5 Classification Systems Relevant to Complex Endovascular Aortic Repair

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Introduction

Endovascular aortic repair (EVAR) has become the first treatment option for most patients with aortic aneurysms and dissections. Anatomical constraints for EVAR include presence of suboptimal necks, angulation, and aneurysm involvement of side branches. In the last decade, technical developments have focused on branch incorporation using a variety of techniques including fenestrations, directional branches, and parallel stent grafts. Specifically designed fenestrated and branched stent grafts were introduced as a minimally invasive alternative to treat complex aneurysms, allowing proximal extension of the stent graft without compromising seal and aneurysm exclusion [1]. This chapter focuses on description of definitions and classification systems which are pertinent to use of complex endovascular techniques to treat aortic aneurysms and dissections [2].

Types of Repair

Branch incorporation has been performed using a variety of methods. In essence the aortic stent-graft component is connected to a specific target vessel by means of a bridging stent, but the specific connecting mechanism varies. The classification of stent design takes into consideration that connecting mechanism and the quality or actual diameter of the aorta at the level of the side branch. It is important to acknowledge that definitions represent the most common terminology used in the literature and by pioneers, but these terms have not yet been validated by society reporting standards.

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Fenestrated and Branched Stent Grafts

The term *fenestrated endovascular repair* is applied when a fenestrated stent graft is used to repair an aneurysm with inadequate or short infrarenal neck (Fig. 5.1a), yet the target vessels (e.g., renal arteries) arise from normal aorta. There is no gap between the fenestration and the target vessel. Alignment stents are typically used to prevent vessel occlusion or stenosis from misalignment between the fenestration and the origin of the target vessel.

Branched endovascular repair is the term used to describe endovascular repair of aneurysms with frank involvement of side branches. The target vessel originates from the aneurysm and there is a gap between the main stent graft and the aortic wall. Branched stent grafts are currently performed using one of the two approaches. *Fenestrated branches* are based on reinforced fenestrations bridged by balloon-expandable covered stents (Fig. 5.1b). *Directional or cuffed branches* are based on pre-sewn cuffs (Fig. 5.1c), which can be straight, helical, downgoing, upgoing, internal, or external. These branches are bridged by self-expandable stent grafts.

Parallel Stent Grafts

Parallel stent-graft techniques have been widely used as bail out or as primary treatment in patients with compromised aortic necks. This broad term includes a variety of techniques. Chimneys or snorkel stent grafts imply the use of stents placed from brachial access with downgoing orientation (Fig. 5.2a). The technique was first described by

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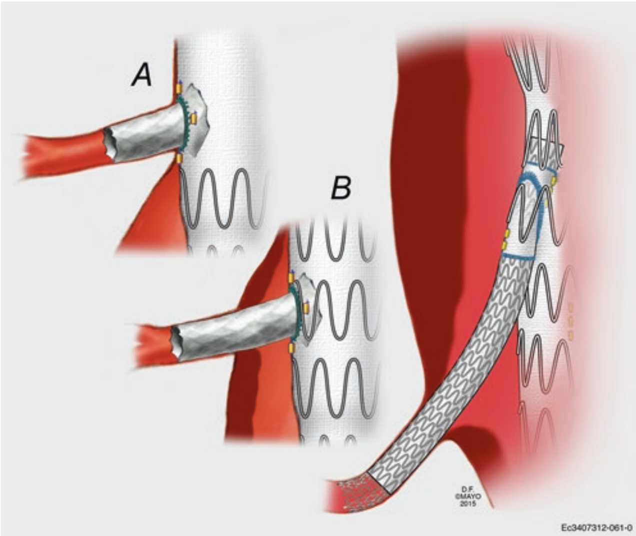


Fig. 5.1 Classification of type of repair includes fenestrated repair (**a**), fenestrated branched repair (**b**), and directional branched repair. By permission of Mayo Foundation for Medical Education and Research.

Roy Greenberg and popularized by Frank Criado. Larger clinical experience has been accumulated by the Zurich (Mario Lachat), Muenster (Giovanni Torsello), and Stanford groups (Jason Lee). Upgoing branches placed from femoral approach define periscope technique (Fig. 5.2b). The use of aortic components and multiple parallel branches anchored into limbs of bifurcated aortic devices as initially described by Kasirajan from Emory University in 2011 (Fig. 5.2c). The use of parallel stents between aortic components was described and popularized by Armando Lobato from Sao Paulo as the sandwich technique (Fig. 5.2d).

Hybrid Endovascular Repair

Hybrid techniques represented the first step towards extending endovascular repair to complex anatomy (Fig. 5.3). The first hybrid endovascular repair was described by William Quinones-Baldrich from the

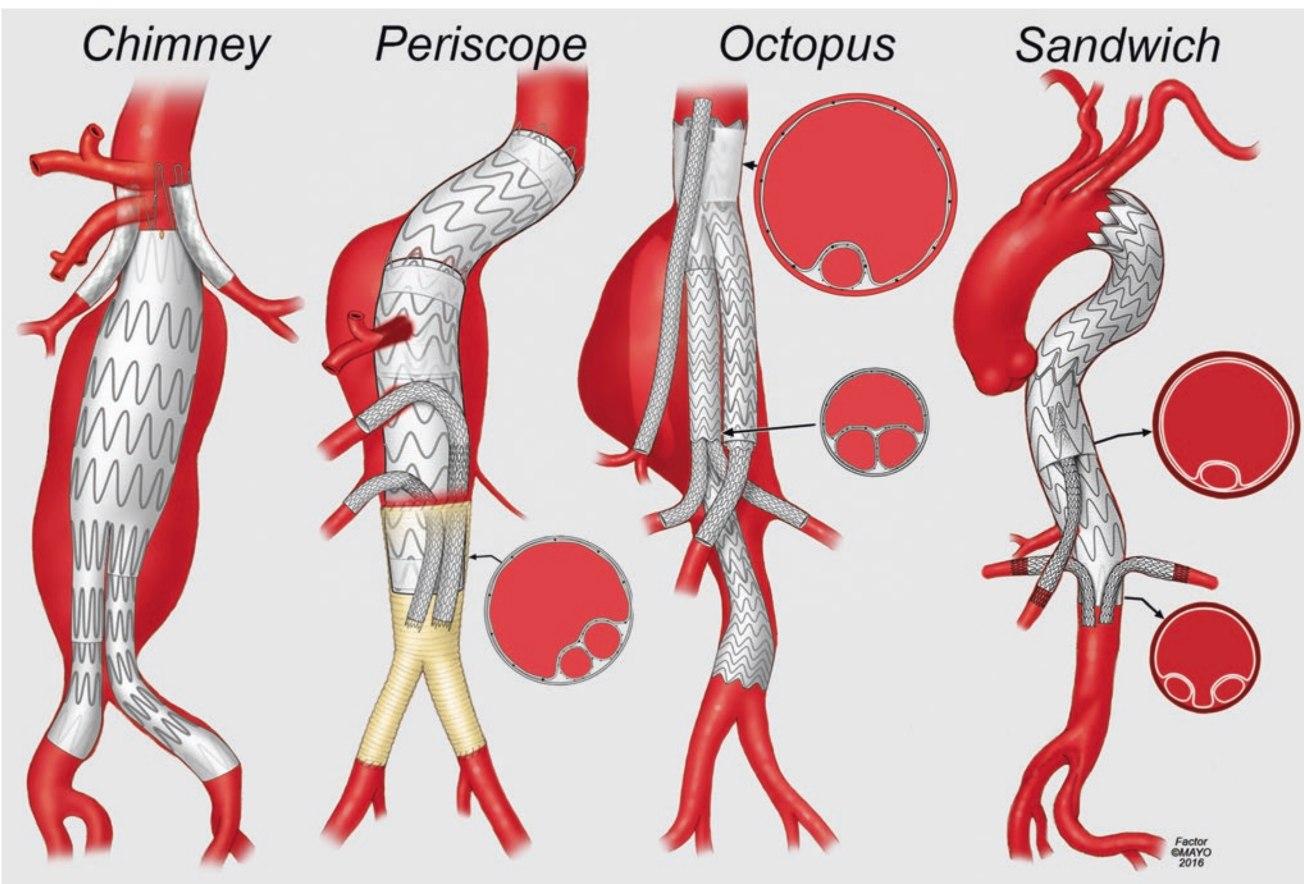


Fig. 5.2 Parallel stent-graft techniques. By permission of Mayo Foundation for Medical Education and Research.

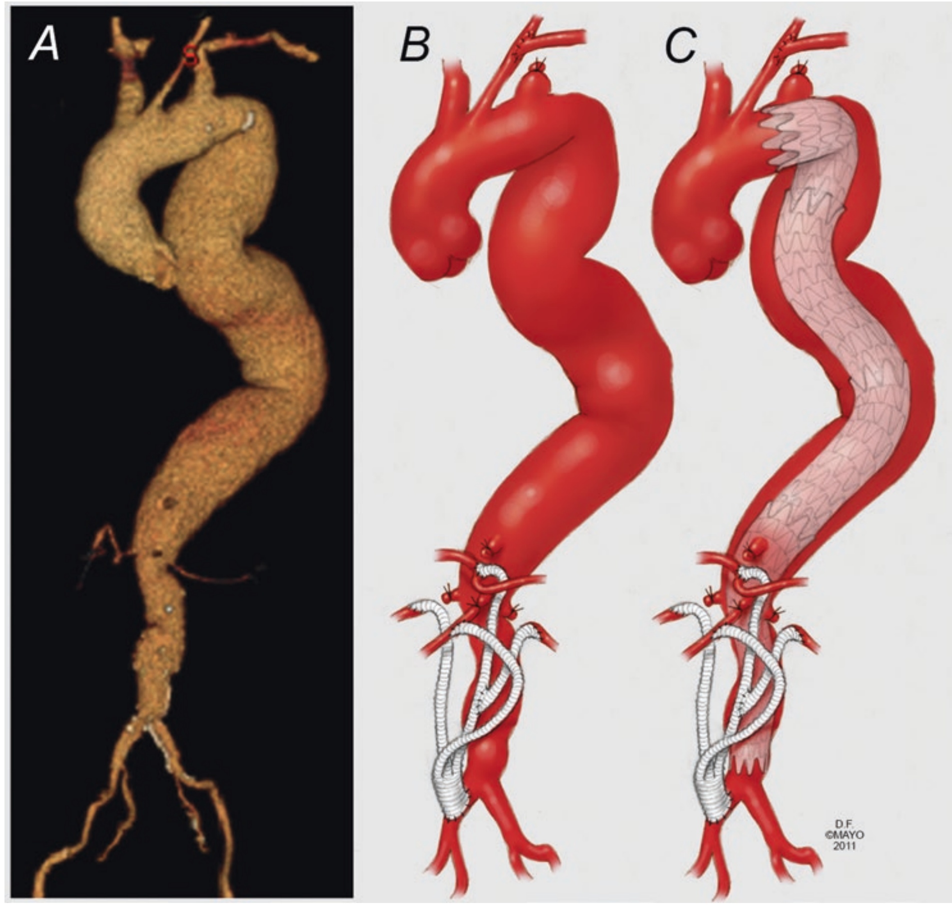


Fig. 5.3 Hybrid technique illustrated in a patient treated for Extent II TAAA (**a**) using staged visceral debranching (**b**) followed by stent-graft placement (**c**). By permission of Mayo Foundation for Medical Education and Research.

University of California, Los Angeles, in 1999 to treat a high-risk patient with Extent IV thoracoabdominal aortic aneurysm. The technique has been widely applied to treat aortic arch, thoracoabdominal, pararenal, and aortoiliac aneurysms. Aortic debranching implies the use of extra-anatomical bypasses based in the aorta, iliac, and visceral arteries or within an aortic graft.

Spectrum of Aortic Disease

Aortic aneurysmal disease is the 13th most common cause of death in the USA and is increasingly diagnosed since the introduction of screening programs. The pathogenesis of aortic aneurysms is complex and not completely defined. Aortic wall degeneration induced by atherosclerosis, proteolytic enzyme activation, and inflammatory processes are the leading hypothesis; other theories include infectious, connective tissue disorders from genetic predisposition, and hemodynamic influences. It is likely that aneurysm formation is multifactorial rather than a single process.

Atherosclerotic Aneurysms

The association of aortic aneurysm with aortic atherosclerosis has long been recognized. Most patients with an abdominal aortic aneurysm have evidence of atherosclerosis in other vascular beds, notably the coronary, carotid, and/or peripheral arteries. The pathogenesis of atherosclerosis is a complex and dynamic process involving cellular proliferation and migration, intimal lipid deposition, inflammation, fibrosis, and necrosis with dystrophic calcification [3]. This has led to the theory that aortic aneurysmal disease is part of the atherosclerosis process involving the aorta. Therefore, aortic aneurysms are commonly referred as atherosclerotic, although this is likely an oversimplification of the actual pathogenesis. A characteristic feature of atherosclerosis is plaque deposition in the intima of the arterial wall. Atherosclerotic intimal plaques cause thinning of the adjacent media, leading to weakening of the arterial wall. The media is the major structural unit of the aorta and is composed of layers of musculo-elastic fascicles, or lamellar units. The elastic fibers distribute mural tensile stresses and provide recoil during the cardiac cycle, while the collagen network prevents over-distention, disruption, and enlargement. Proteolytic activation with increased amounts of collagenase, elastase, and metalloproteinases have been associated with aneurysm development and risk of rupture.

Macrophages are consistently found in the adventitial layer of aneurysms as well as in association with atherosclerotic plaques. Many proteinases are released by macrophages, including a number of important matrix metalloproteinases (MMPs). These include the interstitial collagenase (MMP-1), stromelysin (MMP-3), a 72 kDa gelatinase/type IV collagenase (MMP-2), and a 92 kDa gelatinase/type IV collagenase (MMP-9). All these MMPs have the capacity to degrade all the major connective tissue components of the aortic wall, including collagen, elastin, proteoglycans, fibronectin, and laminin. These proteinases are inhibited by tissue inhibitor of metalloproteinase (TIMP), which is also produced by macrophages.

Inflammatory Aneurysms

Inflammatory aneurysms account for approximately 5 % of abdominal aortic aneurysms. Their characteristic feature is chronic inflammatory infiltrate of varying degree in the outer layers of the media and adventitia. Inflammatory cells are also seen in non-atherosclerotic aortic aneurysms such as those caused by various types of aortitis, including giant cell arteritis, rheumatoid arthritis, systemic lupus erythematosus, polyarteritis nodosa, syphilis, and Takayasu's, Behcet's, and Kawasaki's diseases. This suggests that the possibility that inflammatory cells, through the release of proteolytic enzymes, may play a primary role in either the causation or the exacerbation of aneurysmal dilation. Macrophages, along with T and B lymphocytes, are the major cellular components of chronic inflammation. Inflammatory aneurysms of the abdominal aorta tend to encase the ureters causing hydronephrosis. Renal insufficiency may result from hydronephrosis and this may be the primary manifestation.

Genetically Triggered Aortic Diseases

Genetically triggered aortic diseases are discussed in detail in Chaps. 2 and 3. It is well recognized that a positive family history (first-degree relative) increases the risk of aortic aneurysm. Several specific genetic abnormalities have been identified in "non-atherosclerotic" aneurysm groups, such as fibrillin gene abnormalities in patients with Marfan's syndrome and procollagen type III defects in patients with vascular Ehlers-Danlos syndrome.

Classification of Blunt Aortic Traumatic Injuries

Traumatic aortic injury is the second most common cause of death among victims of blunt trauma. In a cohort of 275 patients with traumatic rupture, Parmley et al. [1], [4] reported that 88 % of the patients with traumatic aortic injuries die within the first hour, and only 2 % survive long enough to develop a chronic aneurysm. The classification of traumatic aortic injury is depicted in Fig. 5.4. The classification is based on imaging and pathology evaluation as depicted in Fig. 5.5, [5]. These injuries are often result of transection of the descending thoracic aorta at the level of the ligamentum arteriosum, a point of fixation of the mobile aortic arch, but can also occur in the distal thoracic or abdominal aorta (Fig. 5.6). The mechanism of injury involves a combination of increased shear stress due to rapid deceleration and acute increases in intraluminal pressure. Little is known about the management and long-term outcomes of chronic traumatic thoracic aortic aneurysms [6, 7].

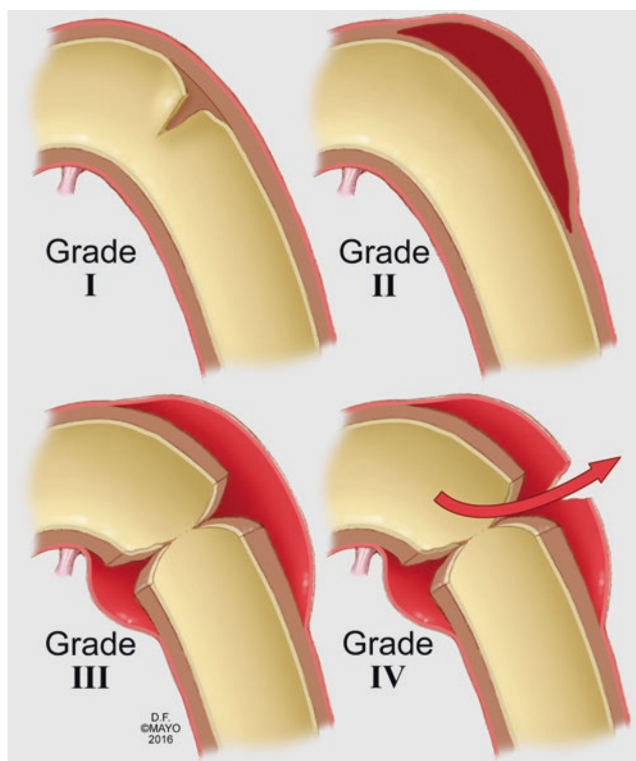
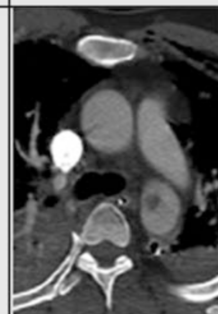


Fig. 5.4 Classification of traumatic aortic blunt injury. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

ABSENT EXTERNAL CONTOUR ABNORMALITY

Type of aortic injury	*Definition*	*Example*
Intimal tear	No aortic external contour abnormality: Tear and/or associated thrombus is <10mm	
Large intimal flap	No aortic external contour abnormality: Tear and/or associated thrombus is >10mm	

PRESENT EXTERNAL CONTOUR ABNORMALITY

Pseudoaneurysm	Aortic external contour abnormality: Contained	
Rupture	Aortic external contour abnormality: Not contained, free rupture	

Fig. 5.5 Imaging findings of traumatic aortic blunt injury. Reprinted from Journal of Vascular Surgery, 55(1), Starnes BW, Lundgren RS, Gunn M, Quade S, Hatsukami TS, Tran NT, et al., A new classification scheme for treating blunt aortic injury, 47–54, Copyright 2012, with permission from Elsevier

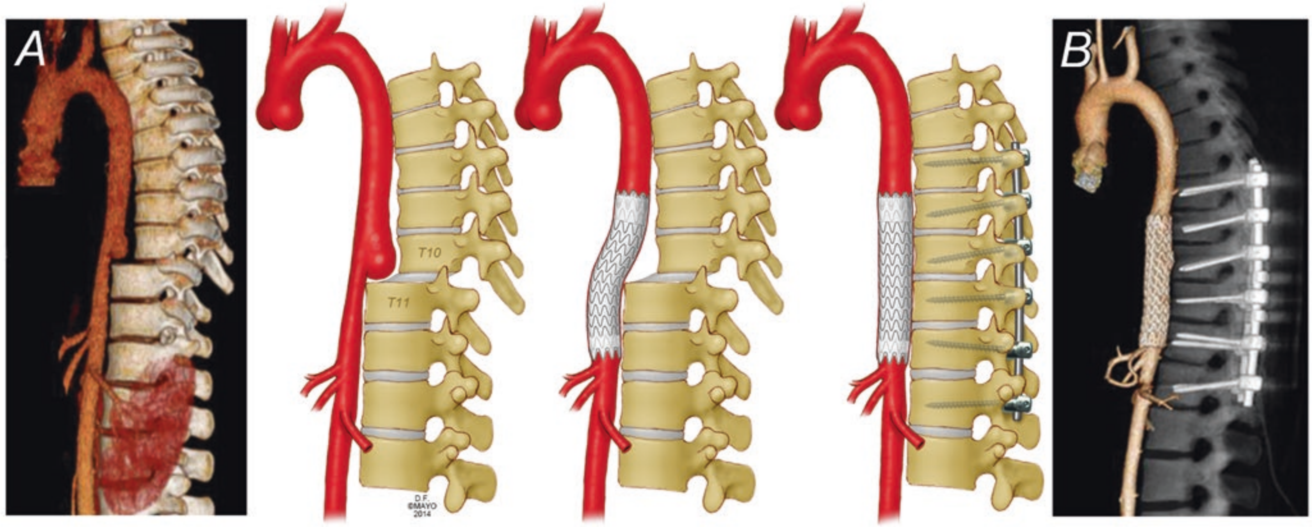


Fig. 5.6 Traumatic blunt aortic injury associated with fracture-dislocation of lower thoracic spine (**a**) was treated by endovascular repair and reduction of dislocation (**b**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

Classification of Aortic Coarctation

Aortic coarctation is a congenital arch disease that is anatomically described in relationship to the ductus arteriosus (ligamentum arteriosum). The narrowing can be preductal, ductal, or postductal. Most commonly, in adults an aortic coarctation is immediately distal to the atrophied ductus (postductal), but such cases are often associated with a hypoplastic, more proximal aortic arch. Rarely in adults, the arch or the descending aorta is completely interrupted. This defect can occur between the left subclavian artery and descending thoracic aorta (type A), the left subclavian and carotid arteries (type B), or the left carotid and brachiocephalic arteries (type C).

Classification of Aortic Aneurysms

Ascending Aorta and Arch

Aneurysms of the ascending aorta are commonly classified as supracoronary, annuloaortic ectasia (alsoknown as Marfanoid type), and tubular. Arch aneurysms can be isolated or representing proximal extension of a thoracic aortic aneurysm or distal extension of ascending aortic aneurysm (Fig. 5.7).

Descending Thoracic Aneurysms

Thoracic endovascular aortic repair (TEVAR) has become the first treatment option for most aneurysms and for acute type B aortic dissections that are complicated. A classification scheme has been proposed to describe the extent of coverage during repair of descending thoracic aortic (DTA) aneurysms (Fig. 5.8). This classification includes type A DTAs from the left subclavian artery to T6, type B DTAs from T6 to the diaphragmatic hiatus, and type C DTAs from above T6 or the left subclavian artery to the diaphragmatic hiatus.

Thoracoabdominal Aortic Aneurysms

The first report of open surgical repair of a TAAA in the USA was by Etheredge in 1955 [8]. The same year, Charles Rob, an English surgeon, also reported on his experience of 33 abdominal aortic aneurysms, six of which required lower thoracic aortic clamping via thoracoabdominal incision. Cooley and DeBakey's initial report of repair of a descending thoracic aortic aneurysm in 1953 predated Etheredge's report, but there was no direct reconstruction of the visceral arteries [9]. Shortly thereafter, DeBakey reported four cases of TAAA repair using aortic homograft and in a subsequent report in 1965 he included 42 patients treated by knitted Dacron grafts, marking the beginning of a new era of open surgical reconstruction of the thoracoabdominal aorta using prosthetic grafts [10].

Stanley E. Crawford is credited with pioneering techniques of TAAA repair by adding intra-aortic anastomosis after longitudinal division of the sac. The origins of the celiac axis, superior mesenteric artery, and right renal artery were included as a Carrel patch, followed by left renal anastomosis by reimplantation or separate graft. In his first report he had a single death among 23 consecutive cases. Along with the utilization of cardiopulmonary bypass and hypothermic circulatory arrest, Crawford's approach most resembles contemporary techniques performed at major centers today.

In 1986, Crawford (Fig. 5.9) described the first TAAA classification scheme based on the anatomic extent of the aneurysm [11]. Extent I involves most of the descending thoracic aorta from above T6 to the level of the renal arteries but not including the infrarenal aorta. Extent II is the most extensive from, starting above T6 in the thoracic aorta and extending distally into the infrarenal aorta or aortic bifurcation. Extent III involves the distal thoracic aorta below T6 with variable distal extension to the renal arteries or beyond. Extent IV TAAA was described above as a more proximal extension of complex abdominal aortic aneurysm above the level of the celiac axis.

Based on this classification, Crawford stratified outcomes for 1509 patients who underwent 1679 TAAA repairs between 1960 and 1991 [12]. The report included 378 Extent I (25 %), 442 Extent II (29 %), 343 Extent III (23 %), and 346 Extent IV (23 %) TAAAs. The 30-day mortality was 8 % and was influenced by age, renal function, concurrent proximal aortic aneurysms, coronary artery disease, chronic lung disease, and total aortic clamp time. Spinal cord injury was noted in 16 % of patients and was associated with clamp time, extent of aorta repaired, rupture, age, and history of chronic kidney disease [12].

Hazin Safi reported a modification of the Crawford classification (Fig. 5.10) to describe the distal aortic involvement of Extent III TAAAs. In his classification, Extent I, II, and IV remain unchanged. A fifth type was added to describe disease starting below T6 and extending up to the renal arteries but not beyond [13].

Abdominal Aortic Aneurysms

Approximately 80 % of the aortic aneurysms are located in the abdominal aorta. Of these, the majority of aneurysms are infrarenal, which imply treatment by open repair using infrarenal clamp and reconstruction or endovascular repair with infrarenal fixation and a minimum aortic neck of 10 mm in length. Aneurysms that do not meet the criteria of infrarenal fixation and require incorporation of at least one of the renal arteries are termed complex abdominal aortic aneurysms. The anatomic classification (Fig. 5.11) of complex abdominal aortic aneurysms includes short-neck infrarenal (<10 and >4 mm infrarenal neck), juxtarenal aneurysms (0–4 mm infrarenal neck), and suprarenal aneurysms. The latter group is subdivided into pararenal aneurysms, which involve at least one renal artery and extend up to superior mesenteric artery (SMA) and paravisceral aneurysms, which involve the renal arteries and the SMA but extend not beyond the celiac axis. A type IV TAAA represents cranial extension of aortic aneurysm above the celiac axis and into the diaphragmatic hiatus. This anatomical classification has been widely utilized in reports dealing with open conventional repair with reasonably good correlation between location of the healthy aorta and extent of open surgical reconstruction (Fig. 5.12).

Iliac Artery Aneurysms

Iliac aneurysms have been previously classified as (a) isolated unilateral, (b) isolated bilateral, and (c) aortoiliac aneurysm. The latter group (c) represents the majority of the iliac aneurysms [14]. A more contemporary classification has taken into account endovascular alternatives and divided iliac aneurysms into one of the five broad categories based on feasibility of endovascular or open treatment (Fig. 5.13) [15].

In this classification, patients with isolated CIA aneurysms who have adequate proximal and distal landing zones within the CIA are classified as type A. A minimum landing zone of 10 mm with no thrombus or calcification is considered adequate. Type B aneurysms include those with adequate proximal CIA neck but distal extension into the CIA bifurcation. Patients with adequate proximal neck in the CIA but who have aneurysm extension into the external iliac artery, which is uncommon, are classified as type C. In practical terms, type B and C aneurysms are treated identically in most cases. Type D consists of patients with solitary IIA aneurysms and normal CIA. Finally, patients with either a CIA with an inadequate proximal neck (aneurysm involving CIA ostium or aortic bifurcation), or bilateral CIA aneurysms, or CIA and abdominal aortic aneurysms are classified as type E [15] (see Fig. 5.13).

Classification of Aortic Dissections

Aortic dissection is more common in men (3:1) and is associated with long-standing hypertension, cocaine use, connective tissue disorders (e.g., the Marfan syndrome), and congenital anomalies (e.g., bicuspid aortic valve and aortic coarctation). Other genetic and autoimmune disorders,

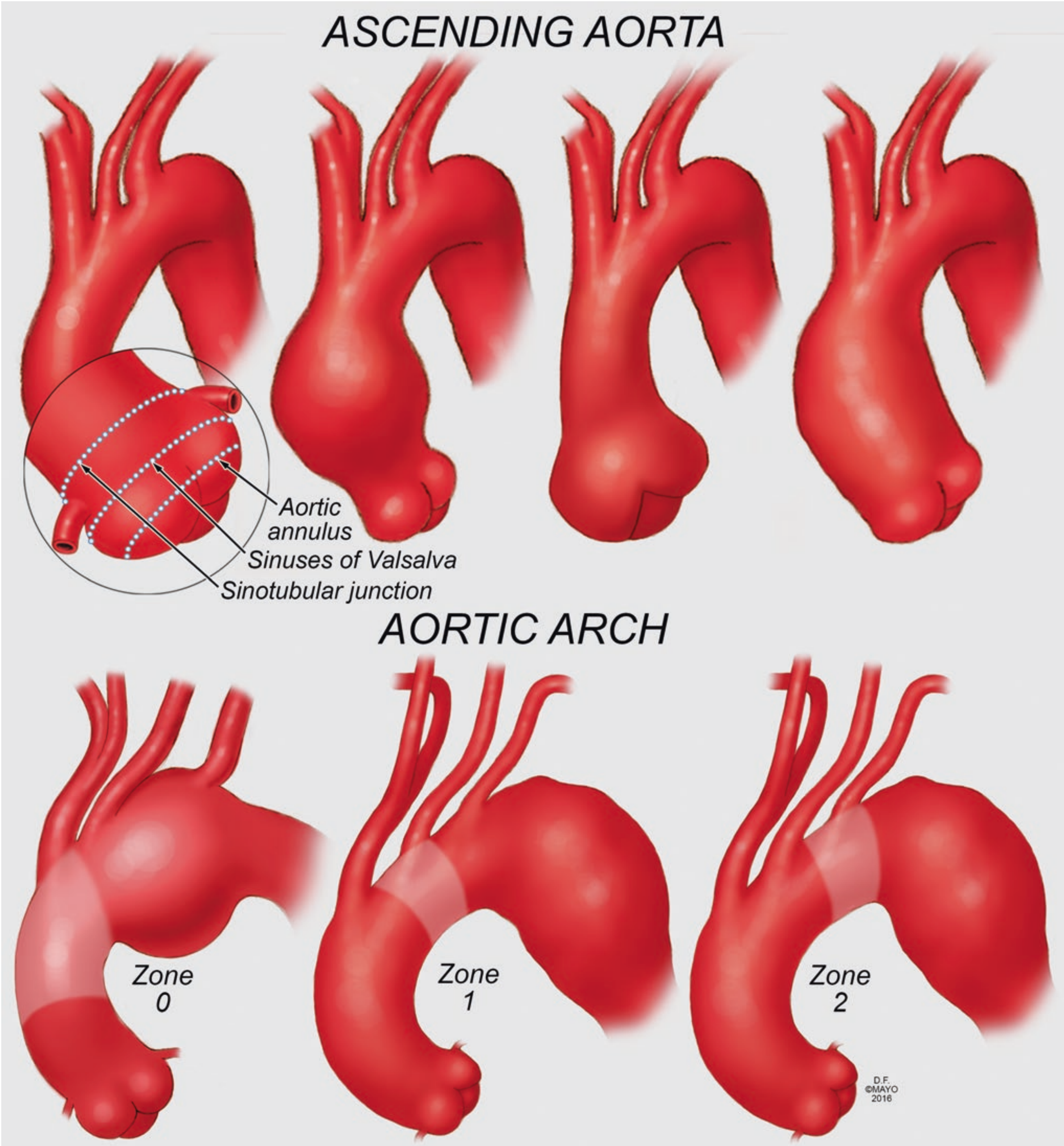


Fig. 5.7 A schematic illustration comparing the normal ascending aorta to three common patterns of ascending aortic aneurysmal disease: supracoronary, annuloaortic ectasia (also known as Marfanoid-type aneurysm), and tubular. Arch aneurysm classification using zones of Ishimura. By permission of Mayo Foundation for Medical Education and Research.

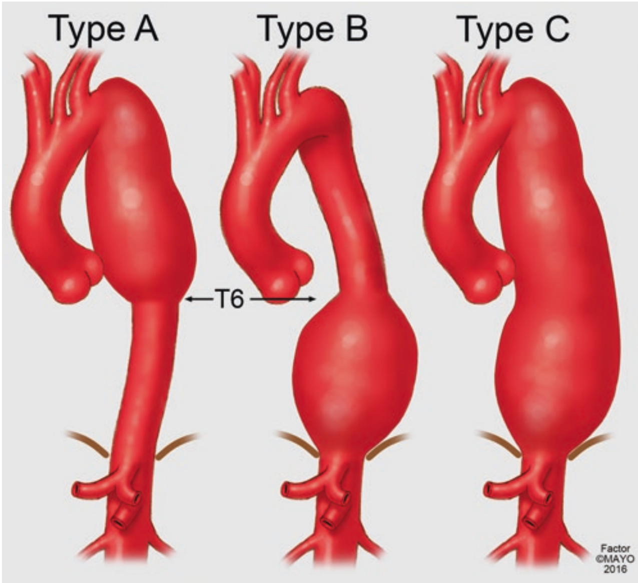


Fig. 5.8 Classification of descending thoracic aortic aneurysm repair using endovascular stent grafts. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

such as Turner's syndrome, Noonan's syndrome, polycystic kidney disease, giant-cell aortitis, systemic lupus, and relapsing polychondritis, are associated with aortic dissection. Iatrogenic aortic dissection can also occur from aortic cross-clamp placement, aortotomy, or endovascular manipulations. Aortic dissections have been classified anatomically with respect to location of entrance site and its distal extension.

DeBakey's Classification

The DeBakey's classification system (Fig. 5.14) published in 1956 provides more detailed description of the distal extension of the dissection with respect to the thoracic and abdominal aorta [16]. The classification includes three types. DeBakey type I dissections originate in the ascending aorta or arch, proximal to the left subclavian artery, with distal extension to the aortic arch and often beyond it distally. These are most often seen in patients less than 65 years of age and represent the most lethal form of the disease. DeBakey type II dissections originate in ascending aorta and are confined to the ascending aorta with no involvement of the distal aortic arch or descending thoracic aorta. DeBakey type III dissections originate in descending thoracic aorta, and are further subdivided into IIIa (distal extension to the diaphragmatic hiatus) or IIIb (distal extension into the abdomen or iliacs).

Stanford Classification

The *Stanford classification* was introduced 1 year after DeBakey classification and is divided into two groups, A and B, depending on whether the ascending aorta is involved (Fig. 5.15) [17]. Stanford type A involves the ascending aorta and/or the aortic arch, with or without distal extension to the descending thoracic aorta and beyond. The tear can originate in the ascending aorta, the aortic arch, or, more rarely, the descending aorta with retrograde extension. A Stanford type B dissection involves the descending thoracic aorta or the arch (distal to the left subclavian artery), without involvement of the ascending aorta.

Aortic Arch Dissections

Involvement of the aortic arch by dissection is further classified based on the location of the entry intimal tear either proximal or distal to the innominate artery. Tears in the aortic arch can be classified into five groups (Fig. 5.16). Class I tears (10 %) are located just above the aortic root and cause the classic two lumen dissection with a flap or septum in between. Class II tears are those with intramural hematoma not identifiable on CTA because of the clot and always seen at the time of the operation. Class III tears are rare localized intimal tears, most commonly in the ascending aorta in patients with Marfan's syndrome that do not cause dissection. Class IV tears are associated with penetrating ulcers. It is not infrequent to see associated calcifications or atheromatous ulcer. The dissection plan penetrates into the medial layer and causes an intramural hematoma. Class V tears are those associated with iatrogenic maneuvers such as cardiac catheterization and aortic stenting.

Endovascular Classification Schemes

Endovascular classification schemes have been based largely on the location of the landing zone, anatomical configuration, or extent of reconstruction, which is based on the number of vessels requiring incorporation by fenestrations, branches, or parallel grafts. The extent of endovascular repair does not always correlate with the proposed anatomical classifications that are used for open surgical repair. For example, a paravisceral aortic aneurysm that can be treated using a transabdominal approach with clamping above the SMA may require four fenestrations with an extent IV TAAA approach if treated by endovascular means. The Society for Vascular Surgery (SVS) proposed a classification system based on landing zones.

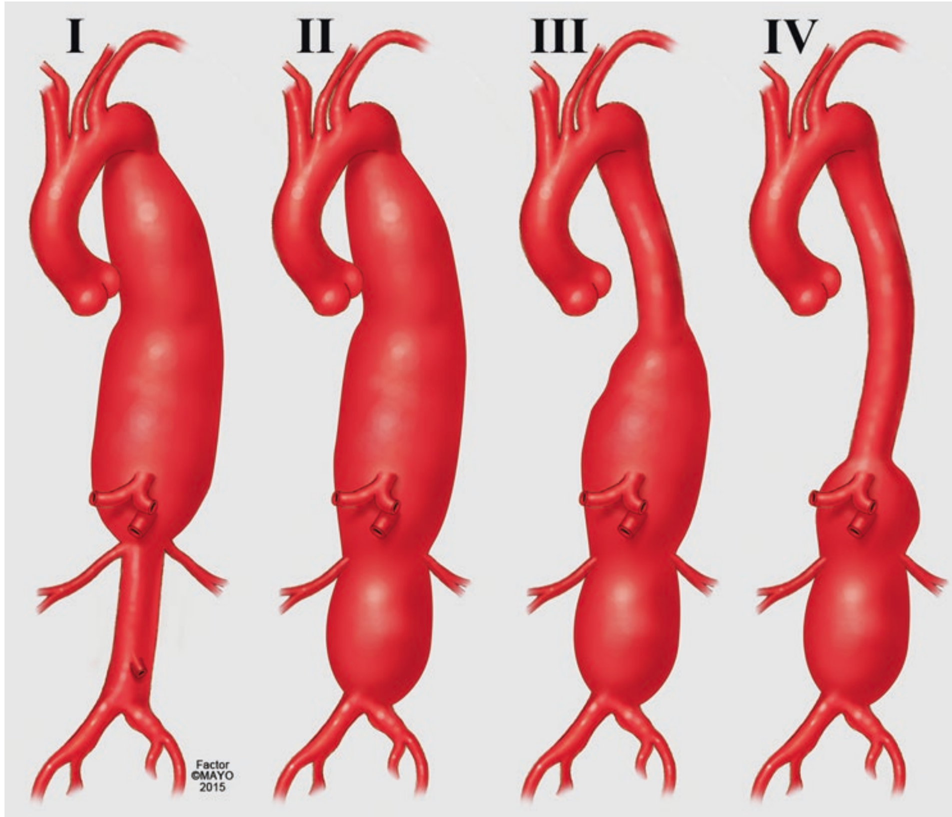


Fig. 5.9 Classification of thoracoabdominal aortic aneurysms proposed by Stanley E. Crawford. By permission of Mayo Foundation for Medical Education and Research.

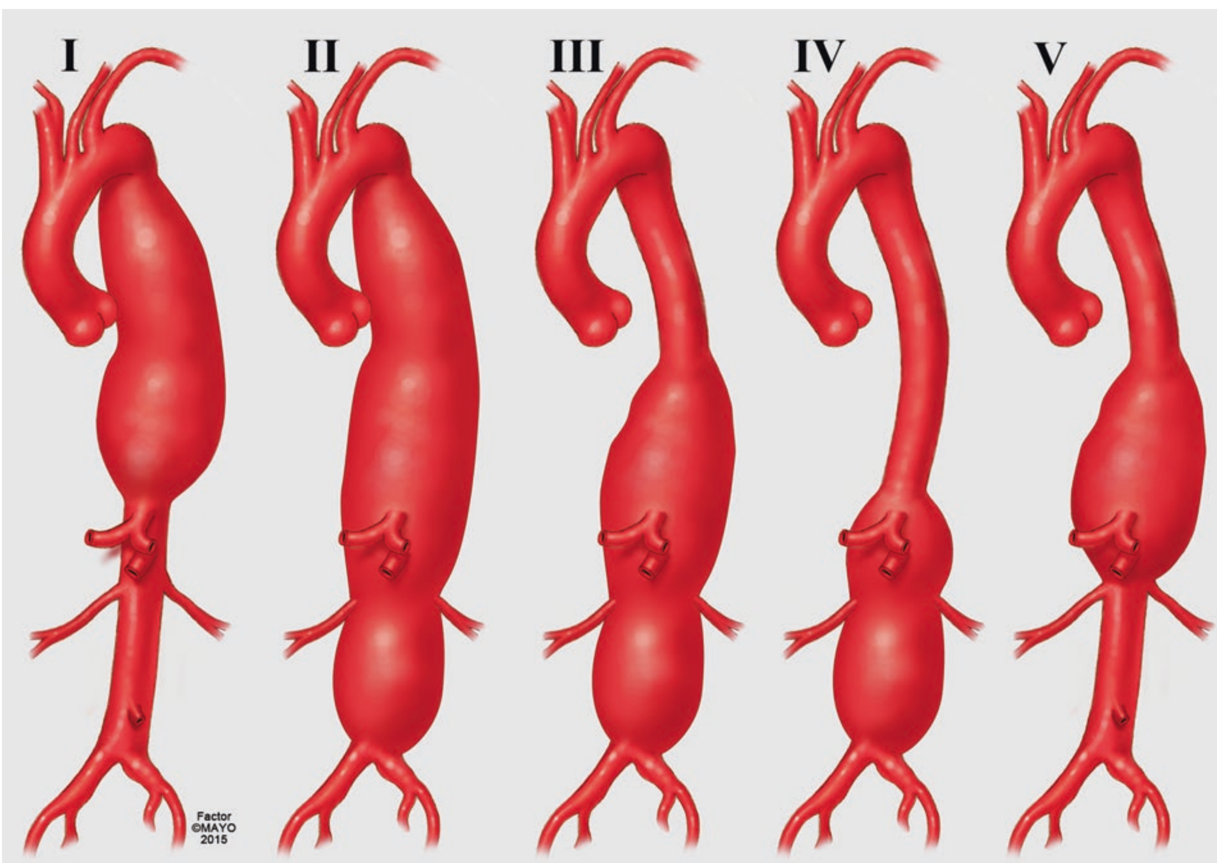


Fig. 5.10 Classification of thoracoabdominal aortic aneurysms proposed by Hazin Safi. By permission of Mayo Foundation for Medical Education and Research.

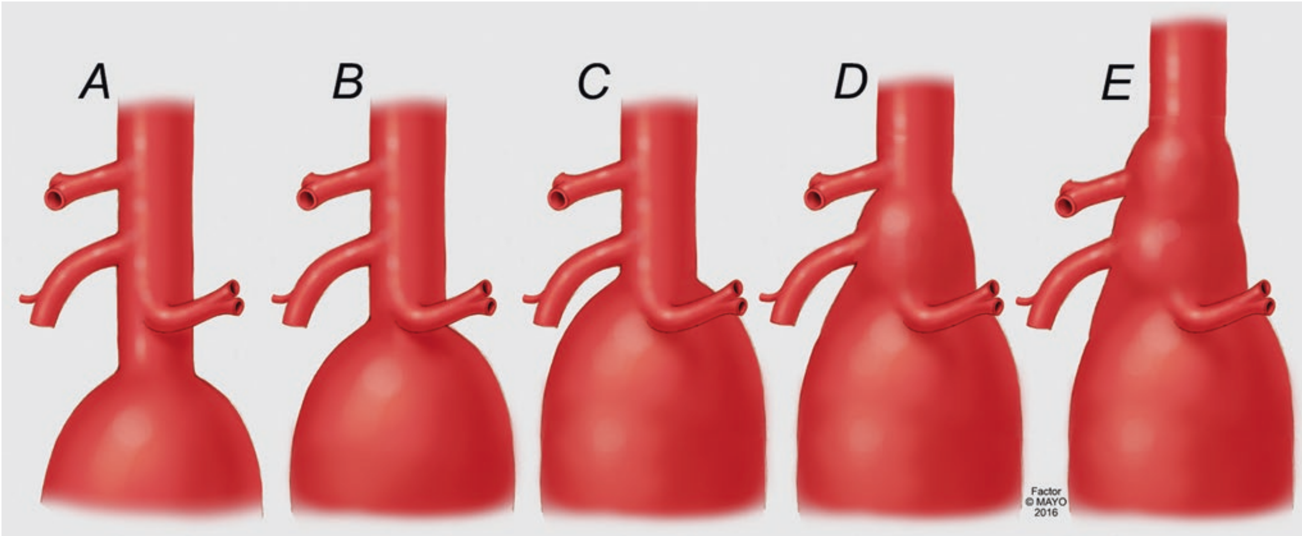


Fig. 5.11 Anatomical classification of complex abdominal aortic aneurysms includes short neck infrarenal (**a**), juxta-renal (**b**), pararenal (**c**), paravisceral (**d**), and type IV TAAA (**e**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

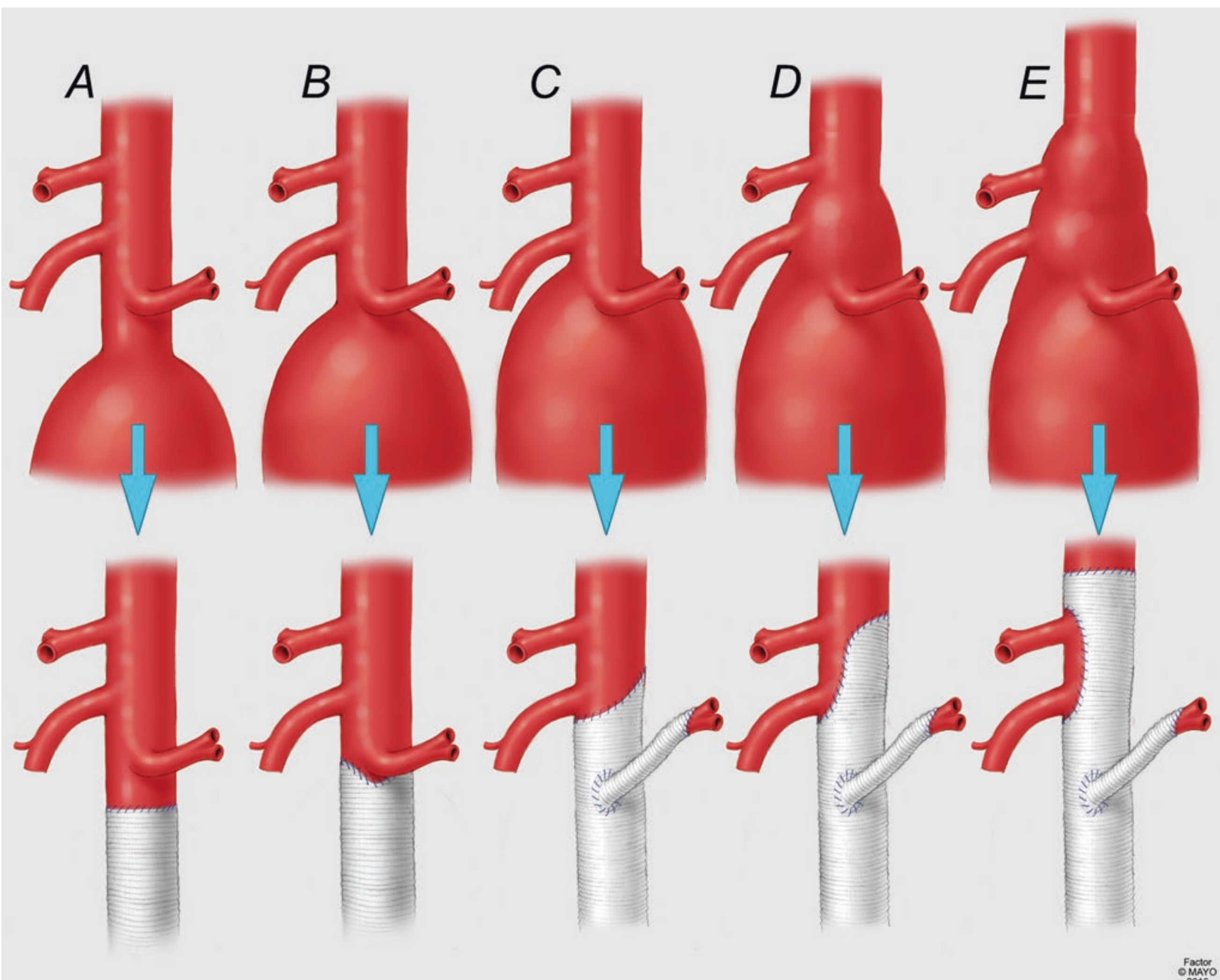


Fig. 5.12 Correlation of complexity of open repair of complex abdominal aortic aneurysms for short neck infrarenal (**a**), juxtarenal (**b**), pararenal (**c**), paravisceral (**d**), and type IV TAAA (**e**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

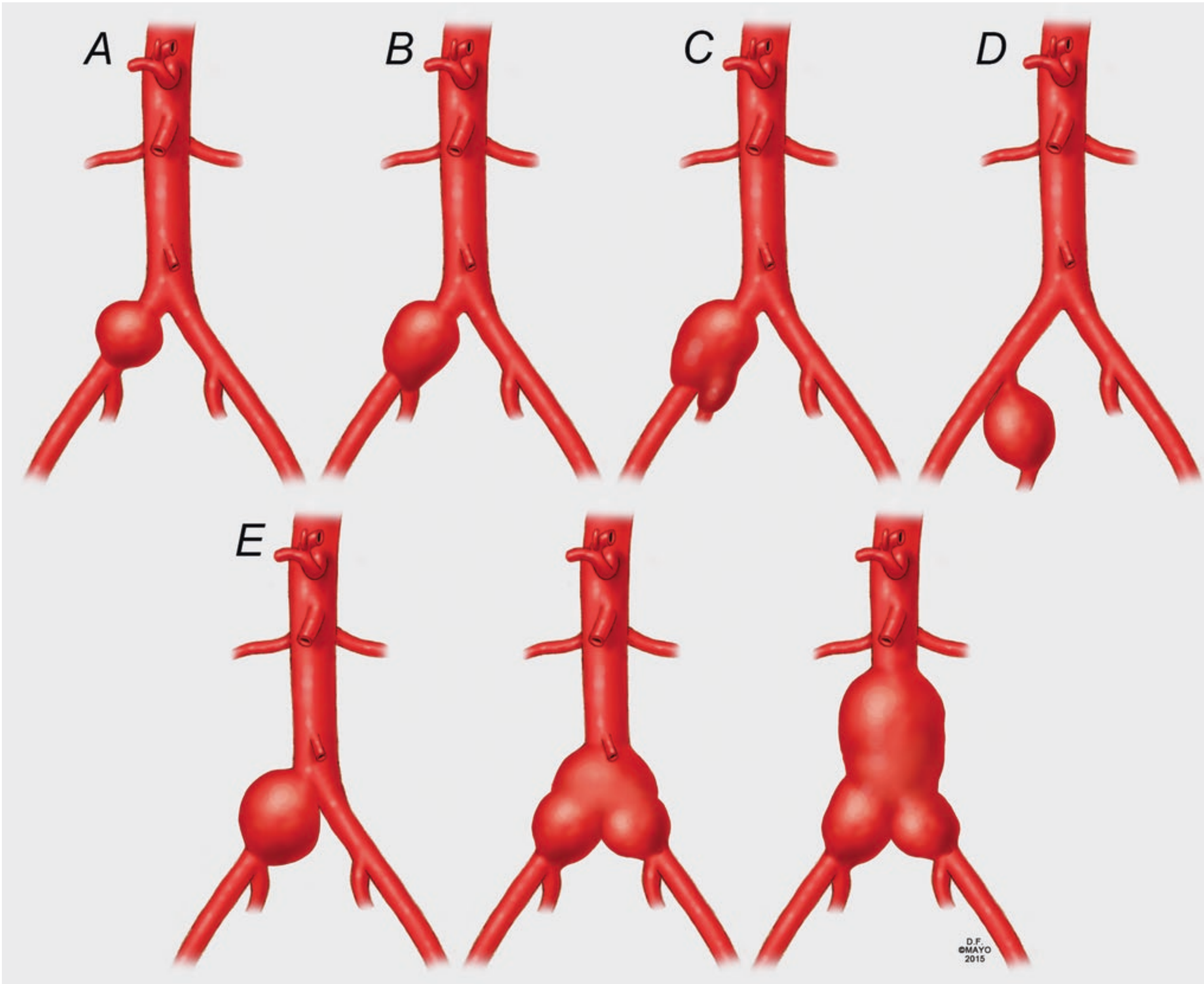


Fig. 5.13 Classification of iliac artery aneurysms (**a**–**e**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

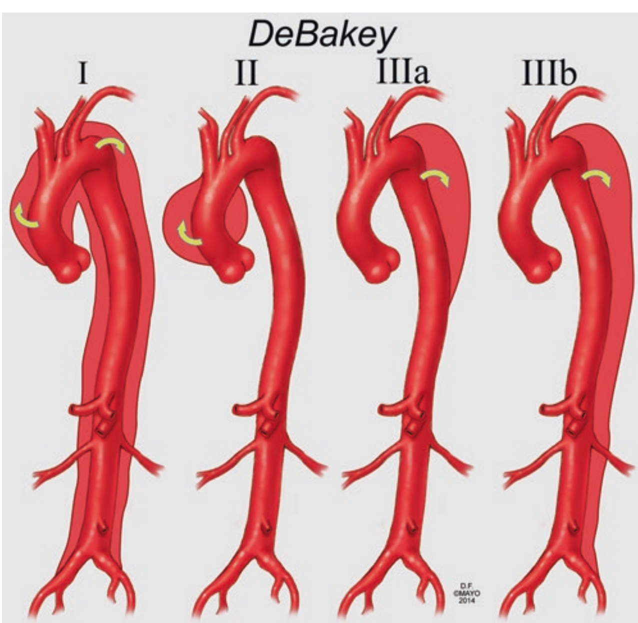


Fig. 5.14 DeBakey classification of aortic dissections. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

Aortic Arch Type

The classification of the types of arch into one of the three types is widely utilized to grade technical difficulties and assist with patient selection for procedures requiring arch manipulations (Fig. 5.17). With aging there is migration of the supra-aortic vessels towards the ascending aorta, which leads to increasing angulation in the aortic arch. The classification scheme uses imaginary lines traced in the outer and inner curvature of the aortic arch. Origin of the innominate artery above the outer line describes a type I arch, where the vessels are centered in the dome or top of the aortic arch, which is commonly seen in the younger individual. Origin of the innominate artery between the upper (outer curvature) and lower (inner curvature) line describes a type II aortic arch, which is the most common type among patients with aortic aneurysms. Further proximal migration of the innominate artery with origin proximal to the lower line (inner curvature) defines a type III aortic arch, which increases technical difficulty for selective catheterization of the supra-aortic trunks, particularly the innominate artery.

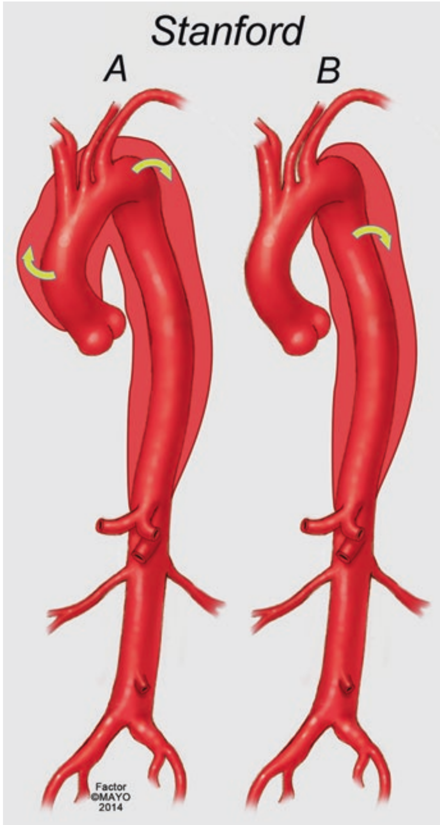


Fig. 5.15 Stanford classification of aortic dissections. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

Ishimura Zones of Implantation

A classification system proposed by Ishimura describes the zones of implantation within the aortic arch based on location of normal aortic segment relative to the supra-aortic trunks (Fig. 5.18) [14, 15, 18, 19]. Ideally, segments of normal aorta are selected for placement of endografts with minimum of 2.0 cm length of "normal" parallel aortic wall without excessive thrombus or atherosclerotic debris. Inadequate landing zones are the single most frequent cause of persistent endoleaks leading to sac growth or rupture. Selection of the landing zone in relationship with the aortic curvature is important to anticipate problems related to lack of apposition of the stent-graft and inner aortic curvature.

The Ishimura classification includes four aortic arch zones, which have been incorporated in the SVS reporting standards classification previously described. Zone 0 extends from the sino-tubular junction to distal to the innominate artery or a bovine trunk. Zone 1 extends from the innominate artery to distal to the left carotid artery. Zone 2 extends from distal to the left common carotid artery to distal to the left subclavian artery. Zone 3 extends from distal to the left subclavian artery to the most proximal curvature of the descending thoracic aorta, typically 2–4 cm distal to the left subclavian artery. Zone 4 involves most of the descending thoracic aorta.

In practical terms, novel designs of arch branch endografts are placed either proximal or distal to the innominate artery, as there is rarely enough length between the left common carotid artery and the innominate artery in Zone 1. A simplified classification proposed by Oderich divides the arch into two zones: *proximal arch*, which includes the ascending aorta and innominate artery and distal arch, which implies placement of endografts distal to the innominate artery (Fig. 5.19) and *distal arch*, which involve placement of the endograft most often into zone 2 or rarely in zone 1. This classification facilitates greatly the comparison with hybrid techniques, which require median sternotomy for proximal arch or only cervical approach for distal arch lesions.

Society for Vascular Surgery Zones of Implantation

The reporting standards for endovascular repair of abdominal and thoracic aortic aneurysms proposed a standardized classification system based on the location of the proximal landing zone (Fig. 5.20). In essence, this classification extends the zones of Ishimura into the thoracic and abdominal aorta. The proximal attachment zones (0–4) have already been described. Zone 4, or the transition zone, implies placement of the endograft at least 2 cm distal to the left subclavian artery extending distally up to T6. Zone 5 starts in the distal half of the descending thoracic aorta beyond T6 and extends to proximal edge of the celiac artery origin. Zone 6 extends from the proximal edge of the celiac origin to the proximal edge of the superior mesenteric artery (SMA). Zone 7 extends from the proximal edge of the highest renal artery. Zone 8 extends from the proximal edge of the highest renal artery to the distal edge of the lowest renal artery. Zone 9 involves the entire infrarenal aorta from the distal edge of the lowest renal artery to the aortic bifurcation. The distal attachment zones are usually located in Zone 9 for distal extension of TAAAs or in the iliac arteries. Zone 10 extends from the aortic bifurcation to the common iliac artery bifurcation. Zone 11 implies placement of the endograft into the external iliac artery, covering the origin of the internal iliac artery [20].

Mayo Clinic Endovascular Complex Abdominal Aneurysm Classification

The correlation between an anatomical and endovascular classification was studied in 490 patients treated for complex abdominal aortic aneurysms at the Mayo Clinic between 2000 and 2010. Because of the wide variation in

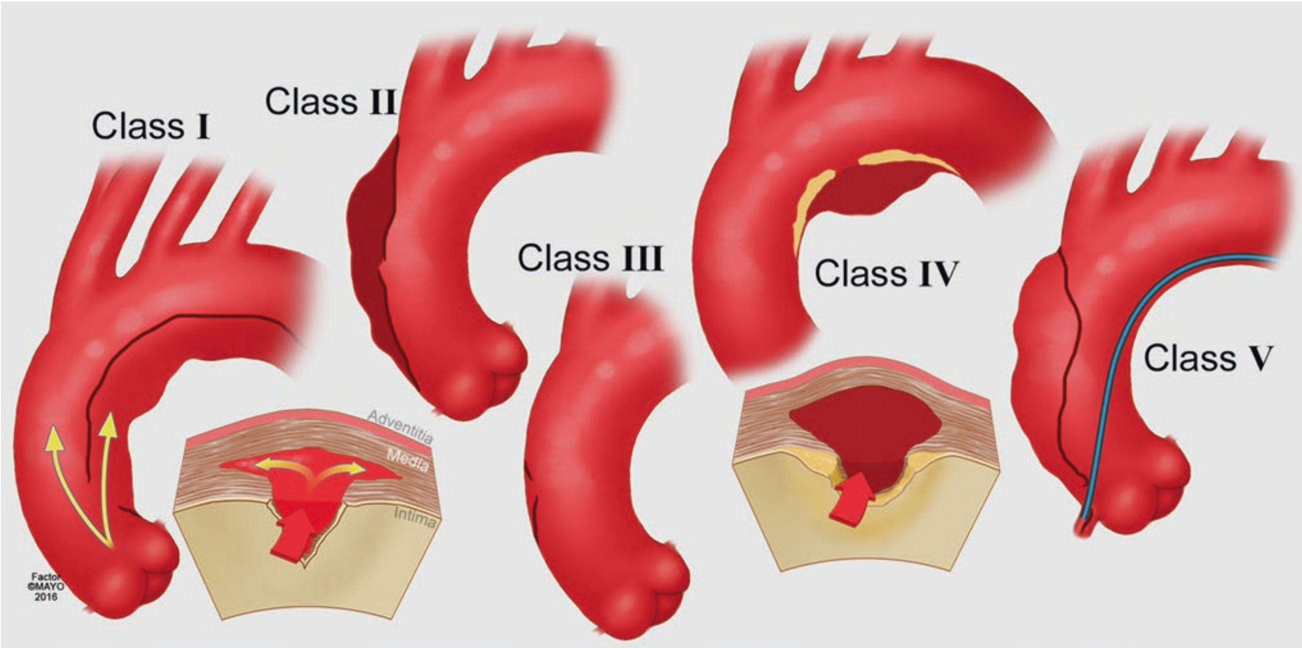
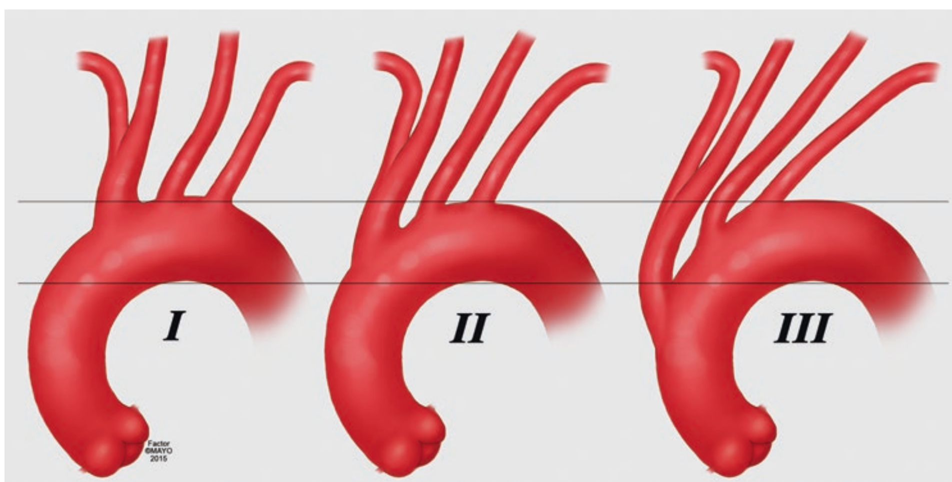


Fig. 5.16 Classification of aortic arch dissections. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

Fig. 5.17 Classification of aortic arch types. By permission of Mayo Foundation for Medical Education and Research. All rights reserved



open surgical techniques and potential discrepancy between the extent of open repair and the number of vessels that need incorporation by endovascular repair, this classification was devised as a means to standardize reporting of fenestrated and branched endografts. For example, a juxtarenal aortic aneurysm (Fig. 5.21) can be repaired with one, two, three, or even four fenestrations depending on relative length of the landing zone in relation to the origins of all four renal-mesenteric arteries. In general, the anatomical extent of aortic disease based on location of healthy aortic segment has linear correlation with the number of vessels requiring incorporation (Fig. 5.22). Therefore, for a juxtarenal aneurysm, most repairs would be done using an infrarenal or juxtarenal surgical graft (with "fish-mouth" anastomosis) and two renal fenestrations and an SMA scallop, whereas for a type IV TAAA the standard endovascular repair would be a four-vessel design (Fig. 5.23). An endovascular classification was proposed based on the minimum number of vessels requiring incorporation by fenestrations and/or branches (Fig. 5.24) assuming a proximal landing

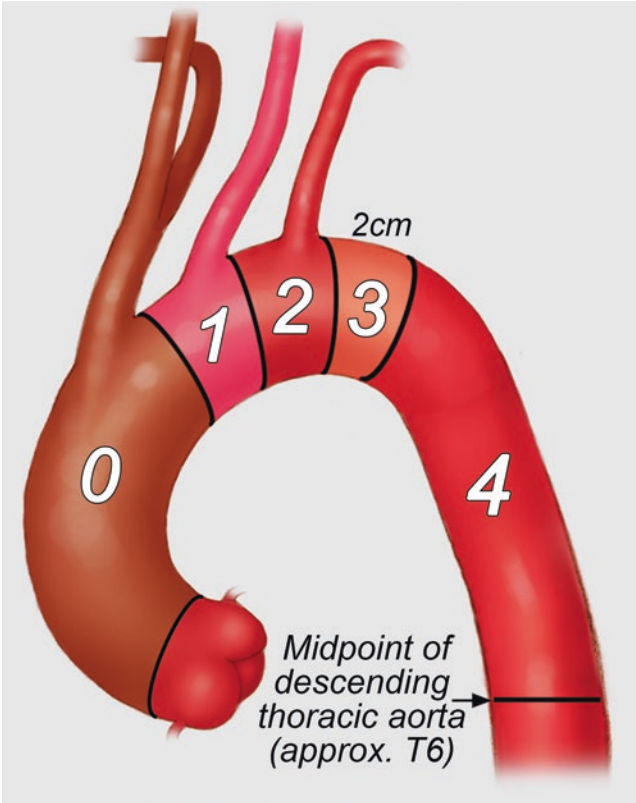


Fig. 5.18 Classification of zones of implantation in the aortic arch. By permission of Mayo Foundation for Medical Education and Research.

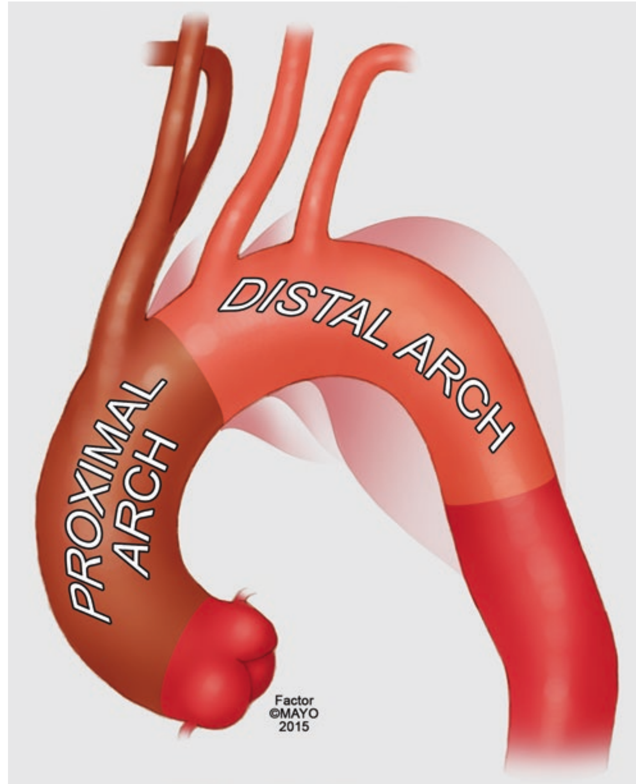


Fig. 5.19 Simplified classification of zones of implantation in the aortic arch. By permission of Mayo Foundation for Medical Education and Research.

zone of >2 cm based on healthy aortic segment with parallel aortic wall. A type I endovascular repair would imply one renal fenestration with or without one scallop to the contralateral renal artery or SMA. This design is rarely utilized in current practices. A type II repair included two fenestrations with or without a scallop. A type III repair implies three fenestrations with or without a scallop and a type IV repair four or more fenestrations or branches. The highest variation in the extent of endovascular repair was observed for suprarenal aneurysms.

Mayo Clinic Supra-celiac Coverage Classification

Banga and associates presented at the 2015 European Vascular Meeting a new classification concept to analyze outcomes of fenestrated and branched endografts based on supra-celiac sealing zones. A 4 cm line (equivalent to two sealing stents) was used above the upper aspect of the celiac artery origin to define high supra-celiac coverage (Fig. 5.25). Infra-celiac coverage designs include two or three fenestrations (Fig. 5.26), whereas supra-celiac coverage implies use of four fenestrations, branches, or combinations of fenestrations and branches.

Conclusion

Endovascular repair has gained widespread acceptance. Novel techniques and results continued to be compared to open surgical repair. It is critical that standardized classification systems are used to allow meaningful comparison of results with both modalities.

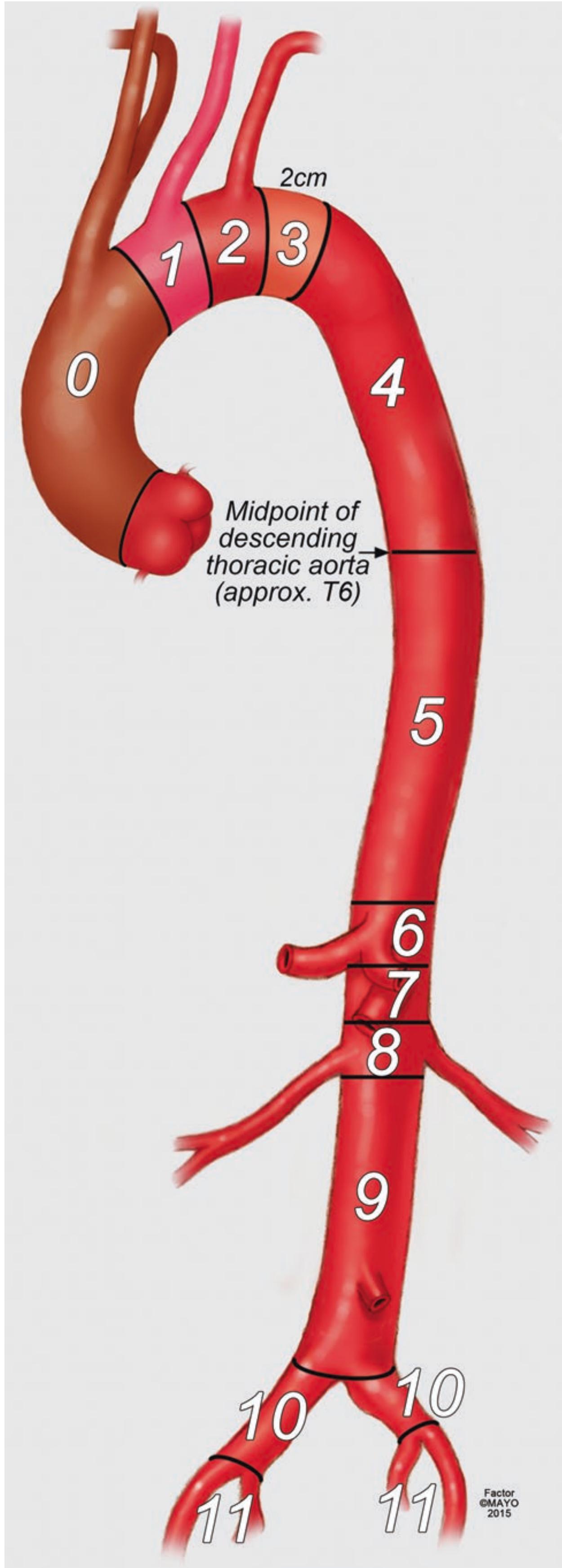


Fig. 5.20 Society for vascular surgery classification of zones of implantation. By permission of Mayo Foundation for Medical Education and Research.

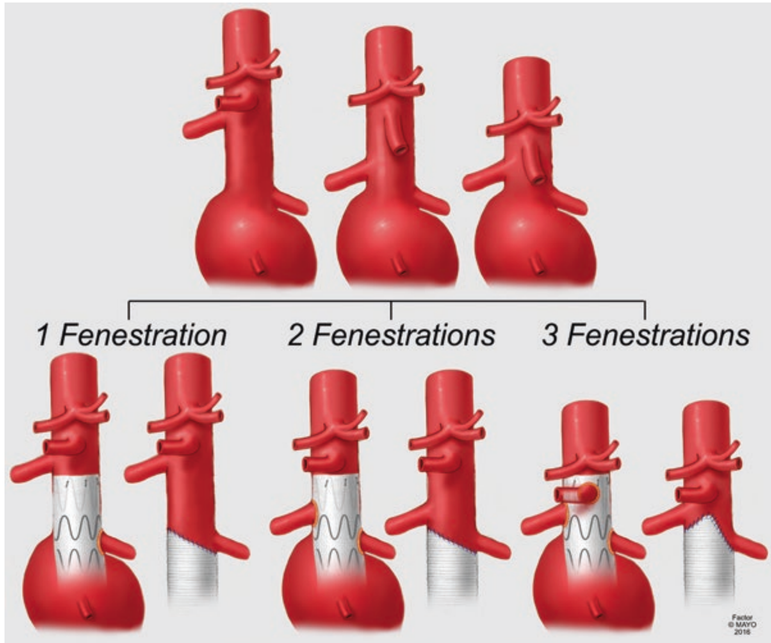


Fig. 5.21 Variations of stent-graft design and open repair options for juxtarenal aortic aneurysms. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

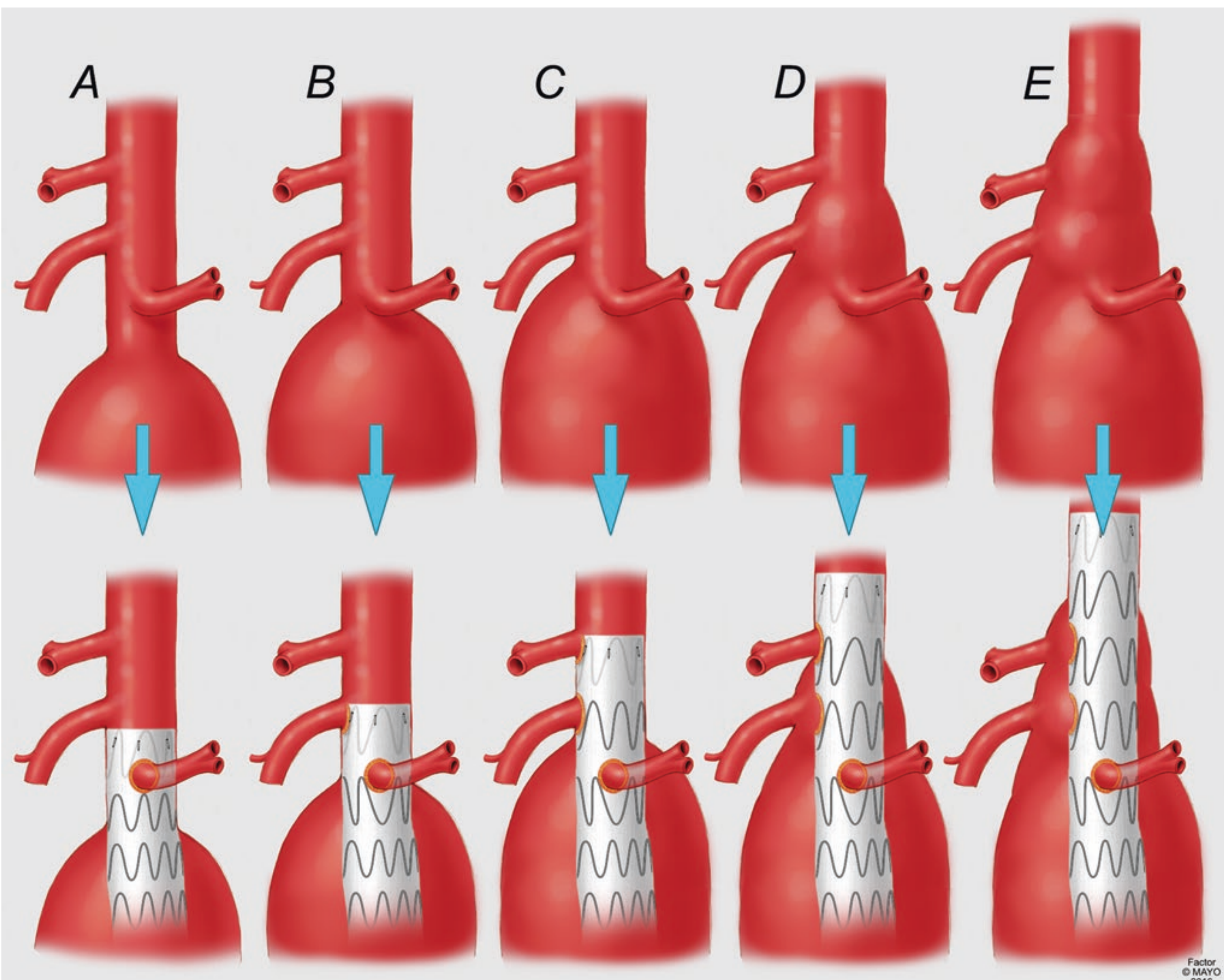


Fig. 5.22 Correlation of complexity of endovascular repair of complex abdominal aortic aneurysms for short-neck infrarenal (**a**), juxtarenal (**b**), pararenal (**c**), paravisceral (**d**), and type IV TAAA (**e**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

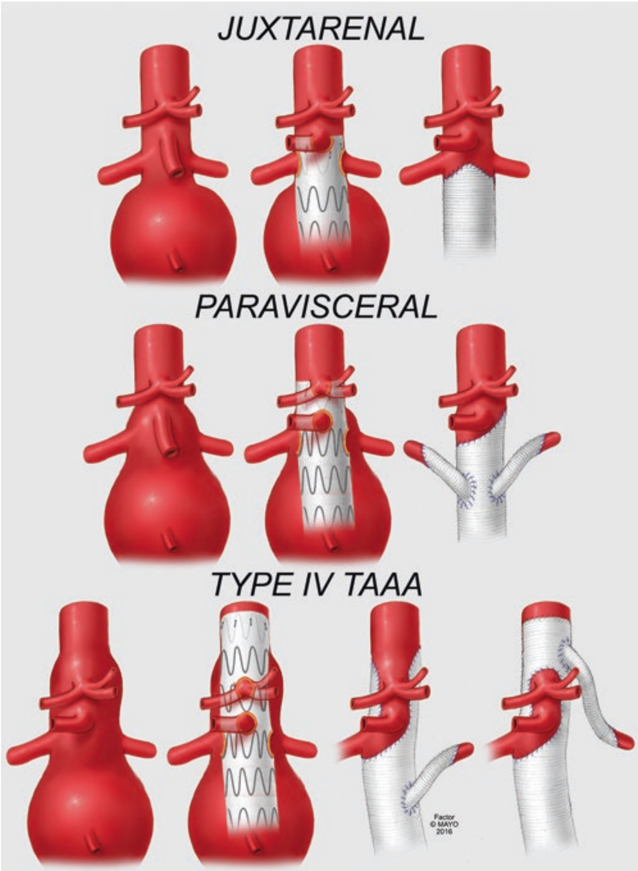


Fig. 5.23 Most common types of endovascular and open repair configuration for juxtarenal, paravisceral, and type IV TAAAs. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

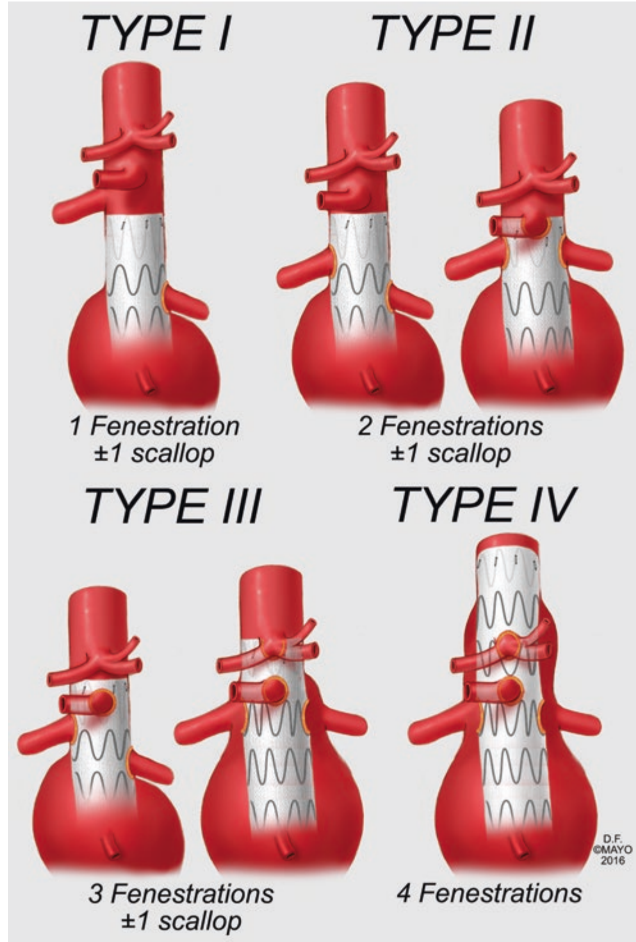


Fig. 5.24 Mayo Clinic endovascular classification of fenestrated and branched repair of complex abdominal aortic aneurysms. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

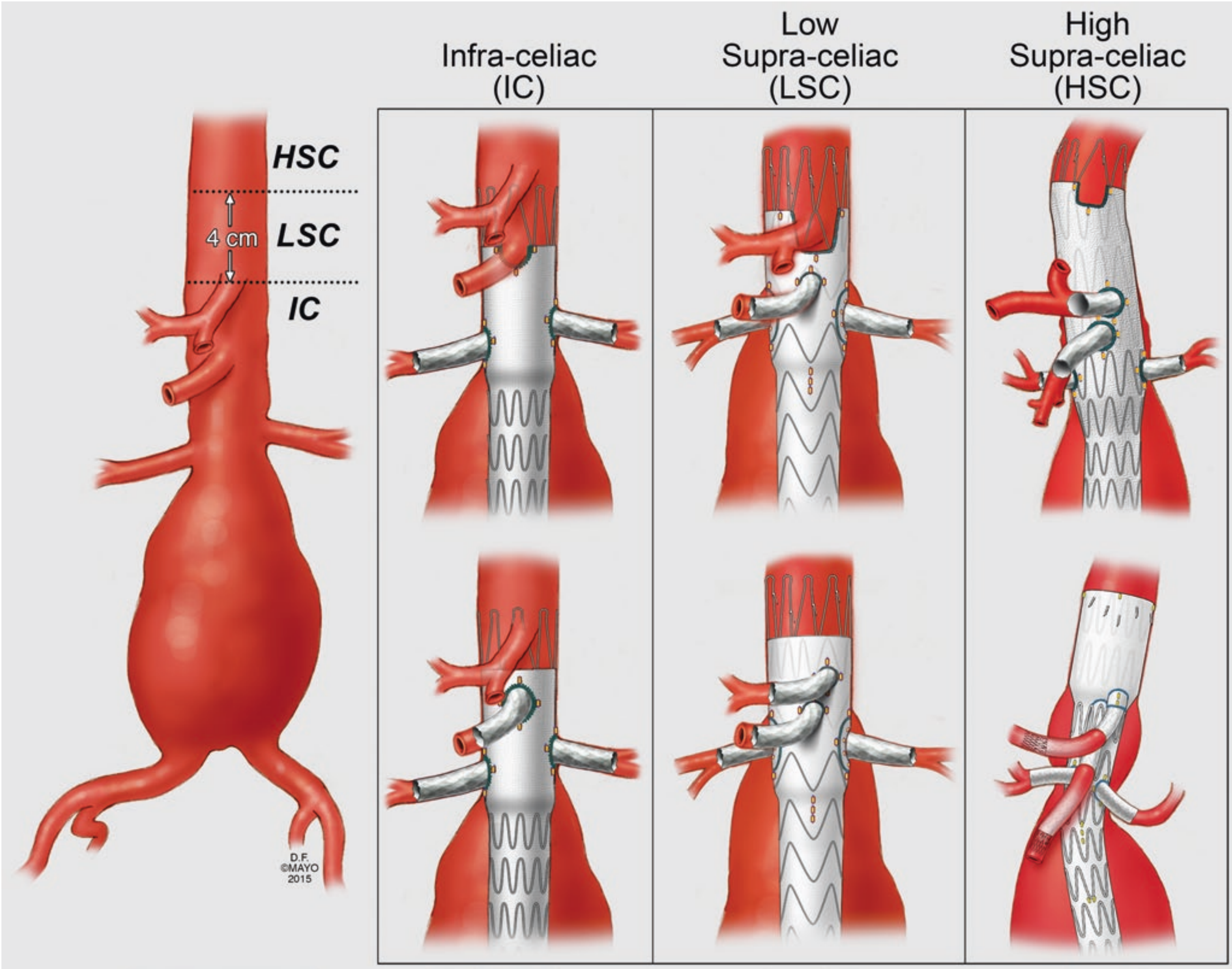


Fig. 5.25 Mayo Clinic endovascular classification of supra-celiac sealing zones for fenestrated and branched endografts. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

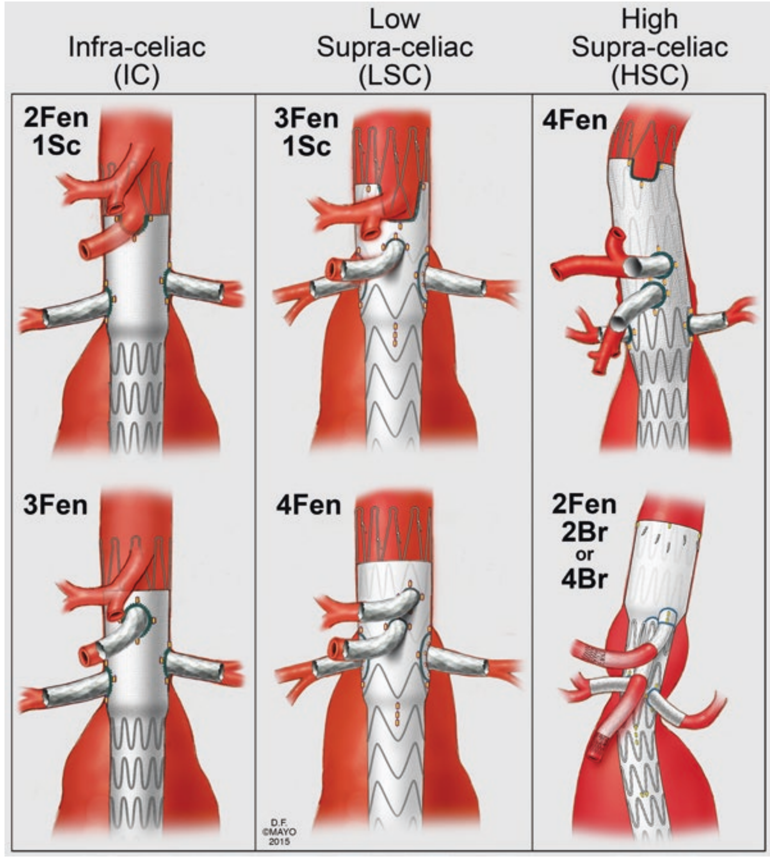


Fig. 5.26 Mayo Clinic endovascular coverage classification based on anatomical location of the aneurysm. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

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