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A new guiding strategy for treating the free margin of the leaflet in an aortic root remodelling procedure

Xinjin Luo[1*], Shaoye Wang[1], Juntao Qiu[1], Xuanshu Li[1], Peng Zhang[1], Yuetang Wang[1] and Cuntao Yu[1]

Abstract

Backgroud In valve-sparing aortic root replacement procedure, leaflet prolapse can be corrected by shortening the length of the free margin. But precisely determining the extent of the reduction remains a problem. This study wants to explore the effectiveness of a guiding strategy in treating the free margin of the leaflet in a modified aortic root remodelling procedure with external sub-valvular ring.

Methods Between January 2021 and May 2024, 12 patients with aortic root aneurysms underwent modified aortic root remodelling with an external sub-valvular ring (10 males and two females). Their mean age was 42 ± 14 years. The graft diameter was determined according to the criteria of the Lansac group, based on the aortic annulus diameter. The free margin of the leaflet was treated with central plication based on a standard (target length of the free margin of the leaflet = the diameter of the selected graft + 3 ~ 5 mm).

Results The surgery was successfully completed in all 12 patients, with no hospital deaths or complications. Four patients required central plication of the free margin of three leaflets, two required treatment of two leaflets, three required treatment of one leaflet, and three did not require treatment of the free margin of the leaflet. No more than mild degree of residual aortic regurgitation was observed postoperatively. After reconstruction of the aortic root, the measured effective height and coaptation length were 8.9 ± 1.3 mm and 5.3 ± 0.9 mm, respectively.

Conclusions A guiding strategy based on the diameter of the selected graft can be effectively used to manage the length of the free margin of the leaflet in a modified aortic root remodelling procedure with external sub-valvular ring.

Keywords Valve-sparing aortic root replacement, Aortic root remodelling procedure, Aortic annuloplasty

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Backgroud

Yacoub et al. were the first to propose the valve-sparing aortic root remodelling procedure [1] to improve the postoperative quality of life in patients with aortic root aneurysms. Furthermore, Lansac et al. proposed the modified aortic root remodelling procedure involving an external aortic annular ring [2], which improved long-term efficacy, aiming at the defect that classical aortic root remodelling failed to stabilizing the basal ring.

However, during the valve-sparing aortic root replacement procedure, the normalisation of the aortic root dimension, especially that of the sinotubular junction (STJ), may cause the prolapse of one or more aortic valve leaflets. This prolapse should be corrected by reducing the length of the free margin (FML) using techniques such as central plication of the leaflet. Therefore, the extent to which the length of the free margin of the leaflet should be reduced to restore the cusp height to normal is a critical challenge. Dr Schäfers guided the procedure using a self-designed leaflet-height-measuring calliper [3]. In the valve-sparing reimplantation procedure, Dr Yu Cuntao proposed the following empirical formula to guide FML treatment: the target length of FML = the diameter of selected artificial graft for root reconstruction + 3 ~ 5 mm.

In this study, we hypothesised that a method that manages the length of the free margin of the leaflet based on the diameter of the selected graft could be effectively used in a modified aortic root remodelling procedure with an external sub-valvular ring. We reviewed the results of patients with aortic root aneurysms treated at our institution to confirm the effectiveness of this strategy.

Methods

This study was a retrospective study. We analyzed data from January 2021 to May 2024 on consecutive patients with aortic root aneurysms who received modified aortic root remodelling with external sub-valvular ring. A total of 14 patients were admitted during this period, 2 patients with bicuspid aortic valves were excluded, and 12 patients with tri-leaflet configuration were included in the analysis.

The mean age of the 12 patients (10 males and two females) was 42 ± 14 years. Marfan syndrome was diagnosed in three patients. Notably, all the patients had aortic valve insufficiency preoperatively. Table 1 shows the degree of insufficiency and the status of aortic root dilation.

Notably, all patients underwent full-phase aortic root scans with Siemens dual-source computed tomography (CT) (Siemens Healthcare GmbH, Forchheim, Germany) preoperatively, and the data were analysed using 3mensio software (Dutch PIE Medical Imaging Company, Maastricht, Netherlands) to calculate the diameter of each patient's aortic annulus (basal ring) based on the area and circumference. Furthermore, based on the calculated aortic annulus size, the Lansac group's experience [4] was recommended for deciding the diameter of the Dacron graft to be reconstructed for the aortic root (26 mm, 28 mm, and 30 mm grafts for an annulus diameter of 25–27 mm, 28–30 mm, and 31–35 mm, respectively).

The surgery was performed under conventional cardiac surgery anaesthesia and cardiopulmonary bypass support with femoral artery perfusion.

Furthermore, the quality of the valve leaflets was assessed after dissecting the ascending aorta, and the geometric height (gH) of each leaflet was measured. Annulus size was confirmed using a St Jude mechanical valve size plug gauge (St. Jude Medical, Minneapolis, MN, USA) that approximated the preoperative CT

Table 1 Preoperative and postoperative echocardiographic data

	G	Y	TTE Preoperative			Pre-discharged		Postoperative 6 M	
			Sinus	AI	LVDD	AI	LVDD	AI	LVDD
1	M	46y	53 mm	mild-moderate	53 mm	none	47 mm	trace	48 mm
2	M	52y	59 mm	severe	72 mm	none	56 mm	trace	58 mm
3	M	28y	49 mm	moderate	52 mm	trace	41 mm	none	46 mm
4	M	59y	49 mm	severe	64 mm	trace	49 mm	mild	51 mm
5	F	30y	52 mm	moderate	47 mm	trace	36 mm	trace	43 mm
6	M	61y	53 mm	moderate	55 mm	mild	50 mm	mild	52 mm
7	M	52y	72 mm	moderate-severe	58 mm	trace	44 mm	mild	49 mm
8	F	25y	58 mm	mild-moderate	57 mm	trace	48 mm	trace	55 mm
9	M	23y	57 mm	moderate -severe	54 mm	mild	48 mm	mild	51 mm
10	M	56y	66 mm	severe	67 mm	mild	56 mm	mild	55 mm
11	M	37y	66 mm	severe	58 mm	trace	58 mm	trace	53 mm
12	M	42y	54 mm	moderate -severe	60 mm	mild	55 mm	mild	52 mm

Note: G, gender; Y, year; M, month; TTE, transthoracic echocardiography; AI, aortic insufficiency; LVDD, left ventricular end-diastolic diameter

estimate value, and the diameter of the selected Dacron graft was finally determined.

A 7/0 prolene suture (PROLENE™ Polypropylene Suture, Ethicon LLC, Johnson & Johnson, New Brunswick, NJ, USA) was applied to the nodule of Arantius in the centre of each of the three leaflets, and the leaflets were gently pulled toward the centre of the aortic orifice without excessive tension. After straightening the free margin of the leaflet on both sides of the 7/0 prolene traction suture, the length of the free margin of each leaflet was measured in two sections using medical calliper forceps (Jinzhong Surgical Instrument Factory, Shanghai, China) with the suture point of 7/0 prolene traction suture as the boundary (Figs. 1 and 2). The sum of these two sections was known as the FML.

The standard for evaluation was as follows: target length of the FML = the diameter of the selected artificial graft for root reconstruction + 3 ~ 5 mm. Leaflets with the FML lengths within this range were not processed. In cases exceeding this range, the free margin of the leaflet was centrally plicated with a 6/0 prolene suture (Fig. 3) to reduce the FML to the target length of approximately 'the diameter of selected artificial graft + 4 mm'.

The left and right coronary artery openings were freed as a button, and the aortic root was dissected along the lateral aortic wall to the sub-valvular level of the basal ring.

Furthermore, at the nadir of each sinus and the same level as the bottom of the interleaflet triangle, a 2/0 polyester braided suture (Ethicon 3/8 25-mm needle; Ethicon LLC, Johnson & Johnson, New Brunswick, NJ, USA) with pericardial patch was sewn, with a total of 5–6 stitches. The suture was perforated from the arterial lumen to the lateral side of the aortic wall and was used as the external ring fixation suture. Therefore, to protect the membranous septum, no suture was placed at the interleaflet triangular area of the Right-Non commissure junction. However, a 5/0 prolene suture with a patch was sewn onto the roof of the right atrium just against the outer wall of the aorta as an external ring fixation suture.

The aortic sinus wall was trimmed, leaving a tissue margin of 3–5 mm from the fibrous annulus as the suture margin. One end of the selected Dacron graft was cut along three longitudinal incisions into three equal parts, and each part was then trimmed to a scalloped shape. The height of the longitudinal incision (the position of the apex of the new leaflet commissure junction after root reconstruction) was equal to the diameter of the selected Dacron graft. A 5/0 prolene suture was used to anastomose the three scalloped part to the remaining tissue margins of the three sinus walls.

A circular ring approximately 4 mm in height, corresponding to three to four folds on the graft, was cut from the selected Dacron graft as the external sub-valvular ring. The external ring was then pushed into a sub-valvular position along the sutured graft. Pre-set fixation sutures were used to pass around the Dacron ring and knots.

Two holes were made using an electric cautery in the suitable position on the Dacron graft and got trimmed. Then, they were anastomosed to the left and right coronary artery openings, respectively. Finally, the graft was anastomosed with the distal incision of the ascending aorta.

The surgery was completed only when transoesophageal echocardiography confirmed that the aortic valve had no more than mild regurgitation or remnants of mild regurgitation of central reflux after the cardiopulmonary bypass support stopped. Otherwise, cardiopulmonary bypass should be performed again and the aortic valve should be further treated. By using echocardiography, aortic valve function was evaluated, the diameter of the newly formed aortic sinus was measured, and the effective height (eH) and coaptation length (CL) of the leaflets were also measured.

The medical records of the patients were collected during hospitalisation, and echocardiographic data were collected at 3-, 6-month and 1 year after discharge. Furthermore, continuous variables were described in terms of mean ± standard deviation.

Results

All 12 patients with aortic root aneurysms and valve insufficiency successfully underwent valve-sparing aortic root replacement without in-hospital mortality or complications. Furthermore, all patients underwent simultaneous ascending aortic replacement, one underwent partial aortic arch replacement, and another underwent tricuspid valve repair. Table 2 shows the intraoperative measurements of the gH and FML valves. The aortic cross-clamping and cardiopulmonary bypass time were 222.1 ± 32.2 min and 262.3 ± 34.1 min, respectively. However, the average length of hospital stay postoperatively was 9 ± 2 days.

For aortic root reconstruction, a straight tubular graft (Hemashield Platinum; Maquet, Rastatt, Germany) was used in nine patients. In the other three patients, a Valsalva graft (Terumo Aortic, Renfrewshire, United Kingdom) was used. The Valsalva graft was preferred, and straight tubular graft was used when a Valsalva graft not available. A 28-mm diameter graft was used in seven patients (one with a Valsalva graft); a 26-mm diameter graft, in four patients (two with a Valsalva graft); and a 30-mm tubular graft, in one patient.

Furthermore, based on the standard for determining the length of the free margin of the leaflet in this study, intraoperatively, all three free margins of the leaflets were treated with central plication in four patients, the

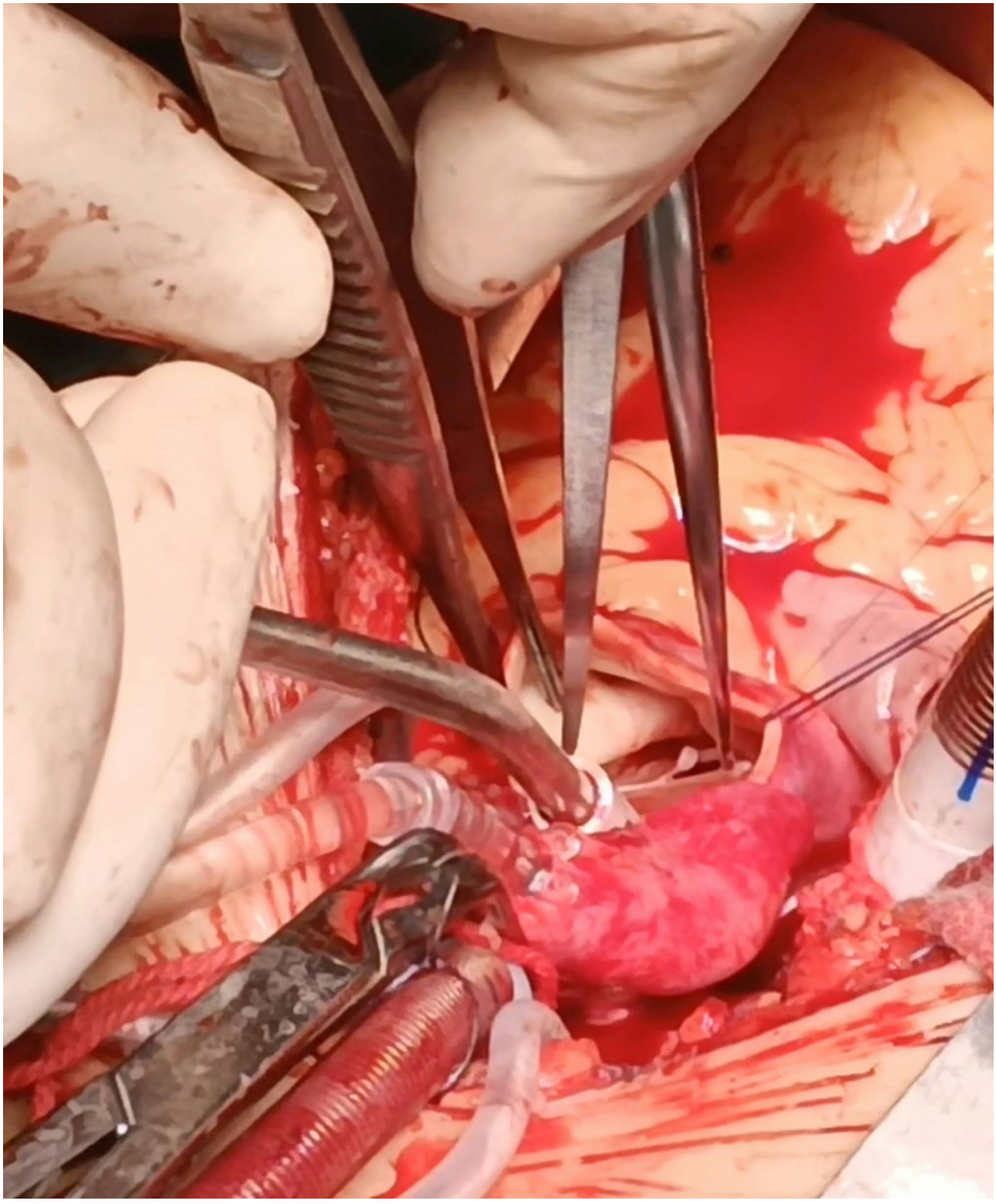

Fig. 1 Measuring the free margin of the leaflet

Fig. 2 The calliper forceps used during the operation

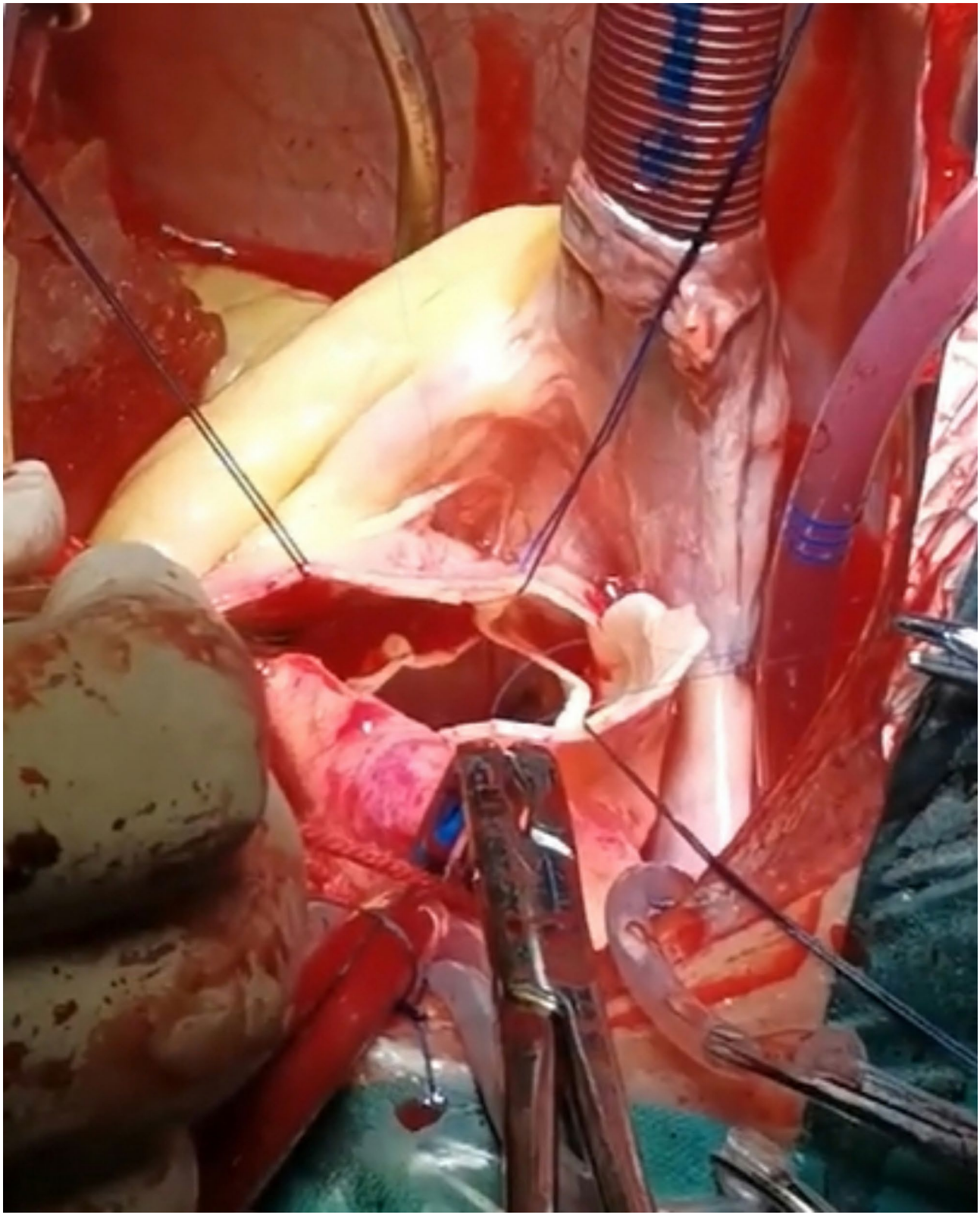

Fig. 3 Central plication of the free margin of the leaflet

Table 2 The measured data during the surgery

	BSA (m^2)	Aortic annulus (mm)	Size and type of the graft	L- leaflet gH FML (mm)		*R*- leaflet gH FML (mm)		*N*-leaflet gH FML (mm)		TEE eH (mm)	TEE CL (mm)
1	1.76	25	26 mm T	18	30	20	31	20	32	10	6
2	1.84	27	26 mm V	19	32	19	30	22	32	10	6
3	1.51	28	28 mm T	16	35#	17	32	17	31	9	5.5
4	2.09	28	28 mm T	20	32	16	32	20	35#	10	5.5
5	1.55	28	26 mm T	17	32	15	31	20	38#	7	4
6	1.93	29	28 mm V	18	33	18	31	20	34	8	4.5
7	1.94	25	26 mm V	25	42#	20	48#	20	55#	11	7
8	2.04	32	30 mm T	20	45#	18	40#	22	41#	8	5
9	2.01	29	28 mm T	22	38#	22	34	22	38#	7	5
10	1.84	28	28 mm T	17	33	19	44#	19	46#	10	5.5
11	2.11	29	28 mm T	25	41#	25	43#	25	41#	8	4
12	2.01	28	28 mm T	20	41#	21	43#	20	39#	9	5

Note: BSA, body surface area; V, Valsalva Dacron graft; T, tubular Dacron graft; L-leaflet, left coronary leaflet; R-leaflet, right coronary leaflet; N-leaflet, noncoronary leaflet; gH, geometric height; FML, free margin length; eH, effective height; CL, coaptation length; TEE, transoesophageal echocardiography. #, indicating the leaflet be plicated

free margins of two leaflets needed to be treated in two patients, only one free margin of the leaflets needed to be treated in three patients, and no free margin needed to be treated in three patients. In 5 patients, 6 leaflets with FML equal to "the diameter of the selected graft + 6 mm" were also not treated. Because it has technically difficult to shorten the length of free margin by 2 mm through central plication (Table 2).

After aortic root reconstruction, the eH measured through intraoperative transoesophaegeal echocardiography was 8.9 ± 1.3 mm, and the CL of the leaflets was 5.3 ± 0.9 mm. However, regardless of whether Valsalva or tubular grafts were used, transoesophaegeal echocardiography revealed an obvious sinus morphology after aortic root remodelling. The diameter of the new sinus with the 28-mm Valsalva graft reconstruction was 35 mm (the maximum value in the whole group). However, the average diameter of the new sinus was 33.5 mm after reconstructing the root with six tubular grafts with diameters of 28 mm. In two other patients, the new sinuses reconstructed with a 26-mm Valsalva graft were 32 mm and 30 mm in diameter, respectively. Furthermore, in two patients, the diameter of the new sinus after root reconstruction with the 26-mm tubular graft was 29 mm. The diameter of the new sinus after root reconstruction with the 30-mm tubular graft was 33 mm.

Postoperatively, aortic valve closure function improved in all patients (Table 1).

Notably, all patients completed a 6-month postoperative follow-up, and echocardiography showed that the degree of aortic regurgitation was not more than mild; the left ventricular dilatation at the end of diastole was reduced postoperatively compared with preoperative conditions (preoperatively: 58.1 ± 6.9 mm vs. 6 months postoperatively: 51.1 ± 4.1 mm). Six patients were followed up for > 1 year; the degree of aortic regurgitation was not more than mild.

Discussion

Valve-sparing aortic root replacement for treating aortic root aneurysms comprises two main categories of techniques: remodelling and reimplantation. In the early days of valve-sparing aortic root replacement, it was thought that restoring normal configuration at the STJ would improve aortic valve closure in patients with aortic root aneurysms. However, in 2002, the Hannover group in Germany reported the treatment experience of reimplantation in the largest group of cases at that time [5]. They found that if the aortic valve leaflets were not specifically treated intraoperatively, postoperative aortic valve coaptation would take on three forms: Type A coaptation point ≥ 2 mm above the lower prosthetic rim; Type B, coaptation close to the lower border of the woven Dacron graft; and Type C, coaptation ≥ 2 mm below the prosthesis. Notably, all patients with type C presented with an AI ≥ grade 2 at 1 year postoperatively [5].

Furthermore, Schäfers et al. proposed the concept of "eH" [3], which suitably explained the clinical findings of the Hannover group. He found that the reduction of STJ diminishes eH during the remodelling procedure. A reduction in the STJ diameter by 3–4 mm consistently led to a height decrease of 2–3 mm [6]. Therefore, to maintain proper closure of the aortic valve, eH must reach 8–9 mm or > 45% of a leaflet gH. To correct the prolapse caused by the root reconstruction procedure, it is necessary to use a technique of free margin shortening, such as leaflet central plication, to increase eH to the normal level. In a large series of valve-sparing root replacements, these techniques were reported to be necessary in 60–90% of patients [7].

Thus, to accurately guide the management of the free margin, Dr Schäfers used a specially designed intraoperative eH measuring calliper. Through direct measurement with callipers, a leaflet with eH < 8–9 mm was centrally plicated, the length of the free margin was shortened, and the leaflet was raised to achieve the ideal eH target value. However, other researchers have used the proportional relationship between critical anatomical structures of the aortic root to guide the treatment of the free margin length of the leaflet. In 2021, Dr Yu Cuntao of Fuwai Hospital proposed an empirical formula to guide reimplantation procedure. His empirical formula was as follows: 'the diameter of artificial graft selected for root reconstruction = (gH of the smallest leaflet of the three leaflets– 2 ~ 3 mm) *2' and 'the target length of FML = the diameter of selected artificial graft + 3 ~ 5 mm'.

The patients in this study received modified aortic root remodelling; however, the guidance method of 'the target length of FML = the diameter of selected artificial graft for root reconstruction + 3 ~ 5 mm' was also directly used in the treatment of free margin length of the leaflet. Aortic valve closure function improved postoperatively, and eH and CL measured using oesophageal ultrasound also reached a satisfactory level.

Anatomical studies on the aortic root have been conducted for many years [7–9]. Owing to different research times, measurement methods, specimen types, and simulated states of the aortic root, the proportional relationship between critical anatomical structures of the aortic root obtained by various studies is not completely consistent. According to De Kerchove et al. [7], the ratio of the FML to STJ diameter is approximately 1.29:1. Based on this relationship, FML is approximately equal to 'the diameter of selected artificial graft + 8 mm'. However, De Kerchove et al. studied normal homogenous aortic root specimens. In this batch of specimens, the height of the leaflet commissure junction was 70% of the STJ diameter. When modified root remodelling was performed, the fixed height of the new leaflet commissure junction was equal to the diameter of the STJ (diameter of the artificial graft). In these two states, the angles formed between the free margins of the leaflets and the horizontal planes were different, which may account for the difference.

Morishita et al. performed root remodelling based on the fact that the diameter of the STJ was approximately 90% of the FML of the leaflet. The size of the artificial graft used in the procedure was selected based on the FML of the leaflet [10]. Based on the proportional relationship they provided, the FML was approximately equal to "the diameter of the selected artificial graft + 3 mm", which is similar to our empirical value. Morishita et al. laid sutures along the free margins of the casts of the aortic leaflets and measured the lengths of the sutures [10]. We sewed 7/0 prolene traction sutures on the nodule of Arantius, and the free margin of the leaflet on both sides of the traction suture was straightened without excessive tension. The two straightened free margins were measured directly using a calliper, and the sum of the two sections was the FML. During the measurement, the outer edges of the two measuring arms of the calliper were aligned with the traction line and inner wall of the leaflet commissure junction to ensure that the length of each section was the distance between the outer edges of the two measuring arms.

The choice of graft size for aortic root reconstruction was based on the diameter of the aortic annulus (basal ring), according to the empirical Table provided by Lansac et al. In one patient, the aortic annulus diameter was 28 mm, and a 28-mm diameter artificial graft should be selected. However, the geometric height of the smallest leaflet measured intraoperatively was only 15 mm in this patient. Therefore, due to the concern regarding small leaflet areas, an artificial graft with a diameter of 26-mm was used based on the selection principle of graft calibre proposed by Dr Yu Cuntao.

In the present study, the selection of the external subvalvular aortic annuloplasty ring was inconsistent with that of Lansac et al., and a circular Dacron ring with the same calibre as the selected artificial graft was used as the external ring. According to Ismail et al. [11], the diameter of the aortic basal ring is reduced to 4 ~ 5 mm smaller than that of the external Dacron ring after extra-aortic annuloplasty ring implantation in the root remodelling procedure. Therefore, the ratio of STJ diameter to basal ring diameter after root reconstruction can reach the level of 1.1–1.2:1 required by De Paulis et al. [12] and De Kerchove et al. [7], using a Dacron ring with the same diameter as the selected graft.

Of course, this study is only a single-center pilot study, with a limited number of cases and a short follow-up period. A larger number of cases will need to be accumulated to further confirm the effectiveness of this guidance strategy.

Conclusion

The clinical experience of this group of patients showed that the method based on the diameter of the selected graft to manage the length of the free margin of the leaflet can be effectively used in the modified aortic root remodelling procedure with an external sub-valvular ring.

Abbreviations

AI	Aortic insufficiency
CT	Computed tomography
eH	Effective height
CL	Coaptation length
STJ	Sinotubular junction
FML	Length of the free margin
gH	Geometric height

Author contributions
Xinjin LUO provided original ideals and performed the operation, and was a major contributor in writing the manuscript; Shaoye WANG took part in the research work and collected data; Juntao QIU performed the follow-up work and analysied data, and made contribution in writing; Xuanshu LI analysied the CT data and took part in the opertaion; Peng ZHANG took part in the opration and prepared the Tables and Figures; Yuetang WANG examined the data in the manuscript; Cuntao YU checked the manuscript and made correction. All authors reviewed the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This was a retrospective study, and informed consent was not obtained from the patients. The Ethics Committee of Fu Wai Hospital approved all clinical and follow-up data (ethics approval number: 2023 – 2018).

Consent for publication
This manuscript does not contain data from any individual person, consent for publication is not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Yacoub M, Fagan A, Stassano P, Radley-Smith R. Result of valve [abstract] onserving operations for [abstract]ortic [abstract]egurgitation [Abstract]. Circulation. 1983;68:III–321.
2. Lansac E, Di Centa I, Sleilaty G, et al. Root remodelling repair with external aortic ring annuloplasty. J Thorac Cardiovasc Surg. 2017;153:1033–42.
3. Schäfers HJ, Bierbach B, Aicher D. A new approach to the assessment of aortic cusp geometry. J Thorac Cardiovasc Surg. 2006;132:436–8.
4. Youssefi P, Zacek P, Debauchez M, Lansac E. Valve-sparing aortic root replacement using the remodelling technique with aortic annuloplasty: tricuspid valves with repair of specific lesion sets: how do I teach it? Ann Thorac Surg. 2019;107:1592–9.
5. Pethig K, Milz A, Hagl C, Harriger W, Haverich A. Aortic valve reimplantation in ascending aortic aneurysm: risk factors for early valve failure. Ann Thorac Surg. 2002;73:29–33.
6. Schäfers HJ, Aicher D, Langer F, Lausberg HF. Preservation of the bicuspid aortic valve. Ann Thorac Surg. 2007;83:S740–5. discussion S785-90.
7. De Kerchove L, Momeni M, Aphram G, et al. Free margin length and coaptation surface area in a normal tricuspid aortic valve: an anatomical study. Eur J Cardiothorac Surg. 2018;53:1040–8.
8. Swanson M, Clark RE. Dimensions and geometric relationships of the human aortic valve as a function of pressure. Circ Res. 1974;35:871–82.
9. Kunzelman KS, Grande KJ, David TE, Cochran RP, Verrier ED. Aortic root and valve relationships. Impact on surgical repair. J Thorac Cardiovasc Surg. 1994;107:162–70.
10. Morishita K, Murakami G, Koshino T, et al. Aortic root remodelling operation: how do we tailor a tube graft? Ann Thorac Surg. 2002;73:1117–21.
11. Basmadjian L, Basmadjian AJ, Stevens LM, et al. Early results of extra-aortic annuloplasty ring implantation on aortic annular dimensions. J Thorac Cardiovasc Surg. 2016;151:1280–5.
12. De Paulis R, Salica A. Surgical anatomy of the aortic valve and root: implications for valve repair. Ann Cardiothorac Surg. 2019;8:313–21.

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