The STRATO trial: a multicenter, prospective study of the Multilayer Flow Modulator in high-surgical-risk patients presenting with Crawford type II and III thoracoabdominal aneurysms

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INTRODUCTION

Outcomes are now available out to 4 years for the prospective nonrandomized STRATO trial. This 10-center French study was undertaken between April 2010 and February 2011 in order to assess the efficacy, safety, and performance of the Multilayer Flow Modulator (MFM) (Cardiatis, Isnes, Belgium) and its device delivery system in patients ineligible for surgical or endograft repair presenting with Crawford type II and III thoracoabdominal aneurysms (TAAA).[1, 2] The MFM is an uncovered, self-expanding stent with high radial force and flexibility constructed of braided fatigue- and corrosion-resistant cobalt-alloy wire (Phynox). The device was designed to thrombose and stabilize the aneurysm sac while creating an organized laminar flow into covered branch vessels without the need for the extra steps involved in cannulation.[3] The MFM received CE marking for peripheral artery aneurysms in 2009 and for aortic aneurysms in 2011.

It was thought that the flow-diverting MFM technology could have numerous potential advantages for treating challenging TAAA — particularly type II and III TAAA that span the ostia of visceral and renal arteries — as an alternative to physician-modified or commercially customized fenestrated and/or branched endografts. Those endovascular approaches have been associated with high costs, long manufacturing delays, extended learning curve, and outcomes including perioperative spinal cord ischemia (SCI), renal insufficiency, type I and III endoleak, and frequent need for reintervention.[4-9]

By contrast, the MFM is an off-the shelf device available in a wide range of sizes. While preoperative assessment of patient anatomy and pathology and evaluation of landing zones and device sizing are still important with the MFM, extensive measurements and calculations are not required regarding visceral side branch location, diameters, and angulation. Treatment with the MFM can also be less invasive, with vascular access limited to a single sheath in one femoral/brachial artery for introduction of an angiographic catheter and another sheath in the other femoral artery for introduction of the device, without the need for additional upper-extremity access. Implantation of the MFM requires <5 minutes, using pin-and-pull deployment, with potentially less operative trauma and shorter procedure time and hospital stay.

DEVELOPMENT OF MFM ALTERNATIVE TO ENDOGRAFT TECHNOLOGY

The development process for the MFM has included *in vitro* tests, benchtop simulation

studies, computerized fluid dynamics and molecular modeling, and *in vivo* preclinical studies in porcine animal models.[3, 10-14] The case of the first human to be implanted with the MFM, for renal artery aneurysm, was published in 2008.[15] Since then, more than 3500 patients have received the MFM, and multiple reports on separate cases and registry data have supported the clinical benefits of the flow-modulating technology in the treatment of TAAA, type B dissection, juxtarenal aortic aneurysm, and peripheral and visceral artery aneurysm.[15-30] In addition to the CE marking and registration in European countries, worldwide regulatory acceptance of the MFM has included device approval in Brazil, Colombia, Venezuela, Argentina, Thailand, Israel, Sri Lanka, India, Saudi Arabia, Morocco, and South Korea.

The evolution of an aortic aneurysm is associated with endothelial dysfunction, elevation of peak wall shear stress (PWSS), and hemodynamic disturbance. Aneurysm rupture is in fact not due primarily to increase in sac diameter (the parameter that is most commonly used to assess risk) but rather occurs with the development of flow vortices within the sac that alter viscoelasticity, plasticity, and cellular wall activity, as the turbulence induces increased local PWSS relative to weakening at vulnerable points in the aortic wall.[14, 31, 32] While aneurysm exclusion with covered stent grafts is intended to reduce stresses and improve hemodynamics to normal non-aneurysmal aortic levels, drag forces and high aortic neck stresses with these stiff noncompliant devices create complications including endograft migration, loss of branch patency, rupture, compromised spinal artery perfusion, and intense systemic inflammatory reaction leading to postoperative acute renal insufficiency.[3, 14, 31, 33-36]

The MFM was designed to avoid the drawbacks of endografts. As blood flows through the three-dimensional wire layering (permitting porosity in the range of 65%) and moves toward a branch and then exits at the outermost layer of the device, it is organized into a laminar flow channel for perfusion of the branch vessel.[37] Where there is no branch involvement, the dynamic shear vortex within the aneurysm is eliminated, and the flow is redirected along the aortic wall in the same direction as the systemic pressure. The lamination of flow promotes maintenance of spinal cord perfusion and avoidance of SCI.

The comparatively rapid re-endothelialization promoted by the MFM and the potentially more complete integration with the aortic wall can limit intimal hyperplasia and systemic inflammatory response.[3, 11] With the aneurysmal sac remodeling, the formation of organized thrombus reduces aortic aneurysm wall stress, with a shielding or buffering effect.[3, 38] The thrombus formation can cause an initial increase in aneurysm volume after device implantation. But as long as the ratio of thrombus volume to total volume increases correspondingly with a decrease in the ratio of residual aneurysm flow volume to total volume, any increase in total volume does not imply rupture risk but can rather be understood as a mechanism by which the body self-modulates healing.[3] Depending on factors such as the shape and size of the aneurysm, the diameter of the efferent vessels, and the rigidity of the aneurysm wall, the rates of sac retraction and of aneurysm diameter reduction after MFM deployment are variable, but the substantial reduction of local PWSS within the sac protects against rupture. Thus going beyond the conventional outcome measure of stabilization or reduction of aneurysm diameter, the calculation of three-dimensional volume ratios provides a more accurate assessment of the device performance.

THE STRATO PROTOCOL

TRIAL ENROLLMENT, ENDPOINTS, AND SURVEILLANCE

The STRATO protocol was approved by the French Health Authority. Data analysis and statistical reporting were performed through the European Cardiovascular Research Center. An independent clinical events committee reviewed all safety events in follow-up and adjudicated any concerns. The 10 trial centers had expertise in the treatment of TAAA but no prior experience using the MFM.

To test the hypothesis that the MFM would reduce the likelihood of aneurysm rupture by dissipating wall stress in tandem with the development of organized luminal thrombus and the lamination of flow in the aortic sac, a seriously ill patient cohort was required with established aneurysm risk factors, making them unsuited for open surgery or implantation of fenestrated and/or branched endografts. Thus patients were eligible for STRATO if they had TAAA with maximum diameter >5 cm, had life expectancy >12 months, and were determined by both a surgeon and an anesthesiologist to be ASA (American Society of Anesthesiologists) class ≥3. The actual enrollment included 23 patients (mean age 75.8 years, 19 male) with Crawford type II (N.=10, 43.5%) and III (N.=13, 56.5%) TAAA with mean diameter 6.5±0.9 cm (range 4.6 to 8.5 cm) and mean length 162.5 mm (range 36 to 408 mm). The patients had significant risk factors and comorbidities/medical history (Table 3.I). For each case, a multidisciplinary vascular team assessed the risks of open surgery and the potential for use of conventional endovascular repair or MFM implantation.

To support confirmation of the ability of the device to preserve collateral patency, the treated TAAA had to involve at least one visceral branch vessel. Overall, 53 MFM devices were implanted in the 23 index procedures, covering 55 branch vessels — 13 celiac arteries, 15 superior mesenteric arteries (SMA), 26 renal arteries, and 1 left subclavian artery (LSA). The MFM was available in diameters ranging from 25 to 45 mm and in lengths ranging from 80 to 150 mm. Patients were required to have healthy proximal and distal landing zones of at least 20 mm. The devices were oversized 15% to 25% compared with the transverse aortic diameter at the proximal landing zone. The implantation procedures were successful in all patients, with the devices introduced through surgical cutdown of the common femoral artery in 15 patients, through an iliac conduit in 1 patient, and percutaneously in 7. Post-implantation balloon angioplasty was employed for 7 patients; mean procedure duration was 84 minutes.[1]

Table 3.I. Patient characteristics and baseline medical history

	Number (%) or mean±SD (range)
Variable	N.=23 patients
Age (years)	75.8±10.8 (59 to 93)
Male sex	19 (82.6%)
Body mass index (kg/m^2)	25.4±4 (19 to 38)
Congestive heart failure	2 (8.7%)
Coronary artery disease	6 (26.1%)
Diabetes mellitus	2 (8.7%)
History of stroke	4 (17.4%)
Hyperlipidemia	13 (56.5%)
Hypertension	20 (87.0%)
Myocardial infarction	2 (8.7%)
Peripheral artery disease	13 (56.5%)
Previous aortic intervention	15 (65.2%)
Renal insufficiency	7 (30.4%)
Smoking, active and history	15 (65.2%)

The rigorous surveillance plan for STRATO began with pre-discharge physical examination and imaging evaluation of branch vessel patency, and patients were scheduled for follow-up at 1, 3 (option), 6, 12, 24, 36, 48, and 60 months with physical examination and computed tomography (CT) or magnetic resonance (MR) imaging. Assessments of device integrity and migration as well as aneurysm sac dimensions and branch vessel patency were recorded in a dedicated database along with procedural details.[1, 2]

In addition to all-cause mortality, the trial safety endpoints included rates of complications that have figured prominently in trial reports on open repair and the use of fenestrated and/or branched endografts: endoleaks, secondary interventions, SCI, device migration, loss of device integrity, aneurysm rupture, and serious adverse events (SAE). Since the MFM is a porous stent, endoleak was defined as persistent blood flow into the aneurysm due to incomplete or ineffective sealing at either the proximal or distal end of the stented segment [type I (failure mode I)] or due to inadequate overlapping of multiple devices [type III (failure mode II)]. Types II and IV endoleak are not applicable to the MFM.

Reflecting the MFM design principle (physiological exclusion of the aneurysm from circulation by means of flow modulation rather than passive exclusion with stiff noncompliant covered stents) and its anticipated advantages, the primary efficacy outcomes were: 1) no circulating flow within the aneurysm, except for residual flow adjacent to any covered branches, and 2) patency of all covered side branches. In addition to changes in two-dimensional aneurysm sac diameters, a key outcome focus was on three-dimensional volume measurement and the determination of the ratio of aneurysm flow volume to total volume and the ratio of thrombus volume to total lumen volume.[1]

STRATO OUTCOMES THROUGH 4-YEAR FOLLOW-UP

PATIENT DISPOSITION AND ADVERSE EVENTS

The disposition of the STRATO cohort through 4 years is diagrammed in Figure 3.1. Through 4 years, 3 patients were lost to follow-up (at 2, 12, and 27 months). Two study devices from the index procedure were explanted — at 21 months (in a patient who had undergone pneumonectomy 5 days post-implantation and then a 7-month course of chemotherapy) and at 29 months (due to uncorrected type I endoleak). Subsequently, active or planned chemotherapy has come to be understood as a contraindication for MFM implantation.[39] There was no in-hospital or 30-day mortality, but 11 patients have died, including 4 during the fourth year of follow-up due to type A dissection, heart attack, cardiac arrest, and unknown cause (Table 3.II). No death was confirmed as being aneurysm related.

Table 3.II. All-cause mortality in STRATO through 4 years.

Follow-up	Deaths (N.=23)
30 days	0
6 months	0
1 year	1
2 years	2
3 years	4
4 years	4
Cumulative	11

CT imaging was available for 21 of 23 patients at discharge, 13 of 23 patients at 1 month, 18 of 23 patients at 3 months, 20 of 23 patients at 6 and 12 months, 13 of 17 remaining patients at 24 months, 10 of 11 remaining patients at 36 months, and 4 of 7 remaining patients at 48 months. In addition, the eleventh remaining patient at 36 months and

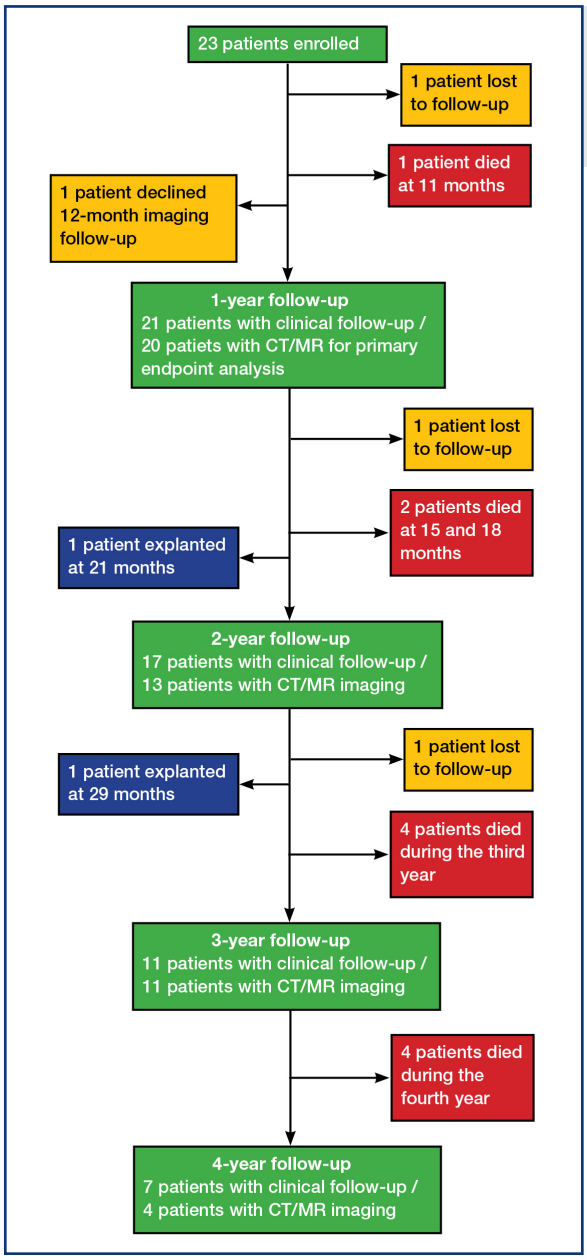

FIGURE 3.1. Patient flow and disposition through 4 years in the STRATO trial.

a fourth patient at 48 months had MR imaging with contrast, which allowed assessment of aorta and branch patency, aneurysm thrombosis, endoleaks, and aneurysm size changes, but did not provide sufficient images for generating a three-dimensional reconstruction or mathematically extrapolating aneurysm volume data for that patient. The CT/MR imaging showed that aortic and device patency was 100% through the entire course of the 4-year follow-up.

There were no reported cases of SCI, confirmed aneurysm rupture, device migration or fracture, or respiratory, renal, or peripheral complications. During the first year of follow-up, 6 patients experienced at least 1 SAE — including 1 periprocedural stroke, 1 vascular access complication requiring surgical repair, 1 aneurysm expansion requiring reintervention, 1 device misplacement, 1 hematoma related to another procedure, and occlusions detected in 2 covered visceral branches in 1 patient at 14 days (after surgical reintervention, these branches were patent at 12 months). SAEs experienced by different patients during the second year included the explant at 21 months, possible bowel ischemia due to visceral artery thrombosis, increase in aneurysm size, thrombocytopenia, and heart failure. SAEs experienced by different patients during the third year included hepatic abscess, increase in aneurysm diameter, thyroid neoplasia, progression of the aneurysm, hospitalization due to uncorrected type I endoleak, death of unknown cause, and increase in aneurysm size and volume. None of the SAEs during the second and third years were confirmed as being related to the MFM device or the index procedure. The SAEs that occurred in 4 patients during the fourth year are summarized in Table 3.III.

Table 3.III. *Year-4 serious adverse events in STRATO.*

Year-4 serious adverse events	Device or procedure relatedness	Comments
Aneurysm increase in volume, diameter; aortic stenosis due to thrombus	Possibly device related	Surgery currently proposed
Stroke	Neither	Recovered with treatment
Cardiac arrest during surgical procedure	Unknown	Patient died
Heart attack	Unknown	Patient died

PRIMARY EFFICACY OUTCOMES

The primary efficacy outcomes are summarized in Table 3.IV. The outcome of achieving organized stable thrombus and no circulating flow within the aneurysm, except for residual flow adjacent to any covered branches, was met for 13 of 20 patients at 6 months, 15 of 20 patients at 1 year, 12 of 13 patients at 2 years, 10 of 11 patients at 3 years, and 3 of 4 patients at 4 years. Exemplifying the serious illness and high surgical risk of these patients at baseline, the one patient for whom aneurysm sac thrombosis was not possible at 2 years had been implanted with multiple MFM devices, one of which was landed at the curve of a gothic aortic arch; at 2 years, then, a type I endoleak was noted, with diminished overlap between the MFMs, leading to increased aneurysm perfusion. This patient died at home at 30 months. The patient without aneurysm sac thrombosis at 3 years was found to have a type I endoleak at 1 year and then a serious type III endoleak at 3 years, which was due to insufficient overlapping of devices during the index procedure (the implantation occurred outside the MFM instructions for use) and led to aneurysm enlargement and perfusion.[2] Imaging follow-up was not available for this patient at 4 years. The patient without aneurysm sac thrombosis at 4 years had aneurysm sac expansion documented at 3 and 4 years; this patient had previously been implanted with an aorto-bi-iliac graft, which had become kinked, and the index MFM implantation had been performed without a healthy distal landing zone.

The other primary efficacy outcome of patency of covered branches was convincingly achieved for 53 (96.4%) of 55 covered branches at 1 year (primary patency), 32 (100%)

Table 3.IV. *STRATO primary efficacy outcomes through 4 years.*

Follow-up	Aneurysm sac thrombosis (%) of patients with CT/MR imaging	Branch vessel patency N. (%) of covered branches in patients with CT/MR imaging
6 months	13/20 (65.0%)	—
1 year	15/20 (75.0%)	53/55 (96.4%)*
2 years	12/13 (92.3%)	32/32 (100%)
3 years	10/11 (90.9%)	28/29 (96.6%)
4 years	3/4 (75.0%)	9/9 (100%)

*Primary patency; 1-year secondary patency was 100%.

of 32 covered branches at 2 years, 28 (96.6%) of 29 covered branches at 3 years, and 9 (100%) of 9 covered branches at 4 years. At 1 year, the secondary branch patency was 100%, after successful surgical reintervention (thrombectomy with bypass) for occlusions in 2 covered visceral branches (common hepatic artery and superior mesenteric artery) in a patient 14 days after the index procedure (the patient was not administered dual antiplatelet therapy but only aspirin). At 36 months, one left renal artery was occluded in a patient with Horton's disease who had stenosis at the left renal artery ostium during the index procedure. This patient underwent 2 endovascular reinterventions — at 97 days for stent-graft extension and at 200 days for persistent type I endoleak that was considered due to insufficient overlapping of devices in the index procedure.[2] The death of this patient during the fourth year of follow-up was judged by the investigator to have occurred without obvious cause.

ENDOLEAKS AND REINTERVENTIONS

The endoleaks that were observed through 4 years, including those already described, are summarized in Table 3.V. Through the fourth year of follow-up, 3 endoleaks in 2 patients remained uncorrected. One of these cases was a type Ib endoleak (considered permanent) observed in the patient (with the kinked aorto-bi-iliac graft) with aneurysm expansion persisting from preceding follow-up. In the second patient with uncorrected endoleak at 4 years, a type Ia endoleak was persisting after having been reintervened upon with a stent graft during the third year of follow-up, and a new type III endoleak was observed. Altogether through 4 years, 9 patients underwent one reintervention, and 2 patients underwent 2 reinterventions. Four of the 13 reinterventions were surgical, and 9 were secondary endovascular procedures. During the fourth year, 2 patients required reintervention. One involved the implantation of an additional MFM, due to natural evolution of the aneurysmal disease in a previously uncovered segment, in a patient who underwent reintervention for the same reason at 3 years. The other reintervention during the fourth year was a surgical procedure to correct an endoleak that had not been previously documented, and this patient died postoperatively of cardiac arrest.

Table 3.V. *Type I/III endoleaks reported in STRATO through 4 years.*

Endoleak type	Discharge N. (%) patients with CT/MR	1 year N. (%) patients with CT/MR	2 years N. (%) patients with CT/MR	3 years N. (%) patients with CT/MR	4 years N. (%) patients with CT/MR
All type I/III	7/23 (30.4%)	4/20 (20%	2/13 (15.4%)	1/11 (9.1%)	2/4 (50%)*
Type Ia	5/23 (21.7%)	4/20 (20%)	2/13 (15.4%)	0/11 (0%)	1/4 (25%)
Type Ib	1/23 (4.3%)	0/20 (0%)	0/13 (0%)	0/11 (0%)	1/4 (25%)
Type III	1/23 (4.3%)	0/20 (0%)	0/13 (0%)	1/11 (9.1%)	1/4 (25%)

* In one patient with uncorrected endoleak at 4 years, a type Ia endoleak was persisting after having been reintervened upon with a stent graft during the third year of follow-up, and a new type III endoleak was observed at the 4-year follow-up.

CHANGES IN ANEURYSM DIAMETER AND VOLUME RATIOS

Mean maximum aneurysm diameter was 6.8 cm (range 5.3 to 8.1) at discharge (N.=20), 7.2 cm (range 5.4 to 9.0) at 1 year (N.=20), 7.0 cm (range 4.8 to 8.6) at 2 years (N.=13), 7.4 cm (range 6.0 to 9.0) at 3 years (N.=11), and 6.7 cm (range 5.9 to 7.6) at 4 years (N.=4). Table 3.VI breaks out the changes from baseline in aneurysm diameter for the patients with imaging follow-up available at each time point to 4 years. Figure 3.2 then charts the changes from baseline in aneurysm diameter for the 4 patients with follow-up at 4 years. Maximum aneurysm diameter was stable (<10 mm change per year) for 18 of 20 patients at 1 year, for 11 of 13 patients at 2 years, for 9 of 11 patients at 3 years, and for 3 of 4 patients at 4 years. Maximum diameter was increased (>10% increase per year) for 2 of 20 patients at 1 year (both associated with type I endoleak), for 2 of 13 patients at 2 years (again, both associated with type I endoleak), for 2 of 11 patients at 3 years (one associated with type III endoleak, the other due to insufficient distal landing zone in the index procedure in the patient

Table 3.VI. *Changes in aneurysm diameter for patients with CT/MR imaging at each year of follow-up.*

Follow-up	Maximum diameter (cm) (mean [range])
Baseline	6.8 (5.3–8.1)
1 year (N.=20)	7.2 (5.4–9.0)
Baseline	6.5 (5.3–8.1)
2 years (N.=13)	7.0 (4.8–8.6)
Baseline	6.9 (5.5–8.1)
3 years (N.=11)	7.4 (6.0–9.0)
Baseline	6.0 (5.5–6.4)
4 years (N.=4)	6.7 (5.9–7.6)

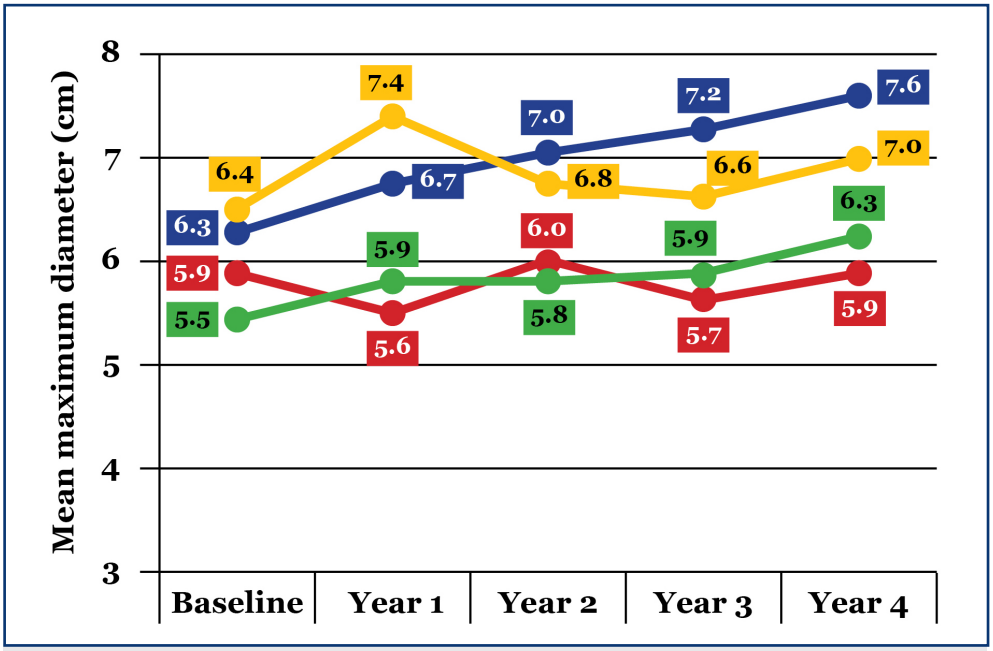

FIGURE 3.2. The evolution of maximum aneurysm diameter for the 4 patients who had CT/MR data for each follow-up time point from baseline to 4 years.

Table 3.VII. *Changes in volume ratios for patients with CT imaging at each year of follow-up.*

Follow-up	Aneurysm flow volume / total volume (mean ratio [range])	Thrombus volume / total volume (mean ratio [range])
Baseline 1 year (N.=17)	14.9% (2.2%–42.9%) 10.1% (0.0%–31.7%)	39.6% (14.7%–60.8%) 55.2% (37.9%–79.4%)
Baseline 2 years (N.=11)	12.7% (2.2%–27.7%) 11.7% (0.0%–44.7%)	38.3% (14.7%–58.0%) 58.6% (9.9%–85.6%)
Baseline 3 years (N.=10)	20.4% (0.4%–58.7%) 3.5% (0.0%–11.8%)	39.4% (19.2%–58.0%) 62.6% (46.7%–85.9%)
Baseline 4 years (N.=3)	19.2% (2.2%–27.7%) 1.5% (0%–2.4%)	36.7% (27.1%–50.2%) 60.8% (58.2%–62.9%)

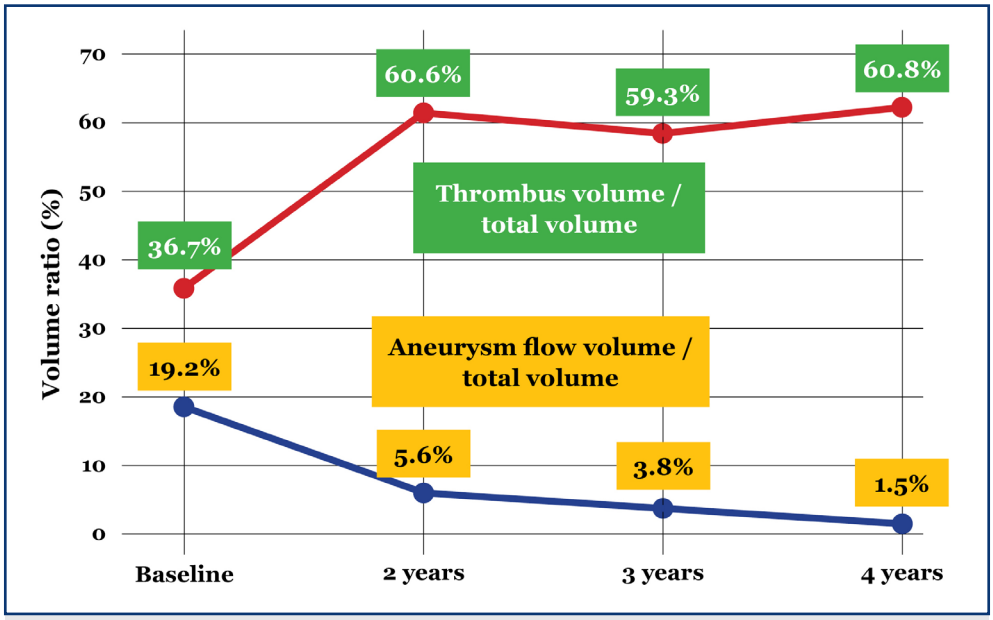

FIGURE 3.3. Graph of the mean decrease in the ratio of aneurysm flow volume to total volume and the mean increase in the ratio of thrombus volume to total volume from baseline to 4 years for the 3 patients who had requisite computed tomography data at baseline, 2 years, 3 years, and 4 years.

with the kinked aorto-bi-iliac graft), and for 1 of 4 patients at 4 years (persisting in the patient with the kinked aorto-bi-iliac graft).

The changes from baseline in the mean ratio of aneurysm flow volume to total volume and the mean ratio of thrombus volume to total volume are represented in Table 3.VII. For the 10 patients with CT imaging available at 3 years, the mean ratio of aneurysm flow volume to total volume had decreased by 83.0% (from 20.4% to 3.5%), while the mean ratio of thrombus volume to total volume increased by 158.9% (from 39.4% to 62.6%); the residual aneurysm flow was <10% for 9 of the 10 patients, excepting the patient with type III endoleak, for whom residual flow was 25%. For the 3 patients with CT imaging available at baseline, 2 years, 3 years, and 4 years, the mean ratio of aneurysm flow volume to total volume had decreased by 92.2% (from 19.2% to 1.5%), while the mean ratio of thrombus volume to total volume increased by 165.7%

(from 36.7% to 60.8%); the mean changes in the volume ratios over the course of the 4-year follow-up for these 3 patients are plotted in Figure 3.3. At 4 years for the 3 patients, residual aneurysm flow was 2.24%, 2.36%, and 0%.

THE STRATO OUTCOMES IN CONTEXT

The 4-year outcomes for the STRATO trial confirm the safety and performance of the MFM. In the enrolled population of 23 patients with nonoperative type II and III TAAA, all involving branch vessels, and multiple comorbidities, there were no aneurysm-related deaths, and there were no reported cases of SCI, confirmed aneurysm rupture, device migration, or fracture. Nor were there any instances of respiratory, renal, or peripheral complications. After 4 years, 7 of the initial 23 patients, who were unsuited for open surgery or implantation of fenestrated and/or branched endografts, were known to remain alive. The 1-year secondary patency of the 55 original covered branches in the STRATO patients was 100%, and the patency of covered branches was confirmed through 4 years for all but one of the patients with CT/MR imaging available — the exception being the left renal artery occlusion at 3 years in the patient with Horton's disease who died during the fourth year of follow-up.[2]

Through 3 years, when 10 remaining patients still had CT volume data available, there was an 83% decrease from baseline in the mean ratio of aneurysm flow volume to total volume, while there was a 158.9% increase in the mean ratio of thrombus volume to total volume.[2] Based on the CT volume data available for 3 of the 7 remaining patients at 4 years, the mean ratio of aneurysm flow volume to total volume had decreased by 92.2%, while the mean ratio of thrombus volume to total volume was increased by 165.7%.

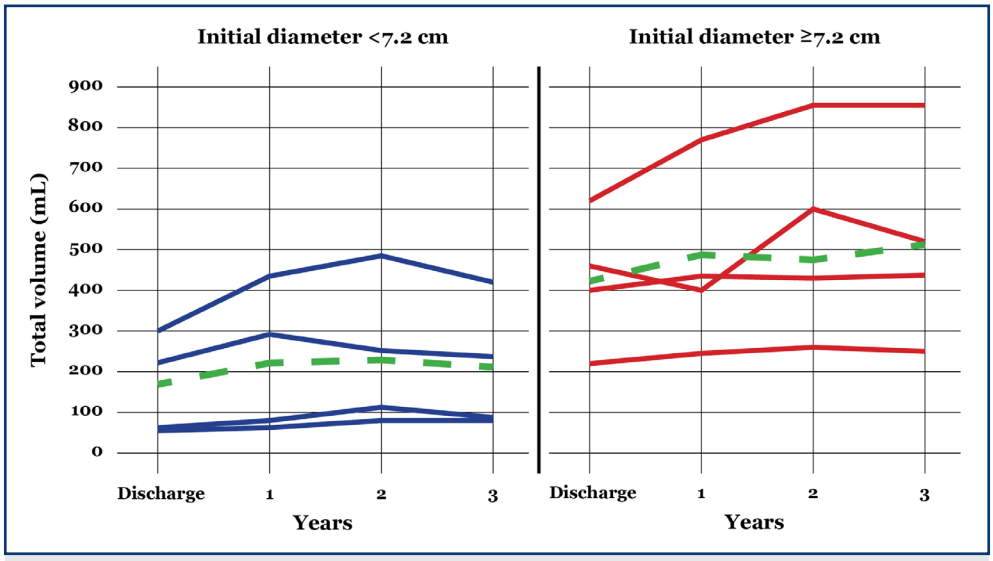

FIGURE 3.4. In an analysis of the 3-year volume data, the 8 patients with CT/MR volume data for all time points were grouped according to an initial aneurysm diameter threshold of 7.2 cm (4 patients <7.2 cm versus 4 patients ≥7.2 cm). The graph plots the evolution of total volume for each patient, with mean total volume for each group indicated by a broken line.

It was noted before that post-implantation increases in total aneurysm volume do not necessarily mean that rupture risk is increased, when thrombus volume is also increased and the aneurysm is thus stabilized.[3, 30] In STRATO, an analysis on 7 patients who had volume data available at baseline and at 2 and 3 years underscores the point. While mean total volume for these 7 patients increased from 232.9 mL to 363.5 mL, the increase in thrombus volume was such that the ratio of thrombus volume to total volume increased from 42.7% to 65.2%, and the decrease in aneurysm flow volume was such that the residual flow ratio decreased from 14.1% to 1.6%. In a further analysis of the 3-year volume data, the 8 patients with CT/MR volume data for all time points were grouped according to an initial aneurysm diameter threshold of 7.2 cm. As Figure 3.4 shows, the capacity of the aorta for elastic recoil and diminution of the total volume was better preserved in those with lower initial diameter. In those with high initial diameter, flow vortices acting on the aortic wall may have damaged adventitial elastin to the point of no return for elastic recoil, with the result that total volume (and residual flow volume) could be stabilized but not diminished as when elastic recoil is retained.[2, 3, 40]

IMPORTANCE OF STRICT COMPLIANCE WITH DEVICE IFU

A now much noted key point about working with the MFM is the crucial importance of strict compliance with the device IFU.[1, 2, 30, 41-43] All 5 of the type I and III endoleaks during the first year of STRATO follow-up were adjudicated as being due to failure of placement or device overlapping, which led to maintained or renewed aneurysm perfusion.[1] Some of the adverse outcomes associated with these endoleaks have been discussed. One example is the patient (with type I endoleak persisting from the first year and serious type III endoleak detected at year 3 judged to be due to insufficient device overlapping) for whom aneurysm sac thrombosis had not been achieved at 3 years.[2] Another serious example is the patient for whom aneurysm sac thrombosis had not been achieved at 4 years due to aneurysm enlargement stemming from the absence of healthy distal landing zone for the index MFM implantation (in the presence of a kinked aorto-bi-iliac graft).

In a review of 380 European cases in the MFM Global Registry, Sultan et al identified 38 patients who were treated outside the IFU — due, for example, to inadequate landing zones or overlap zones or to the technical mistake of employing a smaller MFM inside a bigger device (the smaller MFM should be deployed before the bigger one in order to keep the devices open, maintain radial force, and avoid increasing PWSS and aneurysm flow vortices). Strikingly, during mean 10-month follow-up, the rates of all-cause and aneurysm-related mortality for these 38 patients were 89.5% and 71.1%, respectively.[43] Among other caveats, it is important to beware of the potential for foreshortening during MFM deployment, due to the interwoven design of the device, and to perform the implantation at a deliberate pace to allow the device to achieve its natural compliance.[2]

On the basis of the STRATO trial outcomes through 4 years of follow-up in high-surgical-risk patients with type II and III TAAA, the MFM can be considered safe and effective when used according to the IFU. The near-perfect branch vessel patency and the absence of complications such as rupture, SCI, and renal insufficiency demonstrate the benefit of the MFM mechanism of action as evidenced by the progressive aneurysm sac thrombosis and reduction and elimination of residual aneurysm flow.

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