

Benchtop quantification of gutter formation and compression of chimney stent grafts in relation to renal flow in chimney endovascular aneurysm repair and endovascular aneurysm sealing configurations

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ABSTRACT

Background: The chimney technique has been successfully used to treat juxtarenal aortic aneurysms. The two main issues with this technique are gutter formation and chimney graft (CG) compression, which induce a risk for type Ia endoleaks and stent thrombosis, respectively. In this benchtop study, the geometry and renal artery flow of chimney endovascular aneurysm repair configurations were compared with chimney configurations with endovascular aneurysm sealing (ch-EVAS).

Methods: Seven flow phantoms were constructed, including one control and six chimney endovascular aneurysm repair (Endurant [Medtronic Inc, Minneapolis, Minn] and AFX [Endologix Inc, Irvine, Calif]) or ch-EVAS (Nellix, Endologix) configurations, combined with either balloon-expandable or self-expanding CGs with an intended higher positioning of the right CG in comparison to the left CG. Geometric analysis was based on measurements at three-dimensional computed tomography angiography and included gutter volume and CG compression, quantified by the ratio between maximal and minimal diameter (D-ratio). In addition, renal artery flow was studied in a physiologic flow model and compared with the control.

Results: The average gutter volume was $343.5 \pm 142.0 \text{ mm}^3$, with the lowest gutter volume in the EVAS-Viabahn (W. L. Gore & Associates, Flagstaff, Ariz) combination (102.6 mm^3) and the largest in the AFX-Advanta V12 (Atrium Medical Corporation, Hudson, NH) configuration (559.6 mm^3). The maximum D-ratio was larger in self-expanding CGs than in balloon-expandable CGs in all configurations (2.02 ± 0.34 vs 1.39 ± 0.13). The CG compression had minimal influence on renal volumetric flow (right, $390.7 \pm 29.4 \text{ mL/min}$ vs 455.1 mL/min ; left, $423.9 \pm 28.3 \text{ mL/min}$ vs 410.0 mL/min in the control).

Conclusions: This study showed that gutter volume was lowest in ch-EVAS in combination with a Viabahn CG. CG compression was lower in configurations with the Advanta V12 than with Viabahn. Renal flow is unrestricted by CG compression. (J Vasc Surg 2016;■:1-9.)

Clinical Relevance: Chimney endovascular aneurysm repair and chimney endovascular aneurysm sealing are used more commonly for elective repair of juxtarenal abdominal aortic aneurysms. Gutter formation and chimney graft compression may occur because of a mismatch in architecture between the chimney stent grafts and the endograft or endosystem, and this may induce a risk for complications such as type Ia endoleaks and stent thrombosis. This benchtop study evaluated gutter formation and chimney stent graft compression for various chimney endovascular aneurysm repair and chimney endovascular aneurysm sealing configurations in relation to renal flow.

Endovascular aneurysm repair (EVAR) has become the standard treatment for abdominal aortic aneurysm (AAA) because of an improved 30-day outcome and a shorter rehabilitation period compared with open repair. EVAR has proven long-term durability when it is used on label.¹ Applicability of EVAR is mostly limited by

unfavorable proximal neck characteristics, including short (<15 mm) or severely angulated (>60 degrees) infrarenal necks, and dilations that involve the juxtarenal aorta, present in around 20% of patients.² These characteristics are associated with a substantial risk for adverse events after EVAR, including migration and type Ia

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endoleaks.^{3,4} Fenestrated EVAR (FEVAR) has been demonstrated to be an alternative treatment option for this group of patients, with good short- and intermediate-term outcomes.^{2,5} However, anatomic characteristics may preclude the use of custom-made devices, the construction is expensive, and the technique is unsuitable for ruptured AAA repair because of 4 to 6 weeks of manufacturing.^{6,7} Moreover, these devices are not globally available.

Chimney EVAR (ch-EVAR), in which a standard modular graft is combined with chimney, or parallel, stent grafts (CGs) to maintain flow in side branches (ie, renal arteries, superior mesenteric artery [SMA], and celiac trunk), provides an off-the-shelf solution in patients with a juxtarenal AAA⁸ with a 30-day mortality rate comparable to that of FEVAR.^{6,9} However, ch-EVAR has been associated with a higher incidence of stroke and early type Ia endoleaks in comparison to FEVAR.⁶ Moreover, a difference in stent geometry and architecture (ie, material stiffness) of standard modular grafts and CGs may result in gutter formation (GF) and induce a risk for early type Ia endoleaks. In addition, compression or kinking of the CG may be caused by the radial force of the endograft that occurs from oversizing of the endograft in the aortic neck. CG compression is supposed to influence renal flow (ie, volumetric flow rate, flow profile), and changes in flow profile may induce a risk for thrombosis.

Endovascular aneurysm sealing (EVAS) is an alternative technique for AAA repair, obliterating the aneurysm sac by polymer filling of endobags that surround dual cobalt-chromium endoframes.¹⁰ EVAS was designed to reduce the incidence of migration and endoleaks, and according to the instructions for use, AAAs with an infrarenal neck length of >10 mm can be treated with EVAS.¹¹ Its potential has also been demonstrated in combination with chimneys (ch-EVAS) in several case reports in both an elective and an acute setting.¹²⁻¹⁴ The endobags potentially allow a better conformation to the CG geometry after ch-EVAS, which could reduce the incidence of gutters and subsequent type Ia endoleaks in comparison to ch-EVAR. In addition, after curing of the polymer, the filled endobags will no longer compete with the radial strength of the CG, in contrast to the situation after ch-EVAR.

In this benchtop research, the geometry of several ch-EVAR and ch-EVAS configurations was studied, including CG compression and GF. In addition, volumetric flow for each CG was measured.

METHODS

Flow phantoms and stents. Flow phantom geometry was based on an average aortoiliac anatomy of 25 elective juxtarenal AAA patients, performed at preoperative computed tomography (CT) scans, including a short proximal neck (aneurysm starting at a distance of 10 mm) and branches of the SMA, renal arteries, and

Table I. Model geometries

Suprarenal aorta		
Diameter, mm		26
Length, mm		65
Angulation, degrees		0
SMA		
Diameter, mm		8
Length, mm		120
Takeoff angle, degrees		60
Renal arteries	Right	Left
Diameter, mm	5	5
Length, mm	120	120
Takeoff angle, degrees	111	115
Infrarenal aorta		
Diameter, mm		
Infrarenal neck, mm		26
Baseline, mm		26
Baseline + 15 mm, mm		38
Maximum AAA, mm		50
Aortic bifurcation, mm		26
Length, mm		105
Angulation, degrees		0
Common iliac arteries	Right	Left
Diameter, mm	12	12
Length, mm	130	130
Takeoff angle, degrees	27	23

AAA, Abdominal aortic aneurysm; SMA, superior mesenteric artery.
The model geometry was based on an average AAA anatomy of 25 elective patients with a juxtarenal aortic aneurysm.

common iliac arteries (Table I). The infrarenal neck morphology was reverse tapered with an infrarenal neck diameter of 26 mm and a linear increase to 38 mm over a distance of 15 mm. The manufacturing of seven juxtarenal AAA flow phantoms was conducted by Elastrat (Geneva, Switzerland). One model was used as a reference without stents, and the others were used to implant six different CG configurations, including EVAR with Endurant II (ETBF 32 16 C 166 EE; ETLW 16 16 C 124 EE; Medtronic Inc, Minneapolis, Minn) and AFX (BA28-70/I16-30; A34-34/C100-020V; Endologix Inc, Irvine, Calif) and EVAS with Nellix (Nx-10-150, Endologix) combined with either balloon-expandable Atrium Advanta V12 (known as iCast in the United States; 6 × 58 mm; Atrium Medical Corporation, Hudson, NH) or self-expanding Gore Viabahn (6 × 38 mm; W. L. Gore & Associates, Flagstaff, Ariz) CGs. The proximal graft diameter of the EVAR devices was 32 mm and 34 mm for the Endurant and AFX, respectively. This size resulted in 23.7% and 30.7% oversizing for the Endurant and AFX endografts, respectively.

Implantation in the models was performed by two experienced vascular surgeons (J.-P.V., M.M.R.). The intended position of the endograft was at the distal

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