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CLINICAL INVESTIGATION ARTERIAL INTERVENTIONS

Comparison of Chimney Technique and Single-Branched Stent Graft for Treating Patients with Type B Aortic Dissections that Involved the Left Subclavian Artery

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Abstract
Objective To compare the short-term efficiency of two different endovascular repairs for type B aortic dissection involving the left subclavian artery.
Methods From February 2013 to March 2016, a cohort of 43 patients with TBADs involving the LSA underwent thoracic endovascular aortic repair (TEVAR) in two departments, consisting of 22 (Group A) with chimney grafts (CGs) and 21 (Group B) with single-branched stent graft (SBSG). Results of the two groups in perioperative and follow-up period ($\geq$ 3 months) were comparatively analyzed, especially on aortic remodeling.
Results Endoluminal repair of the two groups was successfully carried out. The median follow-up period was 19 months (range, 3–43 months) in Group A and 12 months in Group B (range, 6–32 months). During the TEVAR, one CG compression occurred in Group A and one type I endoleak in Group B. During follow-up, four complications occurred in Group A (two CGs occlusion, one type I endoleak and one death from dissecting aneurysm rupture), compared with two occurred in Group B (one sidearm graft twist and one death from myocardial infarction). Complete thrombosis of the false lumen (FL) in thoracic aorta was revealed in 83.3% (15/18) cases in Group A and 89.5% (17/19) in Group B. Partial thrombosis of the FL was revealed in 16.7% (3/18) cases in Group A and 10.5% (2/19) in Group B. In the abdominal aorta, complete thrombosis of the FL was noted in 23.1% (3/13) cases in Group A and 36.4% (4/11) in Group B. Partial thrombosis of the FL was revealed in 76.9% (10/13) cases in Group A and 63.6% (7/11) in Group B. Significant true lumen re-expansion and false lumen regression were observed in different levels of the descending aorta by computed tomography angiography (CTA) in both Groups A and B ($P < 0.05$). No significant diametric changes of abdominal aorta were found during follow-up in both groups.
Conclusions For patients with TBADs involving the LSA, the chimney technique and the SBSG revealed comparable results. Further evaluation of more patients with longer follow-up is needed to substantiate these results.

Keywords Type B aortic dissection · Thoracic endovascular aortic repair · Chimney technique · Single-branched stent graft · Left subclavian artery

Abbreviations

LSA	Left subclavian artery
TBADs	Type B aortic dissection
TEVAR	Thoracic endovascular aortic repair
CGs	Chimney grafts

Honggang Zhang and He Huang have contributed to this work equally and shared first authorship.

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SBSG	Single-branched stent graft
FL	False lumen
TL	True lumen
CTA	Computed tomography angiography
CFA	Common femoral artery

Introduction

Since first described by Dake et al. [1] and Nienaber et al. [2], TEVAR has been developed as a safe and effective treatment for aortic dissection [1–3]. A lot of studies reported TBADs treated with TEVAR with favorable mid-term and long-term results [4, 5]. For traditional TEVAR, a minimum of 15 mm of normal aortic wall is needed for adequate sealing of the stent graft [6, 7]. Intentional coverage of LSA without reconstruction is often performed to obtain good fixation of stent grafts for patients with an inadequate proximal sealing zone. However, coverage of LSA may cause serious complications, such as stroke and upper extremity ischemia [8, 9]. Chimney technique and SBSG are the solutions to this dilemma. Both techniques can extend the sealing zone while preserving blood flow of LSA. There are growing reports on CGs and SBSG but no study compares these two methods, especially on aortic remodeling [10–13]. In this study, we summarized our initial experience of TEVAR with CGs and SBSG and evaluate the perioperative and follow-up results for TBADs involving the LSA.

Methods

Patients

This study was initiated by the Vascular Surgery Department of Nanjing Drum Tower Hospital and the Vascular Surgery Department of the First Affiliated Hospital of Nanjing Medical University. Informed signed consents were obtained from each patient involved in this study, and institutional ethics committee approval was obtained before initiation of the study. From February 2013 to March 2016, a total of 43 patients with TBADs involving the LSA underwent TEVAR in the two departments. All the patients were diagnosed with an insufficient proximal landing zone (the entry tear located < 15 mm distal to the LSA), which was confirmed by the CTA (Fig. 1A). The diameters of LSA, the primary entrance locations and the distance between LSA and left common carotid were also evaluated to determine the sizes of chimney grafts and branched stent grafts. These patients were considered unsuitable or unwilling for open surgery, and they all agreed to undergo TEVAR with LSA reconstruction. Elective endoluminal repair was considered when no evidence of ongoing intractable chest pain, rupture, refractory hypertension, unstable hemodynamics or significant organ ischemia occurred at the time of admission. Otherwise, emergency TEVAR was performed. These patients were divided into two groups according to the technique used for LSA reconstruction, including 22 patients in the chimney group (Group A) and 21 in the SBSG group (Group B). In a previous article, we had reported the early results of a series of 27 patients with TBAD treated with the chimney technique [14]. The cases of endografts deployed in zone 2 were included in this study, and cases of endografts deployed in zone 0 and 1 were excluded. When the TBADs had an aneurysm close to the LSA, or the entry tears were very close to the LSA orifice, especially on the outer curvature of the arch, chimney grafts were not chosen to avoid risks of endoleak. Patients' characteristics are listed in Table 1.

TEVAR Procedure Group A

All endovascular procedures were performed in a hybrid interventional suite with the patients under general anesthesia. The common femoral artery (CFA) was exposed through a small incision, and a pigtail catheter was inserted via the CFA puncture under the guidance of appropriate wires. After aortography, the pigtail catheter was replaced by a super-stiff guidewire. The CG was delivered using a 7F sheath after puncturing the left brachial artery. A pigtail catheter was sent into the ascending aorta along with a guidewire via the sheath. The relative positions of super-stiff wire for aortic endograft and guidewire for CG were adjusted in order to avoid endoleak as described in our previous publication [14]. The CG was delivered into the planned position along with the super-stiff wire but was not deployed. After the aortic endograft was successfully released, the CG was quickly deployed parallel to the main aortic stent graft, with 1 cm protruding proximally. In order to prevent stent graft-induced distal dissections, tapered stent grafts (usually 8 mm in taper) or distal restrictive stent grafts were used when distal oversizing (between the distal size of stent graft and the distal size of true lumen) $> 20\%$ [15]. Complete ascending aortic angiogram was performed to evaluate the immediate results (Fig. 1B).

Group B

General anesthesia was administered in all cases. The left brachial artery was exposed and cannulated with a short 8F sheath. Then, a 4F long catheter was advanced toward the

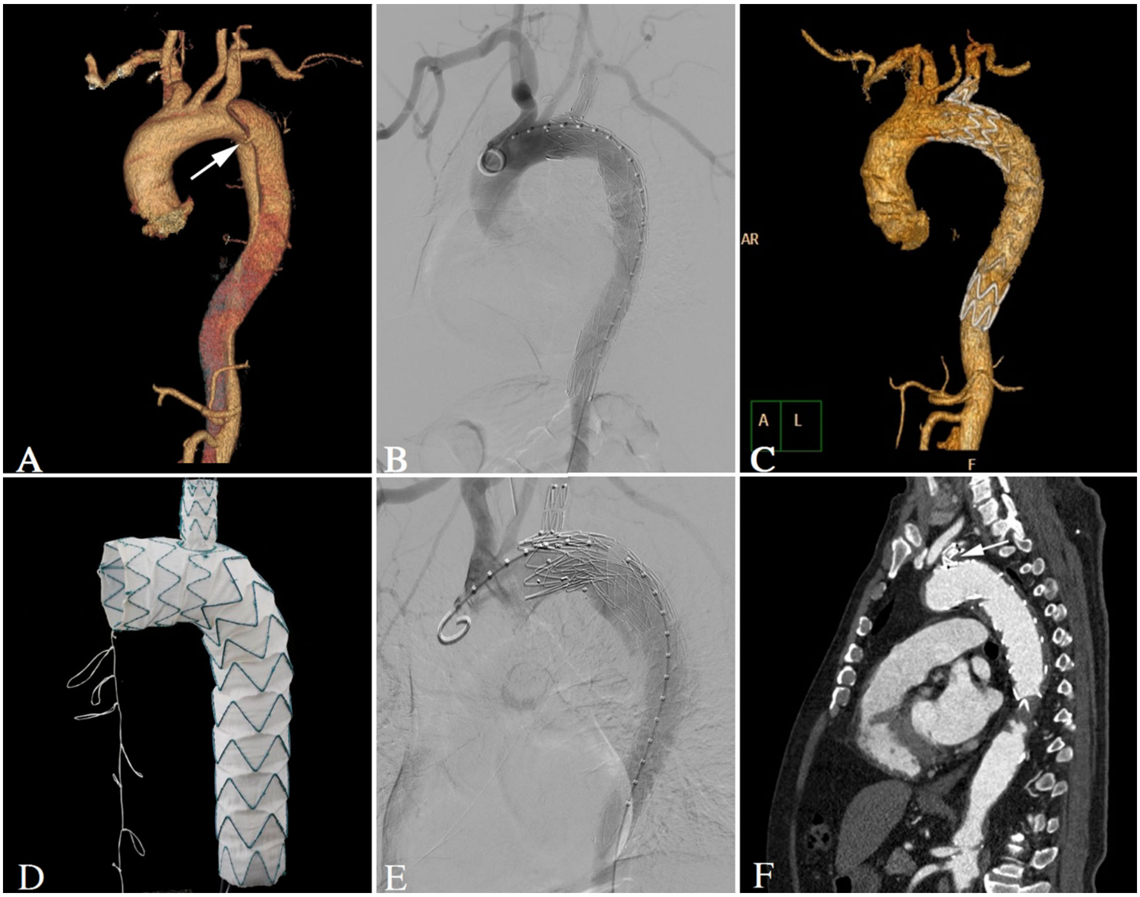

Fig. 1 Imaging of a patient using single-branched stent graft. **A** 3-D reconstruction showing the location of the primary tear (white arrow). **B** Postoperative aortogram demonstrating complete seal of the entry tear. **C** 3-D reconstruction showing good patency of the stent graft during follow-up. **D** The factual picture of the single-branched stent graft. It has a unibody structure, and no bare stent is at the proximal end of main graft. **E** Final aortogram of a patient with type Ia endoleak. After balloon dilatation and deployment of another stent graft, the endoleak still existed. **F** Sagittal plane of the patient with a twisty sidearm graft. The white arrow showing the tortuous side branched stent

Table 1 Patient characteristics

Variables	Group A No (%) or mean ± SD	Group B No (%) or mean ± SD	*P* value
Patient total	22	21	
Age (year)	56 ± 12.4	64.3 ± 12.2	< 0.01
Sex			
Male	18 (81.8)	15 (71.4)	< 0.05
Female	4 (18.2)	6 (28.6)	
Hypertension	18 (81.8)	16 (76.2)	> 0.05
Diabetes	3 (14.3)	1 (4.8)	< 0.05
CAD	2 (9.1)	4 (19.0)	< 0.05
Renal insufficiency	1 (4.5)	3 (14.3)	< 0.05
Previous CVA	3 (13.6)	2 (9.5)	> 0.05
Previous aortic repair	3 (13.6)	2 (9.5)	> 0.05
Tobacco abuse	3 (13.6)	2 (9.5)	> 0.05
Phase of TBADs			
Acute/subacute/chronic	15/5/2	6/13/2	< 0.01

CAD coronary artery disease, *CVA* cerebrovascular accident, *SD* standard deviation ascending aorta with a guidewire via the sheath. After a cutdown was performed over the femoral artery, the catheter was advanced to the femoral artery and taken out from the incision site. The guidewire was then withdrawn, leaving the 4F catheter as the traction conduit, through which the traction wire of the branch section of the stent graft was exited and the branch section could be consequently pulled into the LSA. The traction wire of the branch section was advanced into the traction conduit and taken out from the left brachial artery; meanwhile, the SBSG and delivery system was advanced into the descending aorta over a super-stiff guidewire. The main body was deployed into the target position in the arch, and subsequently the branch section was released by withdrawing the traction wire through the traction conduit. Final angiogram was performed to evaluate the entry tear exclusion and the LSA patency. These steps had been summarized in an image in our previous study (Fig. 2) [16].

In both groups, primary technical success was defined as the instant postoperative aortogram demonstrating successful exclusion of the entry tear, preserved LSA patency and absence of endoleak.

Follow-Up

Follow-up was planned at 3 months, 6 months, 12 months and annually thereafter, including a physical examination, a CTA examination of whole aorta (Fig. 1C) and an assessment for adverse clinical and device-related events. The measurements of aorta included diameters of true lumen (TL), FL and the whole aorta at the LSA ostium level (Level A), the tracheal carina level (Level B), the diaphragmatic level (Level C) and the renal arterial level (Level D). CTA images were transferred to a workstation

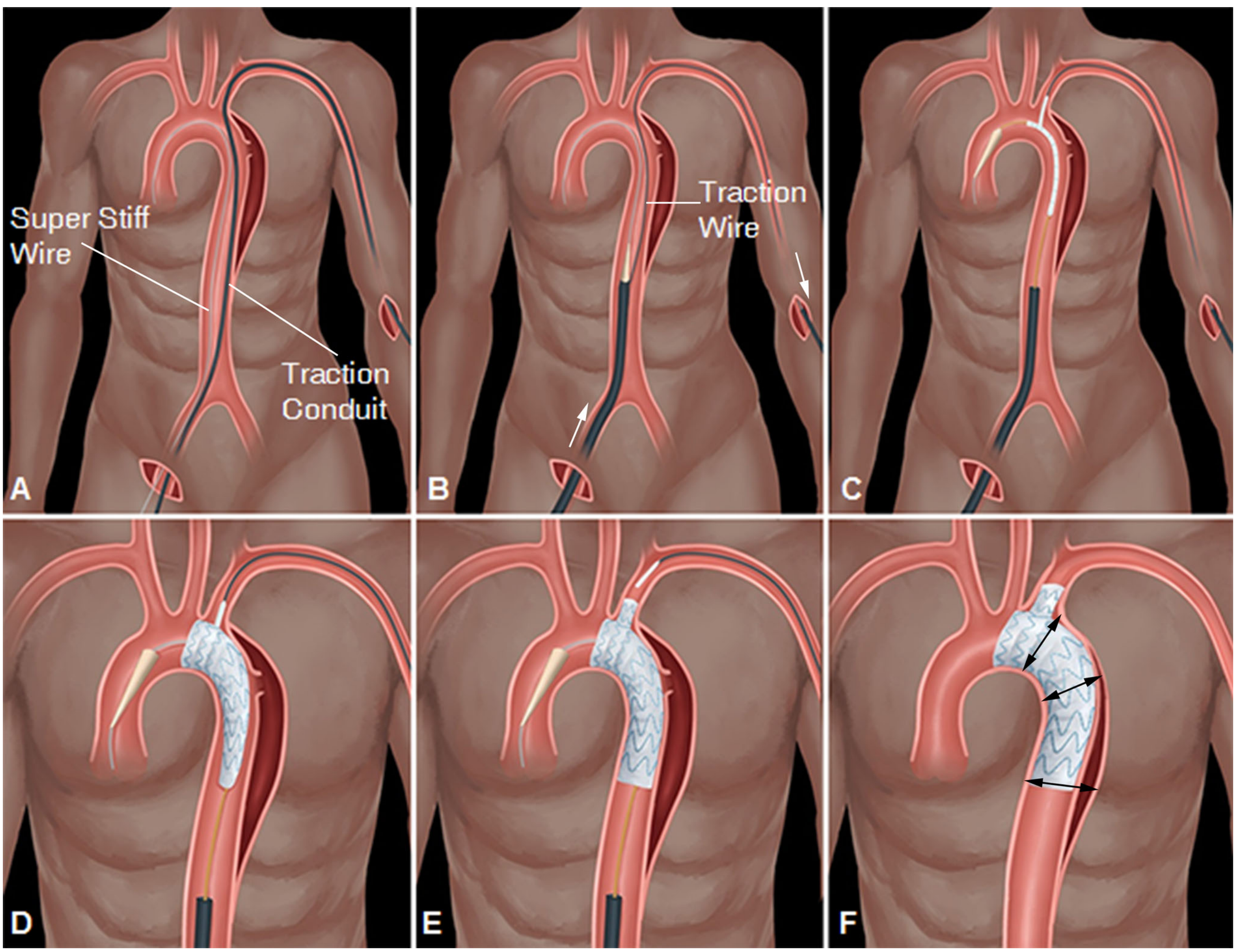

Fig. 2 Endoluminal repair with the use of single-branched stent graft. **A** Establishing the traction conduit. **B** Advancing the stent graft into the descending aorta and simultaneously withdrawing the traction wire of the branch section. **C** Advancing the stent graft to the target site. **D** Deploying the main body of Castor. **E** Deploying the branch section. **F** Three levels measured in our previous study [16]

and analyzed using OsiriX (Version 8.0.1; OsiriX Foundation, Geneva).

Statistical Analysis

SPSS 21 (SPSS, Inc., Chicago, IL, USA) was used for statistical analysis. Categorical variables were presented as numbers and proportions and were analyzed using Chi-square or Fisher's exact tests, as appropriate. Continuous variables were presented as means ± standard deviations. Diameters were compared using a two-sided paired-sample t test. A P value < 0.05 was considered significant.

Results

Patient Characteristics

As reported in Table 1,the patients in Group B were older than those in Group A ($P < 0.05$). And Group B had more CAD and renal insufficiency patients. These risk factors were detrimental to survival and aortic remodeling for Group B. Group A had more acute patients than Group B ($P < 0.05$). There were 15 acute [17], five subacute and two chronic TBADs in Group A, compared with six acute, 13 subacute and two chronic TBADs in Group B. Group A had more patients with diabetes, and Group B had more patients with renal insufficiency and coronary artery disease ($P < 0.05$). The other past medical history, including previous cerebrovascular, previous aortic repair and tobacco abuse, was similar in the two groups (P = NS).

Perioperative Results

As listed in Table 2, average operation time was 139.4 ± 61.4 min in Group A and 139.4 ± 49.3 min in Group B (P = NS). Technically successful was 100% (n = 22) in Group A and 95.2% (n = 20) in Group B. In Group A, elective endoluminal repair was performed in 12 patients and emergent in 10, while elective endoluminal repair was performed in all 21 patients in Group B ($P < 0.05$).

In Group A, the CGs were generally oversized by 10% with a diameter of 8–10 mm and a length of 40–60 mm and were placed 1 cm ahead the main aortic stent graft. As CGs, bare stents were used in five patients (Luminexx, Bard, Murray Hill, NJ, USA) and covered stents (Fluency, Bard Peripheral Vascular, Tempe, AZ, USA) in the other 17 patients. The devices implanted in the descending aorta were Ankula (Lifetech Scientific, Shenzhen, China) in 12 and Valiant (Medtronic Endovascular System, Santa Rosa, Calif) in 10. In Group B, the Castor Branched Aortic Stent Graft System (Microport Medical, Shanghai, China) (Fig. 1D) was used in all 21 cases and the oversize rate was 7.1–13.3%.

No immediate endoleak was detected In Group A. However, a CG compression by the main aortic stent graft was observed in one case (4.5%) during the procedure, and balloon dilatation was performed and solved the problem. In Group B, immediately proximal endoleak was detected in one case (4.8%) and remained existing despite various attempts to seal it (Fig. 1E). No device migration or graft compression was observed in perioperative period.

Follow-Up

As listed in Table 2, four (18.2%) patients were lost to follow-up in Group A, compared with one (4.8%) in Group B ($P < 0.05$). The median follow-up was 19 months (range, 3–43 months) in Group A and 12 months (range, 6–48 months) in Group B. Table 3 reports the results of FL thrombosis in thoracic and abdominal aorta. Diametric changes between pre-operation and final follow-up at different levels were presented in the form of bar graphs (Figs. 3, 4).

Complications in Follow-Up

In Group A, one death occurred at 41 months after TEVAR, resulting in an overall mortality of 5.6% (1/18) among the patients with complete follow-up data. This 58-year-old male had been revealed with huge FL in thoracic segment before TEVAR. The FL did not shrink during follow-up, and endoleak was not detected. Secondary intervention was rejected by the patient for economic reasons. In the end, he died from aortic dissecting aneurysm rupture. A type I endoleak was detected in the 3-month examination, limited to the root of LSA and still existed without significant change at 41 months after TEVAR. And therefore, a secondary intervention was not performed. In this case, a Bard bare stent was used as a CG. Two cases of CG occlusion were found during follow-up. One CG was revealed with a 30% stenosis at 5 months after TEVAR and occluded with thrombosis at 33 months postoperatively. And another CG was occluded at 32 months after TEVAR. Both patients showed no symptoms of stroke and upper extremity ischemia. In Group B, one patient died within 6 months after TEVAR from myocardial infarction, considered unrelated to the stent implantation. Consequently, there were 19 patients with complete follow-up data. A twist of a sidearm graft was detected in the 6-month examination and remained with no change in angle at 12 months postoperatively (Fig. 1F). No stroke and severe upper extremity ischemia happened to the patient in follow-up.

Table 2 Results in perioperative period and follow-up

Variables	Group A No (%) or mean ± SD	Group B No (%) or mean ± SD	*P* value
Operation time (min)	139.4 ± 61.4	139.4 ± 49.3	> 0.05
Onset to TEVAR (day)	20.9 ± 15.7	19.7 ± 12.5	> 0.05
PHS (day)	8.4 ± 3.7	8.0 ± 4.0	> 0.05
Emergent/elective TEVAR	12/10	0/21	< 0.001
Technical success	22 (100)	20 (95.2)	> 0.05
Complications in TEVAR			
Endoleak	0 (0)	1 (4.8)	> 0.05
Endograft compression	1 (4.5)	0 (0)	> 0.05
Follow-up			
Lost to follow-up	4 (18.2)	1 (4.8)	< 0.05
Median follow-up	19, range 3–43 months	12, range 6–32 months	
Complications in follow-up			
Endoleak	1 (4.5)	0 (0)	> 0.05
Endograft compression	2 (9.1)	1 (4.8)	> 0.05

PHS postoperative hospital stay, *SD* standard deviation

Table 3 False lumen thrombosis in thoracic and abdominal aorta

Variables	Group A No (%) or mean ± SD		Group B No (%) or mean ± SD		*P* Value
Thoracic aorta Patient total	Pre-op 18	Post-op	Pre-op 19	Post-op	
Patent	16 (88.9)	0 (0)	16 (84.2)	0 (0)	> 0.05
Partial thrombosis	2 (11.1)	3 (16.7)	3 (15.8)	2 (11.1)	> 0.05
Complete thrombosis	0 (0)	15 (83.3)	0 (0)	17 (88.9)	> 0.05
Abdominal aorta Patient total	Pre-op 13	Post-op	Pre-op 11	Post-op	
Patent	9 (69.2)	0 (0)	8 (72.7)	0 (0)	> 0.05
Partial thrombosis	4 (30.8)	10 (76.9)	3 (27.3)	7 (63.6)	< 0.05
Complete thrombosis	0 (0)	3 (23.1)	0 (0)	4 (36.4)	< 0.05

SD standard deviation

False Lumen Thrombosis

As reported in Table 3, in thoracic aorta, three (16.7%) partial thrombosis cases of FL and 15 (83.3%) complete thrombosis cases of FL were found in Group A, while there were two (11.1%) partial thrombosis cases and 17 (88.9%) complete thrombosis cases in Group B. No significant difference was found between the two groups. There were 13 cases of dissections extending to the abdominal aorta in Group A (11 cases in Group B). Partial thrombosis of FL was found in ten (76.9%) patients and complete thrombosis of FL in three (23.1%) patients in Group A (seven [63.6%] partial thrombosis cases and four [36.4%] complete thrombosis cases in Group B, $P < 0.05$). So in abdominal aorta, false lumen thrombosis was slightly better in Group B. In both groups, there was obvious false lumen thrombosis in thoracic and abdominal aorta by preoperative and postoperative comparison. Both techniques were beneficial for aortic remodeling.

Diametric Changes

As seen in the bar graphs, TL and FL changed significantly at different levels in both groups, especially in thoracic segment (Levels A, B and C). However, No significant difference was found at any level between the two groups. As reported in Table 4, the whole aortic size was not significantly different between pre-operation and the last

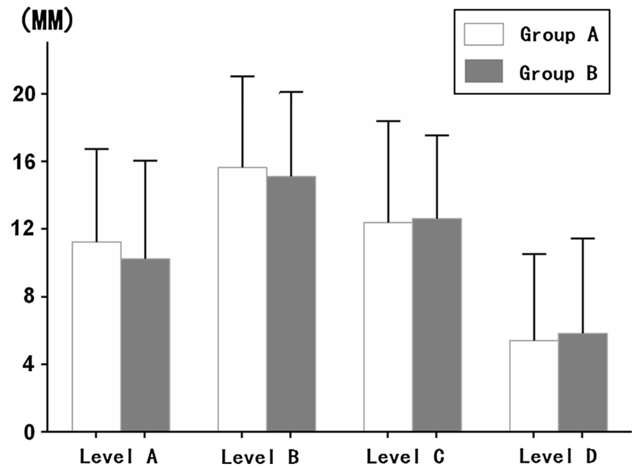

Fig. 3 Diametric changes of the false lumen. The shrinkage of FL was obvious at different levels in both groups. However, no significant difference was found at any level between the two groups

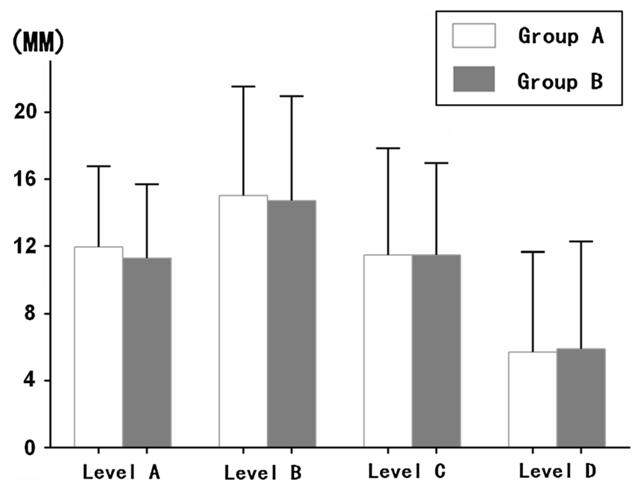

Fig. 4 Diametric changes of the true lumen. The recovery of TL was evident but the difference between the two groups was not significant

Table 4 Diametric changes of the whole aorta at the four levels

	Group A (mm) Mean ± SD	Group B (mm) Mean ± SD	*P* value
Level A	− 0.1 ± 0.8	0.7 ± 0.9	> 0.05
Level B	− 0.3 ± 0.7	0.7 ± 0.8	> 0.05
Level C	− 0.3 ± 0.5	− 0.2 ± 0.6	> 0.05
Level D	0.3 ± 0.7	0.4 ± 0.5	> 0.05

SD standard deviation

follow-up at the four levels, and the differences were not significant between the two groups ($P > 0.05$).

Discussion

In the past years, there are increasing evidences showing a high risk of the left upper extremity ischemia and stroke after TEVAR with intentional LSA coverage [8, 9, 18]. And as early as 2009, routine revascularization of LSA has been suggested in all elective settings by the Society for Vascular Surgery Practice Guidelines [19]. In our clinical experiences, we also deem that reconstructing the LSA has more benefits than maladies.

Criado [20] systemically introduced chimney technique for aortic endovascular repair. In the past few years, this technique has been increasingly used to expand proximal landing zone in TEVAR and has been reported with favorable results [21, 22]. However, the gutter between the main aortic graft, the aortic wall and the CG is inevitable and therefore type Ia endoleak frequently occurs following TEVAR [23, 24].

Regarding chimney graft selection, no consensus has existed so far. In the beginning of our study, self-expanding bare chimney stents were chosen to reconstruct LSA. Self-expanding bare stents have the characteristics of good flexibility, weak radial force and some elasticity, which help to fit closely with the main aortic graft. Bare stents were used in five cases. Though immediate postoperative endoleaks were not noted, there was an occurrence of endoleak 3 months postoperatively. And two cases of bare CG occlusion were found during follow-up. We speculate that the endoleak might come from the flow via the meshes of bare stent into the gutter. Compared with bare stent, covered stents can provide excellent seal and higher radial force, which can reduce the risk of stent compression and the occurrence of endoleak. In the following 17 patients who used covered CGs, no endoleak occurred and only one CG compression was noted during TEVAR, which was corrected after immediate balloon dilatation.

Compared with self-expanding stent graft, the balloon-expandable stent can provide stronger radial strength for the compression from the tortuous aorta arch and the thoracic endograft. And due to its strong radial strength, it can be accurately deployed and can avoid device migration. However, taking into account the tortuosity of LSAs, the self-expanding stents are irreplaceable.

Inoue et al. [25] designed a single-branched stent graft to treat distal arch pathologies involving the LSA. Recently, many clinical trials have been conducted on the use of SBSG in aortic arch reconstruction, and favorable short-term results have been reported [12, 13, 26, 27]. The SBSG used in this study was the Castor Branched Aortic Stent Graft System (Microport Medical, Shanghai, China). Due to its unibody design and the approximate right angle relationship between the LSA and descending aorta, the branch section of Castor can avoid the device from migration after deploying in LSA. And because no gutter forms in the SBSG implantation, endoleak is less likely to occur compared with the chimney technique. However, when device migration does occur, the twist of the branch section is inevitable because of its unibody design. And this was revealed in one case 6 months postoperatively.

Due to a mismeasurement of an aorta diameter, an inappropriate stent size was used in one case, which therefore caused an endoleak during the TEVAR. We consider that the root reason for the mismeasurement was the static CTA that does not provide the accurate visualization of the aorta. We decide to use electrocardiogram-gated CT scan in our future study to avoid motion artifact and therefore to bring us a more accurate imaging.

As reported before, the CG was greatly used in emergency settings. It is especially suitable for the emergent cases due to the relatively simple maneuver and the applying of available off-the-shelf stents. On the contrary, the SBSG was not used in emergency situations because it was custom-made and associated with long manufacturing times and increased costs. However, a previous study of our department reported that 20 configurations of Castor could treat up to 54.8% patients who had an inadequate proximal landing zone [26]. Taking in the huge population in China, we believe it is possible to apply SBSG in emergent settings.

In 2005, Sueyoshi reported that for TBAD patients with a patent FL, the growth rate of aortic diameter was 3.3 mm/year [28]. Therefore, sealing the entry tear to induce false lumen thrombosis is quite meaningful. In 2007, Maria Schoder reported significant TL diameter increase and FL thrombosis after stent graft placement [29]. And these results are consistent with ours. As reported before, FL thrombosis was significant in thoracic aorta, but was not that evident in abdominal aorta. We speculate that the persistent blood flow in the FL perfused by distal tears was responsible for this difference. In addition, significant TL expansion and FL shrinkage were found in thoracic aorta in both groups. And because these structural changes occurred synchronously, the diameters of whole aorta had no statistical difference between pre-operation and follow-up.

The diametric changes of TL, FL and the whole aorta in abdominal aorta were not significant between pre-operation and follow-up. We think the reasons include persistent perfusion of FL, slow thrombus absorption and relatively short follow-up. Therefore, long-term follow-up is quite needed for the evaluation of aortic remodeling. Furthermore, anti-platelet therapy is required after stent deployment, which hinders the thrombosis of FL and the process of vascular remodeling, thus also increasing the necessity of long-term follow-up.

There are several limitations in the present study, including a small sample size and a short follow-up period. The high rate of lost to follow-up also heavily limited the already small cohort of patients. Group B had more risk factors that would be detrimental to survival and aortic remodeling, which limits the power of the analyses.

Conclusions

Both the chimney technique and the single-branched stent graft are good choice for treating TBAD patients involving the LSA. Our study demonstrated that there were no significant differences between the two techniques. A larger series of cases with longer follow-up are needed to draw definitive conclusions.

Compliance with Ethical Standards

Conflict of interest None.

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