Tested by Time

The story of the evolution of endovascular aneurysm repair and the GORE® EXCLUDER® Device.

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The repair of abdominal aortic aneurysms (AAA) has parallels in the history of clockmaking, which began more than 5,000 years ago with the creation of the Egyptian obelisk sun clock in 3500 BC. Based on humankind's needs and empowered by advances in technology, the clock evolved dramatically over time. Similarly, fueled by competitive market pressure and based upon applied technical knowledge, the repair of AAA progressed relentlessly, but over a much shorter period.

Open surgical repair of AAA was first described by French physician Charles Dubost in 1951. His work set the standard until 1986 when Nickolay Volodos first described aortic stent graft repair of a post-traumatic descending thoracic aortic aneurysm. Shortly thereafter, in 1991, the more well-known Juan Parodi, MD, published his first endovascular aneurysm repair (EVAR) manuscript. Despite EVAR having a history from the 1990s—a very short timescale when compared with thousands of years of clockmaking—both reflect a pattern of systems moving up-market by responding to the pressure of unanswered needs.

Indeed, EVAR has surged and now dominates the market. For most patients with acceptable anatomy, it has disrupted open surgical repair as the new gold standard. Over time, outcome data have demonstrated that EVAR offers tremendous morbidity and mortality benefits in the perioperative period. The trade-off, however, seems to be dealing with long-term aneurysm concerns and commitment to ongoing device imaging and management. The long-term durability of EVAR has been established, and EVAR outcomes continue to improve. Currently, several endografts have received Food and Drug Administration (FDA) approval, with more in development or under clinical evaluation. To date, most of these have offered very strong outcomes and have excellent track records for safety and efficacy. However, it has become clearer that differences in device delivery and design provide certain advantages that may favor one anatomical milieu over another. The goal of this article is to describe the history and evolution of the GORE® EXCLUDER® AAA Endoprosthesis, a product whose development draws analogy to the field of clockmaking.

DISRUPTIVE INNOVATION, MECHANICAL CLOCKS, AND THE FIRST-GENERATION GORE EXCLUDER DEVICE

Because of the imperfect function of sundials and second-century water clocks, mechanical clocks were introduced in the 10th century. Similarly, the first endovascular repairs centered on a solution for the imperfect outcomes associated with open AAA repair in patients with poor physiology. The early endovascular approach was limited to physician-made devices using graft material sutured to available stents. Those early homemade endovascular devices, like early mechanical clocks, were clunky and poorly efficacious. As described by the Harvard School of Business’s Clayton Christensen in his book The Innovator’s Dilemma, this phase of inadequacy is typical and even required of all disrupting technologies. Since first described by Dr. Parodi a quarter-century prior, numerous commercial endograft devices are now in use and in various phases of evaluation. These devices have undergone aggressive iterations as new needs are identified based on growing clinical experience and lessons learned with older models.

The GORE EXCLUDER Device has undergone several refinements since its original release in Europe in 1997. The original GORE EXCLUDER Device was used from 1997 to 1999, where it was then modified and in use until 2004. It received FDA approval for commercial distribution in the United States in 2002. In 2004, the low-permeability GORE EXCLUDER Device was introduced and remains in use today.

The device is a modular system consisting of a bifurcated main body with a single docking limb and assorted contralateral limbs, with optional iliac and proximal extenders (Figure 1). The proximal portion of the main body is covered with paired nitinol anchors for infrarenal fixation. The proximal edge is identifiable by
ADVANCING INNOVATION: THE GORE® C3® DELIVERY SYSTEM

Whether building clocks or repairing aortic aneurysms, advancement requires careful observation to pinpoint market needs and guide innovation. Early mechanical clocks became more accurate when their design changed from heavy weights to spring power to a pendulum concept design. Comparable to this trend, the accuracy of EVAR was advanced with the GORE C3 Delivery System (introduced in 2010) for the device. The GORE C3 Delivery System allows more precise and controlled deployment with three advantages over its predecessor and other endografts on the market. First, the delivery system supports users in readjusting the stent graft for proximal-level orientation for precise infrarenal artery deployment (which is advantageous for training inexperienced users, as well as experienced users confronted with difficult proximal anatomy). Second, the deployment mechanism offers rotational adjustment, which facilitates gate reorientation in challenging gate cannulation. Finally, a separate deployment of the ipsilateral limb of the bifurcated trunk component allows for the device to remain on the catheter for improved control throughout the deployment process.4,6

Responding to the demand for larger proximal aortic and distal iliac landing zones, Gore & Associates has frequently brought additional components into the market. These new components have expanded our EVAR reach and increased the GORE EXCLUDER Device applicability for treating aortic aneurysms of different sizes and anatomies.

DURABILITY AND EFFICACY

In his publication Competing Against Luck: The Story of Innovation and Customer Choice,7 Christensen describes his “Job to Be Done” theory. This theory requires the question “What needs to be designed, developed, and delivered so that it does the job well?” It also requires that the solution be incorporated into the enterprises’ operations and capabilities to “nail the job” consistently. The GORE EXCLUDER Device, now in its second generation, has “nailed the job” consistently. It has been used for 19 years with proven safety, efficacy, and long-term durability in more than 250,000 patients. Two important design improvements have been noted: low permeability and the GORE C3 Delivery System. These enhancements, along with a flexible, low-profile delivery catheter and simple deployment mechanism, have led the GORE EXCLUDER Device to become the United States market leader for EVAR devices and the worldwide leader for most implants of any single-device design.

Based on the company-sponsored trials and registries shown on clinicaltrials.gov, the GORE EXCLUDER Device is the most studied of all currently available endografts.
The Low Permeability Post Approval Study (2005-2006) reported a 100% freedom from aneurysm mortality and < 1% type I or type III endoleak during a 2-year follow-up period. The Global Registry for Endovascular Aortic Therapy (GREAT) was established to identify global trends in device usage and to track long-term device performance and patient outcomes. During GREAT’s ongoing study, 2,970 patients implanted with a GORE EXCLUDER Device for treatment of an AAA have been enrolled with a 1.3% type I endoleak rate, a 0.2% type III endoleak rate, a 0% migration rate, and 99.1% freedom from aneurysm mortality. This data is based on reported serious adverse events in GREAT. Finally, the newest addition to the GORE EXCLUDER Device family is the GORE® EXCLUDER® Iliac Branch Endoprosthesis (IBE). The IBE trial, with 63 total patients enrolled from 2013–2015, demonstrated a 0% type I and type III endoleak rate, 0% migration, and 100% freedom from aneurysm mortality.3

Several independent studies demonstrate the durability of the GORE EXCLUDER Device for AAA repair. Goncalves et al reported 144 GORE EXCLUDER patients with treated AAA from 2000-2007, with median follow-up of 5 years, had a low rate of AAA-related mortality or rupture (2.8%), up to 11 years postimplant, and an overall life expectancy after EVAR at 6.8 years.7 Maleux et al detailed that 121 AAA patients treated with the GORE EXCLUDER Device between 1998 and 2010 near 5-year (4.98 years) follow-up had an estimated intervention-free survival after 5 and 10 years at 90% and 77.7%, respectively, with no aneurysm rupture during follow-up.7 In a 2014 study, Prastesi et al reported on a large, retrospective, nonindustry-sponsored, multisite Italian registry of more than 800 patients with implanted GORE EXCLUDER Devices. Their results included a freedom from all causes of death estimated to be 97.9% at 1 year, 93.4% at 3 years, and 88.5% at 5 years. Aneurysm-related mortality was 1.6%, and freedom from reintervention at 1, 3, and 5 years of follow-up were 98.6%, 94.6%, and 86.5%, respectively. Overall low rates for mortality, migration, reintervention, and limb thrombosis were described in this recent large multicenter study.10,11

**ATOMIC CLOCKS AND THE FUTURE OF THE GORE EXCLUDER DEVICE**

The past 100 years of clockmaking are analogous to the past 5 years of EVAR with the GORE EXCLUDER Device. The longstanding traditional grandfather clocks were phased out by quartz clocks, which have been phased out by atomic clocks. The piezoelectric properties of quartz revolutionized the clockmaking industry by eliminating gear-based design and allowing for mass-base distribution. The stability and reliability of atomic clocks have since surpassed quartz. For atomic clocks, the cesium atom’s natural frequency redefined the internationally recognized unit of time: the second. The days of measuring time to the nearest quarter hour are long over, as modern market pressures demand more precision in timekeeping.12

Precision deployment highlights the future of the GORE EXCLUDER Device platform. The days of hypogastric artery embolization and stent graft coverage have been replaced with the IBE. Preservation of internal iliac artery flow decreases the risk of spinal cord ischemia, impotence, and gluteal/hip claudication. The GORE® EXCLUDER® Conformable AAA Endoprosthesis* (Figure 3) delivery system has been designed to provide angulation control of the proximal endograft and to give physicians the option to bend the device to achieve placement orthogonal to the aortic lumen in short and hostile proximal aortic landing zones. The GORE® EXCLUDER® Thoracoabdominal Branch Endoprosthesis* (TAMBE) (Figure 4) will aim to treat thoracoabdominal aortic aneurysms involving the visceral branch vessels. Clinical trials are planned for both devices.

*Caution: Investigational device. Limited by United States law to investigational use.
CONCLUSION

The evolution of the GORE EXCLUDER Device for EVAR is comparable to the history of clockmaking, both of which have exhibited disruptive and sustaining design innovation. Numerous independent studies positively demonstrate the durability of this device. Extreme competitive pressures in the EVAR field will require continued improvements and result in better therapy for our patients with aortic aneurysms. As with modern clockwork design, the GORE EXCLUDER Device design, which is based on improved precision, will lead the next generation of endovascular aortic aneurysm treatment.

In this arena, it is all about outcomes. Cumulative data delineated in this manuscript demonstrate very low perioperative morbidity and mortality and excellent protection from aneurysm-related complications with Gore aortic endografts. Superior ease of use, excellent trackability, and rare failure modes characterize the GORE EXCLUDER Device. By addressing the market pressures of clinical demands with aortic endografting, Gore has become a market leader, developing endografts that continue to offer unique advantages.

4. Verhoeven ELG, Katafmgis A, Milner R. The GREAT Registry: Lessons learned from real-world experience with the