Future Paradigms of Aortic Dissection

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KEYWORDS

• Acute type A aortic dissection • Aortic dissection management • Root replacement
• Total arch replacement • Frozen elephant trunk

KEY POINTS

- Acute type A dissection (ATAAD) remains a challenging disease to manage, which is associated with high morbidity and mortality.
- The literature on ATAAD suggests increasing prevalence of intevention, with outcomes improving, but still carries a mortality risk between 10 and 20%.
- The proclivity for degeneration in ATAAD, necessitates not oly life-long surveillance, but also consideration of primary operations that facilitate subsequent intervention.

AORTOPATHY AS A LIFELONG DISEASE

Acute type A dissection (ATAAD) remains a challenging disease to manage, which is associated with high morbidity and mortality. Published series have demonstrated in-hospital mortality after surgical treatment of ATAAD ranging from 5.6% to 32.5%.[1,2] Several factors contribute to such discrepancy across series including center experience, time period of intervention, patient comorbidities, and extent of operation. Findings from the International Registry of Acute Aortic Dissection (IRAD) and large database analyses have given us greater perspective suggesting that over time there has been an increased rate of intervention for ATAAD with a temporal improvement in operative mortality, now overall 18%.[3,4] Among patients who survive the initial insult, patent false lumen flow persists in 43% to 77.5% of cases, which leads to residual aortic growth and mortality.[5] Indeed, the rate of aortic reintervention after ATAAD is estimated to be between 10% and 40%.[5]

Due to this proclivity of degeneration, ATAAD patients need lifelong follow-up and surveillance imaging. Follow-up is critical to continually optimize medical management and reinforce the patient's education regarding impulse control and lifestyle modifications. Surveillance imaging is mandatory to follow aortic remodeling both proximally and distally, with attention to further aortic growth and pathology. Furthermore, even in patients with isolated ATAAD without residual dissection, ATAAD increases the risk of developing further major vessel aneurysms and dissections.

To address the high rate of aortic reintervention, some groups have advocated for a more complex and invasive initial procedure to either more completely address the pathology, or to provide a platform for reliable future endovascular interventions.[1,2,6] With modern advances in open surgical techniques, improved perioperative outcomes, and novel endovascular options, the paradigm for ATAAD has become more tailored and nuanced.

BUILDING CONSENSUS

Seeking the optimal management of ATAAD has introduced numerous debates including which patients to operate on, cannulation strategy for bypass, route and temperature for cerebral protection during circulatory arrest, and proximal/

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Abbreviations	
ATAAD	acute type A dissection
FET	frozen elephant trunk
IRAD	International registry of acute aortic dissection

distal extent of the operation.[7–11] In the most contemporary IRAD cohort, 90% of patients presenting with ATAAD underwent an operation, confirming the general consensus that a majority of patients should undergo emergent open repair.[3] Exceptions are moribund patients with prolonged preoperative cardiopulmonary resuscitation or progressive/profound neurologic injury, placing them at prohibitively high risk of mortality with or without intervention and therefore precluding surgical candidacy.[10,12] Additionally, for patients presenting with static mesenteric malperfusion with end organ dysfunction, some authors propose addressing the mesenteric malperfusion first through endovascular means while maintaining patients on strict blood pressure/control, and allowing time for metabolic recovery before open aortic intervention.[9,13,14] Critics of this approach argue that a majority of patients will restore flow to malperfused beds after proximal entry tear exclusion and true lumen pressurization; furthermore, it is difficult to determine preoperatively which patients truly have static malperfusion.[15] Institutional experience and resource availability are likely to drive management in this subset of ATAAD patients.

Regarding arterial cannulation strategy for bypass, several approaches have demonstrated safety and efficacy. Peripheral femoral or right axillary cannulation allow for arterial access before sternotomy and can facilitate early initiation of bypass and cooling especially in patients with contained or impending rupture.[16] Femoral cannulation has been criticized for a higher risk of adverse neurologic outcomes and potential false lumen pressurization versus true lumen compression given retrograde flow.[17] Axillary cannulation may offer a neuroprotective advantage by flushing innominate/aortic emboli retrograde while providing antegrade cerebral perfusion during bypass, remaining available for cerebral perfusion during circulatory arrest. More recently, central aortic cannulation using the Seldinger technique with epi-aortic ultrasound or transesophageal echo guidance has gained popularity and been validated as an acceptable route of arterial cannulation.[18–20] With a slight preference for axillary and central aortic cannulation given improved neurologic outcomes, all 3 of these approaches can remain in the surgeon's armamentarium when treating ATAAD.

Nadir temperature and route of cerebral perfusion if administered during circulatory arrest have also been debated with no single strategy found to be superior. What has become clear however is that some degree of hypothermia (moderate [20–28°C] or deep [<20°C]) combined with either antegrade or retrograde cerebral perfusion has improved neurologic or mortality outcomes compared to hypothermic circulatory arrest with no cerebral perfusion.[21]

The ideal proximal and distal extent of surgery remain subjects of dispute and will likely continue to be so, as there is no *one size fits all* approach here. Contributing factors in this decision making include patient and dissection specific anatomy, presence of connective tissue disease, and surgeon experience and comfort.

In 2021 the American association for thoracic surgery published an expert consensus about the preoperative and operative management of ATAAD.[22] The document includes the considerations summarized in this section. It further states that aortic valve resuspension and ascending replacement for resection of the primary entry tear with hypothermic circulatory arrest during the distal anastomosis are recommended in most patients. Root replacement is recommended in patients with an aneurysmal root or primary entry tear in the root. Total arch replacement is reasonable in patients with entry tear in the arch, aneurysmal arch, or malperfusion with consideration of connective tissue disorders and frozen elephant trunk (FET) for improved distal aortic remodeling.[22]

CURRENT STANDARD OF CARE

As stated in the consensus above, current standard-of-care for ATAAD includes the *hemiarch* technique with an open distal anastomosis beveled on the underside of the proximal aortic arch, using hypothermic circulatory arrest, with aortic valve resuspension.

The primary goals of this approach are such: 1. Separate the heart from the dissection with the graft & suture line, thus preventing retrograde dissection to the root and subsequent pericardial tamponade, intrapericardial aortic rupture, or myocardial ischemia. 2. Resuspending the aortic valve to prevent incompetence. 3. Resecting the primary entry tear thereby pressurizing the true lumen and allowing for false lumen thrombosis.[23]

The advantages of the hemiarch technique are numerous and have been well studied. The open distal anastomosis removes any tissue that could have been injured with cross clamping. The

procedure is relatively simple, reproducible, and avoids the longer circulatory arrest time often needed with more extensive arch replacements. Furthermore, it achieves the primary goals of ATAAD repair while minimizing procedural and periprocedural complications, which are significant with ATAAD. Additionally, even in more complex dissections with arch branch vessel involvement, hemiarch replacement has been shown to be adequate in the acute setting.[2,24] And finally, despite the presence of significant aortic insufficiency, an adequate valve resuspension with recreation of a normal sinotubular junction corrects aortic insufficiency in the vast majority of cases.[2]

This approach is acceptable and appropriate in a majority of cases as it allows for an expeditious repair in the emergent setting. However, patient pathoanatomical considerations may warrant more extensive proximal and/or distal repair at the index operation. Adjunct root or valve procedures include root replacement, valve sparing root repair, and sinus replacement, depending on valvular pathology and/or the extent of dissection into the aortic root (**Fig. 1**). Distally, many groups have developed more aggressive strategies dealing with ATAAD with excellent outcomes. The strategy employed is generally a total arch replacement, often with placement of an antegrade thoracic stent graft (frozen elephant trunk).

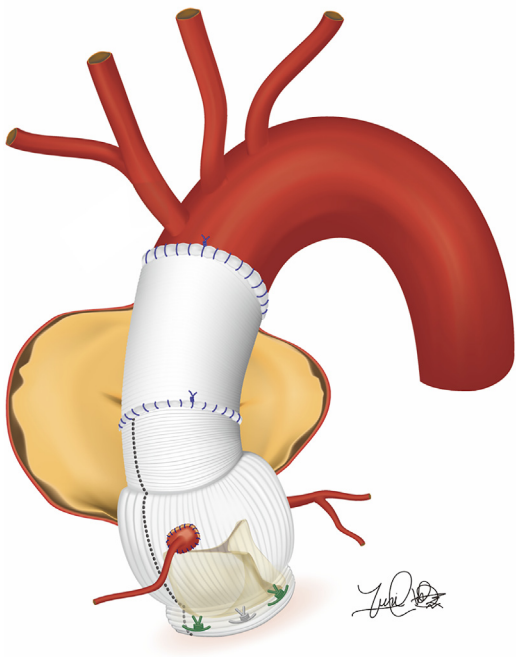

Fig. 1. Bio-Bentall Hemiarch for repair of acute type A aortic dissection in cases with more extensive root pathology. (*With permission from* Yuki Ikeno, MD.)

PATHOANATOMICAL CONSIDERATIONS: THE TAILORED APPROACH

ATAAD is a heterogenous disease with variable presentation and anatomy that is unique to each patient. The hemiarch repair with aortic valve resuspension is the standard of care because it addresses the primary pathology and above stated goals in most patients who present with the entry tear in the ascending aorta but is insufficient for patients with more complex anatomy.

Proximally, several anatomic findings either as noted by imaging (contrasted cross-sectional studies or echocardiography) or direct visualization in the field should prompt a more extensive root repair or root replacement rather than commissural resuspension: entry tear in the root, extensive disruption of the sinuses, dissection involving the coronary arteries, root aneurysm (>4.5 cm), and connective tissue disorder.[2,16,22,25] Coronary malperfusion that persists despite coronary button reimplantation or extensive coronary intimal disruption must be addressed with vein bypass grafting.[16] Depending on the indication, these are intended to eliminate persistent life-threatening pathology or prevent highly probable future degeneration.

Distally, proposed indications for a more extensive operation include large entry tear in the arch unable to be excluded with the hemiarch anastomosis, arch vessel involvement with cerebral malperfusion, arch aneurysm, connective tissue disorder, and ongoing distal malperfusion.[2,22,26,27] In the short-term, total arch replacement can address cerebral and lower body malperfusion if the entry tear anatomy is not amenable to hemiarch repair, but the remaining indications seek to mitigate late aortic degeneration. Therefore, surgical decision-making must balance the imperative of comprehensively addressing the immediately life-threatening pathology while minimizing operative risk with long-term durability of the repair.

PROXIMAL REINTERVENTION AFTER *STANDARD* REPAIR

All segments of the aorta left intact during initial dissection repair are at risk of degeneration with time. Several retrospective studies have evaluated the long-term outcomes after root sparing ATAAD repair. Ikeno and colleagues presented a cohort of 339 patients who had undergone supracoronary ATAAD repair. Twenty-five patients required root-related reoperation with a cumulative incidence of 2.6% at 5 years and 8.8% at 10 years. Indications for reoperation were recurrent dissection in 13 patients (4.4%), pseudoaneurysm in 6 patients

(2%), root dilation in 3 patients (1%), infective endocarditis in 2 patients (0.7%), and aortic regurgitation in 1 patient (0.3%).[28] Notably, contemporaneous patients underwent root replacement at their index operation for similar anatomic considerations as described in the previous section. The results from Kobe University thus provide insight into the long-term fate of the root appropriately selected ATAAD patients for root sparing operations.

Bojko and colleagues describe the experience from University of Pennsylvania, which demonstrated 1.5% incidence (9/585 patients) of reoperation at a median time of 5.5 years in patients who underwent root sparing ATAAD repairs, which was lower than the reoperation rate in the root replacement cohort from the same time period (6.1%, 8/131 patients). Indications for reoperation included aneurysm, pseudoaneurysm, and aortic insufficiency.[29]

Fleischman and colleagues and Jormalainen and colleagues similarly found that with well-defined criteria stratifying patients to root sparing repair versus root replacement, root sparing repair can achieve reasonable durability with low reintervention rates (5.4% and 3.7% respectively).[30,31]

These data reinforce the importance of appropriate patient selection for root sparing repair versus root replacement in ATAAD, allowing for good long-term outcomes. Many series have also validated both valve-sparing and valved conduit root replacements in ATAAD as having acceptable outcomes and therefore safe to perform when indicated.[2,29–32]

RATIONALE FOR MORE EXTENSIVE INITIAL OPERATION DISTALLY

Advantages of a more aggressive arch approach include resecting existing disease in the arch, preventing future arch degeneration, setting the patient up for future endovascular aortic interventions, and improved aortic remodeling. While the primary entry tear is usually in the ascending aorta, the dissection extends in many patients to the aortic arch and beyond, typically to the aortic bifurcation.[33] Proponents of a more aggressive arch strategy argue that a solely proximal repair does not address the dissected arch or descending aorta, which is prone to aneurysmal degeneration.[6,33] Advocates of a total arch/FET strategy suggest it is a safe method that allows for dissection repair with obliteration of the false lumen and improvement in aortic remodeling.

A more extensive initial approach to ATAAD has many flavors depending on institution/surgeon experience and the individual patient's pathology. Despite modern developments and perioperative care, morbidity and mortality of ATAAD remains high.[34] Furthermore, there is a distal reoperation rate of 5% to 15% at 5 years and 15% to 25% at 10 years.[1] Additionally, ATAAD limited to the ascending aorta and/or arch represent only 35% of all ATAAD.[35] For the approximately 65% of ATAAD with distal disease, the persistence of false lumen patency predicts worse 10-year survival and lower freedom from distal reintervention.[36] Reoperative surgery to address distal disease is well described and can be performed safely in high-volume centers of excellence; however, it still carries significant operative risk.[37] Finally, managing patients with residual disease is predicated on regular surveillance, and many are unfortunately lost to follow-up.[38]

These arguments provide the rationale for a more extensive initial operation. For patients with arch or descending involvement, extending the initial operation to include zone 2 aortic arch replacement or FET avoids the risk of arch degeneration and provides a platform for future descending repair. Furthermore, more partial or total arch replacement not only prevents future aneurysmal degeneration but also addresses arch or distal entry tears. With the advent of branched aortic endoprostheses, the feasibility of TEVAR to definitively manage these complex patients increases.[39]

ZONE 2 ARCH REPLACEMENT

The zone 2 partial arch replacement has been well described and has several advantages. The zone 2 open anastomosis is technically not significantly more complex than a standard hemiarch anastomosis, increasing the applicability of the technique to a larger percentage of cardiac surgeons. The zone 2 anastomosis also addresses a large proportion of arch entry tears, eliminating false lumen pressurization for the innominate and left carotid arteries. By creating the anastomosis in zone 2 instead of the more traditional zone 3 total arch solution, there is a significantly lower risk of left recurrent laryngeal nerve injury.[40] Finally, with the advent of off-the-shelf branched thoracic endoprostheses such as the Gore TBE device, future aortic pathology can be dealt solely endovascularly.[39]

TOTAL ARCH REPLACEMENT/FROZEN ELEPHANT TRUNK

Total arch replacement with FET is a popular technique in aortic centers to address the entire arch pathology as well as the proximal descending aorta

(Fig. 2). This technique was pioneered in 1996 and offers a single-stage hybrid total arch replacement (figure). The FET outperformed the conventional elephant trunk, not only with ease of use but also patient survival.[41] The advantages of FET over a zone 2 replacement is that a FET provides a total arch replacement with an endoprosthesis that extends the repair into the descending aorta, allowing for false lumen thrombosis, improved aortic remodeling, and a platform for relatively straightforward future aortic reinterventions if necessary. Additionally, the FET open anastomosis can be performed at zone 2 as well, allowing for a reduced risk profile over the traditional zone 3.[42]

The outcomes are acceptable for traditional hemiarch, zone 2, and FET. However, hemiarch is associated with the best short-term survival but a somewhat higher risk of distal aortic degeneration and need for subsequent interventions.[5] Zone 2 replacement offers a similar risk profile to the hemiarch, while also providing an adequate platform for future endovascular interventions, and also removing the dissection from the innominate and carotid arteries. Finally, FET replaces the entire arch and provides coverage for the proximal descending aorta; however, this comes with some increased morbidity. There is some incidence of spinal cord ischemia with FET depending on patient pathology and length of coverage.[43,44]

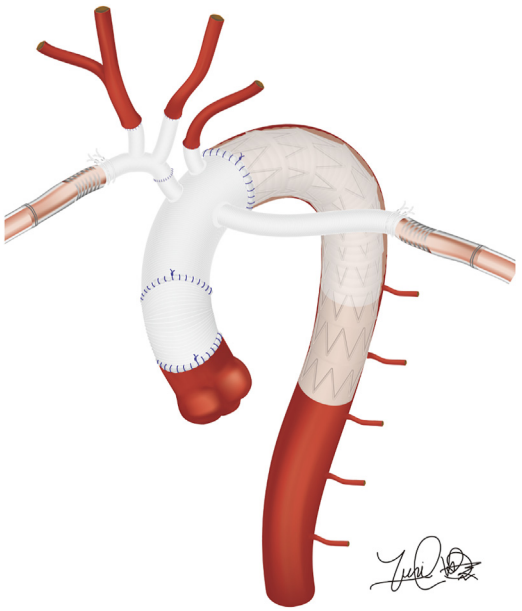

Fig. 2. Total arch replacement with FET. The arch vessels are addressed by sequential debranching and anastomosis to a multi-branch graft during cooling, which is subsequently attached to an additional arterial inflow cannula from the bypass circuit, allowing for continuous antegrade cerebral perfusion. The distal anastomosis is performed under circulatory arrest with deployment of the FET stent into the descending thoracic aorta. During rewarming the multi-branch graft and proximal aorta vs root conduit are anastomosed to the arch graft. (*With permission from* Yuki Ikeno, MD.)

The current data is somewhat mixed regarding long-term outcomes comparing modalities; however, our view is that despite the increased surgical complexity and potential morbidity of a FET, the data suggests a long-term survival benefit and aortic remodeling benefit. FET has been shown to be beneficial in younger patients who in particular have an increased risk of future aortic events and are most likely to require future reinterventions. This also extends to patients with connective tissue disorders or a strong genetic predisposition, with FET providing a reduced reintervention rate and improved long-term survival.[45]

DICHOTOMIES AND THE FUTURE

Chikwe and colleagues and Dobaria and colleagues used data from the National inpatient sample to determine volume dependence on outcomes in ATAAD surgery. Not surprisingly, there is a stark divergence in outcomes between high-volume and low-volume centers/surgeons. High-volume centers achieve operative mortality nearly half of what is observed at low volume centers. Despite this, a plurality of ATAAD care is provided at low-volume centers.[46,47] This reality has prompted the question of whether or not to centralize ATAAD care to high-volume centers with experienced aortic specialists poised to manage the complex operative/perioperative needs of these patients.[15] Ironically this would be most feasible to achieve in dense urban areas with well-organized/coordinated emergency services that tend to have multiple high-volume aortic centers within short range. Yet a majority of the American land mass is occupied by empty space with hundreds of miles separating one center of excellence from another, making tertiary care inaccessible to many dissection patients who require emergent care. Therefore, surgical management of ATAAD will remain the burden of the general cardiac surgeon as much as the aortic specialist. As a result, there will be a persistent dichotomy of competing interests in its management: on one hand we will continue to ask what is the minimum necessary to address patients' pathology and save their life, what is accessible, reproducible, and safe; on the other hand, aortic specialists will be asking how much more can we do now to minimize and/or prepare for future intervention.

Surgical decision-making needs to be tailored to the individual patient. Patient comorbidities, condition at presentation (shock, neurologic deficits,

malperfusion, or malperfusion syndrome), anatomy, and extent of dissection tears (root involvement, coronary involvement, arch or arch vessel involvement, distal involvement, location of re-entry tears), and surgeon experience should factor into the operative approach. This is complex and multifactorial, but in a pinch it can be simplified for the generalist: (1) pick a familiar cannulation strategy, (2) cool the body, (3) protect the heart and the brain, (4) hemiarch unless brain not flowing, (5) decide the root. The downstream fate of the aorta can be decided at a later date by a multidisciplinary team of aortic specialists once the patient has survived the initial insult. Branched endovascular prosthesis will make redo sternotomy for distal reintervention optional if indicated. All patients should be followed routinely for surveillance.

In summary, ATAAD is a complex and heterogenous disease that is associated with high morbidity and mortality. It is a disease process that is both immediately life-threatening and in the long-term as the aorta continues to remodel or degenerate. Thus, it requires a technically demanding salvage, serial evaluation, and reintervention when indicated. In the chronic phase, it is best managed by specialists. The persistently elevated morbidity and mortality poses an ongoing challenge for surgeons to continue to refine operative strategies.

CLINICS CARE POINTS

- Primary goals of ATAAD care remain separation of the dissection from the root and getting the patient through this high risk situation.
- Extent of repair, bot proximally and distally remains subject to anatomic issues, patient ability to tolerate the procedure, and, most importantly, surgeon preference.
- Increasingly, procedures are becoming more extensive with a deliberate approach to facilitating subsequent endovascular reintervention.

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