REVIEW ARTICLE

ADVANCING ENDOVASCULAR SOLUTIONS FOR COMPLEX ABDOMINAL AORTIC ANEURYSMS: PATIENT SELECTION, IMAGING, AND DEVICE INNOVATIONS

Mariana Martins-Lopes[1]; Miguel Santos-Venâncio*[1]; João Rocha-Neves[2,3], Mario Marques-Vieira[4]

[1] Faculdade de Medicina da Universidade do Porto
[2] Department of Vascular Surgery, ULS do Alto Ave
[3] RISI-Health, Departament of Biomedicine - Faculdade de Medicina da Universidade do Porto
[4] Department of Vascular Surgery, ULS Braga

* **Corresponding author:** miguelven-fcp@live.com.pt

Abstract

Background: *Abdominal aortic aneurysm (AAA) poses a significant health risk, with a prevalence of 4.8%, and becomes a surgical concern when the diameter exceeds 5.5 cm due to the heightened risk of rupture. Endovascular aneurysm repair (EVAR) has emerged as the primary approach, especially for infrarenal AAAs, offering advantages over traditional open surgery. However, complex anatomies challenge standard EVAR, leading to the development of innovative endografts. This study reviews the literature on treating complex abdominal aortic aneurysms (C-AAAs), focusing on patient selection, preoperative imaging, and available devices.*

Methods: *A comprehensive literature review was conducted on C-AAAs, encompassing treatment options, patient selection criteria, and preoperative imaging. Searches in Pubmed and Google Scholar utilized keywords such as "complex abdominal aortic aneurysm", "fenestrated endovascular aortic repair (FEVAR)", "branched endovascular aortic repair (BEVAR)", "Chimney endovascular aortic repair (chEVAR)" and "patient selection." Additional relevant articles were included through cross-referencing.*

Results: *Patient selection for C-AAA endovascular treatment involves assessing rupture risk, operative mortality, life expectancy, and anatomical considerations. The impact of age on outcomes remains inconclusive across different studies. Preserving renal function is crucial, particularly in patients with renal anomalies, which require careful evaluation. Precise measurements guide decisions, considering factors like aortic tortuosity. Preoperative imaging, particularly computed tomography angiography (CTA), is vital, providing comprehensive anatomical information. Intraoperative fusion imaging enhances real-time assessment, contributing to procedural precision. Device selection, including FEVAR, BEVAR, and Chimney endovascular aortic repair, is tailored to individual anatomy, with custom-made, off-the-shelf, and physician-modified devices offering diverse options.*

Conclusion: *The endovascular treatment of C-AAAs has undergone significant advancements, transforming therapeutic approaches. Optimal outcomes hinge on meticulous patient selection, comprehensive preoperative imaging, and tailored device selection. The evolution from traditional to innovative endografts reflects a paradigm shift. Ongoing research should refine risk assessment, optimize device modifications, and expand endovascular interventions' applicability for C-AAAs.*

Keywords: *Aortic Aneurysm, Abdominal; Endovascular Procedures; Renal Insufficiency, FEVAR; Stents.*

INTRODUCTION

An aneurysm is characterized as a localized enlargement of a blood vessel that equals or exceeds 150% of its the normal diameter. For practical purposes, the definition also, considers aneurysmatic when the abdominal aorta diameter reaches or surpasses 30 mm[1].

Abdominal aortic aneurysm (AAA) has a prevalence of 4.8% in individuals aged 65 and older[2]. Due to the significantly increased risk of rupture, surgical intervention is generally recommended once the aneurysm diameter reaches 55 mm in male and 50 mm in female[3].

Since the first successful reported endoluminal repair of AAA in 1991[4], the adoption of endovascular

aneurysm repair (EVAR) has significantly risen, establishing itself as the leading approach for addressing infrarenal abdominal aortic aneurysms[5,6]. This transition is attributed to the apparent advantages of EVAR over traditional open surgical repair, such as shorter procedure durations, decreased hospital stays, and diminished perioperative morbidity and mortality[7,8].

However, standard EVAR has some requirements to be successful, such as adequate infrarenal aortic neck length, angulation that enables device fixation, absence of visceral vessels and adequate vascular access[2,9]. When these criteria are not met and patients present complex aortic anatomy, including complex aneurysms involving side branches, innovation in the field of EVAR has led to the development of more complex endografts, like parallel, fenestrated, and branched. These devices have broadened the anatomical spectrum of AAAs that can be treated with an endovascular approach[10].

Fenestrated and branched endografts are devices with openings and side branches arising directly from the graft that allow perfusion of the visceral and renal arteries[11]. Recent studies indicate that fenestrated and branched device placement is safe, effective and durable in patients with a high-surgical risk treated for complex abdominal aortic aneurysms (C-AAAs)[12,13].

The aim of this study is to review the literature regarding the treatment of C-AAAs, focusing on patient selection, preoperative imaging and the various available devices.

METHODS

A comprehensive review of the literature was conducted out to identify studies focused on C-AAAs that included different treatment options, patient selection criteria and preoperative imaging. The search was conducted in PubMed and Google Scholar with the keywords "complex abdominal aortic aneurysm", "fenestrated endovascular aortic repair", "FEVAR", "branched endovascular aortic repair", "BEVAR", "Chimney endovascular aortic repair", "chEVAR" and "patient selection".

Additional articles of scientific relevance for this non-systematic review were identified through cross-referencing.

RESULTS

Patient selection

Patient selection for endovascular treatment of C-AAAs is a critical aspect of ensuring successful outcomes. Clinical decisions are based on rupture and operative mortality risk, life expectancy, and criteria such as anatomical considerations, age, comorbidities and risk assessment[14].

Thus, comprehensive evaluation begins with a thorough history, physical examination, and investigation of familial and personal connective tissue disease history. The commitment to lifelong surveillance should be discussed and agreed upon with the patient.[15]

Precise measurements using center lumen line reconstruction software are crucial for accurately determining the diameter, distance, and angulation of the aorta, access vessels, and target arteries. Landing zones, defined as 25 mm of a healthy, normal-diameter artery with parallel walls, free of significant calcific or thrombotic disease, plays a vital role in patient selection. In cases where the proximal landing zone (PLZ) is diseased, the risk of aneurysm sac enlargement and the likelihood of reintervention significantly increase. A poor PLZ can lead to Type IA endoleak, requiring complex secondary interventions. Ideally, the PLZ should be in a native descending thoracic aorta or a previously placed surgical graft, as these provide better durability and lower rates of reintervention compared to a diseased aortic segment[15]. Factors such as aortic tortuosity influence the safety of endovascular device sealing, requiring longer overlap in highly tortuous segments[16]. Anatomic contraindications such as small-diameter target arteries, excessive angulation, early bifurcations that are not suitable for bridging stents, as well as diffuse thrombotic or atherosclerotic debris, should be identified and addressed before further testing[15]. An important and well-known risk factor for late complications after EVAR – large aneurysm diameter – should also be evaluated during pre-operative studies[17].

Diverging results from different studies have led to an inconclusive understanding of age as a risk factor for worse outcomes in the endovascular treatment of C-AAAs[18]. Some studies have shown that advanced age is associated with a higher 30-day mortality rate[19] and a greater risk of being discharged to non-home locations[20]. However, a recent study showed that age was not associated with adverse outcomes after FEVAR, including mortality, lower technical success rates, complications or hospital length of stay[18].

Renal function is a critical determinant of morbidity and mortality, emphasizing the need to preserve renal function during fenestrated and branched endovascular repair (F/BEVAR)[21,22]. Anomalies such as solitary functional, horseshoe, or pelvic kidneys require careful assessment, with renal scintigraphy or perfusion studies aiding in determining vessel incorporation into repair[23,24].

Risk assessment plays a pivotal role in the patient selection process. A recent study with 256 patients validated the functional status of the patient as a strong predictor of 2-year mortality: patients with a high level of dependency had a higher rate of 2-year mortality[25].

Preoperative imaging

Preoperative imaging and planning for the endovascular treatment of C-AAAs are imperative to ensure procedural success[10]. Cross-sectional imaging, particularly computed tomography angiography (CTA), is the reference standard for preoperative imaging, offering comprehensive information on aneurysm sac anatomy, proximal and distal landing zones, and iliac vessels[14].

Some centers advocate a protocol of a CTA of the chest, abdomen, and pelvis with a slice thickness of ≤1 mm. This high-resolution imaging accurately assesses the entire aorta and its first-order branches[15]. Protocols include contrast-enhanced examinations in arterial and portal venous phases, facilitating detailed analysis on dedicated workstations[26]. Modern multi-detector helical CTA enables comprehensive study from the aortic valve to the femoral bifurcation, providing essential diameter, length, and aortic lumen measurements in multiple projections[10].

In addition to conventional CTA, intraoperative fusion imaging is considered a crucial tool[27]. This real-time assessment allows for immediate evaluation of aortic and target artery deformation. Techniques such as small-volume digital subtraction angiography sequences or newer real-time synchronization technologies aid in calibration, reducing radiation exposure while enhancing the likelihood of technical success[28].

While CTA is widely utilized, alternative imaging modalities have their roles. Once the standard, digital subtraction angiography (DSA) offers real-time evaluation but is invasive and only provides inner wall characteristics[11]. Magnetic resonance imaging (MRI) is non-invasive, avoiding ionizing radiation and iodinated contrast agents, but is more susceptible to motion artifacts. Even so, measurements obtained with MRI were equally as accurate as CTA[29]. Ultrasound and intravascular ultrasound (IVUS) have been employed, with IVUS providing intraoperative measurements for stent choice and deployment[30].

Quantitative measurements based on pre-procedure imaging are critical in determining the technical success of endovascular interventions. The evolving landscape of imaging technologies continues to enhance the precision and safety of preoperative planning for complex abdominal aortic aneurysms, allowing for tailored approaches and improved patient outcomes[11].

DEVICE SELECTION

FEVAR vs BEVAR: A comparative overview

Fenestrated endovascular aortic repair (FEVAR) and branched endovascular aortic repair (BEVAR) are the two most used methods of target artery incorporation, each one with advantages and disadvantages, although there is some overlap, most cases are very different[15].

However, all of the studies acknowledge that FEVAR and BEVAR not directly comparable at baseline given that they have instructions IFU and characteristics that define them[31].

FEVAR is typically the preferred method for incorporating target vessels that originate from narrow aortic segments (<42 mm) or those that are perpendicular to the aorta or angled upward[32]. This method also has the advantages of less supraceliac aortic coverage and higher long-term patency, making it a better option than BEVAR for renal arteries. However, it requires precise planning and alignment[15].

In contrast, BEVAR is usually used in patients with wider aortic segments and target vessels that are caudally oriented and tortuous (minimum 25 mm)[32]. The benefits of directional branches are easier implantation with more room for planning errors compared to fenestrated endografts and they can fit a wide range of anatomy. The drawbacks are the more extensive supraceliac coverage and lower primary and secondary patency, particularly for renal artery targets[33].

Device selection in C-EVAR involves a nuanced consideration of various manufacturers and their specific offerings.

The Cook Zenith Fenestrated Stent Graft (ZFEN) is the sole fenestrated stent graft currently FDA-approved. Comprising a proximal body graft, a distal bifurcated graft, and one iliac limb, this modular system utilizes woven polyester fabric sewn to self-expanding Cook-Z stents. Fenestrations are available in small, large, or scallop configurations[9]. Studies, including a multicenter prospective trial[34], establish its safety and efficacy. Results indicate a low incidence of aneurysm-related events, with promising outcomes at intermediate and long-term follow-ups. The high primary renal artery patency and low incidence of endoleaks are noteworthy, reinforcing its durability and effectiveness.

The Anaconda Fenestrated Stent Graft, though not FDA-approved in the United States, is commercially available in Europe. Comprising an aortic endograft and two separate iliac limbs, it boasts a unique design with nitinol ring stents and hooks for sealing. Its distinctive feature lies in full repositioning post-deployment[9]. Clinical studies demonstrate its efficacy in addressing juxtarenal, pararenal, and type IV thoracoabdominal aneurysms[35,36]. While primary patency rates are encouraging, the repositioning feature, while advantageous, may pose challenges, warranting careful consideration[37].

Branched devices, integral to self-expanding stent grafts, offer versatility in orientation and configuration. The Cleveland Clinic's experience with branched sidearm devices, particularly those with an external helical branch, showcases excellent patency rates[38]. Cook Zenith T-Branch and Gore Excluder Thoracoabdominal Branch Endoprosthesis represent off-the-shelf multibranched endografts with promising early results in Europe[39,40]. Ongoing studies will shed light on their long-term performance.

ChEVAR

However, when the anatomy is not favorable or when FEVAR devices are not available in an emergency setting, for instance, other alternatives can be considered such as parallel graft or chimney technique (ChEVAR). The Chimney endovascular aortic repair (chEVAR) or Snorkel technique is another option for treating C-AAAs[41]. This device is also called a Parallel stent graft, because it is inserted parallel to the aortic stent-graft, in other words, the graft stays between the aortic wall and the main stent-graft to preserve normal perfusion to the involved

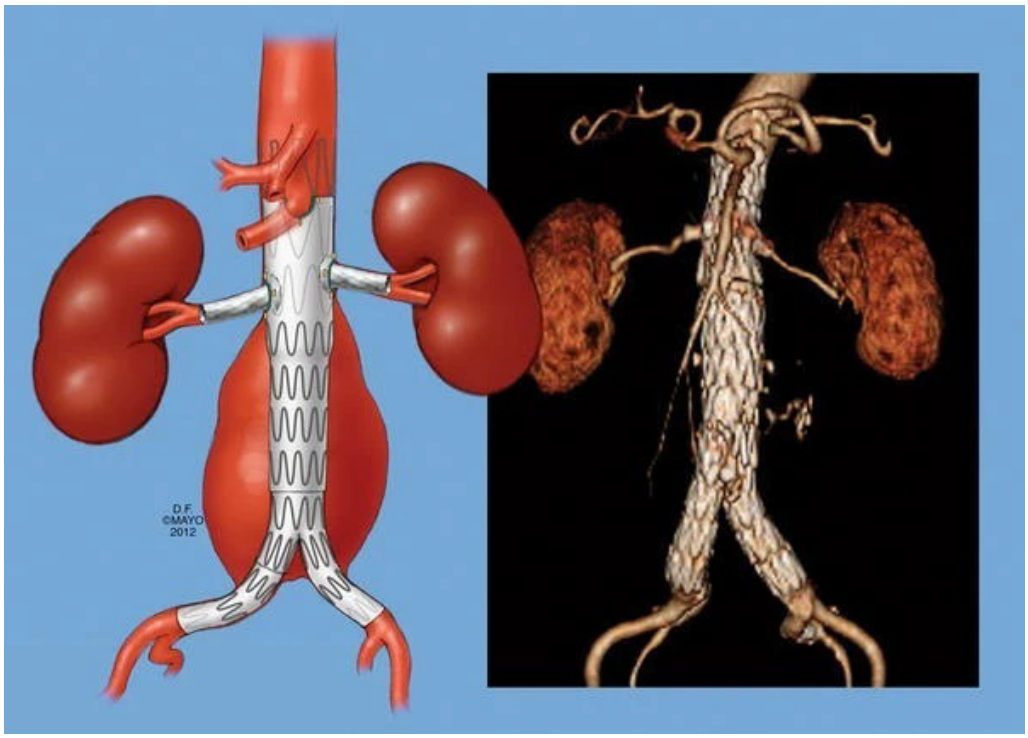

Figure 1

Endovascular repair of a juxtarenal abdominal aortic aneurysm with a fenestrated stent graft, and 3D reconstruction of postoperative computed tomography angiography demonstrating patency of visceral arteries and exclusion of the aneurysm sac. Image from Mendes, B.C., Oderich, G.S., Correa, M.P. et al. Endovascular Repair of Complex Aortic Pathology. Curr Surg Rep 1, 67–77 (2013). https://doi.org/10.1007/s40137-013-0019-9.

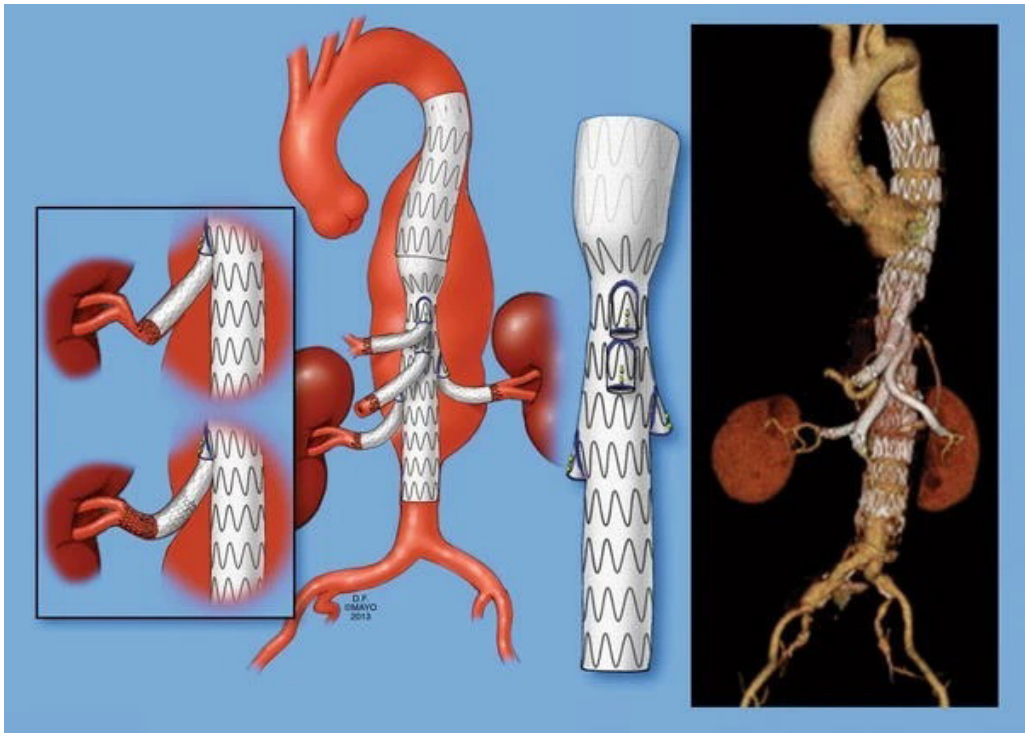

Figure 2

Endovascular repair of a type II thoracoabdominal aortic aneurysm using a physicianmodified branched stent graft with a post-operative computed tomography angiography demonstrating exclusion of the aneurysm and patency of the visceral branches. Note in the inset the use of bare-metal stents to avoid kink in the renal artery after deployment of the covered stent. Image from Mendes, B.C., Oderich, G.S., Correa, M.P. et al. Endovascular Repair of Complex Aortic Pathology. Curr Surg Rep 1, 67–77 (2013). https://doi.org/10.1007/s40137-013- 0019-9.

target branches[14,42]. This technical strategy has its own disadvantages, especially the creation of a "channel" that results from the interaction between the chimney graft and the main aortic graft, so chEVAR is associated with an elevated risk of type Ia endoleak (>10%)[43].

CMDs, PMDs and off-the-shelf devices

Within FEVAR and BEVAR endografts, three different types have been described: Custom-made devices (CMDs), Physician-modified devices (PMDs) or Physician-modified endovascular graft (PMEGs) and off-the-shelf endografts[2,44].

Typically, fenestrated endografts are custom-made[45]. Thus, they are specifically tailored to the patient's individual anatomy, contributing to precision-based medicine[46]. If they are built to fit each specific patient, they will also require an extra manufacturing and delivery time (sometimes up to 12 weeks)[2], which is a limitation for their use in urgent situations, besides the increased risk of rupture during the waiting period[47].

An alternative for the CMDs is the off-the-shelf endografts, because they are designed to fit the anatomy of the majority of the general population, Therefore they can be used in urgent situations, if the patient does not diverge from the "population standard" [9].

From this arises, an obvious problem: the patients who need an urgent complex endovascular repair but may not be suitable for an off-the-shelf endograft. This group may benefit from a device that was previously produced but it's modified to suit in that individual patient's anatomy[2]. So, PMEGs have the advantages of eliminating time of manufacture and delivery but keeping the individualized and precise structure. Nevertheless, stent graft modification is technically challenging and corresponds to a device modification that is uncontrolled[47]. Even so, PMEGs appear to be safe and effective in the endovascular treatment of C-AAA[48].

CONCLUSION

In conclusion, the endovascular treatment of C-AAAs has witnessed significant advancements since its inception, transforming the therapeutic landscape for patients with intricate vascular pathologies. The prevalence of abdominal aortic aneurysms, reaching 4.8%, underscores the importance of effective intervention to mitigate the heightened risk of rupture associated with larger aneurysm diameters. The evolution from traditional open surgical repair to EVAR, especially with the introduction of fenestrated and branched endografts, reflects a paradigm shift in managing C-AAAs.

Meticulous criteria for patient selection are imperative for technical success. A comprehensive evaluation, considering anatomical factors, comorbidities, and risk assessment is crucial for optimal outcomes in this challenging patient population.

Preoperative imaging, particularly CTA, stands as the gold standard for assessing aneurysm anatomy and guiding procedural planning and intraoperative fusion imaging further enhances real-time assessment, contributing to the precision and safety of endovascular interventions.

Device selection is tailored to the individual patient's anatomy, with fenestrated and branched endografts providing effective solutions for complex anatomies. The choice between FEVAR and BEVAR depends on factors such as aortic segment width, target vessel orientation, and the need for precise planning. CMDs, PMEGs, and off-the-shelf endografts present diverse options, each with its advantages and limitations.

The ongoing evolution of endovascular techniques and technologies, coupled with a nuanced understanding of patient selection criteria, emphasizes the dynamic nature of the field. Future research endeavors should focus on refining risk assessment, optimizing device modifications, and expanding the applicability of endovascular interventions for complex abdominal aortic aneurysms.

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