Original Article

Long-term outcomes of balloon-expandable bare stent as chimney stent in thoracic endovascular aortic repair for supra-aortic branches reconstruction

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Background: To report the long-term outcomes of balloon-expandable bare stent (BEBS) as chimney stent (CS) in thoracic endovascular aortic repair (TEVAR) for supra-aortic branches reconstruction.

Methods: A total of 33 patients with thoracic aortic diseases underwent TEVAR using BEBSs as CSs for supra-aortic branches reconstruction in our center from 2010 to 2015. The demographics and procedural details were prospectively collected and retrospectively reviewed. All patients were followed up at 1, 3, 6 months and every 1 year thereafter. Postoperative complications and long-term outcomes were recorded.

Results: The technical success rate was 100%. A total of 36 BEBSs were utilized as CSs to reconstruct the supra-aortic branches during TEVAR. The rate of immediate endoleak was 42.4% (14/33), including 12 (36.4%) type Ia endoleaks and 2 (6.1%) type II endoleaks. Two of type Ia endoleaks were managed by balloon dilation and disappeared, while the rest were left with close follow-up. Two type II endoleaks were embolized by coils and excluded by a plug, respectively. One patient (3.0%) died 2 days after the procedure due to the acute rupture of aortic dissection. The mean follow-up time was 61.8 (ranged from 12 to 102) months. The unmanaged 10 type Ia endoleaks were closely observed during the follow-up, of which 7 disappeared at 1 year and 1 disappeared at 2 years. The rest 2 type Ia endoleaks existed without further dilation of the aorta. One patient (3.0%) was re-intervened for the increased false lumen due to the distal residual tears. The long-term mortality was 9.1% (3/33). All CSs kept patent till the end of follow-up. No other complications were found.

Conclusions: The balloon-expandable stent (BES) is a feasible choice as CS for supra-aortic branches reconstruction with long-term patency during TEVAR. However, BEBS may be related to a higher rate of early endoleak.

Keywords: Chimney stent (CS); balloon-expandable bare stent (BEBS); supra-aortic branch; thoracic endovascular aortic repair (TEVAR)

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Introduction

Thoracic endovascular aortic repair (TEVAR) is characterized with less invasion and promising prognosis, and the published European Society for Vascular Surgery (ESVS) guideline has recommended TEVAR as the first-line option when the aortic repair is indicated (1). Despite emerging as a prevalent modality, TEVAR may be limited under some situations due to the inadequate proximal landing zone. Multiple solutions have been put forward to extend the proximal landing zone, including hybrid approach, fenestrated/branched endografts and chimney technique. Hybrid approach, in which aortic arch debranching is in conjunction with endovascular aortic repair, demonstrates high early- and long-term mortality (2,3). Fenestrated/branched endografts are mostly limited in elective settings since they must be customized with high cost and long waiting time (4,5). Chimney technique has become an availability at the emergent settings, in which a bare or covered stent is deployed in the supra-aortic branch with part paralleled with the endograft in the aorta.

Type Ia endoleak has been the major concern of chimney technique because of the gutter between the main endograft and chimney stent (CS) (6,7). Several factors about stents were considered related to the incidence of type Ia endoleak, such as the option of self-expandable stent or balloon-expandable stent (BES), covered or bare stent and so on. Generally, BES were used more often in supra-aortic branches reconstruction because of its greater radial strength (8-10). Furthermore, the correlation of covered or bare BES with endoleak has not been specifically discussed. Therefore, a cohort of patients who underwent TEVAR with supra-aortic branches reconstruction using balloon-expandable bare stent (BEBS) was followed up in terms of endoleak and other complications in this study. The present study will provide evidence to chimney technique using BEBS for supra-aortic branches reconstruction.

Methods

From February 2010 to April 2015, chimney technique was applied to extend the proximal landing zone in 40 patients, who received TEVAR for thoracic aortic dilation diseases in our center. Of them, 33 patients were implanted BEBS as CSs. Data including demographics, peri-operative complications and follow-up consequences were prospectively collected and retrospectively analyzed. This study has received the approval of the institutional research ethics committee review board. Written informed consents were obtained from all patients. Of them, planned chimney technique was carried out for 32 patients while 1 was applied as a bailout approach for the intraoperative inadvertent coverage of the left common carotid artery (LCCA). The diseases treated included 18 Stanford type B aortic dissections (TBAD), 3 type Ia endoleaks after initial TEVAR, 10 thoracic aortic aneurysms (TAA), and 2 pseudoaneurysms. The mean age was 61±14 (ranged from 34 to 86) years old, and the proportion of male was 87.9% (29/33). The comorbidities and other demographics were listed in *Table 1*.

Indications for TEVAR with chimney technique included: the proximal landing zone was shorter than 1.5 cm; patients with high risk were not suitable for hybrid surgery or bypass surgery; intraoperative bailout for the unintentional coverage of the vital aortic arch branches.

All patients were treated with general anesthesia in a hybrid suite. Supra-aortic branches as well as the dominant vertebral artery were evaluated through preoperative enhanced computed tomography angiogram (CTA). After the systemic heparinization, the thoracic aorta endograft was delivered from the common femoral artery access. CSs implanted in the left subclavian artery (LSA) and innominate artery (IA) were introduced from the left and right brachial artery access with cut down exposing, respectively. Whereas the CS implanted in the LCCA was delivered from the LCCA access. After a 5 F pigtail catheter (Cordis Corporation, Miami Lakes, FL, USA) advanced through the right femoral artery sheath to the thoracic ascending aorta, the angiography was performed to determine the location of the proximal end of the aortic dilatation lesion and the orifice of the supra-arch branches. In addition, the cephalic artery angiography was also performed to confirm which side of the vertebra artery was the dominant one. LSA originating from the dominant vertebral artery was implanted with a CS. The main endograft was released firstly, then the BES was following deployed. CS was placed with the proximal end extending 5–10 mm over the aorta endograft, and with the distal end approximate 20 mm extending into the supra-arch branches. The completion angiogram was performed to confirm the position and shape of stents as well as immediate endoleaks.

All patients were followed up at 1, 3, 6 months and every 1 year thereafter. The CTA was performed to evaluate the endoleaks and the patency of CS during the follow-up session.

Table 1 The summary of demographics

Variable	TBAD (n=21)	TAA (n=10)	Pseudoaneurysms (n=2)	Total/mean
Age				61±14
Gender (M/F)	17/4	10/0	2/0	29/4
Smoking	12	7	1	20
Comorbidities				
Hypertension	5	2	–	7
CHD	4	2	–	6
CRI	5	1	–	6
DM	1	1	–	2
Hyperlipidemia	9	3	–	12
Marfan syndrome	1	–	–	1
History of TEVAR	3	–	–	3

TBAD, type B aortic dissection; TAA, thoracic aortic aneurysm; M, male; F, female; CHD, coronary heart disease; CRI, chronic renal insufficiency; DM, diabetic mellitus; TEVAR, thoracic endovascular aortic repair.

Results

There were 33 patients undergoing chimney technique in TEVAR to preserve the flow of supra-aortic branches. The technical success rate was 100%. All procedures were elective and one LCCA was reconstructed by CS due to the intraoperative unintentional coverage. Single LCCA in 22 cases and single LSA in 8 cases were reconstructed (*Figure 1*). LCCA and LSA were stented simultaneously for 1 patient while LCCA and IA were stented simultaneously for 2 patients. Thoracic aorta endografts used in our group included 14 of Zenith endografts (Cook Inc., Bloomington, Ind, USA), 10 of Valiant thoracic stent grafts (Medtronic Vascular, Santa Rosa, Calif, USA), 5 of Valiant Captivia stent grafts (Medtronic Vascular, Santa Rosa, Calif, USA), 3 of Ankura thoracic stent grafts (Lifetech, Shenzhen, China), and 1 of Relay thoracic stent graft (Bolton Medical, Sunrise, Fla, USA). CSs used in this group were all BEBSs, including 25 of Express stents (Boston Scientific Corporation, Natick, MA, USA), 9 of Scuba stents (Medtronic, Minneapolis, MN, USA), 1 of Genesis stent (Cordis, J&J Medical, Miami Lakes, Florida, USA), and 1 of Omnilink stent (Abbott Corp., Santa Clara, CA, USA).

All CSs were expanded successfully by the balloon dilation with accurate position during the procedure. Fourteen immediate endoleaks (42.4%, 14/33) were found in the completion angiogram, including 12 (36.4%) type Ia endoleaks and 2 (6.1%) type II endoleaks. Two type II endoleaks appeared in two patients whose LCCAs were reconstructed, and the endoleaks both originated from LSA. One LSA was embolized by coils (Nester, Cook, Bloomington, USA) from the left brachial artery access, and the other LSA was excluded by a Plug (Lifetech, Shenzhen, China). For patients with type Ia endoleaks, 2 of them were managed by the balloon dilation and the endoleaks disappeared; the rest had been left with close surveillance. No other complications were found in the completion angiogram. One patient (3.0%) died 2 days after the operation owing to the acute rupture of aortic dissection.

The mean follow-up time was 61.8 (ranged from 12 to 102) months, and the follow-up rate was 84.8% (28/33). The unmanaged 10 type Ia endoleaks were closely observed during the follow-up, of which 7 disappeared at 1 year and 1 disappeared at 2 years. The rest 2 patients with aortic dissections still had endoleaks but without further enlargement. During the follow-up, one patient was re-intervened for the increased false lumen due to the distal residual tears. This patient had LCCA reconstructed by chimney technique previously and another C-TAG stent graft (W.L. Gore and Assoc. Inc., Flagstaff, AZ, USA) was placed next to the first endograft, with the distal end landed above the celiac orifice (*Figure 2*). The long-term mortality was 9.1% (3/33). One patient, who had LCCA and LSA reconstructed simultaneously, died of cardiac infarction at 4 years. One died of renal failure at 6 years and the rest one died of unknown reason at 5 years.

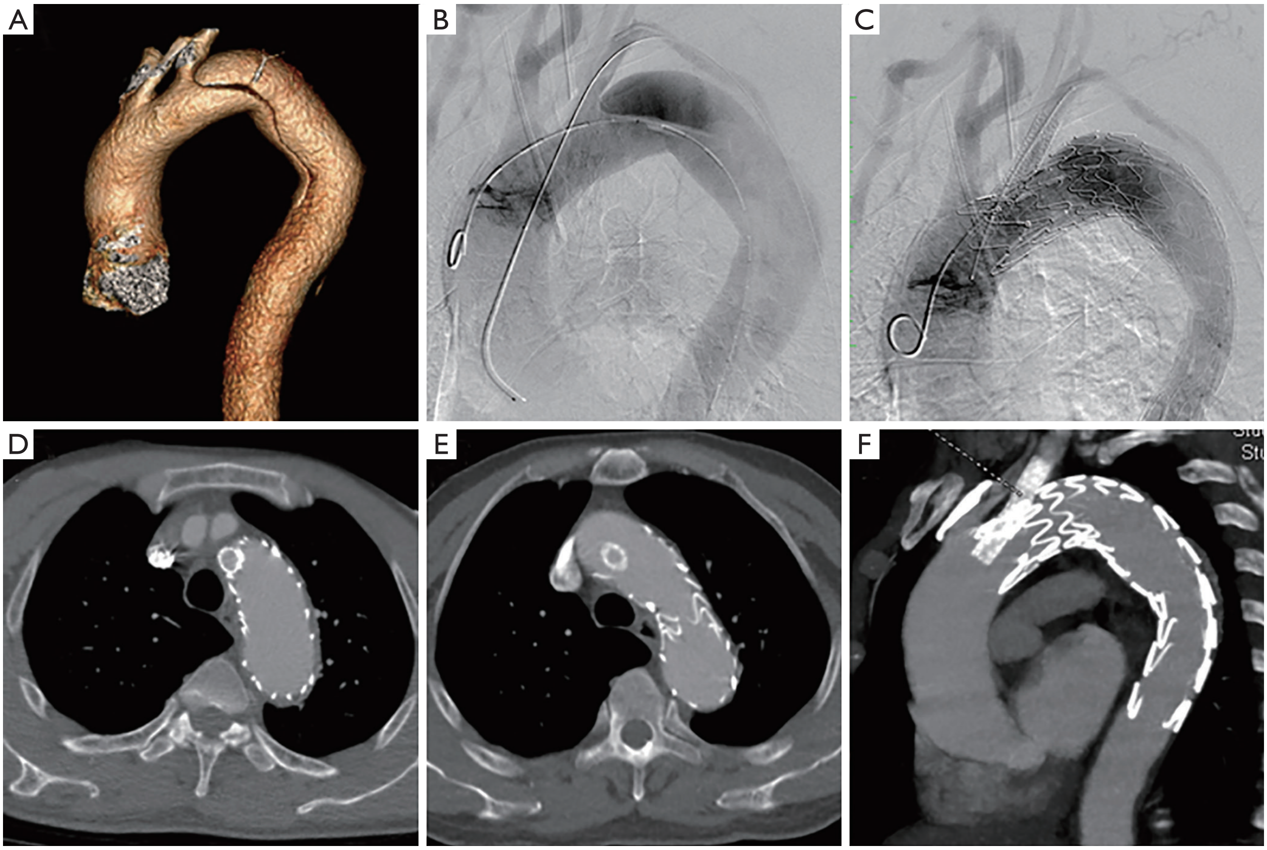

Figure 1 One patient underwent TEVAR with concomitant revascularizaiton of LSA using the chimney stent. (A) Preoperative three-dimensional reconstruction CTA showed an aortic dissection of which the tear was close to the LSA orifice; (B) intraoperative angiogram; (C) the completion angiogram showed that one chimney stent was placed in the LSA without immediate endoleak; (D) follow-up CTA at 1 year showed the patent chimney stent with no endoleak; (E,F) follow-up CTA at 3 years showed the patent chimney stent with no endoleak. CTA, computed tomography angiogram; LSA, left subclavian artery.

All CSs kept patent during the follow-up. One patient with sole LCCA reconstructed complained about coldness of the left upper limb without stent compression, and the symptom was relieved by medicine. No other complications, such as late endoleak, stroke, stent occlusion or migration, and so on, were found during the follow-up (*Table 2*).

Discussion

Multiple approaches have been developed to extend the proximal landing zone for TEVAR. Chimney technique is effective to extend the proximal landing zone, especially in the emergent settings. This technique is also utilized in elective procedures increasingly because of its less demands on the devices and technology.

Compared with the hybrid surgery, the incidence of stroke is lower after the chimney (2.6% *vs.* 7.6%) (9). Besides, the calculated 30-day mortality also seemed a little bit lower for the chimney (7.9% *vs.* 11.9%) in the meta-analysis by Ahmad *et al.* and Moulakakis *et al.* (6,9). Fenestrated/branched stents are also developed to preserve the blood flow of supra-aortic branches with lower procedural mortality (2.4%), as well as low incidence of type I endoleak (11). However, this technique demands highly on the technology and requires custom-made stents, which are costly and often time consuming (12,13). Therefore, their applications have been restrained in emergent settings as well as occasions where the aorta is tortuous or the access is compromised. Chimney technique is initially developed for emergent or accidental situations, where a CS can be implanted in branch from the peripheral access. It has also been used in elective settings due to the easily

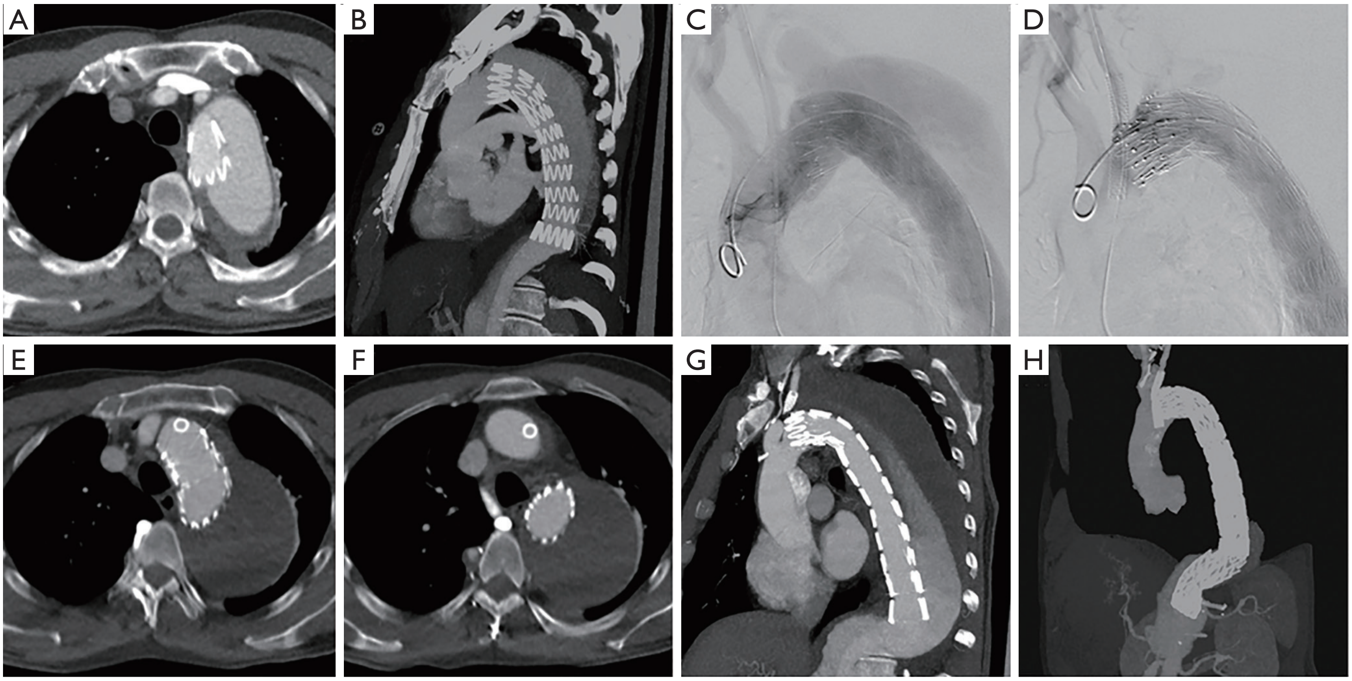

Figure 2 One patient was re-intervened for the increased false lumen after the previous TEVAR with the LCCA revascularized using the chimney stent. (A,B) Preoperative CTA showed a type Ia endoleak of an aortic dissection after initial TEVAR; (C) intraoperative angiogram; (D) the completion angiogram showed that the endoleak still existed after the placement of an aortic endograft and a chimney stent in LCCA; (E) follow-up CTA at 1 year showed the endoleak disappeared; (F,G) follow-up CTA at 5 years showed the patent chimney stent and disappeared proximal endoleak, but increased false lumen due to distal residual tears; (H) follow-up CTA after the placement of an additional aortic endograft to exclude the distal tear above the celiac orifice. No sign of the endoleak was showed. CTA, computed tomography angiogram; TEVAR, thoracic endovascular aortic repair; LCCA, left common carotid artery.

achievable devices and comparable results. Nevertheless, type I endoleak is the major concern for CS due to the gutter, which is the channel between the CS and the aortic endograft and difficult to seal. Several factors of CSs have been considered related to the rate of endoleak.

Firstly, the self-expandable stent is more flexible and causes less vascular trauma, whereas the BES is characterized with more radial strength and facilitates the accurate placement. The endoleak and other complications about self-expandable and BES were nearly the same with 20% and 16% by the meta-analysis of Hogendoorn *et al.* (8). But this result required further investigation due to its insufficient number in each type of stents for reliable comparisons. In contrast, the systematic study of chimney technique in supra-aortic branches reconstruction in China by Zhao *et al.* demonstrated that the balloon-expandable bare CSs were associated with good early-term outcomes and a lower rate of endoleaks (14). In addition, the PERICLES registry, which compared balloon-expandable covered stent (BECS) with other non-BECS, showed improved survival of BECS group though with a higher risk of type Ia endoleak in endovascular repair of juxtarenal and pararenal aortic diseases. This study suggested the preference of BES for chimney (10). What's more, the technical success of self-expandable stent might be lower than the BES due to its less radial force. As for the high blood flow within the aorta arch and pulsatile thoracic aorta, the self-expandable stents might be compressed by the endograft, which can be bailed out by BESs (15). Therefore, BES might be preferred for supra-arch branches chimney. Nevertheless, more studies are still needed to compare the effectiveness of these two kinds of stents for supra-arch branches chimney. All CSs used in this study were BEBSs for their greater radial force, to improve the technical success and long-term outcomes.

Secondly, another related factor concerned is whether the covered or bared BES is related to less endoleak. We have retrospectively analyzed a cohort of patients who all

Table 2 The summary of procedural details and follow-up consequences

Chimney vessels	LCCA (%)	LSA (%)	LCCA + LSA (%)	LCCA + IA (%)	Total (%)
Patient number	22 (66.7)	8 (24.2)	1 (3.0)	2 (6.1)	33
Emergent	1	–	–	–	1 (3.0)
Aorta endograft					33
Zenith	11	2	–	1	14 (42.4)
Valiant	6	2	1	1	10 (30.0)
Captivia	3	2	–	–	5 (15.2)
Ankura	1	2	–	–	3 (9.1)
Relay	1	–	–	–	1 (3.0)
Chimney stent					36
Express	15	5	1	4	25 (69.4)
Scuba	5	3	1	–	9 (25.0)
Genesis	1	–	–	–	1 (2.8)
Omnilink	1	–	–	–	1 (2.8)
Complication					
Ia endoleak	9 (40.9)	2 (25.0)	0	1 (50.0)	12 (36.4)
II endoleak	2 (9.1)	0	0	0	2 (6.1)
Compression	0	0	0	0	0
Perioperative mortality	1 (4.5)	0	0	0	1 (3.0)
Follow-up					
Mortality	2 (9.1)	0	1 (100.0)	0	3 (9.1)
Ia endoleak	2 (9.1)	0	0	0	2 (6.1)
Compression	0	0	0	0	0
Reintervention	1 (4.5)	0	0	0	1 (3.0)

LCCA, left common carotid artery; LSA, left subclavian artery; IA, innominate artery.

have BEBS to extend the proximal landing zone. The rate of immediate endoleak reached to 42.5% (14/33), including 12 type Ia endoleaks and 2 type II endoleaks. This rate has apparently overpassed that of the overall stents in the meta-analysis 9.4% by Ahmad *et al.*, and 11% by Lindblad *et al.* (6,7). What's more, a single-center study by Zhu *et al.* demonstrated a rate of immediate type I endoleak as 15% (5/34), and the bare chimney-stent repair had been used in all five cases. In this study, 25 (74%) balloon-expandable and 9 (26%) self-expandable stents were used, of which 7 (21%) were covered stents and 27 (79%) were bare stents (15). In another single-center study of double chimney technique for aortic arch diseases, the rate of immediate endoleak reached to 13% (3/23), all of which utilized were covered CSs (16). Based on our results and other studies, bare stents might be related to a higher rate of endoleak when compared with the rate of overall stents used (7,8,17,18). This might result from the extra blood flow through the bare stent mesh besides that in the gutter. However, great heterogeneity existed among these different studies and no one has intentionally compared the rate of endoleak between bare and covered BES. Thus, further investigations are needed to elucidate the correlation of bare or covered BES with the incidence of endoleak. On the other hand, few covered stents have been developed intended for CSs. As a result, the radial force, shape, length etc. of stents utilized now might not fulfill the best clinical requirement. The short and long-term patency of CS was promising in our study, so was the rate of patency reported in other studies (13,15,17,19,20).

In conclusion, when the chimney technique is chosen for supra-aortic branches reconstruction during TEVAR, the BES stent may be more suitable with long-term patency, while the BEBS may be related to a higher incidence of early endoleak.

Limitations

There are two main limitations in this study. Firstly, it is a retrospective study only including patients who received BEBSs as CSs. The outcomes of other covered stents as CSs therapy cannot be compared. Secondly, the number of patients enrolled was only thirty-four. More cases undergoing TEVAR combined with chimney technique using different kinds of chimney stents in the future are required to be followed up to compare the clinical outcomes. Therefore, the selection of stents for chimney technique can be based on the evidence.

Conclusions

The BES may be more suitable for supra-aortic branches reconstruction with long-term patency when the chimney technique is employed during TEVAR. However, BEBS may be related to a higher rate of early endoleak.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The study was approved by the institutional research ethics committee review board and written informed consents were obtained from all patients.

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