A brief history of aortic surgery: Insight into distal aortic repair

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The contemporary history of aortic surgery is indebted to early visionaries such as Moore, Matas, Carrel, Guthrie, Tuffier, and Halsted, among many others. Moore advocated using silver wire to stimulate thrombosis in aortic aneurysms; Corradi modified this process by adding an electric current to further stimulate thrombosis. Matas¹ promoted the technique of endoaneurysmorrhaphy, reshaping the aorta with 1 or 2 series of continuous suture, which would not compromise any developed collateral circulation because the aneurysm was not resected but rather folded in and secured with suture. The experiments of Carrel and Guthrie² included reattaching blood vessels with direct anastomosis after resection; this technique maintained arterial continuity by using short sections of interpositioned vein.

Sir Astley Cooper is widely considered to have been the first to use simple ligation (partial or full proximal occlusion of the aneurysm with banding materials and without resecting the aneurysm) to treat an abdominal aortic aneurysm, and Tuffier is commonly credited with first applying this approach to a thoracic aortic aneurysm; however, both of these early attempts were unsuccessful. Halsted and Matas also explored ligation approaches: Halsted³ incorporated an aluminum band as ligature material (which had a tendency to cut through the aortic tissue), and Matas,⁴ even as late as 1940, promoted the use of proximal ligation to reduce the aortic stream to about 1/10 or 1/8 of the caliber of a normal aorta, thus inducing the obliteration of the aneurysm through the gradual deposit of clot. Although ligation repairs were occasionally successful, for many patients—especially those treated before 1920—the result was death from necrosis, shock, rupture, or hemorrhage.⁵

Interest in replacing aneurysmal distal sections of the aorta was piqued by the successful use of suture-based

and homograft-replacement repairs of aortic coarctation by Crafoord, Gross, and others in the mid-1940s. Developments in the use of homografts in repairs involving aortic resection and techniques for restoring arterial continuity allowed surgeons to replace increasingly large sections of the descending thoracic aorta, as in the 8-cm repair of a coarctation-related descending thoracic aneurysm.⁶ It remained unclear, however, how patients with distal fusiform aneurysms would respond to aortic cross-clamping; spinal cord ischemia had plagued Blalock's experimental work on aortic coarctation, and the rapid release of the aortic clamp was suspected in the fatal cardiac arrest of Gross's young coarctation patient.⁷ A primary concern was the lack of developed collateral circulation in patients with aortic aneurysm. Additionally, the use of homografts as an arterial substitute was fraught with difficulties, including the complexity of preservation techniques, poor availability, and emerging reports of early degeneration.

Alternate options for aortic repair included the use of nonsuture anastomosis approaches to replace sections of the aorta⁸ (the most successful of which was the replacement of a section of the descending thoracic aorta with a Lucite polymer tube and the ball-and-cage Hufnagel aortic assist valve⁹) and the use of cellophane wrapping (or, less frequently, the application of cellophane's active ingredient, dicetylphosphate) to irritate and scar the outer aortic layer and thereby strengthen it. In 1940, in a canine model, Pearse¹⁰ demonstrated the gradual occlusion of the aorta after ordinary cellophane film was wrapped around it. This technique was popularized by Poppe, who reported his results of treating syphilitic aneurysms in 1947 and 1948. Of note, in 1948, Albert Einstein was treated with cellophane wrapping to repair a symptomatic abdominal aneurysm; when his symptoms returned in 1955, Einstein declined further treatment and died soon afterward of aortic rupture.¹¹

Aortography, introduced by dos Santos in 1929, greatly facilitated the detection of aortic abnormalities. As late as the early 1950s, however, the definitive method of repairing aortic aneurysms had not yet been determined. Ligation, cellophane wrapping, endoluminal wiring, and other techniques were all well-accepted treatments in this era, and often they were used in various combinations in individual cases.¹² Although some techniques were suitable for repairing proximal aortic aneurysms, which were commonly syphilitic and saccular, these techniques were largely unsuitable for the larger, fusiform aneurysms of the distal aorta, which were usually atherosclerotic in origin. By the early 1950s, there had been a few seemingly successful repairs of saccular proximal aortic aneurysms and resections

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of short sections of the descending thoracic aorta in coarctation repairs, but no one had yet attempted to replace the thoracoabdominal aorta.

In 1951, Dubost and colleagues¹³ successfully resected an abdominal aneurysm and replaced it with a homograft through a retroperitoneal approach; this achievement was soon replicated by several other surgeons, including DeBakey and Cooley¹⁴ in 1952, who used a transperitoneal approach. Also in 1951, Lam and Aram¹⁵ attempted a homograft replacement of a true descending thoracic aortic aneurysm and, in deference to Hufnagel, used a Lucite polymer tube as a shunt. When the patient died of a mediastinal abscess caused by necrosis of the residual aneurysm, Lam and Aram¹⁵ opined that the patient might have lived had they fully resected the aneurysm. In 1952, DeBakey and Cooley¹⁶ successfully resected an aneurysm of the latter portion of the descending thoracic aorta (of note, there is current discussion¹⁷ as to whether this case should be considered a thoracoabdominal aortic aneurysm [TAAA] repair) and replaced it with a homograft by using a “clamp-and-sew” approach. Thus these early homograft approaches favored full resection of the aneurysm, entirely unlike contemporary ligation approaches. Tolerance to aortic ischemia appeared to be somewhat unpredictable and multifactorial; paraplegia was therefore a significant concern in these early distal thoracic aortic repairs. Moderate hypothermia and the use of shunts to provide distal aortic blood flow were explored as means to protect against ischemia.

Early attempts to repair TAAAs were complicated by the thoracoabdominal aorta's branching vessels and the persistent threats of spinal cord ischemia and renal failure. Reports of successful repairs involving homograft replacement emerged in 1955 from both Rob¹⁸ and Etheredge and associates,¹⁹ and in 1956, DeBakey and colleagues²⁰ reported 4 such repairs in which a variety of techniques were used, such as hypothermia, shunting, and giving priority to the reattachment of renal arteries. Aneurysms were completely extirpated, and intercostal arteries were not reattached. Only 2 of the 4 patients in that series survived repair.

Contemporaneous with the continued exploration of hard plastic tubes as arterial substitutes, woven plastic arterial substitutes were considered. Synthetic arteries made of vinyon N were first developed by Voorhees and coworkers²¹ in 1952 after Voorhees noticed the endothelialization of suture material and thought that this inert material could serve as a scaffold for cellular infill, somewhat like the fibrin tubes that had been considered for this purpose in the 1940s. Several arterial substitutes (such as Orlon [acrylic fiber], nylon, taffeta, nylon-Dacron polyester fabric, crimped nylon tubes, plastic-dipped Orlon, and Ivalon polyvinyl sponge) were tried, but Dacron (first used by DeBakey) was deemed most suitable, although graft porosity remained a problem in early repairs.

In the late 1950s and the 1960s, distal aortic aneurysm resection and replacement often involved an extra-anatomic approach, which took advantage of these readily available replacement grafts. In thoracoabdominal aortic repair, most often the graft would be anastomosed end-to-side and placed around the aneurysm, such that the graft could be used as an intermediate shunt before full or partial resection of the aneurysm. Branched grafts were frequently used to reattach the visceral arteries, and most commonly, the renal arteries were reattached first. In this era, intercostal arteries continued to be sacrificed. Toward the end of the 1960s, the need for full resection of the aneurysmal section of the aorta was beginning to be questioned, particularly in abdominal and descending thoracic aortic repair. Creech²² suggested that leaving a portion of the back aortic wall (after ligating intercostal arteries) was faster and probably safer than freeing residual, adherent aortic tissue from the lung, the inferior vena cava, or other structures and would help preserve collateral circulation. Crawford and colleagues²³ additionally suggested covering abdominal grafts with the outer layer of the aortic wall to reduce postoperative bleeding.

In the 1970s, Crawford²⁴ popularized techniques for TAAA repair that followed anatomic approaches to aortic replacement, drawing on the earlier work of Carrel and Guthrie, Javid, and Spencer. Crawford used an anatomic endovascular-graft-inclusion technique, reimplanted patches of intercostal arteries to better perfuse the spinal cord, reattached the visceral arteries as an island to an oval opening made in the graft, and avoided full resection of the aneurysm, instead wrapping the remaining wall around the replacement graft. Crawford's techniques improved early survival to 92%²⁴; however, this anatomic approach to TAAA repair was not without controversy. It was thought to increase the risk of ischemia,²⁵ and even DeBakey²⁶ continued to promote the extra-anatomic, graft-as-bypass approach to repair as late as 1979.⁶ Crawford readily adopted experimental adjuncts and techniques, such as the selective perfusion of renal arteries, cerebrospinal fluid drainage, and Borst's elephant trunk approach, to improve patient outcomes. We have honored Crawford's legacy by conducting randomized trials of different renal perfusion techniques^{27,28} and of cerebrospinal fluid drainage,²⁹ as well as a study regarding the use of left heart bypass to reduce distal ischemia.³⁰

The modern history of distal aortic aneurysm repair has been heavily influenced by the advent of endovascular approaches. First tested experimentally by Dotter in the late 1970s and used clinically by Volodos and colleagues³¹ a decade later, endovascular aortic repair was popularized by Parodi and Dake in the early 1990s. Endovascular repair is now more common than open repair for abdominal aortic aneurysms, and it is frequently used to repair descending thoracic aortic aneurysms. Combined open and endovascular approaches were attempted as early as the mid-1990s

to repair complex aneurysms of the thoracoabdominal aorta in compromised patients; however, the use of hybrid approaches did not become relatively widespread until the 21st century. Likewise, purely endovascular repair of these complex aneurysms has attracted both great interest and great talent but remains an experimental approach, at least for the immediate future, because none of the developing fenestrated and branched endovascular approaches to TAAA repair are likely to receive federal approval in the near future. Furthermore, recent studies of abdominal endovascular aortic repair indicate that its early survival advantages relative to open aortic repair are lost within 24 months after the procedure.³² In addition, questions regarding the long-term durability of endovascular aortic repair remain unanswered. Undoubtedly, the future of aortic surgery will be greatly influenced by advancement in endovascular technology and by those who perform these procedures, but in the near term, open aortic repair continues to be the standard of care for most patients with aortic disease.

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