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Mid- and Longer-term Follow up of Chimney and/or Periscope Grafts and Risk Factors for Failure

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WHAT THIS PAPER ADDS

Long-term follow up of chimney and periscope grafts for the treatment of pararenal and thoraco-abdominal aortic aneurysm is presented. This approach using off the shelf devices has been increasingly reported in recent years and with good results even in emergent settings. This risk factor analysis showed that inadequate branch graft length and chimney and periscope use in small and diseased target arteries contribute to late failure of this technique.

Objective: The aim was to report on chimney and periscope grafts (CPGs) and their mid- and longer-term outcomes when they are used to preserve reno-visceral artery (RVA) perfusion in endovascular repair of pararenal (PRAAs) or thoraco-abdominal aortic aneurysm (TAAAs). In addition, factors associated with CPG failure are presented. Limited data exist on the outcomes of CPGs, and mid- and long-term results are generally not reported.

Methods: This was a prospective study in a cohort of 100 patients with PRAA (69) or TAAA (31). A total of 224 (mean 2.24 per patient) RVAs were preserved with 136 (61%) chimney and 88 (39%) periscope grafts. CPGs were constructed mainly using self expandable stent grafts. Patients were followed by clinical examination, CTA (82%), and/or duplex (18%). Data were collected until February 2015.

Results: CPG immediate technical success was 99% (222/224 branches). Mean follow up was 29 months (range 0–65; SD 17); 59% patients were followed $>$ 2 years, 30% $>$ 3 years, and 16% $>$ 4 years. Post-operatively, CPG occlusion was observed early ($\leq$30 days) in three (1.3%) branches and during follow up in 10 (4.5%). At 36 and 48 months, the estimated primary patency was 93% and 93%. After corrective percutaneous (10) or surgical (3) re-interventions, the estimated secondary patency was 96% and 96%. Thirty day mortality was 2%; at 36 and 48 months the estimated patient survival was 79%. Significant shrinkage (72 [SD 23] vs. 62 [SD 24] mm; $p < .001$) was observed, with a substantial reduction (>5 mm) in 55 patients, and sac enlargement in four. Incomplete aneurysm sac sealing was treated successfully by a secondary intervention in 15 patients.

Conclusions: Self expandable CPGs have proved to be a highly successful and durable treatment for RVA preservation up to 5 years. Incomplete CPG expansion, inadequate length, and CPG use in small and diseased target arteries were risk factors for occlusion. These mid- and longer-term results support CPG use to treat PRAAs or TAAAs in patients unfit for open surgery or fenestrated/branched stent grafts.

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INTRODUCTION

Endovascular treatment of pararenal abdominal aortic aneurysms (PAAAs) and/or thoraco-abdominal aortic aneurysms (TAAAs) is usually performed using fenestrated or branched stent grafts (B/FEVAR).[1] However, because of anatomical limitations, device non-availability, and time consuming customization, a significant number of patients are excluded from B/FEVAR.[2] To overcome these limitations,

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parallel graft techniques using a combination of off the shelf devices have been developed to fit most of such complex cases.[3] Unfortunately, until now data published on chimney and periscope grafts (CPGs) have been limited, especially with regard to long-term results. In order to add supportive data on the value of this technique, mid- and longer-term outcomes of over 4 years of CPGs used in a single center over an 8 year experience are reported. This series includes 100 consecutive patients treated by CPG techniques in an intention to treat protocol, with standardized implantation methods and follow up protocols.

METHODS AND PATIENTS

This was a single center retrospective analysis of prospectively gathered data from 100 patients deemed unsuitable for conventional surgery and treated from January 2008 to August 2013 with at least one renal or visceral chimney or periscope graft. A vascular board including a cardiovascular surgeon and interventional radiologist selected patients. Briefly, patients with low surgical risk (good anatomy for clamping and grafting; young with unrestricted organ function, especially normal heart, lung and renal function) were treated by open surgery.[4] Patients presenting high risk for conventional surgery were treated by hybrid repair techniques (approximately 70–80% of all open repairs), and patients at high surgical risk for open surgery and/or unfit for fenestrated endovascular devices were treated endovascularly with parallel graft techniques. During the study period most patients presenting with aortic aneurysms involving the visceral aorta were treated by the hybrid repair technique (20%) or completely endovascularly (50%). Overall, 10 custom made branched/fenestrated grafts were used. Conventional open surgery was performed in the remaining 30% of cases. This series included 69 PAAAs (no normal aorta between the origin of the aneurysm and the lowest renal artery) and 31 TAAAs.[5] Eight TAAAs extended to the aortic arch. Seventy-three (73%) patients were treated electively and 27 (27%) non-electively (12 ruptured cases). Demographics and comorbidities[5–8] are reported in Table 1.

Investigational informed consent for the procedure and study was obtained from all patients. Clinical data were collected with the university hospital clinical information system (Dendrite, Dendrite Clinical Systems, Ltd, Henley-on-Thames, UK; KISIM 4.901, CISTEC AG, Zurich, Switzerland) and updated in February 2015. Earlier data with shorter follow up for some of these patients have been published previously.[3]

Standardized protocol

An aortic board reviewed all cases pre-operatively to assess CPG feasibility. Pre-operative thoraco-abdominal computed tomographic arteriography (CTA) was performed in all patients. CTA images were analyzed with the 3mensio software (3mensio Medical Imaging BV, Bilthoven, The Netherlands) to assess disease extent, and aortic and branch dimensions and angulations. The material necessary

Table 1. Demographics, comorbidities, and operative details.

Patients		100
Female		21
Mean age		73 ± 9
Hypertension		89
Diabetes		16
Lipid disorders		43
COPD		57
CAD		57
ASA class III/IV		62
class V		27
PAD		42
Hostile Chest/Abdomen		60
Mean GFR at baseline		54 ± 13
GFR<60		46
ESRF		12
Dialysis		5
Pre-operative aneurysm maximal transverse diameter (mm)	Mean, Median, Range	71.76 ± 23, 65, 38–185
Aortic aneurysm type	Pararenal	69
	Suprarenal	25
	Thoraco-abdominal	31
	Crawford I	7
	Crawford II	4
	Crawford III	3
	Crawford IV	9
	Arch to visceral	8
Operation	Elective	73
	Non-elective	27
	Symptomatic	15
	Ruptured	12
Number of CPG	1	21
	2	47
	3	19
	4	13
Main aortic stent graft	Diameter (mm)	33 ± 5
	Excluder and TAG[a]	55
	Endurant and Talent[b]	27
	Evita[c]	17
	Zenith[d]	1
In hospital stay (days)	Mean	10 ± 10
Intensive care unit stay (days)	Mean	2 ± 4
	Median	0
	Range	0–24

Note. Comorbidities were defined according to the Ad Hoc Committee for Standardized Reporting Practices in Vascular Surgery of the Society for Vascular Surgery and the American Association for Vascular Surgery; Juxtarenale, suprarenale und Abschnitt-IV-Aneurysmen classification; the Rutherford classification; and the National Kidney Foundation. COPD = chronic obstructive pulmonary disease; GFR = glomerular filtration rate (mL/min/1.73 m^2); CAD = coronary artery disease; ASA = American Society of Anesthesiologists; PAD = peripheral artery disease; HC/HA = hostile chest/hostile abdomen (previous surgical intervention with open chest or open abdomen); pararenal = juxta- and supra-renal; thoraco-abdominal = all descending aortic aneurysm, including those extending inside the aortic arch; CPG = chimney and periscope graft; ESRF = end stage renal function.

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to construct the CPG(s) and implantation routes were based on patient specific anatomy (Figs. 1 and 2). A 2 cm long sealing zone in the normal vessel wall (diameter and endoluminal morphology) was required in the aorta and its branches. A shorter landing zone in aortic branches (<10 mm) required special deployment techniques (described below).

The aortic devices used are reported in Table 1. Sizing was based on the following formula: mean aortic diameter at landing zone + half the diameter of each CPG used. In patients <70 years, an additional 10% aorta oversizing was used to anticipate future natural aortic growth. In challenging anatomies, repositionable grafts were used for more precise deployment and possible repositioning. CPGs were mostly constructed using a Viabahn device (WL Gore & Associates, Flagstaff, AZ, USA). The length of the Viabahn was chosen to extend, at least one centimeter, the CPG beyond (above or below) the covered part of the aortic stent graft and to leave a 1–2 cm landing zone within the aortic branch. The Viabahn device diameter generally included 1 mm of oversizing. In a few cases, at the beginning of the experience or for CPG stenosis or in the few highly stenotic vessels, self expandable and/or balloon expandable bare stents were used in 12 branches (5%). Overall, 224 (mean 2.24; SD 0.93; range 1–4) aortic branches were treated with CPGs and a mean of 1.49 stent grafts/stents was used per CPG (range 1–4; SD 0.76) (Table 2).

Implantation technique

CPG procedures were performed under local (35 patients; 63 vessels) or general anesthesia (65 patients; 161 vessels). Lidocaine 1% diluted with 8.4% sodium bicarbonate was used for analgesia in remote access site preparation (cut down or percutaneous). Mainly for patient comfort, analgesic sedation was added to local anesthesia. Procedures were performed in a radiology angiography suite (Artis-zeego; Siemens AG, Forchheim, Germany) or in a hybrid operating room (Philips Medical Systems, Inc., Shelton, CT, USA). A bolus of 5,000 units of heparin was injected before endovascular sheath introduction. Heparin was re-administered to keep the activated clotting time value to

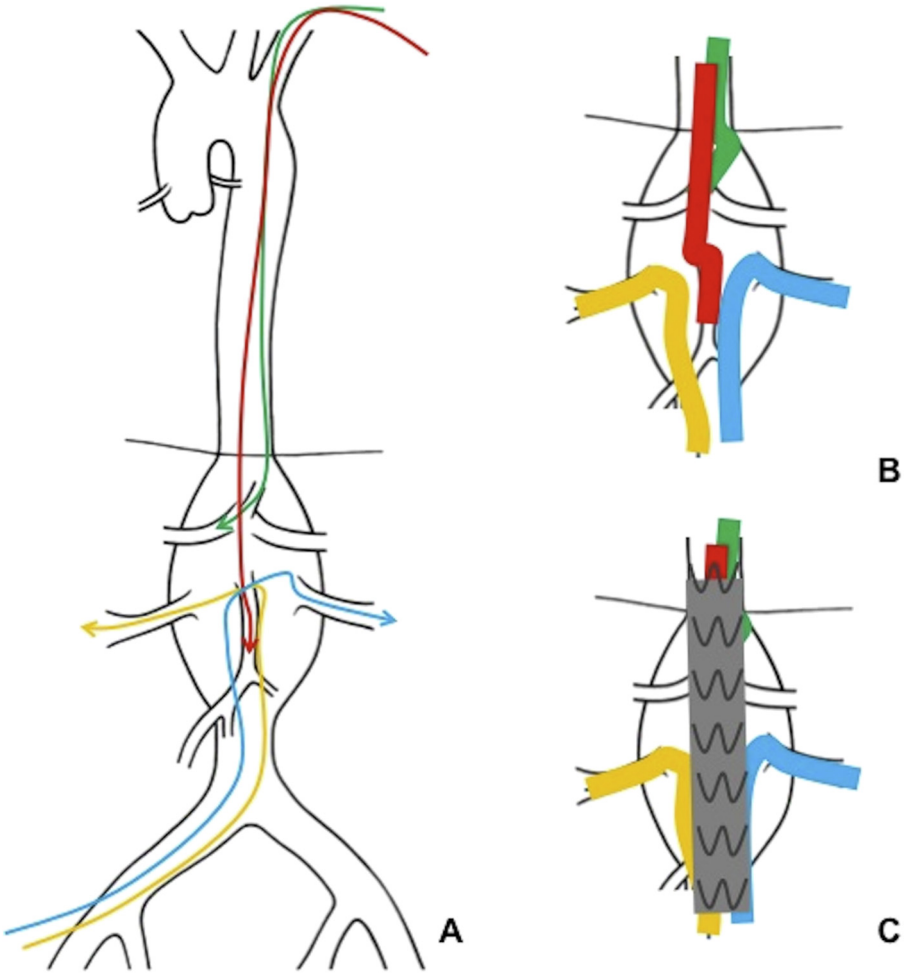

Figure 1. Schematic view of endovascular repair of Crawford IV aneurysm with chimney periscope graft. (A) Access to the reno-visceral arteries. Two chimneys are introduced from the left axillary artery to address the celiac trunk (green arrow) and the superior mesenteric artery (red arrow). Two periscopes are introduced from the right femoral artery to address the right (yellow arrow) and left (blue arrow) renal artery. (B) The Chimney and Periscope endografts have been deployed. (C) After tubular aortic stent graft deployment, the aneurysm is excluded and the blood flow into the reno-visceral arteries is maintained.

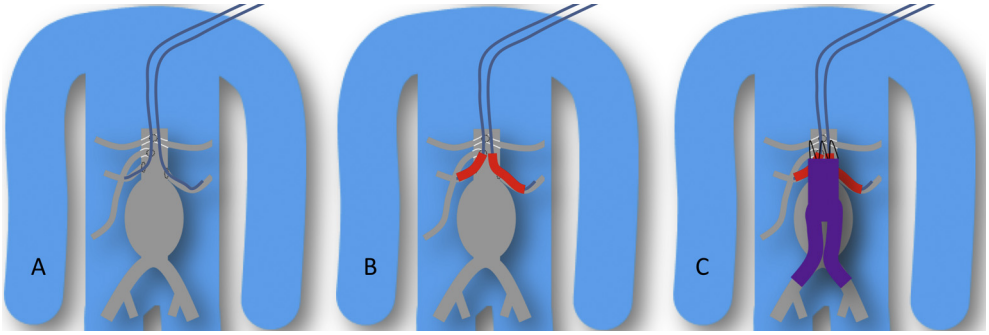

Figure 2. Schematic view of endovascular repair of pararenal aneurysm with chimney periscope grafts. (A) Access to renal arteries. Two chimneys are introduced from left axillary artery to address the renal arteries. (B) The chimneys are deployed into renal arteries. (C) Deployment of a bifurcated aortic stent graft to exclude the aneurysm. The blood flow is maintained into the renal arteries by the chimney graft.

>180 seconds or >250 seconds if supra-aortic access was used. Chimney grafts deliver antegrade flow and were generally introduced and deployed from the left axillary artery. On the other hand, periscope grafts deliver retrograde blood flow and were introduced transfemorally. Following cannulation and sheath placement in the reno-visceral branch, the Viabahn was introduced into the target vessel, deployed, and molded with a 2 cm long angioplasty balloon to achieve good anchorage. Aortic stent grafts were deployed and pullback traction was applied to the CPG balloon(s), to orientate the CPG(s) parallel to the aortic axis. A simultaneous kissing ballooning completed the procedure. Selective angiography and pressure measurements inside any aortic and branch stent graft were performed to exclude relevant endoleak(s) and/or significant pressure gradient(s). Low flow Type Ia (gutters and leaks limited to proximal neck) endoleaks,[9] even in patients with aortic rupture and coagulation disorder, were tolerated. In the latter part of the experience (7 cases; 7%) the CPGs were relined primarily with Wallstents (Boston Scientific Corp., Marlborough, MA, USA) to improve visibility.[10] In 22 (22%) cases a visceral debranching of one or two branches preceded the CPGs.

Special techniques. In short reno-visceral artery landing zones (≤10 mm), the CPG was deployed after the aortic stent graft. The transfemoral lift technique was used to construct 23/224 (10%) reno-visceral chimneys in patients with a highly diseased aortic arch.[11] Twenty-three of 224 (10%) CPGs were constructed using the sandwich technique, by placing the CPG between two aortic stent grafts (12), or a surgical graft and a stent graft (11) to reduce CPG length.[12] Thirteen (57%) sandwiches were constructed in the periscope configuration and 10 (43%) in the chimney configuration.

Peri-operative management

Post-operative quality controls. Duplex ultrasound (DUS) with kidney and liver resistance index measurements was performed immediately after the procedure. In ruptured cases, CTA was performed immediately after the CPG—EVAR procedure. In patients with severe chronic renal failure, contrast DUS and non-contrast CT were used during follow up.

Treatment of endoleaks or CPGs stenosis. High flow endoleaks I/III or relevant CPG stenoses were corrected immediately. Low flow endoleaks,[9] Type II endoleak and slight stenosis not associated with a significant pressure gradient were managed conservatively.

Management of blood pressure. After TAAA treatment, blood pressure was maintained between 120 and 150 mmHg for 6 weeks, to avoid spinal hypoperfusion. Patients developing neurological symptoms while hospitalized were treated with Mannitol 20%, a 50 mL bolus every 2—4 hours and transferred to the ICU for blood pressure (systolic pressure ≥140 mmHg; mean arterial pressure 70—

Table 2. Vessels, configuration, and stents.

	CPG Total	CPG configuration		CPG stent types				CPG dimension	
		Chimney	Periscope	Total	Covered SE	BMS SE	BE	Diameter	Length
RRA	80	41	39	119	110	6	3	6.54 ± 0.84	6.99 ± 2.81
LRA	81	48	33	120	110	6	4	6.67 ± 0.83	6.79 ± 2.49
SMA	38	30	8	55	49	6	0	8.45 ± 1.26	8.39 ± 12.52
CT	24	17	7	38	33	5	0	8.32 ± 1.18	14.17 ± 31.36
IMA	1	0	1	1	1	0	0	7	5
TOTAL	224	136	88	333	303	23	7	7.10 ± 0.94	7.92 ± 7.42

CPG = chimney/periscope graft; BMS = bare metal stent; SE = self expandable stent; BE = balloon expandable stent; RRA = right renal artery; LRA = left renal artery; SMA = superior mesenteric artery; CT = celiac trunk; IMA = inferior mesenteric artery.

90 mmHg) and hematocrit (>30%) optimization. Cerebrospinal fluid drainage (CSFD) was not used peri-operatively and not even post-operatively in symptomatic patients because of its debatable preventive value and because of the serious concerns about inserting the CSFD catheter under heparinization.

Medications. Combined antiplatelet therapy (100 mg/day aspirin) and full therapeutic heparinization were administered during hospitalization. Before discharge, patients were switched to dual antiplatelet therapy or single antiplatelet therapy combined with an oral anticoagulant for at least 3 months. To reduce the risk of post-implantation systemic inflammatory syndrome,[13] vaso-plegic syndrome,[14,15] and/or atrial fibrillation[16] and the consequent low cardiac output,[17] low dose steroids were administered orally for 5 days (prednisone 20 mg/day for 2 days, prednisone 10 mg/day for 2 days and prednisone 5 mg/day for 2 days).

Follow up

Follow up was 6 weeks, 3 months, 6 months, and annually thereafter; all patients were ambulatory. CTA, laboratory testing and clinical examination were performed. Basal CT and DUS were employed when CTA was contraindicated by impaired renal function.[18]

Study outcomes

Short term. The short-term outcomes were to calculate the immediate technical success rate (procedure completed as intended without high flow Type I/III endoleak and/or CPG occlusion), post-operative (30 day/in hospital) mortality and morbidity (including renal, respiratory, visceral, access and infection complications), ICU and hospital duration, CPG patency rates, and the presence of an endoleak at 30 days.

Mid-term

The mid-term outcomes were to calculate survival, CPG patency rates, endoleak rate, maximum aneurysm size and re-interventions during follow up. A significant aneurysm maximum transverse diameter (MAXTD) difference was defined as a variation of ≥5 mm on CTA.

CPG failure risk factor analysis

The following variables were analyzed: (a) diagnosis of PRAA versus TAAA; (b) elective versus non-elective treatment; (c) 1–2 CPG versus 3–4 CPG implantation; (d) CG versus PG versus CPG configuration, (e) renal versus visceral versus all treatment; (f) aortic stent graft fabric; (g) CPG collapse (>70% stenosis), and/or very short CPGs (<5 mm) versus no collapse or short CPG; and (h) target vessel atherosclerosis (stenosis >50%) or diameter < 4 mm versus non-diseased vessels, which were tested for the following late outcomes: (1) mortality at follow up; (2) aneurysm maximum diameter reduction; (3) CPG patency; (4) re-interventions.

Statistical analysis. Means (m), range (r) and standard deviation (SD) were reported for parametric data; absolute values and percentages for non-parametric data. Owing to the inclusion of exactly 100 patients, percentages were generally omitted when dealing with patient numbers. Differences between groups were assessed using the *t* test, and chi-square test. The risk factor multivariate analysis was conducted with multivariate analysis of variance (MANOVA). Kaplan–Meier curves were used to estimate survival, primary, and secondary patency and freedom from re-interventions. Differences in curves were assessed with the Breslow test. Statistical significance was considered to be $p < .05$. For Kaplan–Meier curves confidence interval (CI) and standard error exceeding 10% were reported. Statistical analysis was performed using SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The immediate technical success rate was 99%, as all but one procedure could be completed as intended. In one patient a renal artery could not be preserved. The mean procedure time was 252 (SD 190) minutes. A significantly higher number of patients with multiple (>2) CPGs were performed under general anesthesia than under local anesthesia (2.47 vs. 1.8; $p = .01$). Post-operative mortality occurred in two (2%) patients who developed multiple organ failure (1 rhabdomyolysis and 1 abdominal compartment syndrome after ruptured PAAA). Post-operative complications requiring re-interventions during the initial hospitalization included an axillary hematoma (2; 2%), bilateral lymphatic fistula in the groin (1; 1%), iliac limb occlusion (2; 2%), and mesenteric ischemia (1; 1%). Moreover, seven (7%) patients required CPG-related re-interventions early for CPG thrombosis (3) and/or endoleaks (4) (Table 3). Four subcapsular renal hematomas with no renal functional impairment were treated conservatively.

Table 3. Chimney and periscope graft related re-interventions.

Early (within 30 days)	**7**
CPG thrombosis	3
Treatment	
CPG thrombolysis	1
PTA/stenting	2
Endoleaks	4
Treatment	
Aortic extension	3
Coiling/embolization	1
Late (after 30 days)	**21**
CPG thrombosis	10
Treatment	
CPG extension	7
Bypass surgery	3
Endoleaks	11
Treatment	
Aortic extension	6
Coiling/embolization	5
Total	28

CPG = chimney periscope graft; PTA = percutaneous transluminal angioplasty.

No difference in peri-operative complications was observed between acute and elective patients (5/27 [19%] vs. 10/73 [14%]; $p = .68$). In eight patients, CPG(s) revisions were performed as outpatient procedures.[19] Neurological complications (spinal cord ischemia) occurred in three cases. These were successfully managed by pressure and hematocrit optimization and infusion of 50 mL of Mannitol 20% every 4 hours until the symptoms disappeared.

The overall experience with a median follow up of 28 (mean 29; range 0—65; SD 17) months including 59 patients followed > 2 years, 30 patients followed > 3 years and 16 patients followed > 4 years. Only one patient (1%) was lost during follow up. A 14% reduction in aneurysm maximum transverse diameter (CI 5.39—10.28; $p < .001$) was observed between the pre-operative (71.76 [median 65; range 38—185; SD 23] mm) and the last CTA (61.49 [median 56.5; range 30—162; SD 24] mm). There was a reduction of the maximal transverse diameter in 56 (56%) patients, no change in 40 (40%), and progression in four (4%). No stent graft migration was observed (Fig. 3).

Post-operatively, 28 (28%) CPG related re-interventions (including the 7 early ones mentioned above) were performed at a mean interval of 11.45 (range 0—38; SD 26) months; 25/28 (89%) were performed endovascularly and three of 28 (11%) with open bypass procedures (Table 3).

Of the 28 re-interventions, 15 (54%) were performed for endoleak related issues. At the latest follow up of all cases, a Type I/III endoleak was evident in 5% of cases. Out of the 23 Type I/III endoleaks noted post-operatively, 15 were treated (4 early and 11 late) and three sealed spontaneously. The remaining five Type I/III endoleaks were low flow. These remain under surveillance as long as the aneurysm diameter remains stable (Table 3). The estimated endoleak free survival after secondary procedures is shown in Fig. 4.

Post-operatively, relevant CPG stenosis or thrombosis requiring re-intervention was detected in 13 of 224 (5.8%) branches. The mean interval to re-intervention was 2.6 (range 0—6; SD 2) months; three branches were treated early and 10 later during follow up (Table 3). Primary patency at 12, 24, 36, and 48 months was 94%, 94%, 93% and 93% respectively, and secondary patency 97%, 97%, 96%, and 96% respectively (Fig. 5A). The number of CPGs was not related to patency rates ($p = .10$) or to CPG configuration ($p = .90$).

Estimated freedom from re-intervention(s) at 12, 24, 36, and 48 months was 77%, 73%, 64%, and 53% respectively. No significant difference in the re-intervention rate was observed for the number of CPGs ($p = .35$) or elective versus non-elective patients ($p = .33$). No difference in renal function (glomerular filtration rate) was observed between pre-operative and follow up (54 mL/min/1.72 m^2; SD 13 vs. 56 mL/min/1.72 m^2; SD 16; $p = .84$).

Two patients developed an irreversible delayed paraplegia at 6 and 5 weeks after Type II or Type I TAAA. In both, new onset of atrial fibrillation and systolic blood pressure <100 mmHg were recorded.

Overall estimated patient survival at 12, 24, 36, and 48 months was 91%, 84%, 79%, and 79% respectively. Estimated aneurysm related survival at 12, 24, 36, and 48

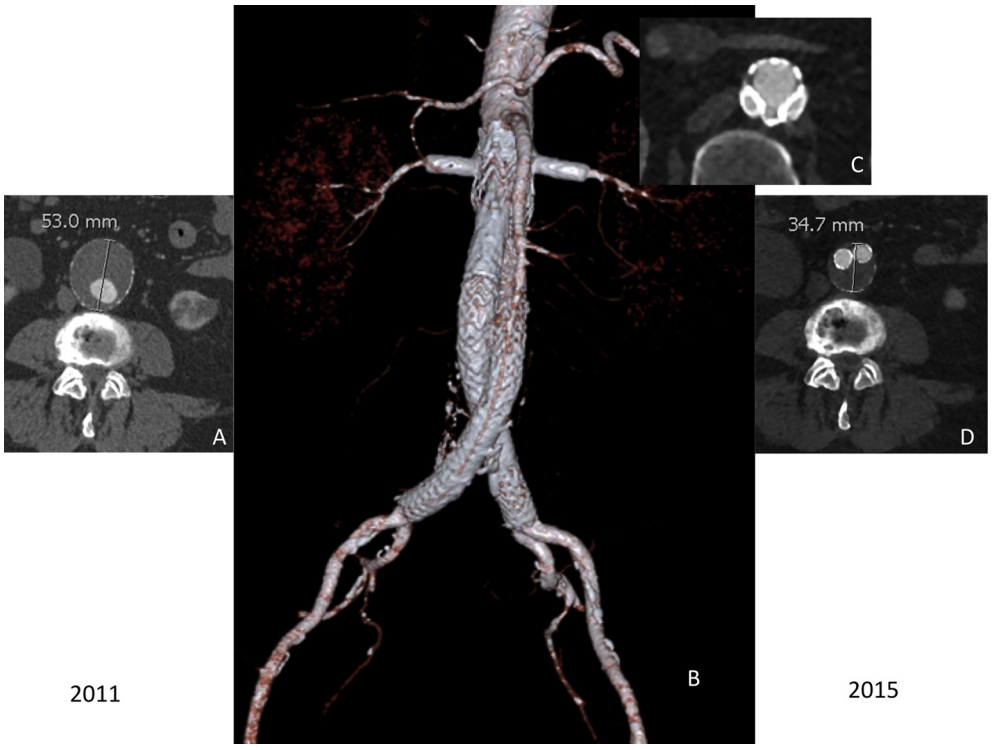

Figure 3. (A) Computed tomography (CT) showing abdominal aortic aneurysm maximum diameter (53 mm). (B) Aneurysm follow up with CT three dimensional reconstruction showing regular patency of renal chimneys and visceral vessels. (C) CT corresponding plain view of renal chimneys and aortic stent graft. (D) CT showing aortic aneurysm sac shrinkage.

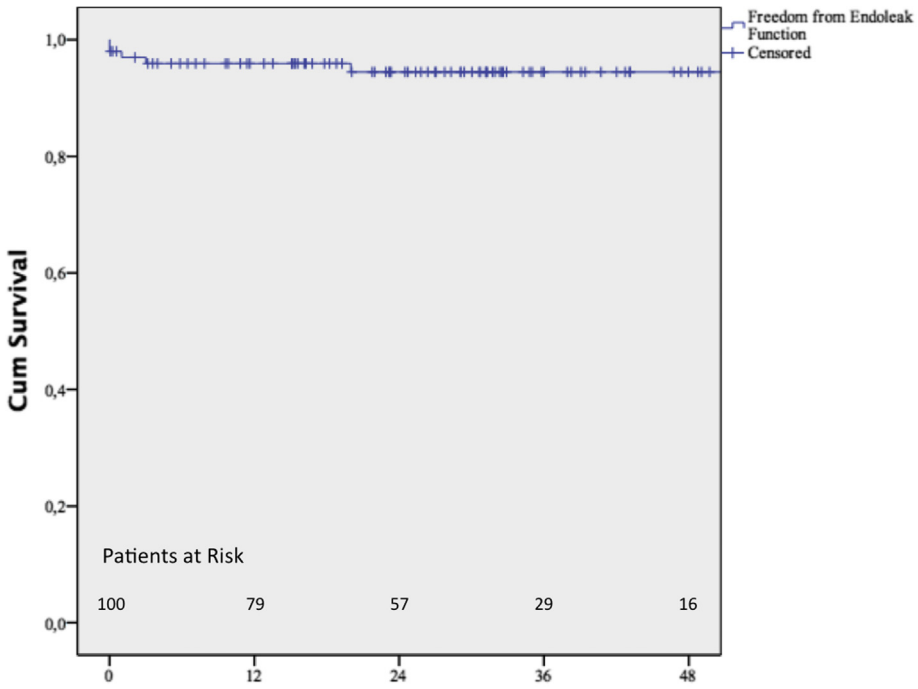

Figure 4. Freedom from Type I/III endoleaks at 12, 24, 36, and 48 months was 96%, 94%, 94%, and 94%. Standard error does not exceed 10% at 48 months (CI 53.18—59.75).

months was 93%, 90%, 90%, and 90% (Fig. 5B). Survival was not related to the type of aortic aneurysm treated (PRAA vs. TAAA) ($p = .077$) but to the type of repair (elective vs. emergent) ($p = .003$). One patient (4%, 1/28) died after re-intervention (irreversible shock after an iliac artery disruption). During the follow up, 19 patients died (2 early and 17 late deaths). Of these 17 late deaths, five were directly related to the initial CPG—aortic stent graft procedure or a re-intervention.

The risk factor multivariate analysis for CPG failure showed a higher mortality ($p = .001$) and re-intervention rate ($p = .01$) in patients treated non-electively; a higher mortality rate in patients treated with multiple (3—4) CPGs ($p = .03$); a higher re-intervention rate in highly stenosed or short CPGs ($p = .02$); and a higher CPG occlusion ($p = .004$) and re-intervention rate ($p = .005$) in stenosed or small target vessels. There were associations with re-interventions for multiple (3—4) CPGs ($p = .06$); with

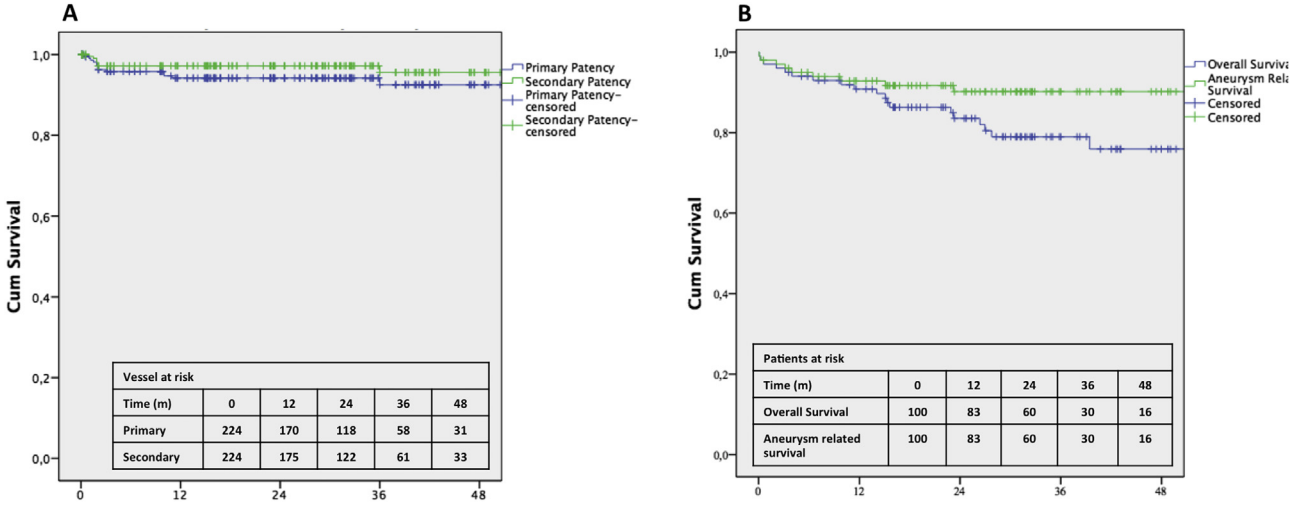

Figure 5. (A) Primary patency at 12, 24, 36, and 48 months was 94%, 94%, 93%, and 93%. Standard error does not exceed 10% at 48 months (CI 50.58—62.83). Secondary patency at 12, 24, 36, and 48 months was 97%, 97%, 96%, and 96%. Standard error does not exceed 10% at 48 months (CI 60.83—64.12). No significant differences in primary and secondary patency (CI 60.24—62.94; p = .17). (B) Overall survival at 12, 24, 36, and 48 months was 91%, 84%, 79%, and 79%. Standard error does not exceed 10% at 48 months (CI 48.86 to 57.85). Aneurysm related survival at 12, 24, 36, and 48 months was 93%, 90%, 90%, and 90%. Standard error does not exceed 10% at 48 months (CI 55.62—62.70).

Table 4. Multivariate risk factors analysis.

Variables	Outcomes Mortality at FUP (*n*)	TD_{max} reduction (mm)	CPG patency (occlusion; *n*)	Re-interventions (*n*)
PRAA (69) vs. TAAA (31)	13 vs. 6; $p = .32$	7 vs. 10; $p = .77$	9 vs. 4; $p = .97$	21 vs. 12; $p = .15$
Elective (73) vs. non-elective (27)	**9 vs. 10; $p = .001$**	14 vs. 6; $p = .62$	10 vs. 3; $p = .52$	**27 vs. 6; $p = .01$**
1–2 CPG (68) vs. 3–4 CPG (32)	**9 vs. 10; $p = .03$**	9 vs. 9; $p = .17$	4 vs. 12%; $p = .84$	13 vs. 20; $p = .06$
CG (50) vs. PG (28) vs. CPG (22)	5 vs. 7 vs. 7; $p = .06$	10 vs. 9 vs. 11; $p = .59$	3 vs. 4 vs. 6; $p = .95$	13 vs. 11 vs. 9; $p = .33$
Renal (58) vs. visceral (10) vs. all (32)	11 vs. 1 vs. 7; $p = .72$	11 vs. 9 vs. 10; $p = .12$	9 vs. 0 vs. 4; $p = .41$	16 vs. 4 vs. 13; $p = .40$
Aortic stent graft (55 vs. 27 vs. 17 vs. 1)	11 vs. 5 vs. 3 vs. 0; $p = .96$	10 vs. 11 vs. 9 vs. 12; $p = .12$	6 vs. 4 vs. 3 vs. 0; $p = .86$	17 vs. 6 vs. 9 vs. 1; $p = .08$
CPG >70% stenosis and/or CPGs <5 mm length (29) vs. no collapse/short CPG (71)	13 vs. 6; $p = .30$	8 vs. 10; $p = .76$	4 vs. 9; $p = .06$	**25 vs. 8; $p = .02$**
Target vessel stenosis >50% or <4 mm diameter (78) vs. not diseased vessels (22)	14 vs. 5; $p = .65$	15 vs. 6; $p = .09$	8 vs. 5; $p = .04$	19 vs. 16; $p = .05$

n = absolute number; PAAA = pararenal aortic aneurysm; TAAA = thoraco-abdominal aortic aneurysm; CPG = chimney periscope graft; CG = chimney graft; PG = periscope graft; FUP = follow up; TD_{max} = maximal transverse diameter.
Significant values are represented in bold.

mortality for combined CPGs ($p = .06$); and with CPG occlusion for highly stenosed or short CPGs ($p = .006$) (Table 4).

DISCUSSION

Studies reporting the mid- and longer-term outcomes of chimney and/or periscope grafts used in reno-visceral vessels are rare and identification of risk factors for chimney and/or periscope graft failure are lacking.[20] As reported recently by the multicenter PERICLES registry, the results at 17.1 months from 517 patients treated by CPGs were similar to those of F/BEVAR. However, in this registry different devices (bare metal, covered, self expandable, or balloon expandable) have been used in reno-visceral vessels and no risk factor analysis for CPG failure was performed.[21]

Based on the VORTEC experience using the Viabahn for sutureless anastomoses in reno-visceral vessels,[22–24] it was felt that felt that the Viabahn device would be ideal for CPG construction and therefore it was used exclusively for the parallel graft(s) in reno-visceral vessels. The intuition was confirmed in the actual series of 100 patients followed for a mean period of 28 months by absence of material failure and the high primary patency rate (93%) in the 16 patients followed >4 years. Post-operatively, CPG occlusion was observed in only 5.8% branches; the risk factors were CPG collapse and/or too short CPGs, target vessel atherosclerosis or a diameter <4 mm. With regard to the aortic stent graft there was no difference in outcome, maybe because of the relatively small samples. Few experimental and clinical data support the use of one device (aortic stent graft or branch stent graft) over another,[3,9,18,25] and long-term results with different types of CPG devices (self expandable or balloon expandable) are needed.[26] The Viabahn is preferred for CPG construction because of its low profile, flexibility, and heparin coating. The excellent results, also in patients with long-term follow up, support this choice. In addition, the Viabahn X-ray visibility may increase with primary Wallstent relining.[10] This tool was employed increasingly in the later procedures, especially in cases of multiple CPGs. Finally, the 4 year cumulative patency rate of aortic branches preserved with CPGs is equivalent to those reported after B/FEVAR treatment for similar aortic pathologies (96% vs. 88.6%).[27–29] In this study, to fit the patient anatomy, different stent graft manufacturers were combined and used concurrently with no differences. This approach has been used with caution, and no drawbacks have been observed to date.

Endoleaks are regarded as a major concern[9] and represent a potential cause of aneurysm rupture.[26,30] The policy to perform very sensitive CTA (arterial and venous phases) early post-operatively might explain the 23% endoleak incidence. However, this high rate must be tempered by the lack of persistence or clinical adverse consequences if endoleaks are addressed appropriately. When the endoleak did not seal spontaneously, it was eliminated by coil-embolization or endograft extension, which showed durable effects over time. Persisting low flow Type I endoleaks did not result in aneurysm enlargement. Overall and despite these endoleaks, aneurysm diameter remained stable or decreased in 96% of patients, which compares favorably with the findings described after FEVAR (92–97%).[29,31,32] Moreover, when compared with data from Schanzer et al.,[33] sac enlargement was less in the current series. It can be argued that this enlargement was related not only to a lower endoleak incidence (32 vs. 23%), but also to aggressive endoleak treatment based on adherence to a stricter follow up protocol.

Clinical outcomes of the mid- and longer-term experience of parallel graft techniques are consistent with 2% peri-

operative mortality and 79% survival rate at 4 years' follow up. Although controversies exist on CPG outcomes,[34] the results compare favorably with those of both B/FEVAR and/or open surgery. The reported peri-operative mortality rate after B/FEVAR ranges between 2.1% for juxtarenal AAA and 7.8% for TAAA;[29,35] the 5 year survival rate ranges between 91% for juxtarenal and 67% for TAAA.[29,36] These survival outcomes of both CPGs and F/BEVAR compare favorably with randomized control trials reporting on infrarenal AAA treatment, such as the EVAR[37] and OVER[38] trial using the older generation devices. Also the more recent cardiovascular medical support can play a role in survival outcome.[39]

General anesthesia was employed more frequently in multiple CPGs and local anesthesia for less complex procedures. Patients treated for TAAAs required significantly longer ICU stays and showed less aneurysm shrinkage than patients treated for PRAAs. Moreover, in this group of patients, CPG outcomes seemed far better than those of similar lesions treated by open aortic surgery.[40] During follow up, patient survival after non-elective procedures and procedures requiring more than two CPGs was worse than after elective procedures with one or two CPGs. Patients requiring elective treatment with only one or two CPGs clearly had the best outcomes. However, the higher risk and challenging nature of patients requiring more complex procedures would seem to justify the CPG techniques in these patients as well.

This study has some limitations. First, there is no contemporary (institutional) clinical comparison with FEVAR or open repair. The main reason for this is that the actual study focus was on outcomes and risk factors for CPG complications, especially when the Viabahn branch grafts were used. As the Viabahn device is generally not used in FEVAR procedures, comparisons might have yielded confusing results of limited value. A second limitation of the study is that it included the learning curve(s) with different skills and techniques developed during experience with CPGs. A third limitation is that the study included a mixed group of different aortic lesions and clinical conditions (elective and emergent). In fact, as experience progressed, the techniques were adapted and developed so the CPG option could be offered to most patients with AAAs and/or TAAAs involving reno-visceral branch arteries. Because of this, and because major differences in constructing CPGs were not identified in these different anatomical and clinical circumstances, the group as a whole was reviewed to obtain sufficient numbers of patients to enable the authors to identify risk factors for CPG complications. Nevertheless, the results may not apply to CPG grafts constructed with different components or configurations. However the PERICLES registry results suggests that this may not be a limitation.[21]

In conclusion, this experience in 100 patients treated with self expanding CPGs shows promising and durable mid- and longer-term term results (>4 years). Diseased native vessels, highly stenosed, or short CPGs and multiple (3—4) CPGs were significant risk factors for CPG failure. Non-elective CPG and multiple (3—4) CPGs were significant risk factors for death. Although the data suggest that the parallel graft methods for reno-vascular revascularization with complex AAAs may be equivalent to open surgery or FEVAR, more widespread experience and direct comparisons will be required to confirm this. The potential advantages of CPG techniques (off the shelf, versatility, generally immediate availability and low-profile devices) are obvious; however, the best indications for CPGs remain to be clarified. However, even at present, the wider use of such parallel grafting techniques, using the Viabahn, seems to be justified in situations in which F/BEVAR is not available and patients are at high risk for open surgical repair.

CONFLICT OF INTEREST

None.

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REFERENCES

1 Haulon S, Amiot S, Magnan PE, Becquemin JP, Lermusiaux P, Koussa M, et al. An analysis of the French multicentre experience of fenestrated aortic endografts: medium-term outcomes. *Ann Surg* 2010;**251**(2):357—62.
2 Pol RA, Tielliu IF, Zeebregts CJ. New insights in (acute) endovascular abdominal aneurysm repair: when fenestrated devices fall short. *J Cardiovasc Surg (Torino)* 2013;**54**(2):173—80.
3 Lachat M, Veith FJ, Pfammatter T, Glenck M, Bettex D, Mayer D, et al. Chimney and periscope grafts observed over 2 years after their use to revascularize 169 renovisceral branches in 77 patients with complex aortic aneurysms. *J Endovasc Ther* 2013;**20**(5):597—605.
4 Schmidt CA, Wilhelm MJ, Mayer DO, Rancic Z, Bangemann A, Felix C, et al. Veno-venous perfusion to cool and rewarm in thoracic and thoraco-abdominal aortic aneurysm repair. *J Vasc Surg* 2013;**58**(1):33—41.
5 Mayer D, Pfammatter T, Lachat M. Juxtarenale, suprarenale und Abschnitt-IV-Aneurysmen. In: Debus ES, Gross-Fengels W, editors. *Operative und interventionelle Gefäßmedizin*. Berlin: Springer; 2012. p. 525—50.
6 Chaikof EL, Fillinger MF, Matsumura JS, Rutherford RB, White GH, Blankensteijn JD, et al. Identifying and grading factors that modify the outcome of endovascular aortic aneurysm repair. *J Vasc Surg* 2002;**35**(5):1061—6.
7 Rutherford RB, Baker JD, Ernst C, Johnston KW, Porter JM, Ahn S, et al. Recommended standards for reports dealing with lower extremity ischemia: revised version. *J Vasc Surg* 1997;**26**(3):517—38.
8 Levey AS, Coresh J. Chronic kidney disease. *Lancet* 2012;**379**(9811):165—80.
9 Donas KP, Pecoraro F, Torsello G, Lachat M, Austermann M, Mayer D, et al. Use of covered chimney stents for pararenal aortic pathologies is safe and feasible with excellent patency and low incidence of endoleaks. *J Vasc Surg* 2012;**55**(3):659—65.
10 Lachat M, Mayer D, Pfammatter T, Criado FJ, Rancic Z, Larzon T, et al. Periscope endograft technique to revascularize the left subclavian artery during thoracic endovascular aortic repair. *J Endovasc Ther* 2013;**20**(6):728—34.
11 Lachat M, Bisdas T, Rancic Z, Torsello G, Mayer D, Gil-Sales J, et al. Chimney endografting for pararenal aortic pathologies

using transfemoral access and the lift technique. *J Endovasc Ther* 2013;**20**(4):492—7.
12 Kolvenbach RR, Yoshida R, Pinter L, Zhu Y, Lin F. Urgent endovascular treatment of thoraco-abdominal aneurysms using a sandwich technique and chimney grafts—a technical description. *Eur J Vasc Endovasc Surg* 2011;**41**(1):54—60.
13 Arnaoutoglou E, Kouvelos G, Papa N, Kallinteri A, Milionis H, Koulouras V, et al. Prospective evaluation of post-implantation inflammatory response after EVAR for AAA: influence on patients' 30 day outcome. *Eur J Vasc Endovasc Surg* 2015;**49**(2):175—83.
14 Wong DR, Lemaire SA, Coselli JS. Managing dissections of the thoracic aorta. *Am Surg* 2008;**74**(5):364—80.
15 Krauss T, Pfammatter T, Mayer D, Lachat M, Hechelhammer L, Marincek B, et al. Hybrid-repair of thoraco-abdominal or juxtarenal aortic aneurysm: what the radiologist should know. *Eur Radiol* 2010;**20**(4):1011—22.
16 Maniar HS, Sundt 3rd TM, Prasad SM, Chu CM, Camillo CJ, Moon MR, et al. Delayed paraplegia after thoracic and thoracoabdominal aneurysm repair: a continuing risk. *Ann Thorac Surg* 2003;**75**(1):113—9. discussions 9—20.
17 Boos CJ, Anderson RA, Lip GY. Is atrial fibrillation an inflammatory disorder? *Eur Heart J* 2006;**27**(2):136—49.
18 Donas KP, Pecoraro F, Bisdas T, Lachat M, Torsello G, Rancic Z, et al. CT angiography at 24 months demonstrates durability of EVAR with the use of chimney grafts for pararenal aortic pathologies. *J Endovasc Ther* 2013;**20**(1):1—6.
19 Lachat ML, Pecoraro F, Mayer D, Guillet C, Glenck M, Rancic Z, et al. Outpatient endovascular aortic aneurysm repair: experience in 100 consecutive patients. *Ann Surg* 2013;**258**(5):754—8. discussion 8—9.
20 Wilson A, Zhou S, Bachoo P, Tambyraja AL. Systematic review of chimney and periscope grafts for endovascular aneurysm repair. *Br J Surg* 2013;**100**(12):1557—64.
21 Donas KP, Lee JT, Lachat M, Torsello G, Veith FJ. PERICLES investigators. Collected world experience about the performance of the snorkel/chimney endovascular technique in the treatment of complex aortic pathologies: the PERICLES registry. *Ann Surg* 2015;**262**(3):546—53.
22 Rancic Z, Mayer D, Pfammatter T, Frauenfelder T, Falk V, Ueda H, et al. A new sutureless telescoping anastomotic technique for major aortic branch revascularization with minimal dissection and ischemia. *Ann Surg* 2010;**252**(5):884—9.
23 Papadimitriou D, Mayer D, Lachat M, Pecoraro F, Frauenfelder T, Pfammatter T, et al. A clampless and sutureless aortic anastomosis technique using an endograft connector for aortoiliac occlusive disease in which the aorta cannot be clamped or sewn due to calcification or scarring. *Vascular* 2012;**20**(5):262—7.
24 Rancic Z, Pecoraro F, Pfammatter T, Mayer D, Veith FJ, Lachat M. Less invasive (common) femoral artery aneurysm repair using endografts and limited dissection. *Eur J Vasc Endovasc Surg* 2013;**45**(5):481—7.
25 Lee JT, Lee GK, Chandra V, Dalman RL. Comparison of fenestrated endografts and the snorkel/chimney technique. *J Vasc Surg* 2014;**60**(4):849—56. discussion 56—7.
26 Chaudhuri A. Periscopes, snorkels and chimneys: no smoke without fire? *Eur J Vasc Endovasc Surg* 2014;**47**(3):218—20.
27 Schepens MA, Kelder JC, Morshuis WJ, Heijmen RH, van Dongen EP, ter Beek HT. Long-term follow up after thoracoabdominal aortic aneurysm repair. *Ann Thorac Surg* 2007;**83**(2):S851—5. discussion S90—2.
28 Grimme FA, Zeebregts CJ, Verhoeven EL, Bekkema F, Reijnen MM, Tielliu IF. Visceral stent patency in fenestrated stent grafting for abdominal aortic aneurysm repair. *J Vasc Surg* 2014;**59**(2):298—306.
29 Verhoeven EL, Katsargyris A, Bekkema F, Oikonomou K, Zeebregts CJ, Ritter W, et al. Ten-year experience with endovascular repair of thoraco-abdominal aortic aneurysms: results from 166 consecutive patients. *Eur J Vasc Endovasc Surg* 2015;**49**(5):524—31.
30 Schiro A, Antoniou GA, Ormesher D, Pichel AC, Farquharson F, Serracino-Inglott F. The chimney technique in endovascular aortic aneurysm repair: late ruptures after successful single renal chimney stent grafts. *Ann Vasc Surg* 2013;**27**(7):835—43.
31 Amiot S, Haulon S, Becquemin JP, Magnan PE, Lermusiaux P, Goueffic Y, et al. Fenestrated endovascular grafting: the French multicentre experience. *Eur J Vasc Endovasc Surg* 2010;**39**(5):537—44.
32 Kristmundsson T, Sonesson B, Malina M, Bjorses K, Dias N, Resch T. Fenestrated endovascular repair for juxtarenal aortic pathology. *J Vasc Surg* 2009;**49**(3):568—74. discussion 74—5.
33 Schanzer A, Greenberg RK, Hevelone N, Robinson WP, Eslami MH, Goldberg RJ, et al. Predictors of abdominal aortic aneurysm sac enlargement after endovascular repair. *Circulation* 2011;**123**(24):2848—55.
34 Scali ST, Feezor RJ, Chang CK, Waterman AL, Berceli SA, Huber TS, et al. Critical analysis of results after chimney endovascular aortic aneurysm repair raises cause for concern. *J Vasc Surg* 2014;**60**(4):865—73.
35 Linsen MA, Jongkind V, Nio D, Hoksbergen AW, Wisselink W. Pararenal aortic aneurysm repair using fenestrated endografts. *J Vasc Surg* 2012;**56**(1):238—46.
36 Oderich GS, Greenberg RK, Farber M, Lyden S, Sanchez L, Fairman R, et al. Results of the United States multicenter prospective study evaluating the Zenith fenestrated endovascular graft for treatment of juxtarenal abdominal aortic aneurysms. *J Vasc Surg* 2014;**60**(6). 1420—8 e1—5.
37 United Kingdom ETI, Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D, et al. Endovascular versus open repair of abdominal aortic aneurysm. *N Engl J Med* 2010;**362**(20):1863—71.
38 Lederle FA, Freischlag JA, Kyriakides TC, Matsumura JS, Padberg Jr FT, Kohler TR, et al. Long-term comparison of endovascular and open repair of abdominal aortic aneurysm. *N Engl J Med* 2012;**367**(21):1988—97.
39 Spanos K, Giannoukas AD. Is the reevaluation of cardiac status and medical treatment mandatory for patients with coronary artery disease after endovascular aneurysm repair? *J Endovasc Ther* 2015;**22**(2):198—200.
40 Pecoraro F, Pfammatter T, Mayer D, Frauenfelder T, Papadimitriou D, Hechelhammer L, et al. Multiple periscope and chimney grafts to treat ruptured thoraco-abdominal and pararenal aortic aneurysms. *J Endovasc Ther* 2011;**18**(5):642—9.