VDM Vascular Disease Management

REVIEW

Are Physician-Modified Endovascular Grafts the Answer for Urgent Aneurysm Repair?

Pedro J.F. Neves, MD[1]; Mazin Foteh, MD[2]; Rafael D. Malgor, MD, MBA[1]

[1]*Division of Vascular and Endovascular Surgery, University of Colorado, Anschutz Medical Center, Aurora, Colorado;* [2]*Division of Vascular Surgery, Baylor Scott & White, Dallas, Texas*

Keywords
Abdominal Aortic Aneurysm
Aneurysm Repair
Endovascular Therapy
Physician-Modified Endovascular Grafts

March 2023
ISSN 2152-4343

VASCULAR DISEASE MANAGEMENT 2023;20(3):E38-E44.

Abstract

Abdominal aortic aneurysms are present in up to 8% of men aged 65 and older, and rupture of an abdominal aortic aneurysm and its associated conditions carries an overall mortality over 80%. While open surgery was classically the solution for aneurysms, high surgical morbidity and mortality led physicians to seek out less invasive options for frail patients. Today, open surgery remains the more durable option but should be designated to well-selected patients with low surgical risk and a life expectancy of more than 5 years, or in genetically associated aortic disease. For patients with a higher surgical risk, the endovascular option holds significant appeal and has been shown to be cost effective and safe, with low morbidity and mortality. Several methods for treating such disease exist today, including fenestrated endovascular aortic repair, branched endovascular aortic repair, parallel graft techniques (snorkel and chimney grafts), and physician-modified endovascular grafts, which are off-the-shelf devices that are modified on the back table by the physician to suit a particular patient's anatomy. The aim of this review is to compare the different endovascular therapies available for urgent complex and thoracoabdominal aortic aneurysm repair, and attempt to establish the role of physician-modified endovascular grafts in the future for these patients.

Introduction

Abdominal aortic aneurysms (AAAs) are present in up to 8% of men aged 65 and older, and rupture of an AAA and its associated conditions carries an overall mortality in excess of 80%; 2% of all deaths are AAA-related.[1] The endovascular revolution in aneurysm treatment was heralded by Volodos[2] and Parodi[3] with endovascular aortic repair (EVAR) and by Dake with thoracic endovascular aortic repair (TEVAR) in the 1990s.[4] Today, over 80% of infrarenal abdominal aortic aneurysms are treated with endovascular technology in the United States.[5] While open surgery was classically the solution for aneurysms, as they can be adapted to any anatomy type, high surgical morbidity and mortality led physicians to seek out less invasive options for frail patients. Today, open surgery remains the more durable option but should be designated to well-selected patients with low surgical risk and a life expectancy of more than 5 years, or in genetically associated aortic disease.[6-8] For patients with a higher surgical risk, the endovascular option holds significant appeal and has been shown to be cost-effective and safe, with low morbidity and mortality.[9,10] The main downside to endovascular therapy is the frequent reinterventions necessary, although these are not associated with decreased survival.[11]

Historically, complex aneurysms were an obstacle to initial endovascular therapy; however, the progress of fenestrated and branched technology has largely overcome these difficulties and most thoracoabominal aneurysms (TAAs) and complex aortic aneurysms (CAAs) can be safely managed with endovascular means.[10] Several methods for treating such disease exist, including fenestrated endovascular aortic repair (FEVAR), branched endovascular aortic repair (BEVAR), parallel graft techniques (snorkel and chimney grafts), and physician-modified endovascular grafts (PMEGs). These technologies can also be divided as to their origin. Off-the-shelf devices are designed to be adaptable to the largest amount of patient anatomy possible, although some limitations are present. Custom-made devices are tailored to the patient, but the main downside is the time of fabrication, which can take weeks and is not feasible in urgent or emergent cases. PMEGs are off-the-shelf devices that are modified on the back table by the physician to suit a particular patient's anatomy. While open surgery remains an effective alternative for patients with suitable surgical risk and is more able to deal with challenging anatomy, this is not within the scope of this review. The aim of this review is, instead, to compare the different endovascular therapies available for urgent complex and thoracoabdominal aortic aneurysm repair, and attempt to establish the role of PMEGs in the future for these patients.

Physician-Modified Endovascular Grafts

PMEGs have existed since the beginning of the endovascular revolution, with the first endovascular stents implanted consisting of metal stents manually sutured to polyester fabric.[2,3] The term *physician-modified endovascular grafts* was coined in 2011 by Dr. Benjamin Starnes.[12] More data on PMEGs, including technical descriptions, variations of technique, and clinical results have recently been published, consolidating them as a viable option in treating aortic disease both urgent and elective.[9,13–18] Currently, data from across the United States show that approximately 20% of complex aneurysms are treated with PMEGs.[19]

As a treatment option, PMEGs are, in a word, heterogeneous. This is a double-edged sword; while PMEGs offer an unrivaled versatility, standardization of PMEGs is also the greatest challenge posed. With this comes the necessary rigorous training and exhaustive attention to detail necessary for any physician to successfully incorporate PMEGs as a potential therapy in their arsenal. The endograft can be planned for as soon as contrast-based imaging is available and does not require the time for manufacturing that custom-made devices do,[20] and changes are made to off-the-shelf EVAR or TEVAR devices on the back table while the patient is prepped for surgery, akin to back table organ preparation before transplants.

The main limitations of PMEGs are the expertise and regulatory approval required to safely perform them, due to the complex nature of AAA repair. This, consequently, makes quality control and standardization of care a currently unsolved dilemma. In the United States, it is strongly encouraged that PMEGs be performed only under the aegis of an Investigational Device Exemption (IDE) from the Food and Drug Administration (FDA), and patients subject to this form of therapy should be enrolled in clinical studies in order to have follow-up, allow for quality improvement analyses, and provide higher-quality data to guide clinical decisions. This is due to the FDA viewing a modified commercially available device as a new device that falls under its oversight and subject to review. In exceptional circumstances, however, PMEGs can be used outside of FDA IDE approval. These circumstances involve compassionate use in dire circumstances, after adequate informed consent of off-label device use and the absence of effective alternative therapies, or an inability to transfer the patient due to clinical status.[15]

In the urgent setting (in patients who cannot be transferred), a PMEG can be done expeditiously if the physician has the expertise to do so. However, some patients in extremis cannot tolerate even the minutes it takes for back table modifications to occur, and therefore these patients may benefit from other techniques that do not require this extra step. Examples are open surgery, which carries higher risk for short-term morbidity and mortality, and parallel stent graft techniques, such as chimney and snorkel grafts, which might need arm access, can carry risks of gutter leaks, and might not be as expeditious depending on aneurysm complex anatomy.

PMEGs in Comparison With Other Technologies

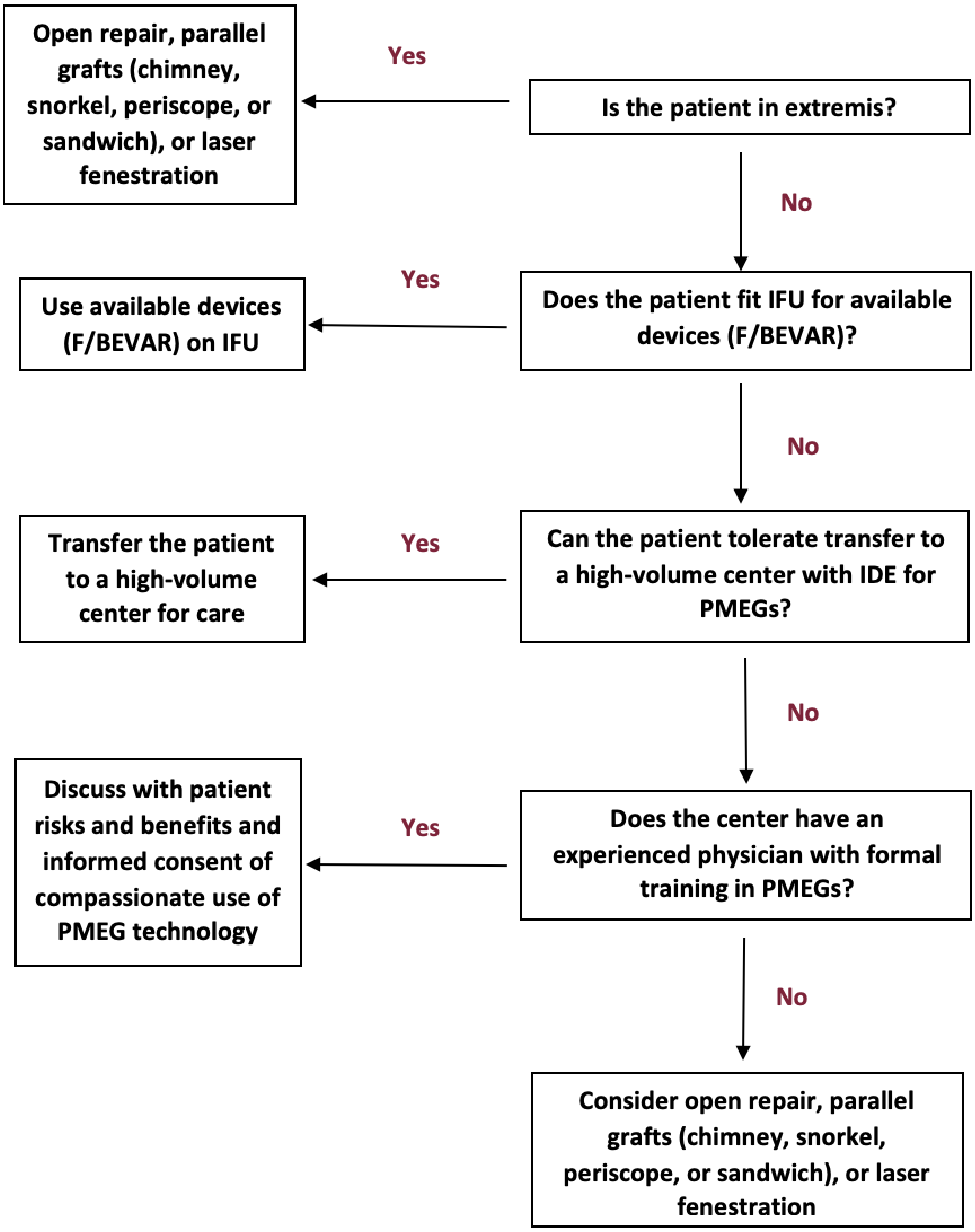
In terms of other technologies for treating urgent CAAs, as compared with PMEGs, custom-made devices are rarely available for urgent cases owing to the time necessary to produce them, which can vary from 3 weeks up to 2 months. Off-the-shelf devices are an excellent alternative, limited only by the fact that not all patient anatomy is adaptable to these devices. This can be due to cranial direction of target vessels, narrow proximal landing zones, or the necessity of excessively long aortic coverage, increasing the risk of spinal cord injury.[20,21] PMEGs are more adaptable to difficult anatomy but are limited by human resources. PMEGs should only be done by physicians well versed in this complex technique, as operator volume has been shown to significantly impact outcomes, radiation exposure, and operative times.[10] Aortic centers, intended to improve the standard of care of aortic diseases, should necessarily have physicians capable of offering these solutions when applicable.[22]

Table 1. Summary of advantages, disadvantages, and ideal scenarios for urgent complex and thoracoabdominal aneurysm repair strategies.			
	Advantages	**Disadvantages**	**Ideal scenarios/current devices**
Branched endovascular aortic repair (off-the-shelf)	- Requires larger aortic lumen - Requires less precision, as branches allow for repositioning - Superior long-term vessel patency for the visceral vessels	- Currently no FDA-approved device - Does not suit 100% of patient anatomy - Future devices will likely be limited by vessels with cranial orientation	- Urgent cases, within IFU (no currently available devices, but devices expected soon) - Cook Zenith t-branch: 39% anatomically within IFU[28] - Gore TAMBE: 33% anatomically within IFU[28] - Jotec E-nside: Not currently in trial in the United States; 43% anatomically within IFU[28]
Parallel stent-grafts (chimneys, snorkels, periscopes, sandwich)	- Can be done intraoperatively as a rescue maneuver - Can quickly be used to stabilize patients in extremis	- Lower long-term patency - Risk of gutter endoleaks and need for reinterventions	- Emergent cases, where no off-the-shelf device is available or suitable for use, and patient cannot tolerate transfer - Intraoperative rescue maneuver (inadvertent renal artery coverage; type Ia endoleak)
Physician-modified endovascular grafts	- Can be customized to a wider variety of patient anatomy (versatility) - Fashioned from commercially available devices	- Heterogenous - Requires highly trained physician - Not fully reimbursable - Requires time for preparation before patient intervention begins	- Urgent cases, no off-the-shelf devices available at a high-volume center with trained physician experienced with PMEGs - Can be done using most commercially available EVAR or TEVAR devices

IFU = instructions for use; PMEGs = physician-modified endovascular grafts; EVAR = endovascular aortic repair; TEVAR = thoracic endovascular aortic repair.

Current results of PMEGs employed to treat urgent CAAs and TAAs have shown 30-day mortality between 6% and 8%, a technical success rate of 92% to 97%, freedom from aortic-related mortality of 94%, overall 1-year survival rate of 70% to 78%, and 1-year freedom from reintervention of 70% to 83%.[13,17] For total (urgent and nonurgent) cases, PMEGs have shown a 30-day mortality of 5.7%, technical success rate of 91% to 99%, freedom from aortic-related mortality of 92%, and freedom from reintervention at 5 years of 57%.[9] When compared with the only currently FDA-approved device, the Zenith Fenestrated stent graft (Cook Medical), although not in urgent patients, the technical success was 100%, freedom from aortic-related mortality was 96.8% at 5 years, and freedom from reintervention was 63.5% at 5 years.[23] This shows that in trained hands, PMEGs can offer consistent results comparable to commercially available devices. The main advantages and disadvantages of different technologies available to treat CAAs when open repair is unwise are summarized in **Table 1**. An algorithm for urgent case conduction is also summarized in **Figure 1.**

Figure 1. Algorithm for urgent complex aneurysm repair.



F/BEVAR = fenestrated/branched endovascular aortic repair; IFU = instructions for use; PMEGs = physician-modified endovascular grafts

Technical Considerations

Once the decision to proceed with a PMEG has been taken, the process of preoperative planning—arguably the most important part of the procedure—must then begin. Factors to consider include diameter of access vessels (ideally >8.5 mm), degree of calcium in access vessels (for percutaneous closure devices), and any tortuosity in the iliac vessels (risk of iliac artery injury while tracking). For the back table modification of the off-the-shelf device itself, important parameters are target vessel diameters, distance to first branch, and clock face position from the aorta (converted to angle, will be used to calculate the arc length based on the diameter of the aortic stent graft to be modified), as summarized in **Table 2**.[16]

Table 2. Summary of measurements needed for back table physician-modified endovascular graft construction (measurements based on 30-mm Terumo bifurcated graft).							
	Clock face (angle)	**Arc length (distance on the X-axis)**	**Distance from celiac artery (distance on the y-axis)**	**Vessel diameter**	**Aortic flow lumen diameter**	**Distance to first vessel takeoff**	**Optimal parallax angle**
Celiac artery	0045 (21º)	5.5 mm	NA	6 mm (7 mm at ostium)	35 mm	22 mm	65 RAO; 10 CRA
Superior mesenteric artery	0000 (0º)	0 mm	25 mm	5.5 mm (8 mm at ostium)	33 mm	42 mm	60 RAO; 0 CRA
Right renal artery	1030 (-45º)	-11.8 mm	33 mm	4.5 mm (7 mm at ostium)	34 mm	48 mm	30 LAO; 15 CRA
Left renal artery	0345 (115º)	30.1 mm	36 mm	5mm (5 mm at ostium)	34 mm	31 mm	20 LAO; 15 CRA

NA = not applicable; RAO = right anterior oblique; CRA = cranial; LAO = left anterior oblique.

For modification of the stent graft, an option would be to use a transparent sterile plastic piece, such as those used in instrument packaging to measure distances and mark the fenestration positions as demonstrated in **Figure 2**. The blue plastic can then be cut with a scalpel in the center to permit marking of the fenestrations on the stent graft with a marker. The fenestrations are then made using ophthalmic cautery, with care taken to avoid involvement of metallic stents in the graft itself. Fenestrations should be 8 x 8 mm for visceral arteries and 6 x 6 mm for renal arteries. After they have been burned into the fabric, reinforcement with the metallic wire from a snare should be performed with 6-0 Prolene sutures and radiopaque coils or gold markers, whenever available, placed for fenestration visualization on fluoroscopy. Once this is completed, the device is once again enclosed within the delivery system with the help of vessel loops, umbilical tape, or Rummel tourniquets. This portion of the procedure usually takes from 45 to 60 minutes but can take longer, depending on the complexity, the number of fenestrations, and the incorporation of mini-cuffs or inner branches.[24]

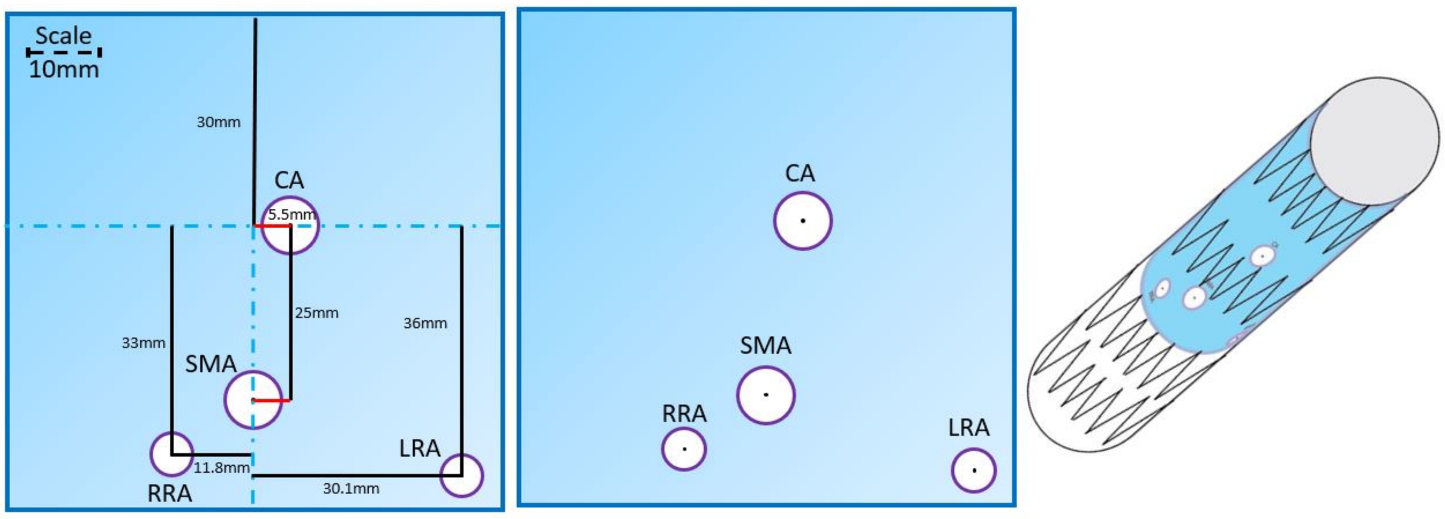


Figure 2. For modification of the stent graft, an option would be to use a transparent sterile plastic piece, such as those used in instrument packaging to measure distances and mark the fenestration positions. CA = celiac artery; SMA = superior mesenteric artery; RRA = right renal artery; LRA = left renal artery.

Following PMEG construction, endovascular intervention may then begin, and the preoperative planning must be strictly followed for optimal results. Optimal parallax angles are useful in providing the best image for target vessel catheterization (**Table 2**); modern positioning systems and fusion imaging are useful adjuncts.[25-27] Balloon-expandable bridging stents must be used, and proximal flaring performed to avoid type IIIc endoleaks. Bridging stents are sized according to target vessel diameter and length to the first branch (**Table 2**). Minute deviations can result in extreme difficulty in target vessel incorporation, which is why precision in planning and execution is crucial.

From this description, it is evident that excruciating attention to detail is paramount and the margin for error is practically inexistent. Therefore, the importance of preoperative planning and rigorous physician training standards cannot be overstated, and mistakes on this step can doom the procedure to failure.

Conclusions

PMEGs might play an important role in urgent treatment of complex abdominal and thoracoabdominal aortic aneurysms due to their versatility. However, owing to the complex nature of these interventions, PMEGs should only be used by physicians with specific training, ideally with FDA IDE overview and patient enrollment in clinical studies. PMEGs offer a solution that has less perioperative morbidity and mortality than open repair, albeit less durable. Patients in extremis might benefit instead from other interventions that do not require back table device modifications, such as open repair (with higher morbidity and mortality) or parallel stent grafts (with lower long-term durability, risk of gutter leaks).

In the future, PMEGs are likely to continue to occupy a niche in urgent cases when other devices are unsuited to repair and time is of the essence, but should be limited to high-volume centers and highly trained operators. In the future, standardization of training for physicians apt to perform PMEGs should be pursued to guarantee high-quality care. ■

Disclosure: The authors have completed and returned the ICMJE Form for Disclosure of Potential Conflicts of Interest. The authors report no financial relationships or conflicts of interest regarding the content herein.

Manuscript accepted February 6, 2023.

Address for correspondence: Rafael D. Malgor, Division of Vascular Surgery, Department of Surgery, University of Colorado, Anschutz Medical Center, 12631 E. 17th Ave., Room 6111, Aurora, CO, 80045. E-mail: Rafael.malgor@cuanschutz.edu

Related Article

Evolution and Future Direction of Fenestrated and Branched Aortic Endografts for Complex Abdominal Aortic Aneurysms and Thoracoabdominal Aortic Aneurysms

REFERENCES

1. Nordon IM, Hinchliffe RJ, Loftus IM, Thompson MM. Pathophysiology and epidemiology of abdominal aortic aneurysms. *Nat Rev Cardiol*. 2011;8(2):92-102. doi:10.1038/nrcardio.2010.180

2. Volodos NL. Historical perspective: the first steps in endovascular aortic repair: how it all began. *J Endovasc Ther*. 2013;20(Suppl 1):I3-23. doi:10.1583/1545-1550-20.sp1.I-3

3. Veith FJ, Marin ML, Cynamon J, Schonholz C, Parodi J. 1992: Parodi, Montefiore, and the first abdominal aortic aneurysm stent graft in the United States. *Ann Vasc Surg*. 2005;19(5):749-751. doi:10.1007/s10016-005-6858-9

4. Dake MD, Miller DC, Mitchell RS, Semba CP, Moore KA, Sakai T. The "first generation" of endovascular stent-grafts for patients with aneurysms of the descending thoracic aorta. *J Thorac Cardiovasc Surg*. 1998;116(5):689-703; discussion 703-704. doi:10.1016/S0022-5223(98)00455-3

5. Suckow BD, Goodney PP, Columbo JA, et al. National trends in open surgical, endovascular, and branched-fenestrated endovascular aortic aneurysm repair in Medicare patients. *J Vasc Surg*. 2018;67(6):1690-1697.e1. doi:10.1016/j.jvs.2017.09.046

6. Coselli JS, LeMaire SA, Preventza O, et al. Outcomes of 3309 thoracoabdominal aortic aneurysm repairs. *J Thorac Cardiovasc Surg*. 2016;151(5):1323-1337. doi:10.1016/j.jtcvs.2015.12.050

7. Oderich GS, Forbes TL, Chaer R, et al. Reporting standards for endovascular aortic repair of aneurysms involving the renal-mesenteric arteries. *J Vasc Surg*. 2021;73(1S):4S-52S. doi:10.1016/j.jvs.2020.06.011

8. Deery SE, Lancaster RT, Baril DT, et al. Contemporary outcomes of open complex abdominal aortic aneurysm repair. *J Vasc Surg*. 2016;63(5):1195-1200. doi:10.1016/j.jvs.2015.12.038

9. Chait J, Tenorio ER, Hofer JM, DeMartino RR, Oderich GS, Mendes BC. Five-year outcomes of physician-modified endografts for repair of complex abdominal and thoracoabdominal aortic aneurysms. *J Vasc Surg*. 2023;77(2):374-385.e4. doi:10.1016/j.jvs.2022.09.019

10. Tenorio ER, Dias-Neto MF, Lima GBB, Baghbani-Oskouei A, Oderich GS. Lessons learned over 2 decades of fenestrated-branched endovascular aortic repair. *Semin Vasc Surg*. 2022;35(3):236-244. doi:10.1053/j.semvascsurg.2022.07.007

11. Dossabhoy SS, Sorondo SM, Tran K, Stern JR, Dalman RL, Lee JT. Reintervention does not affect long-term survival after fenestrated endovascular aneurysm repair. *J Vasc Surg*. 2022;76(5):1180-1188.e8. doi:10.1016/j.jvs.2022.04.050

12. Starnes BW. Physician-modified endovascular grafts for the treatment of elective, symptomatic, or ruptured juxtarenal aortic aneurysms. *J Vasc Surg*. 2012;56(3):601-607. doi:10.1016/j.jvs.2012.02.011

13. Scali ST, Neal D, Sollanek V, et al. Outcomes of surgeon-modified fenestrated-branched endograft repair for acute aortic pathology. *J Vasc Surg*. 2015;62(5):1148-1159.e2. doi:10.1016/j.jvs.2015.06.133

14. Torrealba J, Panuccio G, Kölbel T, Gandet T, Heidemann F, Rohlffs F. Physician-modified endograft with inner branches for the treatment of complex aortic urgencies. *J Endovasc Ther*. 2022;29(5):697-704. doi:10.1177/15266028211061275

15. Kimball AS, Mydlowska A, Beck AW. Physician-modified endografts for urgent and emergent aortic pathology. *Semin Vasc Surg*. 2021;34(4):215-224. doi:10.1053/j.semvascsurg.2021.07.001

16. Chait J, Mendes BC, DeMartino RR. Anatomic factors to guide patient selection for fenestrated-branched endovascular aortic repair. *Semin Vasc Surg*. 2022;35(3):259-279. doi:10.1053/j.semvascsurg.2022.07.003

17. Biggs JH, Tenorio ER, DeMartino RR, Oderich GS, Mendes BC. Outcomes following urgent fenestrated-branched endovascular repair for pararenal and thoracoabdominal aortic aneurysms. *Ann Vasc Surg*. 2022;85:87-95. doi:10.1016/j.avsg.2022.05.003

18. Melo RGE, Prendes CF, Caldeira D, et al. Systematic review and meta-analysis of physician modified endografts for treatment of thoraco-abdominal and complex abdominal aortic aneurysms. *Eur J Vasc Endovasc Surg*. 2022;64(2-3):188-199. doi:10.1016/j.ejvs.2022.04.015

19. O'Donnell TFX, Patel VI, Deery SE, et al. The state of complex endovascular abdominal aortic aneurysm repairs in the Vascular Quality Initiative. *J Vasc Surg*. 2019;70(2):369-380. doi:10.1016/j.jvs.2018.11.021

20. Farber MA, Vallabhaneni R, Marston WA. "Off-the-shelf" devices for complex aortic aneurysm repair. *J Vasc Surg*. 2014;60(3):579-584. doi:10.1016/j.jvs.2014.03.258

21. Mendes BC, Oderich GS, Macedo TA, et al. Anatomic feasibility of off-the-shelf fenestrated stent grafts to treat juxtarenal and pararenal abdominal aortic aneurysms. *J Vasc Surg*. 2014;60(4):839-847; discussion 847-848. doi:10.1016/j.jvs.2014.04.038

22. Tanious A, Wooster M, Giarelli M, et al. Positive impact of an aortic center designation. *Ann Vasc Surg*. 2018;46:142-146. doi:10.1016/j.avsg.2017.08.009

23. Oderich GS, Farber MA, Schneider D, et al. Final 5-year results of the United States Zenith Fenestrated prospective multicenter study for juxtarenal abdominal aortic aneurysms. *J Vasc Surg*. 2021;73(4):1128-1138.e2. doi:10.1016/j.jvs.2020.08.128

24. D'Oria M, Mirza AK, Tenorio ER, Kärkkäinen JM, DeMartino RR, Oderich GS. Physician-modified endograft with double inner branches for urgent repair of supraceliac para-anastomotic pseudoaneurysm. *J Endovasc Ther*. 2020;27(1):124-12 doi:10.1177/15266028198901089

25. Bailey CJ, Edwards JB, Giarelli M, Zwiebel B, Grundy L, Shames M. Cloud-based fusion imaging improves operative metrics during fenestrated endovascular aneurysm repair. *J Vasc Surg*. 2023;77(2):366-373. doi:10.1016/j.jvs.2022.09.020

26. Finnesgard EJ, Simons JP, Marecki H, et al. Fiber Optic RealShape technology in endovascular surgery. *Semin Vasc Surg*. 2021;34(4):241-246. doi:10.1053/j.semvascsurg.2021.10.001

27. Muluk SC, Elrakhawy M, Chess B, Rosales C, Goel V. Successful endovascular treatment of severe chronic mesenteric ischemia facilitated by intraoperative positioning system image guidance. *J Vasc Surg Cases Innov Tech*. 2022;8(1):60-65. doi:10.1016/j.jvscit.2021.11.001

28. Bertoglio L Grandi A, Carta N. Comparison of anatomic feasibility of three different multibranched off-the-shelf stent-grafts designed for thoracoabdominal aortic aneurysms. *J Vasc Surg*. 2021;74(5):1472-1482.e4. doi:10.1016/j.jvs.2021.04.066