Total Endovascular Repair of Thoracoabdominal Aortic Aneurysms With Non-Customized Stent Grafts

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Background. Total endovascular repair of thoracoabdominal aortic aneurysms with customized branched or fenestrated endografts could be technically challenging outside large-volume centers. This study aims to describe a new endovascular strategy for use of both noncustomized stent grafts and flow-diverting stents in treating complicated thoracoabdominal aortic aneurysms.

Methods. Patients diagnosed with thoracoabdominal aortic aneurysms and deemed unfit for open surgical repair were recruited. The aim of the procedure was to cover the renovisceral segment of the aorta with flow-diverting uncovered stents, while covering the remaining aneurysm with stent grafts. Aneurysm morphologic evolution and the patency of the visceral branches were assessed at follow-up.

Results. Between February 2012 and August 2013, 6 select patients (4 men, mean age 58 years) underwent the novel joint procedure. During mean follow-up of 14 months, aneurysm shrinkage (maximum diameter decrease >5 mm) was demonstrated in 4 patients and aneurysm stabilization (maximum diameter decrease <5 mm) was observed in 2 patients. No aneurysm expansion was observed in any participants. Mean aneurysm diameter decreased from 65.0 ± 8.8 mm to 58.5 ± 12.2 mm (p = 0.054), with a significant increase in average sac thrombus deposition volume (sac thrombosis ratio increased from 23.3% ± 7.4% to 98.0% ± 3.3%, p < 0.001). The majority of side branches (23 of 24) were successfully preserved.

Conclusions. Complete endovascular repair of thoracoabdominal aortic aneurysms with this novel joint procedure may be a feasible alternative in high surgical risk patients. Further validation of this technique is required to substantiate these results.


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Involving the celiac artery (CA) and superior mesenteric artery (14), we attempted to artificially shorten the aneurysm SE by a stent graft covering part of it (Figs 1C, 1D), followed by 2 layers of uncovered stents to cover the residual SE. This case was associated with an acceptable short-term outcome, with a corresponding decrease in aneurysm diameter by up to 19 mm, and all major branches being patent. In the present study, we analyzed the results of the first clinical series of this “joint” endovascular procedure consisting of stent grafts and bare stents in the treatment of TAAAs, and evaluated the safety and efficacy of this novel technique on midterm outcomes.

**Patients and Methods**

This study was approved by the local ethical review board. The written informed consent was obtained from each patient prior to surgery.

**Study Design and Patient Cohort**

Data on all patients diagnosed with TAAAs and treated in our center with the joint procedure of stent grafts and uncovered stents between February 2012 and August 2013 were retrospectively analyzed. All patients enrolled into study were judged as poor candidates for open surgical repair by a multidisciplinary surgical team consisting of vascular surgeons, cardiothoracic surgeons, and anesthesiologists according to the following standards: age greater than 80 years; American Society of Anesthesiologists classification IV or greater; New York Heart Association classification (1994) of cardiac function III/C or greater; or dysfunction of other important organ systems (ie, severe chronic obstructive pulmonary disease or renal insufficiency) [15].

Patient records were reviewed for preoperative, intraoperative, and follow-up data, including demographics (gender and age at hospitalization time), concomitant morbidities (hypertension, stroke, coronary artery disease, diabetes mellitus, chronic obstructive pulmonary disease, renal failure, and hepatitis), intervention details (length of procedural time, X-ray exposure time, blood loss, number of stents and stent grafts implanted) and postoperative events (aneurysm morphologic evolution, sac thrombosis ratio, survival rate).

**Procedural Details**

For a type V TAAA (extended from the distal thoracic aorta to above the renal arteries), a standard joint procedure could be performed (Fig 2A: schematic for the procedure; Fig 2B: pre-surgical image; Fig 2C: post-stenting image).

Under spinal anesthesia, the femoral artery was exposed and heparin given intravenously (80 IU/kg). An angiogram was performed through a pigtail catheter to conform the size and location of the aneurysm. A stiff wire was then placed bridging the lesion segment, after which a tubular stent graft (Hercules-T, MicroPort, Shanghai, China) was advanced and placed covering the proximal part of the aneurysm SE, with a proximal landing zone of 15 mm or greater on the normal aorta. The distal edge of the stent graft should approach the ostia of the CA, but not cover it. Subsequently, multiple overlapping bare stents (Sinus-XL stents; OptImed, Ettingen, Germany) were placed beneath the previous stent graft to cover the residual SE that involved the visceral branches, with an overlapping zone of 15 mm or greater with the stent graft proximally, and a distal landing zone of 15 mm or greater on the distal normal aorta. The number of the bare stents implanted was determined by intraoperative angiogram, with the criterion that a decrease of flow velocity within the aneurysm sac was achieved on fluoroscopy. The diameter of the stents and stent grafts conformed to manufacturers’ instructions, with 10% to 20% oversizing to the aneurysm neck.

Technical success was defined as successful deployment of the stents to target locations without procedure-related complications (stent migration, stent twist and kinks, etc.) [16].

In cases of long-segmental aneurysmal lesions in the thoracic aorta (type I TAAA), 2 tubular stent grafts (Hercules-T, MicroPort, Shanghai, China) could be needed to cover the entire proximal aneurysm SE (Fig 3A). For a TAAA that mainly affected the infrarenal aorta rather than the thoracic aorta (type IV TAAA), a “reversed procedure” could be considered, in which the stent graft (Hercules-B, MicroPort) could be placed at the infrarenal aorta to cover the distal aneurysm SE, while the multiple bare stents were deployed above it to cover the proximal aneurysm residual SE (Fig 3B).
Follow-Up and Parameter Measurement

The patients were examined by computed tomography angiography (CTA) on a multislice CT scanner (Sensation Cardiac 64; Siemens, München, Germany) before intervention and postoperatively at 3 and 6 months initially, and then every 6 months afterward. Data in DICOM format were then
imported into CT-imaging process software (Aquarius Workstation, Version 3.7.0.13; TeraRecon, Foster City, CA) for three-dimensional reconstruction of the aortic contour and measurement (Figs 4A, 4B). Preoperative (Fig 4C) and postoperative aneurysm maximum diameters (Fig 4D) were measured on the cross-sectional images on the same aortic level referring to the vertebrae, as utilized in previous studies [13, 16]. The visceral branches covered by the bare stents were noted during surgery, and the patency of each was assessed during follow-up. Sac thrombosis ratio, defined as the ratio of the sac thrombus volume to the total sac volume, was calculated from the integration of the thrombus and sac areas of each slice. All measurements were made by the first author and independently verified by 2 coauthors. Clinical success was defined as either aneurysm shrinkage or stabilization, combined with patency of major visceral branches [16].

**Statistical Analysis**

Continuous variables were presented as mean ± standard deviation. Changes in aneurysm diameter and sac thrombosis ratio were analyzed using a paired t test. Statistical significance was considered when a p value less than 0.05. All analyses were performed with PASW Statistics software (IBM, Armonk, NY).

**Results**

A total of 6 patients (4 men, mean age 58 years) with TAAAs were treated with this joint procedure during the study period. Patients’ demographics, comorbidities, and surgical details are listed in Table 1. Four patients presented with type V TAAAs (extended from the distal thoracic aorta to above the renal arteries) and received the standard joint procedure with 1 stent graft covering the aneurysm proximal SE, and 2 overlapping bare stents covering the distal SE; in a patient with type I TAAA (involved most of the descending thoracic aorta from the origin of the left subclavian artery to the suprarenal abdominal aorta), 2 stent grafts were placed to cover the aneurysm proximal SE, and 2 uncovered stents for the aneurysm distal SE; another patient presenting with type IV TAAA (mainly affected abdominal aorta below the diaphragm) received a “reversed procedure,” with a bifurcated stent graft placed at the aneurysm distal SE and bare stents at the proximal SE.

Average procedural and X-ray exposure time were 88.3 ± 19.7 and 41.7 ± 8.2 minutes, respectively; mean contrast usage was 103.3 ± 19.7 mL, and mean blood loss was 125 ± 43.7 mL. Technical success was achieved in all patients. Three patients experienced a post-implantation fever, all of which resolved prior to discharge. No signs or symptoms of spinal cord ischemia were observed. Mean length of hospital stay was 9.7 ± 2.8 days. In 3 patients with previous coronary artery disease or stroke, routine antiplatelet medications including aspirin and clopidogrel were prescribed upon hospital discharge.

All patients underwent regular follow-up (mean 14 months, range 6 to 24 months). Aneurysm shrinkage (decrease in diameter ≥ 5 mm) was documented in 4 patients, aneurysm stabilization (decrease in diameter...
< 5 mm) was seen in 2 patients, and no aneurysm expansion was observed. Mean aneurysm diameter decreased from 65.0 ± 8.8 mm to 58.5 ± 12.2 mm (p = 0.054); while a significant increase in average sac thrombus deposition volume was documented (sac thrombosis ratio increased from 23.3% ± 7.4% to 98.0% ± 3.3%, p < 0.001). Complete thrombosis of the aneurysm sac was observed in 4 patients, while mild residual perfusion was seen in the other 2 patients. No procedural-related mortality or complications occurred during the follow-up period.

The superior mesenteric artery, CA, and bilateral renal arteries (RAs) were covered by 2 layers of bare stents in all patients (24 major branches in total). During follow-up, the majority of major branches were patent, based on CT imaging (23 of 24). Only 1 RA, which had been stenotic before intervention, was occluded at 12-month follow-up, translating into a clinical success rate of 83.3% (5 of 6) in the study cohort. No clinical signs of intestinal ischemia were found in any patient.

**Comment**

The concept of using bare metal stents to treat aneurysms was first described 2 decades ago by Geremia and colleagues [17], who suggested that an uncovered stent of low mesh porosity would alter the local blood flow pattern by decreasing the mean flow velocity within the sac, thereby creating a favorable environment for thrombus deposition. Secondary to the formation of mural thrombus, which increases the effective wall thickness, the tensile stress of the aneurysm wall could be decreased according to the Laplace Law, which illustrates that the wall tension is inversely proportional to the wall thickness in an aneurysm. Early clinical application of this theory has been mainly focusing on intracranial aneurysms, with a favorable aneurysm occlusion rate of 85.7% to 94.4% [18–21].

After Henry and colleagues [22] first reported of a renal artery aneurysm successfully treated with the commercial Cardiatis multilayer stents in 2008, this technique has been widely applied in treating complicated peripheral aneurysms. Data from independent centers seem encouraging for both short and midterm outcomes. A multicenter study conducted by Ruffino and colleagues [23] demonstrated an overall aneurysm thrombosis rate of 93.3%, with a branch patency rate of 96.1% at 1-year follow-up.

However, concerns have been raised regarding the safety and efficacy of this technique in treating aortic aneurysms [24]. Persistent sac perfusion and subsequent aneurysm rupture have been reported by Lazaris and colleagues in 2012 [25]; stent rigidity leading to aortic rupture has been noticed by Ferrero and colleagues in 2013 [26]. Sultan and colleagues [27] recently released a result of 38 patients with TAAAs treated by off-label use of multilayer stents, in which an aneurysm-related mortality rate of 71.1% was documented. These drawbacks indicate that further refinements of this technique are required before its large-scale clinical application.

In a computational fluid dynamic study performed by Seshadhri and colleagues [28], the hemodynamic effects of the flow-diverting stents were analyzed, taking into account the morphologic characters of the aneurysm. The investigators found that the “dome to neck ratio (D/N ratio)” was crucial in determining the flow-modulating effect of the porous stents (Fig 5). A larger D/N ratio could lead to a more significant decrease in wall shear stress within the aneurysm sac. This theory is in accordance with our previous clinical investigation [13], in which we found that the aneurysm SE length could influence the thrombosis process within the sac.
A larger D/N ratio would decrease the aneurysm wall shear stress, the ratio between the length of the dome and the length of the neck. In this theory, the “neck” was equivalent to “sac entrance” described in our study.

While the dome length is fixed for a given aneurysm, the neck length could be shortened by a stent graft covering part of it. The first validation of this theory was successful, with significant aneurysm shrinkage documented after intervention [14]. One-year outcomes within our clinical series were also satisfactory; technical success was achieved in all cases, decrease in maximum diameter by over 5 mm was documented in 4 out of 6 patients (range, 5.2 to 18.6 mm), aneurysm stabilization was seen in the remaining 2 patients, and no aneurysm expansion was noticed. This result is in contrast with previously published less-favorable data regarding the flow-diverting stents in treating aortic pathologies [11, 27], and offers a preliminary experience in improving this technique by using the stent grafts as adjuncts.

Branched and fenestrated endografts have been designed for total endovascular repair of complicated TAAAs in high surgical risk patients. Pooled data from different centers revealed a technical success and branch patency rate of 94.2% and 95%, respectively [29]. However, a successful branched or fenestrated procedure often requires meticulous patient selection, appropriate customized device, and experienced technical expertise with endovascular skills, which makes the encouraging figures from high-volume centers difficult to duplicate in less-experienced ones. Furthermore, the endovascular procedure can be technically challenging and time-consuming even for experienced surgeons, especially in the presence of unusual anatomy [30]. The joint endovascular procedure described in this study could offer a potential alternative to the traditional complex and cumbersome branched and fenestrated procedures.

Technically, a joint procedure could be finished within 90 minutes on average and the total X-ray exposure time could be limited to 50 minutes, with low contrast dose and little blood loss. Additionally, this procedure can be conducted safely and effectively without customized stent grafts, which makes it easy to perform in less-experienced centers.

In our series, occlusion of one RA was observed in a 54-year-old male. This event occurred despite administration of dual antiplatelet therapy as recommended by Euringer and colleagues [31]. Interestingly, in the 3 patients without antiplatelet therapy, RA side branches were all successfully preserved at follow-up. This suggests that ostial or proximal side-branch disease before intervention, rather than the antiplatelet therapy initiation, may be a more important factor in determining future side-branch vessel patency.

In conclusion, we describe acceptable midterm outcomes in a pilot study assessing the “joint” endovascular procedures for the treatment of complex TAAAs in high-risk surgical patients. Further validation of this novel and promising technique is now required before adoption into clinical practice.

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