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Editorial

Current Strategies in Repair of Aortic Dissections

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1. Introduction

Aortic dissections can be classified both temporally and anatomically. There are four time domains: hyperacute (<24 h), acute (2–7 days), sub-acute (8–30 days), and chronic (>30 days), and two separate anatomical classifications [1]. The DeBakey classification categorizes dissections based on the origin and extent of the dissection, the Stanford classification divides dissections into whether the ascending aorta is involved (type A) or not involved (type B). Generally, emergent surgical management of type A dissections is indicated, and medical therapy is indicated for the majority of uncomplicated type B cases. In acute type A aortic dissections (ATAAD), emergent surgical management is indicated due to a high mortality with medical management, with pre-hospital mortality estimated at 21%. In-hospital mortality rises exponentially every hour, underscoring the critical need for rapid identification and intervention [2,3,4].

The extent of surgical repair at the time of ATAAD remains controversial. Patients with limited initial acute repair remain at risk for late aortic degeneration, re-intervention, and mortality, prompting consideration for initial therapeutic goals from solely emergent survival to a more durable option with aortic stability [5]. This re-evaluation is marked by the emergence and adoption of advanced surgical and endovascular technologies. However, these must be evaluated not only for their efficacy but also in the context of real-world constraints such as the critical importance of reducing operating room (OR) time, the challenges in low-volume centers, and the surgical team's expertise.

2. Acute Type A Dissection: Balancing Acute Risk and Long-Term Stability

The emergent surgical repair of ATAAD remains a significant procedure where opportunities to reduce OR time and complexity directly impact patient survival [6]. The presence of preoperative malperfusion, affecting up to one-third of ATAAD patients, exponentially worsens outcomes, with mortality rates exceeding 25% even with a successful repair [7]. The standard of care in these patients is graft replacement of the ascending aorta, an easily reproducible procedure, especially in limited-volume centers, where the primary goal is rapid restoration of antegrade flow [8]. However, its major drawback is the residual distal false lumen [9]. Long-term imaging studies show that this patent false lumen is the primary driver for late aortic expansion, with a reoperation rate of 14.1%-33.9% within 10 years [9,10]. In view of this poor long-term outcome, ascending aorta and hemiarch repairs are more of a temporizing measure rather than a definitive repair, prompting future reintervention.

In the management of ATAAD, the rapid deployment of a Multidisciplinary Team (MDT) is key to navigating the decision-making required within the initial 24-hour window. Members of the ATAAD MDT typically include cardiac surgeons, vascular surgeons, cardiovascular anesthesiologists, emergency care providers, and intensive care specialists [11]. To minimize intervention delays, high-volume centers often utilize a streamlined 'Aortic Code' activation system, which simultaneously notifies all core members via a centralized alert once a diagnosis of ATAAD is confirmed by imaging. This coordination allows for parallel processing, where the operating room is prepared and anesthesia is mobilized while the surgical team finalizes the operative plan, thereby reducing the 'door-to-incision' time and ameliorating the hourly rise in mortality associated with delayed interventions.

The high reintervention rate is a driver for more complex arch interventions including total arch replacement, hybrid approaches with ascending replacement and a bare metal stent arch repair (AMDS stent, Ascyrus Medical GmbH, Frankfurt, Germany), and arch debranching with the frozen elephant trunk (FET) technique, which can be more technically and resource demanding (Fig. 1, Ref. [12]) [13]. The long-term data for FET are compelling, with a 2022 meta-analysis reporting a late reintervention rate of 7% [14]. By proactively stabilizing the arch and descending aorta, FET aims to create a "one-and-done" repair, but at the cost of increased technical complexity and operation time. This is a critical issue, as data from the German Registry for Acute Aortic Dissection Type A identified prolonged cardiopulmonary bypass time as an independent predictor of 30-day mortality [7]. The learning curve and technical demands of FET challenge surgeons with limited experience in complex arch reconstruction, especially at low-volume centers. There is evidence demonstrating a strong volume-outcome relationship in aortic surgery. A retrospective review of the Society of Thoracic Surgeons

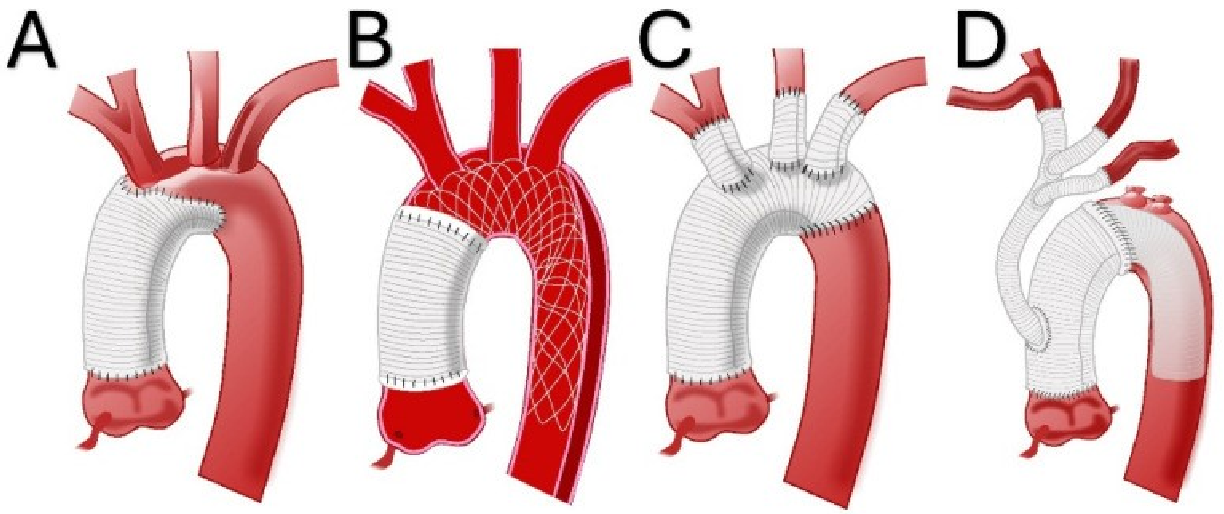

Fig. 1. Surgical management of the aortic arch: Hemiarch repair (A), repair with the AMDS hybrid prosthesis (B), total arch repair (C), and total arch repair with a frozen elephant trunk and debranching to zone 0 (D). Reprinted from El-Andari and Moon [12].

Adult Cardiac Surgery Database (STS ACSD) showed that high-volume centers had significantly lower operative mortality for arch replacement compared to low-volume centers (3.4% vs 5.8%) [15]. This strongly suggests that for many institutions, a safe, well-executed hemiarch repair is superior to a poorly executed or prolonged FET, making the simpler procedure the most appropriate choice.

The management of ATAAD requires a trade-off between the necessity for immediate surgical intervention and the potential benefits of specialized distal reconstruction at high-volume centers. Due to the mortality increasing approximately 1–2% per hour following the onset of symptoms, immediate in-hospital hemiarch repair remains the standard of care for hemodynamically unstable patients presenting with complications such as cardiac tamponade or acute malperfusion [6]. However, for stable patients, there is a shift toward a 'hub-and-spoke' model where transfer to high-volume centers for FET procedures is prioritized if specific anatomical criteria are met, such as primary entry tears located in the arch or the presence of pre-existing arch aneurysms. Recent evidence suggests that the risk of death during a coordinated inter-hospital transfer is offset by enhanced operative outcomes and lower mortality rates achieved by high-volume teams [16]. Ultimately, the decision to refer versus operate on an immediate local repair must be personalized, balancing the patient's physiological reserve, functional status, the complexity of the aortic pathology, and the institutional volume of the presenting facility.

Further complexity is added at the aortic root level. When the dissection tear is in the root or if there is extensive root destruction or dilation, a root replacement is indicated, and the surgical team must decide between composite valve-graft replacement (CVG), valve-sparing root replacement (VSRR), or supra-commissural ascending aorta replacement with aortic valve re-suspension. When replacing the aortic root in ATAAD, the CVG is less technically demanding and reduces operating time, but mechanical CVG necessitates lifelong anticoagulation, and tissue CVG can degenerate and require re-intervention. In younger, suitable patients, who are typically defined as under 60 or 65 years of age, in order to mitigate lifelong anticoagulation and prosthetic valve complications, VSRR offers the benefit of preserving the native valve [17]. However, like FET, VSRR is a technically complex procedure where success is highly dependent on surgical experience with a clear volume-outcome relationship. Long-term data from experienced, high-volume centers reported a 10-year freedom from aortic valve reoperation of 97% [18]. For older patients with intact native valves, the choice must weigh the increased operative complexity and prolonged cross-clamp times of VSRR against the more traditional CVG or another biological root replacement. In these older individuals, the reduced life expectancy may mitigate the long-term concerns of anticoagulation or bioprosthetic degeneration, often making a biological CVG the more effective choice to minimize perioperative morbidity in the acute phase of dissection. Ultimately, the risk-benefit profile shifts from prioritizing long-term valve durability in younger patients to ensuring immediate surgical survival and simplified postoperative management in older patients. In older patients with contraindications to anticoagulation, we favor tissue CVG with plans for a valve-in-valve transcatheter valve replacement if the tissue valve degenerates in the future.

The acquisition of proficiency in complex aortic arch interventions, specifically FET, is significantly accelerated through the integration of simulation-based curricula and long-term clinical proctoring. Simulation allows for the deliberate practice of distal anastomosis and stent-graft deployment in a risk-free environment, which has been validated to shorten the technical learning curve and reduce intraoperative "down-time" during the initial clinical cases [19]. In regard to professional standards for independent performance, there is currently no universal, rigid numerical requirement for supervised cases mandated by global surgical societies.

3. Acute Type B Dissection: Medical Management or Endovascular Repair

The management of acute Type B aortic dissection (ATBAD) has the benefit of not being restricted to solely open surgical management, and is often managed medically. However, the emergence of Thoracic Endovascular Aortic Repair (TEVAR) has proved to be very successful in situations necessitating repair, including ongoing pain or malperfusion. A 5-year follow-up of the Investigation of Stent Grafts in Aortic Dissection (INSTEAD-XL) trial confirmed that preemptive TEVAR provided higher rates of aortic remodeling (90.6% vs. 19.4%; $p < 0.001$) and better 5-year aorta-specific survival (93.1% vs. 80.7%; $p = 0.04$) compared to medical therapeutics alone—establishing clear benefit in intervention. [20,21]. The criteria for "high-risk" have been progressively refined, with key predictors of late aortic expansion identified as an initial aortic diameter >40 mm, then a primary entry tear >10 mm on the inner curvature, and finally a false lumen diameter >22 mm, in order of priority [22,23]. For patients with poorly controlled comorbidities like hypertension, which acts as a powerful driver of false lumen pressurization and aortic growth, these factors need to be considered. In hypertensive patients, the threshold for early TEVAR is often lowered, as the risk of catastrophic aortic rupture may outweigh the risks of early intervention even if the anatomical predictors do not meet the maximum established cutoffs [24]. Additionally, as opposed to open procedures, TEVAR is technically less complex, involves less operative time, and is highly reproducible [25].

Long-term surveillance following TEVAR for the detection of late complications, including endoleaks, stent-graft migration, and progressive distal aortic expansion, involves assessments at 1, 6, and 12 months post-procedure, followed by annual surveillance. To mitigate the risks of cumulative radiation exposure and potential nephrotoxicity from repeated iodinated contrast throughout a patient's lifetime, Magnetic Resonance Imaging (MRI) is the preferred surveillance modality over Computed Tomography Angiography (CTA), only if the implanted stent-graft is MRI-compatible. MRI provides superior soft-tissue characterization for monitoring false lumen thrombosis and aortic wall morphology without the use of ionizing radiation, unlike CTA [26]. Surveillance of chronic dissections is centered around assessment for aneurysmal degeneration of the remaining dissected segments. Criteria for reintervention include size (~5.5 cm) or rapid growth, as well as complications, including malperfusion or an acute aortic event.

Further development of ATBAD procedures, such as the Provisional Extension To Induce Complete Attachment (PETTICOAT) concept using a distal bare-metal stent such as the Ascyrus Medical Dissection Stent (AMDS, Ascyrus Medical GmbH, Frankfurt, Germany), further diversifies the approach to these patients. This streamlined approach helps reduce operative time and may lower the barrier to adoption in low-volume centers, allowing more patients to benefit from the proven advantages of early endovascular repair. The long-term durability of these procedures appears promising; in this cohort, 10-year follow-up data for TEVAR in chronic Type B aortic dissection demonstrated a cumulative survival rate of 89.9% and a freedom from reintervention rate of 79.0% [27]. However, concerns regarding late complications—such as endoleaks and incomplete false lumen thrombosis—persist, necessitating lifelong surveillance to identify and manage potential adverse aortic events.

The application of PETTICOAT in ATBAD is primarily constrained by anatomical factors such as severe aortic tortuosity, narrow true lumen dimensions, and extensive visceral vessel involvement originating from the false lumen. Severe tortuosity increases the risk of stent-graft kinking or incomplete expansion, while visceral vessels arising from the false lumen may be inadvertently compromised during true lumen expansion [28]. To manage these cases, PETTICOAT is often adjusted by incorporating 'chimney' or fenestrated stent-graft designs to maintain branch vessel patency, or by utilizing intravascular ultrasound to ensure precise bare-metal stent placement across the visceral segment. These modifications allow for effective true lumen stabilization and resolution of malperfusion even in the presence of challenging thoracic anatomy.

4. Emerging Technologies and Future Directions

The new frontier in the management of aortic dissections will likely be traversed by advanced diagnostics and the rise of personalized medicine. Computational fluid dynamics (CFD) is emerging as a powerful research tool to analyze aortic hemodynamics. Studies using CFD have identified parameters such as wall shear stress and turbulent flow within the false lumen as potential predictors of aortic expansion, offering enhanced risk stratification beyond current straightforward anatomical measurements [29]. The integration of CFD into routine risk stratification for aortic dissection is currently limited by barriers, primarily high computational cost, specialized engineering expertise, time, and the absence of standardized, automated workflows [30]. The time-intensive nature of patient-specific geometry reconstruction and hemodynamic simulation remains largely incompatible with the rapid decision-making required in acute clinical settings. However, feasible solutions for widespread adoption are emerging, such as the development of artificial intelligence-driven automation for image segmentation and the utilization of cloud-based computing to reduce the need for local infrastructure. When applied to ATBAD and even ATAAD, this could allow for even more precise selection of patients for early intervention or reintervention.

Artificial intelligence and machine learning algorithms are being developed to integrate vast amounts of clinical, surgical, imaging, laboratory, and genomic data to create predictive models for the risk of dissection, growth, rupture, and other adverse outcomes [31,32]. These tools could aid clinicians and surgeons in personalized risk calculation and management of patients with a complicated clinical history and postoperative course. Therapeutic innovations such as novel endografts with enhanced flexibility, lower profiles, and bioactive surfaces are being designed to promote healing. The use of fenestrated and branched endografts may become more standardized for complex arch and thoracoabdominal disease, though this will again raise the issue of the steep learning curve and the need for specialized training centers.

5. The Modern Standard: An Evidence-Based, Multidisciplinary Approach

The recent accumulation of high-quality evidence supports a proactive and anatomically comprehensive approach to aortic dissection - prioritizing reducing reintervention. For ATAAD, the choice between standard hemiarch or more complex arch debranching or replacement with FET must be carefully weighed, balancing the long-term benefit of FET against the immediate, life-threatening risk of prolonged operation, especially in limited-volume centers. The successful implementation of these strategies requires a multidisciplinary aortic team to make nuanced, evidence-based decisions that accurately account for the patient's anatomy, the urgency of the situation, and the specific institutional and surgical capabilities. While the initial goal in managing an ATAAD is immediate survival, more extensive repair can aim to restore the aorta to a stable, durable state for the remainder of the patient's life.

6. Conclusion

The contemporary management of aortic dissections requires a careful balance between securing immediate patient survival and achieving long-term, durable aortic stability. While traditional surgical and medical therapies offer critical rapid stabilization, the persistent risk of late reintervention continues to drive the adoption of more comprehensive surgical and endovascular techniques. Moving forward, the successful integration of these advanced treatments will depend on a multidisciplinary team approach, leveraging emerging diagnostic technologies to personalize care based on individual patient anatomy and institutional capabilities.

Author Contributions

NA and MCH were responsible for the conception of ideas presented, writing, and the entire preparation of this manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

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Conflicts of Interest

The authors declare no conflicts of interest.

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