in addition to the classic symptoms, with systemic signs due to peripheral malperfusion syndrome. We can distinguish between a static and a dynamic malperfusion. The first one could be the result of the propagation of the dissection flap into the branch vessel with resultant false lumen protrusion into the branch vessel with associated thrombosis and obstruction. Dynamic obstruction is more often the cause of malperfusion syndrome than static obstruction and is responsible for approximately 80% of cases [37].

The diagnosis of malperfusion syndrome is made, first of all, thanks to clinical manifestations of mesenteric, renal, and lower extremities ischemia (impaired solute clearance, rising creatinine, refractory hypertension, lactate elevation, peripheral pulses deficits, pain, pallor, paresthesias, poikilothermia, or paresis). Computed Tomographic Angiography, which is needed almost always to diagnose acute aortic dissection, is useful for identifying radiological signs of systemic malperfusion together with clinical signs.

This clinical entity is not only a collateral finding in the case of type A aortic dissection, but it has relevance in terms of postoperative results and patient survival. Mesenteric ischemia has been clearly identified as the second cause of death in the case of acute aortic dissection after aortic rupture [38]. For this reason, the identification of preoperative malperfusion syndrome helps the "dissection team" to decide the operative strategy and optimize the postoperative management of the patient.

4. Fate of false lumen

As discussed previously, the main target in the treatment of the aortic dissection is to replace the interested tract of the aorta to eliminate the entry tear and improve the perfusion of the true lumen, with a progressive decompression of the false lumen. But what happens distally, even if the primary entry tear has been eliminated? There is no consensus about the management of the dissected aortic tract (arch, descending aorta) without an entry tear: some surgeons prefer to limit the treatment to the tract of the aorta interested by the intimal tear; other surgeons support a more aggressive and complete treatment that involves the distal tract of the aorta as well. Nowadays, it is well known that secondary tear or reentry tear, which can supply the false lumen even after surgical correction, could be present distally to the replaced aorta (distal aortic arch, descending aorta, supra-aortic vessels), and these lesions are not so simple to identify. Furthermore, several minimal communications between the true and the false lumen have been found at the level of the distal anastomosis, as the result of micro-lacerations in the fragile tissues of a dissected aorta made by the suture line or by the needle. This phenomenon, called distal anastomosis new entry (DANE), is not so infrequent, as well as the postoperative false lumen supply by small tears in the supra-aortic vessels (**Figures 8** and **9**).

From the early postoperative period to a mid- and long-term follow-up, the presence of communication between the two lumina has been seen to be the cause of late patency of false lumen with subsequent growth of the aortic dimensions, leading to the need for reoperation with a higher operative risk and perioperative mortality [39].

An interesting study from Tamura et al. investigated the influence of patent false lumen (PFL) caused by DANE on long-term outcomes. PFL caused by DANE showed

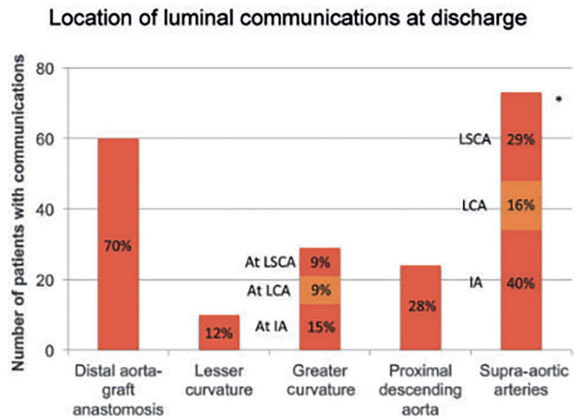

Figure 8.
Rate of communication between true and false lumen. LSCA: left subclavian artery; LCA: left carotid artery; IA: innominate artery [39].

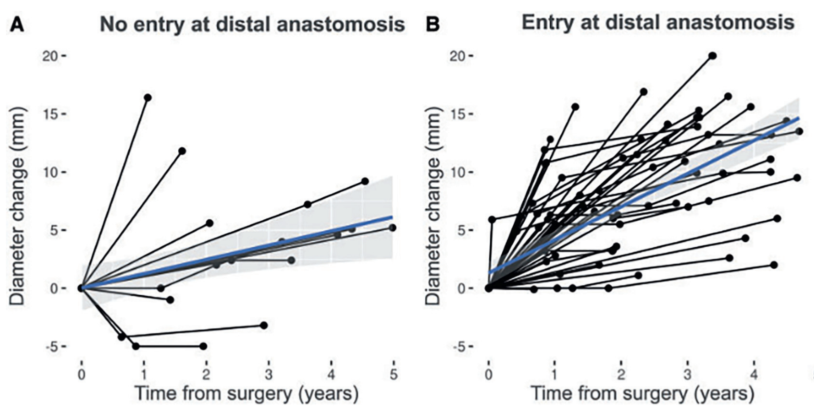

Figure 9.
Interaction between DANE and aortic growth rate (A, B) [39].

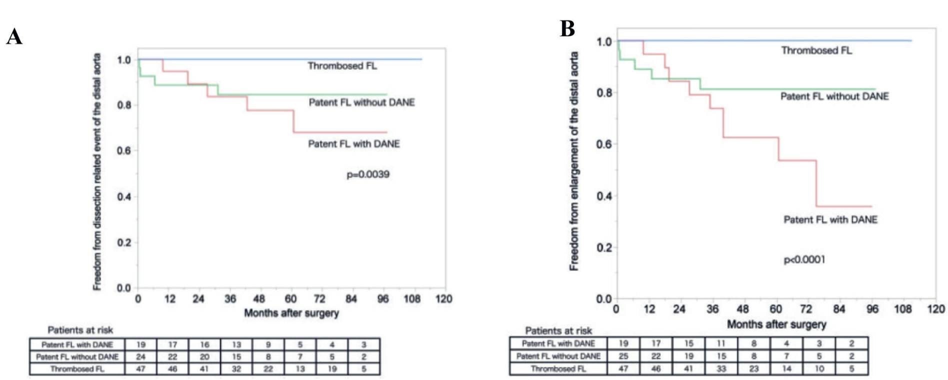

Figure 10.
Kaplan-Meier curves of freedom from the dissection-related event of the distal aorta between thrombosed FL, patent FL without DANE, and patent FL with DANE (A); Kaplan-Meier curves of overall survival rate between thrombosed FL, patent FL without DANE, and patent FL with DANE (B) [40].

a greater aortic growth rate of the descending aorta, and DANE was found to be a significant risk factor for distal aortic events, as we can see from the Kaplan-Meier curves of freedom from dissection-related events (**Figure 10**) [40].

5. Surgical and hybrid strategies

We describe below the most performed techniques for aortic arch management. We will not treat perfusion strategies because this is not a specific topic of this chapter and, moreover, they are dependent on each surgeon's preference. Furthermore, only the "distal procedures" will be described; the order of the anastomosis and the management of surgical times are strictly surgeon-dependent: some prefer to perform the "proximal procedure" before and during the cooling process; others support a distal-first approach just after cooling. In our center, we prefer the distal-first approach. Antegrade bilateral cerebral perfusion is preferred, with cannulation of the subclavian artery (for systemic perfusion as well) and selective cannulation of the left carotid artery.

5.1 Hemiarch replacement

Cerebral perfusion starts, supra-aortic vessels are clamped, and aortic clamp is removed. The distal ascending aorta is resected including the lesser curvature of the aortic arch in an oblong fashion, preserving the convexity of the aortic arch. A Dacron graft is cut in order to have a prosthesis tongue matching the distal aspect of the lesser curvature of the arch. A single polypropylene running suture is started with the first bite on the Dacron graft and then through the arch on the assistant side in the lower half of the lesser curvature; then the suture continues clockwise. When aortic tissue fragility is present, a PTFE strip could be included externally in the suture line. After completing the suture, the Dacron graft is de-aired and clamped, and cerebral perfusion is switched to systemic perfusion.

This technique is recommended when the intimal tear is located in the lesser curvature of the arch. Despite encouraging short- and long-term results are widely described, distal false lumen patency, as the result of a distal anastomosis new entry (DANE), is a common occurrence of hemiarch replacement, with an incidence between 39 and 70% [39].

5.2 Total arch replacement

Differently from the hemiarch technique, the total arch replacement is performed with an extended resection to the first tract of the descending aorta. Cooling, CPB, and cerebral perfusion setup do not differ between the two techniques. After cerebral perfusion starts, the aortic arch is opened, and a cannula is inserted in the left carotid artery to achieve bilateral perfusion. Then the resection is extended to the descending aorta. An appropriate 4-branched prosthesis is sutured to the descending aorta with a single polypropylene running suture, with or without Teflon reinforcement. Systemic perfusion is restarted from the side branch of the prosthesis together with cerebral perfusion, while supra-aortic prosthesis branches and the vascular prosthesis proximal to the reperfusion branch are clamped. Body temperature is progressively restored, and proximal anastomosis is performed at the desired level of the ascending aorta with a single polypropylene running suture, with or without PTFE reinforcement. Then supra-aortic vessels are selective anastomosed to the graft branches.

The described technique allows the surgeon to resect the full extension of the arch, but it is not free from technical difficulties due to the awkward position of the distal anastomosis.

5.3 Frozen elephant trunk

The Frozen Elephant Trunk (FET) technique represents an evolution of the Elephant Trunk technique, in which the ascending aorta and aortic arch are replaced with a Dacron prosthesis that is extended into the descending aorta. Since its first description in 2003 by the Hannover group [41], the FET has become the technique of choice for the treatment of complex arch lesions. It is performed with a hybrid prosthesis that has a covered stent portion to be released in the descending aorta and sutured with a special collar to the edge of the distal resection and a standard Dacron portion to replace the arch and the supra-aortic vessels.

The FET procedure allows to achieve a blood-tight seal in the descending aorta and permits to perform a dual treatment on the arch and the proximal descending aorta [42]. Furthermore, the stented portion of the prosthesis with its radial force facilitates the negative remodeling of the false lumen and allows the exclusion of small reentry tears in the descending aorta. Prosthesis supra-aortic branch configurations fit all the surgical strategies, allowing the surgeon to perform the distal anastomosis between the aorta and prosthesis collar in an arch zone more proximal than zone 3 or 4. Indeed, a trifurcated configuration is particularly indicated when a zone 0 or 1 distal anastomosis is preferred. This is a huge advantage for the surgeon who can perform a more comfortable distal anastomosis with fewer technical difficulties. Furthermore, a FET prosthesis can be easily relined for subsequent endovascular completion of descending and abdominal aorta treatment, offering a stable landing zone.

The resection of the dissected aortic arch is made according to the treatment strategy and the surgeon's preference because specific kinds of FET prosthesis are suitable for distal anastomosis from zone 0 to zone 3. Cooling and cerebral perfusion are achieved in a standard fashion. After aortic resection to the desired zone, the stented portion of the FET graft can be released in the arch/descending aorta and then the collar between stented and non-stented portions is sutured to the distal edge of the aorta. Once the distal anastomosis is completed, systemic perfusion can be restored through the reperfusion branch of the graft, after proximal prosthesis and supra-aortic branches clamping. During rewarming, supra-aortic vessels are anastomosed with each specific branch and proximal anastomosis can be performed.

The FET technique is particularly indicated when a hybrid approach is desired, as described previously, permitting at the same time to treat the arch, the descending aorta, and the abdominal aorta with an endovascular strategy.

In Europe, two hybrid prostheses are available: the E-vita Open Neo (Artivion, JOTEC GmbH, Hechingen, Germany) and the Thoraflex Hybrid (Terumo Aortic UK). Both prostheses have a distal stented portion and a proximal conventional Dacron portion, separated by a sewing collar that facilitates distal anastomosis.

Thoraflex Hybrid prosthesis is available in two configurations, with the distal stented portion that does not differ between the two variants:

- Straight configuration: different from the branched version, the straight configuration is made only with the reperfusion branch; it is chosen when supra-aortic vessels are reimplanted with the island technique.

- Branched configuration: the Dacron portion is made with four branches, three of which for supra-aortic vessels separate anastomoses. The fourth branch is used as a reperfusion branch at the end of the circulatory arrest surgical time (**Figure 11**).

This hybrid graft is particularly suitable when distal anastomosis in zone 2 or 3 is preferred.

E-vita Open Neo graft has three possible configurations, with the stented portion that does not differ from each other. As the Thoraflex prosthesis, the difference between each configuration in the supra-aortic branches:

- Straight configuration: only a reperfusion branch arises from the Dacron portion as a reperfusion line. This configuration is suitable for supra-aortic vessel reimplantation with island technique and distal collar anastomosis in zone 2 or 3.

- Branched configuration: as well as Thoraflex branched configuration, it has three branches for separated supra-aortic vessels and one reperfusion branch. This configuration allows distal collar anastomosis in zone 2 or 3 and, in specific situations, in zone 1.

- Trifurcated configuration: a single branch arises more proximally from the Dacron portion with a trifurcation for supra-aortic vessels separated anastomoses and a lateral reperfusion branch is still present. This configuration represents a great option for a more comfortable distal anastomosis because its more proximal trifurcated branch allows to perform collar anastomosis in zone 0 or 1 for the particular angulation of the head vessels branches, reducing technical problems related to a more distal anastomosis. Furthermore, zones 0–1 are better

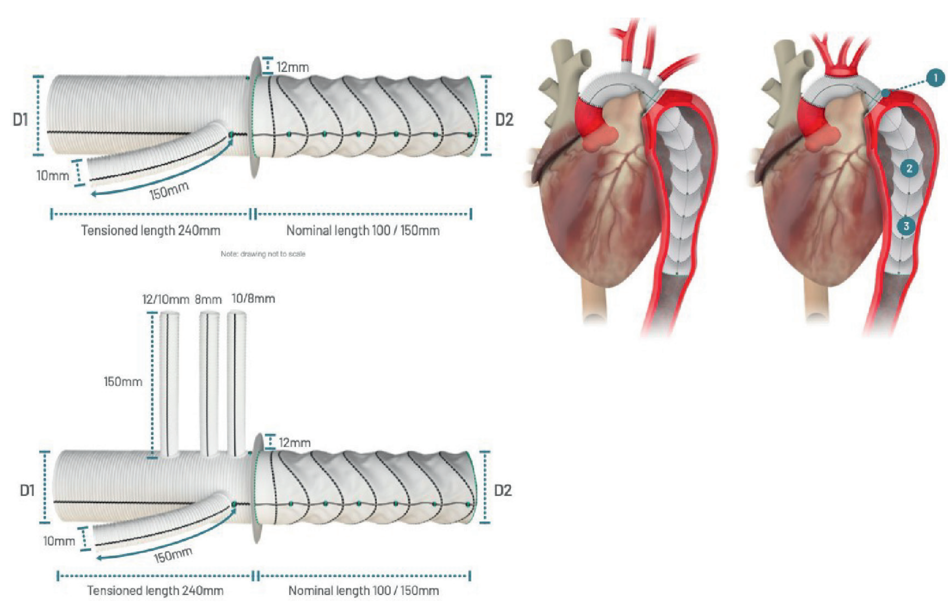

Figure 11.
Terumo Thoraflex configurations.

exposable, especially in minimally invasive accesses. It is also dutiful to consider that a less uncomfortable distal anastomosis could reduce circulatory arrest, cardiopulmonary bypass, and cross-clamp times (**Figure 12**) [43, 44].

5.4 AMDS device: a new paradigm?

As previously discussed, the primary target of aortic dissection treatment is the removal of the primary entry tear, the sealing of the false lumen at the distal anastomosis with false lumen, and pressurization of the true lumen to resolve and avoid further malperfusion. Unless the necessary treatment is FET/total arch replacement, with a more conservative treatment, the sealing of the false lumen at the distal anastomosis cannot be guaranteed, and this can lead to a distal anastomotic new entry. The DANE allows the antegrade flow in the false lumen leading to FL patency in 70% of cases and subsequent malperfusion, early mortality, reinterventions, and decreased long-term survival [45, 46].

Artivion AMDS is a novel, partially uncovered arch stent made with a proximal Teflon graft sewn to a tubular Nitinol stent with a low radial force, which aims to improve malperfusion and promote positive remodeling of the aortic arch and distal dissected aorta, by the active pressurization of the true lumen (**Figure 13**) [45, 47].

As previously described, this device has a proximal PTFE stent-supported cuff to strengthen the aortic tissue and reduce the tension on the suture during conventional graft to aorta anastomosis on a friable tissue, reducing the risk of DANE. The uncovered Nitinol wire braided stent expands and supports the true lumen across the aortic arch and descending aorta, thereby stabilizing the aortic wall and promoting remodeling, without compromising the supra-aortic vessels flow. Preliminary results by the Canadian group suggested that the AMDS is a safe and reproducible adjunct to current surgical strategies for acute DeBakey I aortic dissection repair [47]. The efficacy of the AMDS stent is supported by other studies in terms of clinical results, true lumen expansion, false lumen reduction, and aortic growth stabilization [45, 48, 49]. Furthermore, preliminary results from the DARTS trial seem to suggest that the AMDS device is promising as a technology that not only facilitates the repair of the arch or proximal descending aorta but also allows to achieve positive remodeling in the early to midterm period (**Figure 14**) [50].

AMDS device has a simple delivery system, with a pigtail tip. Sizing of the device (available in four different sizes) is very simple and does not require an advanced DICOM viewer: in a standard axial view, the first aortic measure must be taken

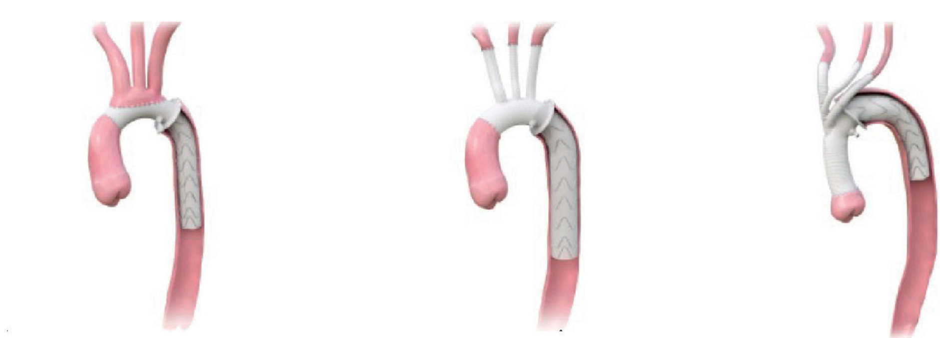

Figure 12.
Artivion e-vita open neo configurations.

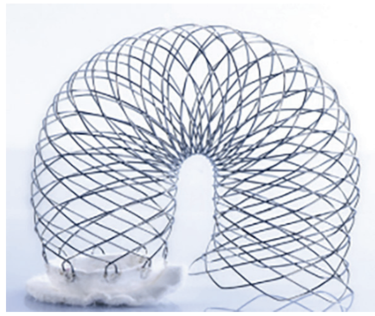

Figure 13.
The fully expanded ascyrus medical dissection stent outside of its delivery system [47].

A

Key Outcome Measures After AMDS	DARTS[1,2]	Berlin 100 Patient Series[4]
Presence of DANE	0%	NR
Malperfusion resolution	96%	80%
Average deployment time*	3 min	8 min
Early mortality	13%	18%
Reintervention	13%**	13%***
Spinal Cord Injury (SCI)	0%	NR

*Does not include suture time. **Average. 3 year follow up. *** 30 day follow up. NR = not reported

Figure 14.
Preliminary results of AMDS devices (derived from Artivion website). (A) Clinical results. (B) False lumen status at 3 years. (C) Aortic diameter changes at 3 years [45, 48–50].

Figure 15.
AMDS device released (left) and on its delivery system (right). The red dot indicates the proximal protective sheath; the blue dot indicates the green cap to remove for stent releasing (green dot).

between the innominate artery and the left carotid artery; the second aortic measure must be taken at the level of the pulmonary artery bifurcation. Then, using a sizing table, the right device size can be easily identified. After the aortic arch resection (most commonly in zone 0) and circulatory arrest, the delivery system is inserted into the aorta, and the proximal protective sheath is removed to release the proximal stented cuff on the edge of the resected aorta; four stitches are placed at the four cardinal points to fix the stent to the aorta and then a continuous suture is performed to stabilize the aorta-cuff sealing. The green cap is removed to release the suture constraining the stent. The special Nitinol stent configuration facilitates the insertion of a cannula for the carotid artery through it. Distal conventional Dacron-aorta anastomosis can be performed in a standard fashion with the interposition of the AMDS cuff (**Figure 15**).

6. Discussion and outcomes

Aortic dissection with aortic arch involvement is still a challenging condition to deal with, especially if its systemic implications are considered. Outcomes of each kind of surgical treatment strictly depend not only on the immediate surgical result or the early mortality but on the "distal" effects of the treatment. Indeed, it is well known that a malperfusion syndrome represents an important cause of death before and after treatment [37]. Furthermore, even if the immediate results could seem satisfying, it has been noticed that a more conservative procedure may leave a residual pressurized false lumen with growth, rupture of the distal aorta, as well as pseudoaneurysms originating from fragile aortic tissue [51, 52].

Results about each surgical strategy suggest that appropriate surgical management should be found for each clinical presentation of type A dissection to achieve a satisfactory outcome, but the choice of optimal procedure is still controversial. Although some authors claim that both conservative and aggressive strategies have similar outcomes [35, 53], the incidence of a patent false lumen and its prognostic impact cannot be ignored [39, 40], if we consider the rate of reoperation for distal aortic events and its operative risk.

With the advent of new surgical and hybrid devices [45, 48–50, 54], aggressive strategies, despite their operative complexity, seem to have better long-term outcomes than a more conservative approach, in terms of survival rate and freedom from reintervention (**Figure 16**) [55, 56].

The lack of randomized studies could justify the controversies existing about the best surgical strategy to obtain good anatomical and clinical results, both on short- and long-term follow-up. The only data we have are derived from non-randomized studies and meta-analyses.

It seems to be clear that a standardized protocol is needed to choose the better surgical strategy for each clinical scenario. In our institution, we are retrospectively analyzing all the aortic dissection operated from 2013. Preliminary results, regarding 303 consecutive patients admitted to our Cardiac Surgery Department for acute type A aortic dissection from 2013 to 2021, seem to confirm that, despite a lower survival rate during the first 24 months, FET patients have better long-term survival if compared to hemiarch patients with a survival rate at 8 years of 75 versus 92% in the FET group. This could be related to the lower incidence of distal aortic events in FET patients, as previously discussed (**Figure 17**).

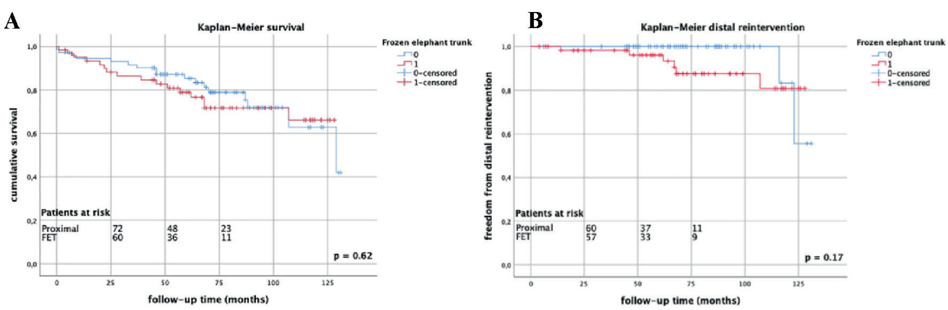

Figure 16.
(A) Kaplan-Meier survival curves comparing FET (red) vs. proximal repair (blue) at 10-year follow-up. (B) Kaplan-Meier curves for the need for reintervention comparing FET (red) vs. proximal repair (blue) at 10-year follow-up [54].

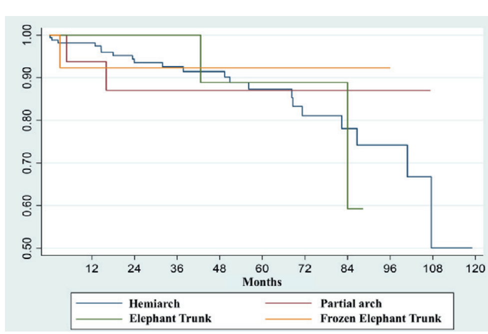

Figure 17.
Our institution (cardiac surgery unit AOU Careggi, Florence) Kaplan-Meier survival estimates comparing the FET group (orange) vs. hemiarch group (blue) vs. partial arch (purple) vs. elephant trunk (green).

As shown in **Table 1**, our preliminary results seem to confirm that a more complete procedure is associated to a lower rate of false lumen patency with a concomitant true lumen positive remodeling.

From March 2023, we implanted 23 AMDS devices. The small population cohort does not allow us to have statistically significant results, but our clinical evidence suggests that this new hybrid prosthesis can improve arch and abdominal aorta results. We had 13% postoperative mortality (2 patients with preoperative critical mesenteric malperfusion, 1 patient with an unknown secondary tear in the innominate artery) and 86.9% false lumen decompression with progressive true lumen positive remodeling. All the surviving patients were discharged in good clinical status. Recently, we

Parameters	Ascending aorta ± hemiarch (n = 234)	Partial arch (n = 23)	Elephant trunk (n = 25)	FET (n = 21)	p-value
FL thrombosis	60 (30.5%)	13 (59.1%)	7 (38.9%)	8 (50%)	<0.05 *
FL partial thrombosis	25 (12.7%)	2 (9.1%)	3 (16.7%)	5 (31.3%)	<0.05 *
FL patency	104 (52.8%)	7 (31.8%)	8 (44.4%)	3 (18.8%)	<0.05 *

$^*p < 0.05$.

Table 1.
Our institution (cardiac surgery unit AOU Careggi, Florence) about false lumen fate at follow-up (mean 36 ± 32.95 months).

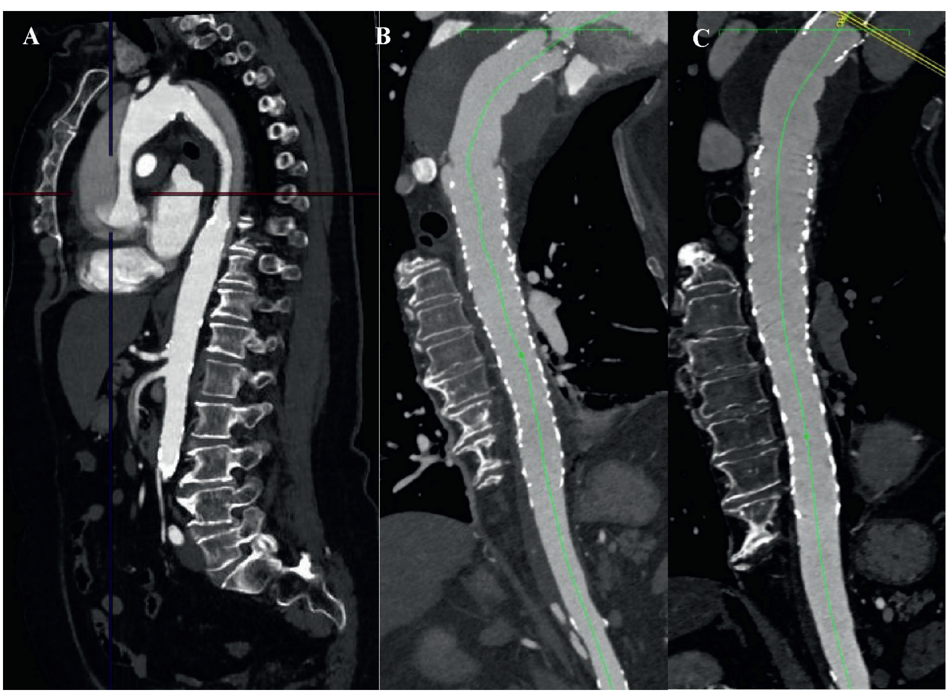

Figure 18.
A recent case admitted to our unit for aortic dissection (A) and treated with aortic valve replacement, ascending aorta replacement, and AMDS implantation. (B) 3-month follow-up CTA that shows a partial obliteration of false lumen. (C) 5-month follow-up CTA that shows a complete expansion of true lumen with the negative remodeling of false lumen.

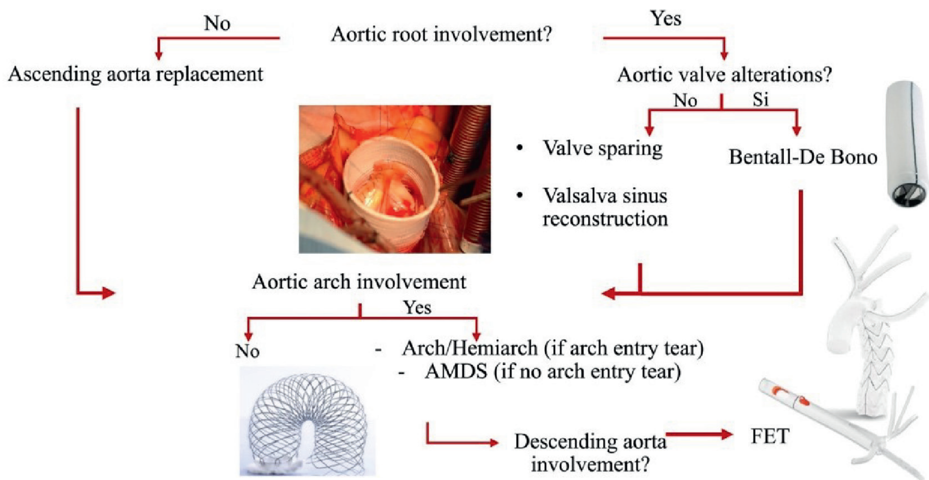

Figure 19.
Our institution (cardiac surgery unit AOU Careggi, Florence) protocol for the management of aortic dissection.

implanted 3 AMDS through IV intercostal space J ministernotomy, with no technical differences if compared to full sternotomy and with optimal results (see **Figure 18**).

On these bases, we elaborated an internal protocol that aims to standardize the surgical strategy, without any improvisation (**Figure 19**).

The advent of the new AMDS hybrid prosthesis, according to our direct experience and on the literature data, seems to offer a promising new surgical strategy to allow the surgeon, even without a deep expertise, to perform an arch procedure, with all its well-known advantages, without increasing procedural complexity and perioperative complication rate. In selected patients, when intimal tear is only proximal to the aortic arch but the intimal flap is extended distally, we suggest always using this aortic stent, considering it as an instrument to achieve the complete recovery from the dissecting pathology, as suggested by several studies reported above and by our results. Moreover, the superiority of an uncovered descending aorta stent over the covered stent of FET prosthesis should be mentioned and analyzed, in terms of risk for spinal cord ischemia. More studies are needed to clarify long-term outcomes of this new device, but as previously discussed, it could be, in the next future, a real change in the paradigm of aortic arch dissection treatment, bringing with it the "paradox" of a less invasive and complex procedure for a more complete, safe, and long-term durable treatment.

In conclusion, nowadays, we have new generation devices that could simplify a challenging procedure, lower the learning curve of young surgeons, and make aortic arch intervention more reproducible as possible.

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