Perspective

The chimney-graft technique for preserving supra-aortic branches: a review

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Evolution in the endovascular era has influenced the management of aortic arch pathologies. "Chimney" or "snorkel" graft technique has been used as an alternative in high risk patients unfit for open repair. We reviewed the published literature on the chimney graft technique for preservation of the supra-aortic branches in order to provide an extensive insight of its feasibility and efficacy and investigate its outcomes. 18 reports were identified, with a total of 124 patients and 136 chimney. Primary technical success was achieved in 123/124 patients (99.2%). The perioperative mortality rate was 4.8% and the stroke rate was 4%, while events of spinal cord ischemia were rare. The overall endoleak rate was 18.5%; 13 patients (10.5%) developed a type I endoleak and 10 (8%) patients a type II endoleak. During a median follow-up period of 11.4 months (range, 0.87-20.1 months) all implanted chimney grafts remained patent. From this, we conclude that endovascular aortic arch repair with chimney grafts is associated with a lower mortality rate compared to totally open or hybrid reconstruction. However, the stroke rate remains noteworthy, and requires longterm data to elucidate.

Keywords: Chimney; snorkel; endovascular; aortic arch

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Introduction

Open surgical repair of pathologies of the aortic arch or the proximal descending aorta is associated with considerable periprocedural risks (1). Evolution in the endovascular era has influenced the management of aortic arch pathologies. Hybrid approaches for these patients have been proposed as alternative options (2,3). Despite the fact that following a hybrid strategy the need for sternotomy and cardiopulmonary by-pass is eliminated, the mortality and morbidity rates still remain relatively high (2). In addition, total endovascular techniques (i.e., fenestrated, branched devices) have been developed. However they need to overcome several anatomic and logistic limitations.

The chimney-graft technique, which was first described by Greenberg and associates (4) and was applied over the last decade for visceral debranching (5), could be a reasonable alternative for preserving supra-aortic branches in patients with pathologies involving the aortic arch.

We reviewed the published literature on the "chimney" or "snorkel" graft technique for the preservation of supra-aortic branches in order to provide an extensive insight of its feasibility and efficacy and investigate its outcomes.

Material and methods

Definition

The "chimney technique" involves deployment of stents/stent-grafts into the supra-aortic branches, with the

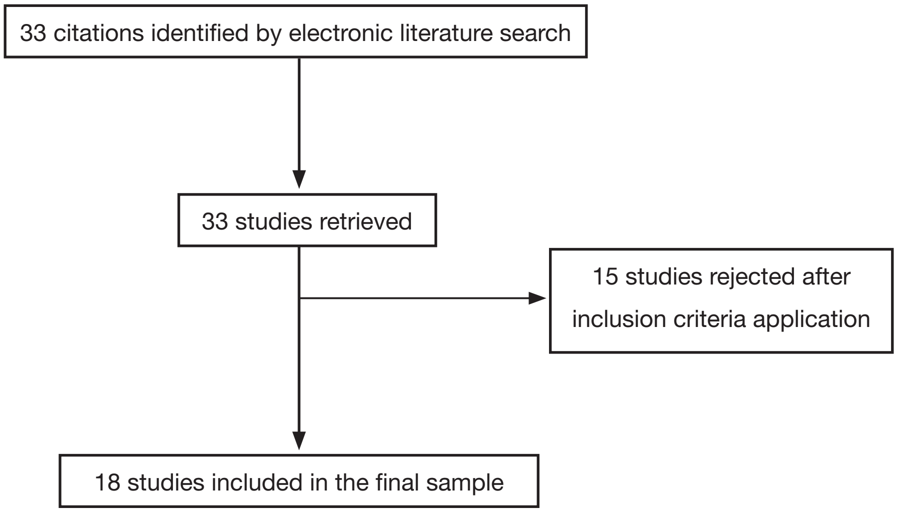

Figure 1 Study flow chart

proximal parts placed parallel to the main thoracic aortic endoprosthesis (between the aortic stent and the aortic wall) and extended above it to ensure perfusion.

Search strategy - eligibility criteria

Multiple electronic health database searches were performed that included Medline, Embase, Ovid, the Cochrane Database of Systematic Reviews, and the Cochrane Database of Abstracts of Reviews of Effectiveness (DARE), aiming to identify studies on "chimney technique" for the treatment of aortic arch pathologies. The search strategy was unrestricted and used exploded MeSH (medical subject heading) terms 'double-barrel', 'triple-barrel', 'thoracoabdominal', 'aortic aneurysm', 'endovascular', 'chimney graft', and/or 'endovascular aortic arch debranching'. In addition, the references of all included articles were examined for further relevant series. All studies were independently assessed, and the full texts of the studies were retrieved.

Studies were included in the present review if (I) supra-aortic branches [left subclavian (LSA), left common carotid (LCCA) and innominate arteries (IA)] revascularization during endovascular treatment of aortic pathologies was achieved via a chimney graft (CG) implantation; and (II) the basic outcome criteria (complications rate; chimney graft patency, endoprosthesis related complications, and primary technical success rate; and the total mortality rate) were stated. Cases of prior thoracic endovascular aortic repair (TEVAR) failure treated with chimney grafts are also included in the present study. Reports on hybrid procedures and branched or fenestration stent-grafts were excluded as well as those detailing the chimney technique for visceral revascularization alone. Articles in languages other than English were also eliminated from further analysis. In cases of duplicated or metachronous publications from the same center, only the latest was included. Furthermore, several studies included patients with chimney graft implantation among other populations; they were included in the present review if separate data for this patient subgroup were provided.

All selected full-text articles were independently evaluated by two authors (S.M. and H.D.). From the attained articles the baseline patient data (mean age); indication of chimney technique application (aortic pathology or endoprosthesis-related complications after prior TEVAR); applied main aortic stent-graft design; number of chimney grafts and adjacent by-pass procedures were extracted and analyzed. Finally, the postoperative outcomes (primary technical success; mean follow-up period (months); endoprosthesis-related complications; post-procedural complications; and 30 d-/in-hospital mortality) were evaluated.

Results

The electronic literature search yielded 18 reports that fulfilled the inclusion criteria (6-23) (*Figure 1*, *Table 1*). A total of 124 patients (79% male; mean age: range, 36-81.5) were analyzed. The aortic pathology was described in 108 patients: 28 (26%) had a degenerative aneurysm, 61 (56.5%)

Table 1 Characteristics of the eligible studies on chimney-graft technique preserving supra-aortic branches

Study	N of patients	Gender (M/F)	Age (mean, years)	Aortic pathology (An/Dis/other)*	N of chimney grafts (total)	Revascularized branches (IA/LCCA/LSA)	Aortic endoprosthesis design	Chimney graft design
Shahverdyan et al., 2013 (6)	6	6/0	73	1/1/4	12	6/6/0	Gore CTAG®	Viabahn®
Samura *et al*., 2013 (7)	2	2/0	82	2/0/0	4	2/2/0	Gore TAG®	Excluder Iliac Extender®, Atrium V12®
Zhu *et al*., 2013 (8)	34	26/8	66	0/34/0	34	3/8/23	Talent®, Zenith®, Hercules-T®, Ankura®	Fluency®, Express®, Scuba®, S.M.A.R.T Control®
Chang *et al*., 2013 (9)	1	1/0	41	0/0/1	1	0/1/0	Talent®, Zenith®, Hercules-T®, Ankura®	Zilver stent®
Zhou *et al*., 2013 (10)	1	1/0	45	0/0/1	2	0/1/1	Valiant®	Fluency®
Vallejo *et al*., 2012 (11)	8	NR	NR	NR	8	3/5/0	Gore TAG®, Talent®, Valiant®	AneuRx®, Palmaz®, Express®
Akchurin *et al*., 2012 (12)	10	NR	NR	6/4/0	10	0/0/10	NR	NR
Cires *et al*., 2011 (13)	9	6/3	64	3/1/5	9	2/2/5	Gore TAG®, Talent®	Bare stents
Yoshida *et al*., 2011 (14)	2	1/1	77	1/1/0	5	2/2/1	Zenith®	Viabahn®
Shu *et al*., 2011 (15)	8	7/1	49	0/8/0	8	0/8/0	Hercules®, Relay®, Zenith®	Fluency®, Passenger®
Feng *et al*., 2011 (16)	1	0/0	36	0/0/1	1	0/1/0	Relay®, Hercules cuff ®	Sinus®
Gehringhoff *et al*., 2011 (17)	9	7/2	57	5/1/3	9	0/3/6	ZentithTX2®, Valiant®	Advanta®, Palmaz®, S.M.A.R.T®, Fluency®
Sugiura *et al*., 2009 (18)	11	10/1	NR	4/5/2	11	3/7/1	Zenith®, Gore TAG®	Various
Baldwin *et al*., 2008 (19)	7	4/3	70	1/4/2	7	3/3/1	Gore TAG®	Fluency®, Luminex®, Wallstent®, Zilver, Biliary Express®
OhrlaNRer *et al*., 2008 (20)	4	NR	70	2/2/0	4	1/2/1	Zenith®, Gore TAG®	Luminex®, Advanta®, Zenith® TFLE®
Criado *et al*., 2007 (21)	8	NR	NR	NR	8	0/6/2	Talent®	Bare stents
Hiramoto *et al*., 2006 (22)	1	1/0	70	1/0/0	1	0/1/0	Gore TAG®	Fluency®
Larzon *et al*., 2005 (23)	2	2/0	73	2/0/0	2	0/2/0	Gore TAG®	Symphony®, Zilver®, Palmaz®
Total	124	74		28/61/19	136	25/60/51		

*An/Dis/other, Aneurysm/Dissection/other (type I endoleak, traumatic transection, penetrating ulcer, pseudoaneurysm); N, number; NR, not reported; Talent (Medtronic, Minneapolis, MN, USA) had aortic dissection, and 19 (17.5%) had other pathologies (type I endoleak, traumatic transection, penetrating ulcer, pseudoaneurysm).

Various aortic endoprosthesis (Zenith®, Gore®, Talent®, etc.) were used for the thoracic aorta and numerous variable bare-stents or covered stents were selected for chimney-grafts. A total of 136 chimney grafts were implanted: 25 to the IA, 60 to the LCCA and 51 to the LSA. In 104 patients a single chimney graft was implanted whereas in 10 patients two chimney grafts were implanted.

It is noteworthy that there was a remarkable heterogeneity among studies regarding the revascularization of the left subclavian artery; some patients were treated with transposition of the LSA to the carotid artery, or carotid-subclavian bypass, or even no surgical revascularization. However, all patients underwent a carotid-to-carotid bypass before the aortic stent-graft was placed in zone 0 and the chimney-graft in the IA. Thus, a total of 28 adjacent by-pass procedures were performed.

Technical success, endoleak rate, and CG patency

Primary technical success, defined as a complete chimney procedure, was achieved in 123/124 patients (99.2%). In the other patient, an infolding Viabahn® of the LCCA at the end of the procedure was detected, making it impossible to reline with another stent and thus an RCCA-LCCA bypass was performed. The overall endoleak rate was 18.5%; 13 patients (10.5%) developed a type I endoleak and 10 (8%) patients a type II endoleak. The majority of type I endoleaks resolved spontaneously or by coil embolization. In 5 patients with a type I endoleak angioplasty was performed, with another patient undergoing deployment of an additional aortic stent graft proximally in the ascending aorta to eliminate the endoleak. During a median follow-up period of 11.4 months (range, 0.87-20.1 months) all implanted chimney grafts remained patent.

Morbidity and mortality

Postoperatively 5 (4%) patients suffered a stroke. In addition, two patients developed paraplegia, one patient developed myocardial infarction, and another iliac hemorrhage. Therefore, the overall perioperative morbidity rate was 10.5%. Six patients (4.8%) died perioperatively: 1 died of lung cancer unrelated to chimney graft procedure and 2 died of stroke related to chimney graft deployment, whereas three more patients died due to undefined specific causes (*Table 2*).

Discussion

Treatment of aortic arch pathologies represents one of the greatest challenges in cardiothoracic surgery. So far there are four options:

(I) Open aortic arch reconstruction;

(II) Hybrid repair combining aortic arch debranching with stent-grafting;

(III) Endovascular repair with fenestrated endografts;

(IV) Endovascular repair with chimney grafts.

Our study aimed to review the results of the chimney-graft technique for the treatment of aortic arch pathologies or extensive aortic lesions in which the aortic arch is involved. The analysis included a total of 124 patients in whom 136 chimney grafts were deployed. Interestingly, the technical success rate was 99.2%, demonstrating the feasibility of the procedure, and a chimney graft patency of 100%, at median follow-up of 11.4 months, illustrating the midterm safety of aortic arch vessels perfusion. The perioperative mortality rate was 4.8%, the stroke rate was 4% while events of spinal cord ischemia were rare. This can be justified first by the fact that, in the chimney technique, there is no need for aortic cross-clamping which eliminates the spinal cord ischemia time, and second by the fact that, for arch aneurysms, the length of aortic coverage with the endograft is relatively short. In 23 cases an endoleak (13 cases of Type Ia) was observed. Recent data suggest that temporarily maintaining elective aneurysmal sac perfusion may reduce the risk of neurologic events after endovascular repair of thoracoabdominal aneurysms and this point could also justify the rare incidence of paraplegia (24).

Sizing is crucial in achieving technical success. An ideal radial force should be exerted from the aortic endograft so as not to compromise the CG while maintaining adequate wall apposition. In the "chimney" technique, excess oversizing is needed to facilitate the formation of channels lateral to the graft in order to accommodate the chimney grafts (5,25). Chimney grafts, however, induce large "gutters" along the main endograft which may cause a proximal type I endoleak, representing the Achilles heel of the technique (5,26). The risk of endoleaks increase with the number of CGs implanted. In a recent review of 93 patients with juxtarenal or complex abdominal aortic aneurysms, the type I endoleak rate was 7.0% among patients who received one CG and 15.6% among patients with two CGs (5). In the present analysis the majority of the patients (104/124)

Table 2 Overall outcomes of the eligible studies

Study	N of patients	Technical success	Endoleak (total/type I)	CG patency	Stroke	Overall morbidity	Mortality	Follow-up (months)
Shahverdyan *et al*., 2013 (6)	6	5	3/2	11	0	1	1	2.5
Samura *et al*., 2013 (7)	2	2	2/0	4	0	0	0	6
Zhu *et al*., 2013 (8)	34	34	5/5	34	0	1	0	16.3
Chang *et al*., 2013 (9)	1	1	0/0	1	0	0	0	12
Zhou *et al*., 2013 (10)	1	1	0/0	2	0	0	0	12
Vallejo *et al*., 2012 (11)	8	8	2/1	8	1	1	1	NR
Akchurin *et al*., 2012 (12)	10	10	0/0	10	0	0	0	6
Cires *et al*., 2011 (13)	9	9	1/1	9	1	2	1	5
Yoshida *et al*., 2011(14)	2	2	0/0	5	0	0	0	13.5
Shu *et al*., 2011 (15)	8	8	2/0	8	0	0	0	11.4
Feng *et al*., 2011(16)	1	1	0/0	1	0	0	0	12
Gehringhoff *et al*., 2011(17)	9	9	1/1	9	0	3	1	15
Sugiura *et al*., 2009 (18)	11	11	2/2	11	1	3	2	20.1
Baldwin *et al*., 2008 (19)	7	7	1/0	8	1	1	0	NR
Ohrlander *et al*., 2008 (20)	4	4	2/1	4	1	1	0	2.5
Criado *et al*., 2007 (21)	8	8	0/0	8	0	0	0	NR
Hiramoto *et al*., 2006 (22)	1	1	0/0	1	0	0	0	1
Larzon *et al*., 2005 (23)	2	2	2/0	2	0	0	0	0.87
Total	124	123/124 (99.2%)	23/13	136/136 (100%)	5/124 (4%)	13/124 (10.5%)	6/124 (4.8%)	Median 11.4 (range, 0.87-20.1)

N, number; CG, chimney graft; NR, not reported

received a single chimney graft whereas only 10 patients had two chimney grafts implanted; as such no further analysis regarding the risk of endoleak could be conducted.

While many techniques of open aortic arch reconstruction have evolved during the last three decades aimed at protecting the brain, stroke still remains a major complication of the procedure. Some of the techniques aim to suppress the metabolic demands of the brain while others aim to maintain the metabolic supply during systemic circulatory arrest. Currently, there are three basic strategies for an open arch reconstruction (1), including deep hypothermic circulatory arrest, hypothermia combined with retrograde cerebral perfusion, and moderate hypothermia with selective antegrade cerebral perfusion as proposed by Kazui (27). All three strategies have shown significant reduction of stroke when performed in centers of excellence and by experienced aortic surgeons. However, the technique that seems to demonstrate experimental and clinical superiority is selective antegrade cerebral perfusion (28).

Lately, several studies have described the use of a combined endovascular and open surgical approach for the treatment of arch pathologies. Hybrid repair of aortic arch pathologies has been considered a less invasive method; as a result, it presents an appealing option for high-risk patients who are unable to withstand an open repair. These "hybrid techniques" involve aortic arch debranching, thereby creating a proximal landing zone of adequate length, followed by stenting over the aortic arch (2,29,30). In a recent meta-analysis evaluating the hybrid repair of aortic arch pathologies the 30-day mortality rate for the "debranching" procedures was 11.9%, with a stroke rate of 7.6% and spinal cord ischemia rate of 3.6%. Cardiac complications occurred in 6.0% and renal insufficiency requiring permanent hemodialysis occurred in 5.7% of patients. The authors concluded that hybrid arch techniques provide a safe alternative to open repair with acceptable short- and mid-term results, although the stroke and mortality rates remain noteworthy (2).

Branched and fenestrated stent-grafts have been developed to treat aortic arch disease (3,31,32). *In situ* fenestration of aortic stent grafts is an alternative that eliminates the need for preoperative custom tailoring and offers a bailout option (33). However, these techniques require extensive manipulation in the aortic arch, which may cause high rates of adverse neurological events. Short- and mid-term data regarding the use of precurved fenestrated endografts appear encouraging. The results of a recent study evaluating fenestrated endograft treatment for thoracic aortic aneurysms and aortic dissection extended to the aortic arch showed that these devices are both safe and effective in carefully selected patients (3,31). In this study, 383 patients were treated with a precurved fenestrated endograft. The endografts were fabricated according to preoperative 3-dimensional computed tomographic images. The technical success rate was 95.8%. The 30-day mortality was 1.6%, while cerebrovascular accident occurred in 1.8% and permanent paralysis in 0.8%. Factors such as the inherent delay in device manufacturing, the high degree of planning and the cost are considerable limitations for the wider applications of the technique.

The outcome of open surgical reconstruction of the aortic arch is very inconsistent in the literature even when considering reports from centers of excellence. The stroke rate ranges from 2% to 13% and the perioperative mortality ranges from 6.2% to 22% (34,35). The same inconsistency is noticed in the outcome of hybrid procedures as well. Stroke rates range from 0% to as high as 13% and the mortality rates range from 0 to 16% (36,37). Heterogeneous results also appeared in our analysis reporting total endovascular aortic arch exclusion with the use of chimneys. This is expected as the technique is newer and the case series have limited number of patients. Stroke rates ranged from 0 to 25.0% and mortality rates ranged from 0 to 18.2%.

The heterogeneity of the studies mentioned above makes the comparison of the various techniques difficult. In most studies the patients were not treated for the same disease. Some of them had aneurysmal degeneration of the aorta, while others had dissection or other pathologies. This mirrors the heterogeneity of the treated patients in terms of age and related comorbidities as well. Moreover, many centers that utilized hybrid or total endovascular techniques selected patients who were unfit or poor candidates for surgery. All these selection biases make comparison hazardous.

Conclusions

The "chimney" technique is a method that requires advanced endovascular skills. Endovascular aortic arch repair with chimney grafts is associated with a lower mortality rate compared to totally open and hybrid reconstruction. However, the stroke rate remains noteworthy. The technique has acceptable short term results. As there are no available longterm data, it should be approached with a skeptical view and a reasonable hesitation for a wide embracement of the method. Compared to fenestrated it has the advantage of avoiding the delay in device manufacturing and the high cost. Long-term data and larger series are needed to determine the safety and efficacy of this technique.

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