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ORIGINAL ARTICLE

Efficacy of ascending aortic banding technique concomitant with type I hybrid aortic arch repair in high-risk patients

Hung-Lung Hsu[1,2,4,5] · Chun-Yang Huang[2,3] · Po-Lin Chen[2,3] · Yin-Yin Chen[2,5] · Chiao-Po Hsu[2,3] · I-Ming Chen[2,3] · Chun-Che Shih[1,2,3]

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Abstracts

Banding of the ascending aorta has been introduced as a less complex procedure to optimize the proximal landing zone of the stent graft in hybrid aortic arch surgery. However, data about the long-term results and effects of this technique are still limited. We aimed to study the efficacy of banding of the ascending aorta in hybrid aortic arch repair. The study included 11 high-risk patients with dilated ascending aorta (wider than 38 mm in diameter) undergoing ascending aortic banding for hybrid arch repair. Clinical outcomes, including technical success, endoleaks, perioperative mortality and morbidity, and sequential remodeling of the ascending aorta were investigated. The average diameter of the ascending aorta had been reduced ($p=0.02$) from 42.1 mm (range = 39.0–46.4) to 37.2 mm (range = 35.6–38.6) after banding procedure. The technical success rate was 100.0%. No type I endoleak occurred, but 2 cases of distal stent graft-induced new entry required re-interventions. The 5-year survival and freedom from aortic events rates both were 81.8%. The ascending aortic diameter remained stable and no proximal migration of the stent graft was observed during the study period. The 5-year results validated the durability of this therapeutic modality, especially in high-risk patients.

Keywords Banding technique · Aortic wrapping · Thoracic endovascular aortic repair · Hybrid arch repair

Introduction

Conventional open repair for aortic arch diseases remains a surgical challenge. The combination of open surgical and endovascular approach can offer a less invasive strategy [1, 2]. Re-implantation or bypass of all supra-aortic vessels with thoracic endovascular aortic repair (TEVAR) landing proximally in the ascending aorta (zone 0) had been proposed as type I hybrid arch repair [3]. However, a dilated ascending aorta is not safe as a landing zone for type I hybrid arch repair. Aortic neck diameter ≧ 38 mm has been noted to be a risk factor for type I endoleak or retrograde ascending aortic dissection [4, 5]. In this scenario, combination of ascending aortic replacement is usually needed to create a more secure landing zone, but at the expense of elevated operative risk, especially in patients with severe comorbid conditions.

Banding of the ascending aorta has been introduced as a less complex procedure to optimize the proximal deployment of the stent graft in type I hybrid arch repair [6–8]. Similar to the literature, our early experience [9] of this technique had shown its applicability. However, more long-term results and its effects on the ascending aorta are still limited. Therefore, the experience at our institution on the banding technique in type I hybrid arch repair with longer cohort is presented and the efficacy of this technique and consequent ascending aortic remodeling is focused.

✉ Chun-Che Shih
ccshih@vghtpe.gov.tw

1 Institute of Clinical Medicine, National Yang-Ming University, Taipei, Taiwan

2 School of Medicine, National Yang-Ming University, Taipei, Taiwan

3 Division of Cardiovascular Surgery, Department of Surgery, Taipei Veterans General Hospital, #201, Section 2, Shipai Road, Taipei, Taiwan

4 Department of Cardiovascular Surgery, Far Eastern Memorial Hospital, New Taipei City, Taiwan

5 Department of Surgery, Taiwan Adventist Hospital, Taipei, Taiwan

Materials and methods

From 2006 to 2012, 362 cases of TEVAR have been performed at our institution. Of these, 15 cases of type I, 5 cases of type II, and 31 cases of type III hybrid arch repair were performed as alternatives to standard total arch replacement (6 cases of conventional total arch repair alone; 3 cases of combination with ascending aortic replacement in the study period) for variable aortic arch pathologies. Among the 15 patients with type I hybrid arch repair, 11 underwent type I hybrid arch repair with banding of the ascending aorta. These patients were at high risk (EuroSCORE II > 7%) for conventional surgery due to underlying chronic diseases or emergent presentations. The indication for the aortic banding was an ascending aortic diameter > 38 mm, which was not safe for proximal landing of stent graft with the maximum available size of 42 mm during the study period. The exclusion criteria are ascending aortic dissection, whole or proximal ascending aortic diameter > 5 cm, severe aortic insufficiency with or without dilated aortic root, known connective tissue disease, significant atheromatosis, mural thrombus, calcification, or visible plaque in the ascending aorta. The demographic features and comorbid conditions are listed in Table 1. Informed consents about the procedure, the data collection, and the need for follow-up examinations were obtained. Technical success was defined as successful ascending aortic banding, supra-aortic debranching, and implantation of the thoracic stent grafts without type I endoleak. The Institutional Review Board approved the study.

Table 1 Patient's characteristics

Variable	*N* or mean (range)	Percentage
Age	73.1 (63.0–88.0)	
Male	9	81.8
CAD with PCI history	5	45.5
Hypertension	10	90.9
COPD	8	72.7
Renal insufficiency[a]	3	27.3
Old stroke	3	27.3
Diabetes mellitus	1	9.1
Hyperlipidemia	2	18.2
Peripheral arterial disease	1	9.1
ASA class		
3	8	72.7
4	3	27.3
EuroSCORE II (%)	9.05 (7.3–16.1)	

ASA American society of anesthesiologists, *CAD* coronary artery disease, *COPD* chronic obstructive pulmonary disease, *PCI* percutaneous coronary intervention

[a]Chronic kidney disease stage 3 or worse (GFR < 60 mL/min/1.73 m^2)

Surgical technique

Bilateral radial arterial pressures and regional cerebral near-infrared spectroscopy were monitored to assess cerebral and upper limb perfusion. After general anesthesia and median sternotomy, the ascending aorta and the supra-aortic vessels were mobilized. Systemic heparinization was initiated to keep activated clotting time (ACT) values greater than 250 s. The ascending aorta was clamped with a side-biting clamp, and a woven bifurcated vascular prosthesis (Hemashield graft; MAQUET Cardiovascular LLC, San Jose, CA, USA) was sutured end-to-side to the aorta. Banding of the ascending aorta was positioned right after the origin of the main trunk of the new supra-aortic vessels (Fig. 1a). A Dacron strip was made to achieve a transverse circumference by multiplying the intended aortic diameter by $\pi(=3.14)$ (Fig. 1b).The intended diameter of the banded ascending aorta was aimed to 10% less than the original one. The Dacron strip was placed around the aorta, and running suture was made along the mark lines. The Dacron strip would create an at least 2 cm of the banded region for proximal landing of TEVAR. Then, the first and second branches of the bifurcated graft were anastomosed end-to-end to the innominate artery and the left common carotid artery (LCCA), respectively. The left subclavian artery was bypassed with another vascular graft directly to LCCA graft.

Endovascular technique

TEVAR was done right after the banding procedure via femoral access. The diameter of the stent graft was 10–20% oversized above the outer diameter of the wrapped ascending aorta. Mosquito clamps were used to identify the distal end of the ascending aortic wrapping and main trunk of the newly created supra-aortic vessels. The proximal landing zone was the aortic segment marked by the Mosquito clamps. TEVAR was done with Zenith TX2 (Cook Medical, Inc, Bloomington, IN, USA).

Follow-up

All patients were scheduled for follow-up assessments, including routine clinic visits and computed tomography (CT) at 6 months and annually after the operation. The CT images were collected to evaluate ascending aortic remodeling and stent graft migration. The Digital Imaging and Communications in Medicine (DICOM) data were analyzed with 3Mensio system (3Mensio Medical Imaging BV, Bilthoven, the Netherlands). A central luminal line was constructed within the aorta. Multiplanar reconstruction of

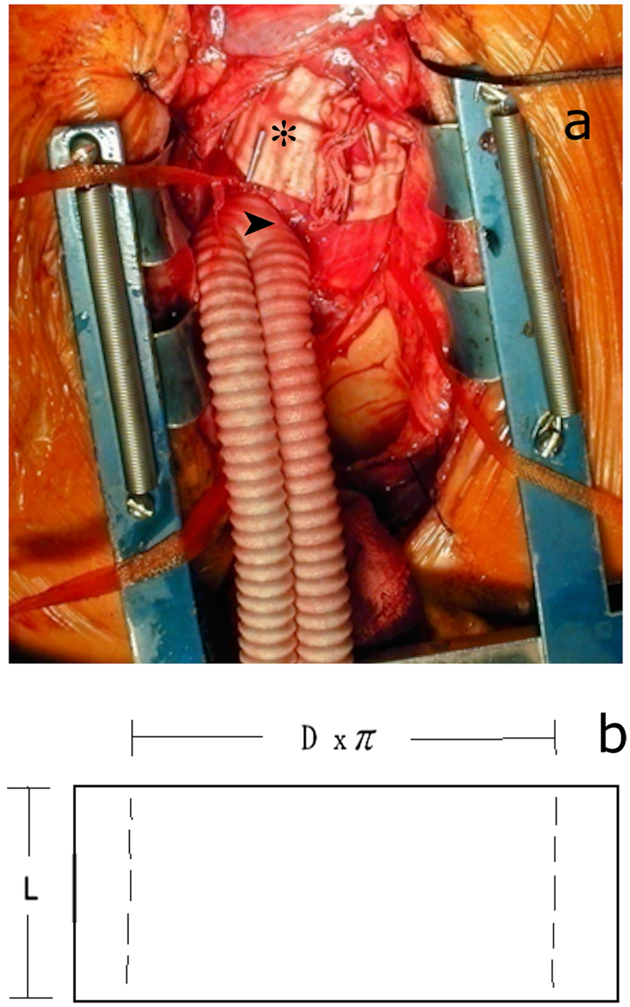

Fig. 1 Surgical technique of banding of the ascending aorta: **a** completion of banding of the ascending aorta; **b** design of the Dacron strip [*D*: the intended diameter of the ascending aorta after banding; *L*: the intended length of the ascending aorta after banding; asterisk: the ascending aorta after banding; arrowhead: the bifurcated vascular prosthesis]

these images in the plane orthogonal to the central luminal line was used for estimation of aortic diameters and lengths (Fig. 2). The diameters were measured as the parameters of ascending aortic remodeling at two aortic levels: the proximal ascending aorta [1 cm above the sinotubular junction (STJ)] and the banded ascending aorta (1 cm above the main trunk of the newly created supra-aortic vessel). The distance from the STJ to the proximal edge of the stent graft was also recorded as the assessment of stent graft migration.

Statistics

Continuous variables were presented as mean with range and categorical data were shown Continuous variables were presented as mean with range, and categorical data were shown using absolute numbers with percentage. The parameters of proximal ascending aortic remodeling were analyzed by Friedman test. *P* value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS version 18.0 (SPSS Inc, Chicago, IL, USA).

Results

The operative data are shown in Table 2. Primary aortic pathology was thoracic aortic aneurysm (63.6%). After banding, the ascending aortic diameter was reduced ($p = 0.02$) from 42.1 mm (range = 39.0–46.4) to 37.2 mm (range = 35.6–38.6), equivalent to downsizing by 12.2% (range = 8.0–16.8). The size of the thoracic aortic endografts was all 42.0 mm. This made the oversizing of the stent grafts (compared to the banded ascending aortic diameter) to be 11.8% (range = 8.1–18.0).

The mean follow-up period was 62.5 months (range = 1.97–120.0). Technical success was obtained in all patients. The outcome data are shown in Table 3. One early (at postoperative 1.97 month) and one late mortality (at postoperative 23.6 month) were noted but not related to aortic events (both of them were died of pneumonia with sepsis). Survival rates were 81.8% at 5 years.

The rate of neurological complications was 9.1% (1/11): small intracranial hemorrhage without motor dysfunction. No type I endoleak was noted at all follow-up points. However, two patients were noted to have distal stent graft-induced new entry. They underwent re-endografting for the new aortic entry tears, respectively, at postoperative 4 months and 38 months. Freedom from aortic events was 81.8% at 5-year follow-up.

The ascending aortic remodeling was evaluated in 7 patients who had completed 5-year image follow-ups. There were no significant changes at the proximal ascending aortic diameters ($p = 0.17$) during 5-year follow-up (Fig. 3a). There was also no significant difference ($p = 0.99$) found in the banded ascending aortic diameters during postoperative follow-up period (Fig. 3b). Analysis of the proximal location of the stent grafts also revealed no significant positional changes ($p = 0.14$) during the follow-up period (Fig. 3c).

Discussion

With the advantage of less invasiveness, endovascular-based arch repairs have become more common in the past years. Among them, hybrid arch repairs with proximal landing zone 0 are the most complex, owing to the necessity of revascularization of all aortic arch vessels. For patients with dilated landing zone 0, ascending aortic banding technique is an alternative modality to minimalize procedure

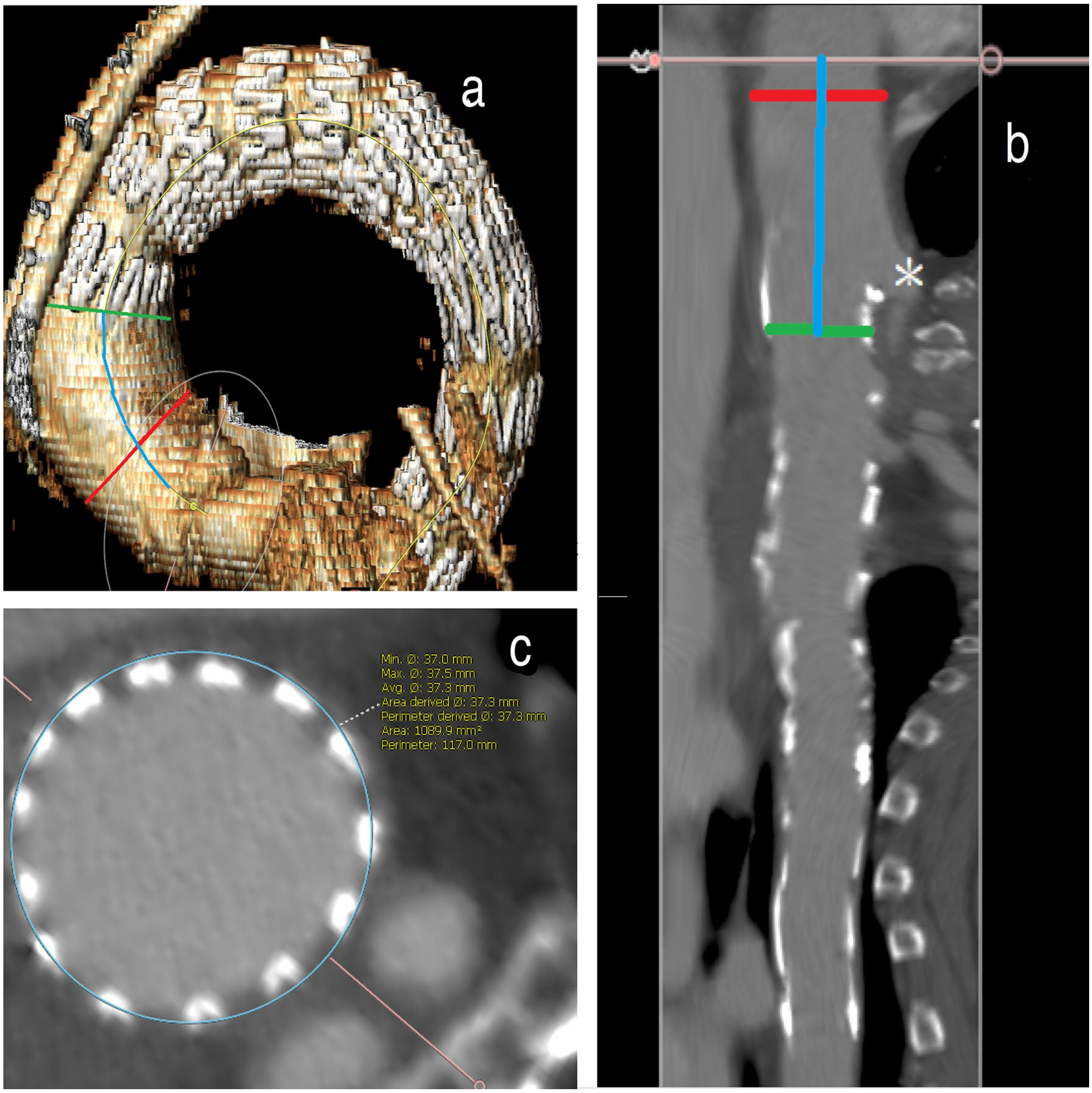

Fig. 2 Measurement of the diameters for ascending aortic remodeling and the distance for stent graft migration: **a** levels of measurement on three-dimensional reconstruction computed tomography scan (CT); **b** corresponding levels on central luminal line. **c** Representative axial CT shows mean diameter of 37.3 mm at the level of the green line. [Red line: the proximal ascending aortic diameter at 1 cm above the sinotubular junction; green line: the banded ascending aortic diameter at 1 cm above the main trunk of the newly created supra-aortic vessels; blue line: the distance from the sinotubular junction to the proximal edge of the stent graft; asterisk: the main trunk of the newly created supra-aortic vessels]

invasiveness, especially for high-risk patients. However, the efficacy of this technique still needs validation. Compared with other studies, two specificities in the current study: ascending aortic remodeling and endograft migration, were used to evaluate the durability of this technique.

Whether the banded and non-banded parts of the ascending aorta will dilate after the banding procedure is always a concern. In our series, changes in the diameters of the non-wrapped ascending aorta were not statistically different. This finding indicates that wrapping the ascending aorta may not cause obvious dilatation in the proximal, non-banded part. Besides, the diameter of the banded ascending aorta did not show significant changes during follow-up period. Although immediate postoperative images were lack in the present study, a study of 33 patients with off-pump ascending aortic wrapping had showed that the aortic diameter at the banded segment was reduced and remained stable by comparison of the images before discharge and during follow-up of 33.5 months [10]. It could be postulated that the aortic diameter should be decreased immediately after banding and maintained steady in our study. Moreover, the fixability of the banding technique to the stent graft was evaluated by

Table 2 Operative data

Variable	*N* or mean (range)	Percentage
Aortic pathology		
Aortic dissection	4	36.4
Acute complicated type B aortic dissection	2	18.2
Chronic type B aortic dissection[a]	2	18.2
Aortic aneurysm	7	63.6
Operative		
Emergent	6	54.5
Preoperative ascending aortic diameter (mm)	42.1 (39.0–46.4)	
Wrapped ascending aortic diameter (mm)	37.6 (35.7–38.6)	
Length of aorta covered by endograft (mm)	198.4 (110.0–292.0)	

[a]Chronic type B aortic dissection with diameter expansion > 1 cm in 1 year

Table 3 Outcomes data

Variable	*N*	Percentage
Technical success	11	100
30-day mortality	0	0
New stroke	1	9.1
Endoleak		
Type I	0	0
Type II	0	0
Prolong intubation[a]	3	27.3
Reoperation for bleeding	0	0
Distal SINE	2	18.2

SINE stent graft-induced new entry

[a]Tracheal intubation > 72 h

measuring the distance between STJ to the proximal endograft edge in the present study. No significant difference was observed in the distance at all follow-up points. All these results demonstrate that the banding technique could provide reliable fixation for endografting.

Except for steady aortic remodeling by the banding procedure, longer proximal landing zone is another important element of ascending aortic banding to stabilize the proximal landing zone in hybrid arch repair. In our study, the banded ascending aorta was 27.6 mm (range = 21.0–30.0) in length and created a distance of 41.8 mm (range = 34.0–51.0) proximal to the treated aortic pathologies for endograft fixation. This is longer than the length suggested by previous reports [11, 12] on landing zone, by a variation of 15.0 to 30.0 mm. Also, the mean oversizing in our series was 14.8%. This corroborates with earlier studies [13, 14] on oversizing suggestion of 10–20% in order to minimize graft endoleak.

Several considerations are taken to increase the success of this technique in our institute: first, no significant atheromatosis, mural thrombus, calcification, or visible plaque in the ascending aorta in the ascending aorta. Atheroma or mural thrombus will cause thromboembolism during the procedure. Calcified plaque will increase the risk of endoleak after endografting and may cause intimal break during manipulation of the aorta. The second is mean blood pressure < 70 mmHg during aortic manipulation. This blood pressure control helps in wrapping on a relatively softer aorta and facilitates the initial deployment of aortic endograft in the banded segment of the aorta. The third is ascending aortic diameter less than 50 mm. The more dilated aorta, the thinner the aortic wall, and the greater chance of rupture during manipulation. When the aorta is significantly dilated, the risk of fold formation in the banded aortic wall increases and the possibility of thrombus formation in the creases or gutters between the aortic wall and the stent graft may exist. Furthermore, the Dacron strips used in the present study were 2 to 3 cm in length to create a more secure landing zone for stent graft, not to treat an ascending aortic aneurysm. There was no need to worry about shaping to fit the aortic curvature. Wrapping of 2 to 3 cm in length is generally adequate to meet the requirement of endograft landing. For situations needing longer wrapping length, such as ascending aortic aneurysm, our method is to use several short wrapping strips to adjust the curvature of the aorta. Overlap of the strips is needed to avoid gaps without coverage. The proximal and distal parts of the strips are fixed to the aorta by stitches. The strips itself are also fixed to each other by stitches.

One of the major issues about ascending aortic banding, like all other hybrid or endovascular arch repairs, is type I endoleak. Owing to the complex morphology of the aortic arch, it is a challenge for the stent graft to fit the anatomical conformation of aortic arch. In addition, there usually exists a struggle for a physician to maintain supra-aortic arch vessel flow and adequate proximal fixation length in aortic arch endografting. These factors make arch TEVAR inferior to conventional open repair due to higher aortic re-intervention rate [15–17]. Additionally, the reported rate of type I endoleak in hybrid arch repair ranged from 3 to 16.6% [17, 18]. However, zone 0 landing TEVAR has been

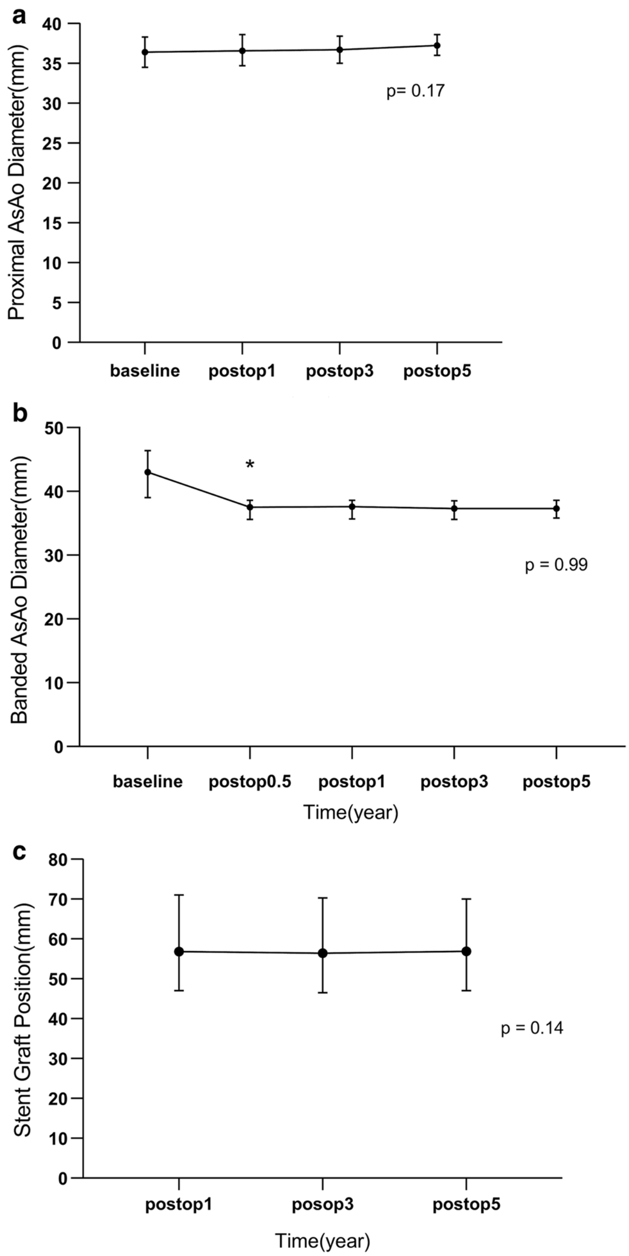

Fig. 3 Ascending aortic remodeling and stent graft migration: **a** the diameter of the proximal (non-banded) ascending aorta at each follow-up points; **b** the diameter of the banded ascending aorta during the follow-up period; **c** the distance between the sinotubular junction and the proximal endograft edge [AsAo: ascending aorta; postop: postoperative; asterisk: significant difference compared between the baseline and the postoperative 0.5-year diameter]

shown to have lower type I endoleak rate than TEVAR in other landing zones [19, 20]. A recent meta-analysis [21] of 1021 patients with zone 0 hybrid arch repair also demonstrated fewer incidences of type I endoleak in total surgical debranching group (5.8%, $p=0.02$) than partial (12.1%) or total (7.1%) endovascular supra-aortic revascularization groups. In our series, no type I endoleak was observed. This finding is in concurrence with the literature and indicates that banding of the ascending aorta could ensure a safe sealing zone.

Retrograde type A dissection is an issue in arch TEVAR, especially in zone 0 landing procedures. The incidence of retrograde type A dissection has been reported up to 8.1% in zone 0 endovascular aortic arch repair [22, 23]. Except for stent graft, aortic side-clamping itself is also a risk factor. Nevertheless, we did not observe this major complication in our patient cohort. Part of the reasons are careful evaluation and manipulation of the ascending aorta when banding or side-clamping the aorta. We avoid calcified plaque in the clamping site and maintain mean blood pressure not exceeding 70 mmHg during side-clamping. Clamps with atraumatic inserts are used to make the clamping force more evenly distributed. Besides, we only use banding procedure in moderately dilated ascending aortic diameter. Aortic diameter > 5 cm has not been tried in our hospital because of thinness of aortic wall, although this procedure has been used in ascending aortic diameter of 6.5 cm [24].This favorable finding of banded ascending aortas was also noted in the meta-analysis [21]. This positive discovery may be partly attributed to changes in hemodynamics (e.g., altered flow patterns and aortic wall shear stress [25, 26]), as well as mechanical properties of the aorta (e.g., improved indexed aortic diameter [27] and the external aortic support by the Dacron strip against the spring-back force of the stent graft) after banding a dilated aorta. The advanced computational analyses showed that wall stress magnitude and distribution in the wrapped aorta were only slightly higher than those of the normal aorta (32 mm), but much lower than those of the moderately dilated aorta (45 mm), on both the outer and inner surfaces [28]. This finding implicated more favorable hemodynamics by aortic banding and a lower risk of aortic dissection than a dilated aorta. Although larger-diameter (> 42 mm) aortic stent grafts have been available later in the study period and could be used directly in dilated aortic landing zones, such stent grafts were rarely used. The landing aorta fitting these sized devices was variably diseased in nature, not to mention the ascending aorta with vulnerable characteristics (e.g., zone 0 landing and ≧ 38 mm in diameter) [4, 5, 22]. Moreover, a stent graft with a diameter of ≥ 40 mm has also been noted as a risk factor for type I endoleak [4]. Generally, ascending aortic replacement is the management of choice in dilated landing zone 0 in hybrid arch repair. However, based on the positive results achieved in our study, the banding technique appears to be a reliable alternative to secure the proximal landing zone, especially in high-risk patients.

The standard treatment for ascending aorta aneurysm is ascending aortic replacement. But ascending aortic banding or wrapping has been continuously evaluated as a therapeutic option in high-risk patients. For wrapping procedure alone, Pecoraro et al. [10] showed stable diameters at the aortic root and ascending aorta in 33 patients with mean preoperative ascending aortic diameter of 5.5 cm and mean follow-up of 33.5 months. For wrapping procedure with concomitant cardiac surgery, one meta-analysis of 272 patients with mean preoperative ascending aortic diameter of 4.8 cm revealed no aortic related mortality and 0.7% aortic reoperation rate in mean follow-up of 41 months [29]. Bicuspid aortic valve was noted in 50% of this study group. Another study focused on aortic wrapping in bicuspid aortic stenosis also suggested comparable outcomes to ascending aortic replacement with 10-year-overall survival rate of 88.1% and no progressive aortic diseases in wrapping group [30]. For combination with aortoplasty (wall resection or plication), the wrapping procedure also be considered as a safe alternative with low aortic reoperation rate of 2.4% in 450 patients [29]. Besides, ascending aortic dissection has been considered as a contraindication because banding procedure does not treat the intimal tear. However, Demondion et al. [31] reported this technique in 15 patients with Stanford type A aortic dissection and mean EuroSCORE II of 10.47. The hospital mortality was 6.6% and follow-up mortality was 13.3% in a mean follow-up of 15 months. Analysis of postoperative CT showed that the diameter of the ascending aorta remained stable with reapplication of the false lumen inside the reinforced segment. All these studies suggested that banding technique could be an effective external support for the ascending aorta, even on extremely fragile aorta.

The possibility that the banding prosthesis might migrate epi-aortically to cause lack of protection and eventual dilatation of areas that were initially covered by the wrapping had been reported [32]. Except for anchoring of the prosthesis to the aortic wall by stitches, the endografting might also help fixation of the banding prosthesis by radial force from inside. Besides, erosion or degeneration of the aortic wall was also criticized in aortic wrapping [33, 34]. Several mechanisms have been cited, including folding of the prosthesis to the aortic wall, compromise of the vasa vasorum of the aorta, chronic inflammation to foreign material [35]. We do not know whether the combination of aortic endograft will cause this kind of histological change, but currently there is no evidence that these structural changes are associated with aortic rupture.

Ascending aortic banding is less invasive than traditional ascending aortic replacement in avoidance of cardiopulmonary bypass, cross-clamping of the aorta, or even hypothermic circulatory arrest. One study of conventional aortic arch surgery in 623 patients showed hospital mortality of 23.1% in acute and 11.1% in chronic cases with postoperative permanent neurological dysfunction in 9.6 and 5.6%, respectively [36]. Studies of type I hybrid arch operation [3, 18, 19, 21] have shown that mortality rate ranges from 0 to 20% and neurological complication rate ranges from 2.2 to 12.1%. Compared with previous reports, the mortality rate (2 patients, 18.2%) and neurological complications (1 patient, 9.1%) in our cohort remained high. One of the reasons was high-risk status (87.5% with American Society of Anesthesiologists class ≧ 3 and mean EuroSCORE II of 9.05%) and greater comorbid burden (45.5% with prior percutaneous coronary intervention, 27.3% with old stroke, and 72.7% with chronic obstructive pulmonary disease) in these patients. Another reason was the high proportion (54.5%) of emergent operation in the present study. Thorough preoperative evaluation and early management would be impossible under such critical condition. Additionally, aortic arch atheroma has been recognized as a risk factor for recurrent strokes, MI and vascular death [37]. 63.6% of our patients were noted to have degenerative aneurysm change in the aortic arch. This unfavorable histological change predisposes the patients to greater risks of atheroembolic events. Considering such high-risk profile, the results of the present study still fared comparable to those of experienced centers in aortic arch surgery and suggested that the banding technique could be a potential alternative to provide a safe proximal landing zone for hybrid arch repair in patients unfit for conventional operation.

The current study has several drawbacks. This is a small series with midterm follow-up. Long-term results are required to approve this technique. The data analysis was retrospective without a comparison group, such as type I hybrid arch repair without ascending aortic banding or type II hybrid arch repair [3] with conventional ascending aortic replacement. Four cases of type I hybrid arch repair without banding were noted in the study period, but their data were limited for comparison (1 of surgical mortality, 2 mortality of not-aortic-events in postoperative 2 years, and 1 lost-follow-up in postoperative 1 year). Besides, by virtue of the high risks associated with the study group, creating a control group of open surgical approach for purpose of comparison is highly difficult. In addition, the diameter of the ascending aorta for banding was around 42 mm in the present study. The efficacy of this technique on more dilated ascending aorta needs further investigation.

In conclusion, our experience showed that the banding technique is feasible for type I hybrid arch repair in high-risk patients with dilated ascending aorta. The ascending aortic diameter remained stable without proximal endoleak or migration of the stent graft. Our results are promising and reflect the efficacy of this technique to provide a safe proximal fixation and sealing zone. A large-series evaluation with longer follow-up is required to validate this technique.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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