Video Article

Standardized Technique of Aortic Valve Re-implantation for Valve-sparing Aortic Root Replacement

Reza Tavakoli[1,2], Guillaume Lebreton[1], Max Gassmann[2], Peiman Jamshidi[3], Pascal Leprince[1]

[1]Department of Cardiovascular and Thoracic Surgery, Pitie Salpetriere University Hospital, Assistance Publique, Hopitaux de Paris (APHP), Institut de Cardiologie

[2]Institute of Veterinary Physiology and Zurich Center for Integrative Human Physiology, University of Zurich

[3]Herzzentrum Hirslanden, Klinik St Anna

Correspondence to: Reza Tavakoli at reza.tavakoli@uzh.ch

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Abstract

Despite the obvious advantages of the preservation of a normal aortic valve during aortic root replacement, the complexity of valve sparing procedures prevents a number of cardiac surgeons from incorporating them into their practice. The aim of this protocol is to describe a simplified and user-friendly technique of an aortic valve-sparing root replacement (VSRR) procedure by re-implantation of the aortic valve. Proper selection of patients and limitations of the technique are discussed.

In 54 consecutive patients, normal appearing aortic valves were re-implanted in a commercially available polyester prosthesis with pre-shaped sinuses by a simplified and standardized technique. Placement of the first row of the proximal suture line, choice of the prosthesis size, and adjustment of the height of the commissures of the patient to the fixed height of the sinus portion of the prosthesis were slightly modified from the reference techniques with the aim of increasing its feasibility for use by other cardiac surgeons. Early mortality and morbidity as well as 5-year survival, freedom from aortic valve reoperation, and freedom from recurrent moderate regurgitation were collected in all patients.

Thirty-day mortality, re-sternotomy for bleeding, re-sternotomy for mediastinitis, and the incidence of stroke were very low, 1.8% for each (1 of 54). No patient required permanent pace-maker implantation. At 5 years, survival, freedom from aortic valve reoperation, and freedom from recurrent moderate regurgitation were 97.5%, 95.2%, and 91.6%, respectively.

Mid-term results of our standardized technique of re-implantation of the aortic valve for valve-sparing aortic root replacement are very good and compare with more complex techniques reported by experienced surgeons. By following the present protocol of the standardized re-implantation technique, a greater number of cardiac surgeons can perform this procedure with comparable good results.

Video Link

The video component of this article can be found at https://www.jove.com/video/56790/

Introduction

During the past twenty years, the surgical treatment of aortic root aneurysm with normal or near-normal aortic cusps has evolved thanks to a series of surgical procedures aiming at preservation of the native aortic valve[1,2,3,4,5]. Valve-sparing aortic root replacement is basically accomplished either by re-implantation of the aortic valve inside a synthetic graft[1,3,4,6] or by a remodeling technique which restores the physiological anatomy of the aortic root[2]. Despite the obvious advantages of the preservation of a normal aortic valve during aortic root replacement, many cardiac surgeons replace the aortic valve with either mechanical or biological valve substitutes. According to the Society of Thoracic Surgeons database, only 14% of patients who underwent aortic root replacement in the United States between 2004 and 2010 received a valve-sparing procedure[7].

In the original re-implantation technique, the aortic valve is sutured inside a tubular horizontally crimped synthetic graft[8]. Although this technique stabilizes the aortic annulus, it eliminates the sinuses of Valsalva. In order to recreate the sinuses of Valsalva, this technique has undergone several modifications by its inventor as well as other authors[9]. A variation of this technique has been proposed by Rama *et al.*, in which the remnants of the aortic wall supporting the commissures are sutured into longitudinal openings made in the tubular polyethylene terephthalate graft[4].

The remodeling technique achieves a more anatomical reconstruction of the aortic root but leaves the aortic annulus unsupported and exposed to future dilatation. Various surgical techniques have been designed to tailor the aortic annular base in aortic root remodeling, including sub-commissural aortic annuloplasty[10], circumferential suture annuloplasty[11], and internal or external annuloplasty by synthetic partial or complete ring[12].

Despite the excellent results reported by experienced authors, the complexity and periodical modifications of these procedures hamper their reproducibility by other cardiac surgeons and thus prevent a number of suitable patients to benefit from retaining their own aortic valve. In order to enhance the reproducibility of the re-implantation technique, we have used a commercially available synthetic graft with an uncrimped, pre-shaped sinus portion and simplified the implantation technique. The aim of this protocol is to describe in detail this standardized and reproducible technique with particular emphasis on the management of the first row of the proximal suture line and of the placement of the commissures inside the graft and the choice of the graft size. Early outcomes and mid-term results are presented. Proper selection of patients for and limitations of this procedure are discussed.

Protocol

The protocol follows the institutional guidelines of the human research ethics committee.

1. Pre-selection of the Patient

1. Identify patients with dilation of the sinuses of Valsalva not exceeding 60 mm using the pre-operative computer tomography (CT) scan.
2. Next, select among these patients a subgroup with normal or near-normal appearing aortic valve cusps on their pre-operative echocardiography.
3. Inform the staff of the possibility of a valve sparing aortic root replacement procedure.
4. Make the final decision intra-operatively after inspection of the aortic valve. Verify the absence of calcifications of the cusps and/or thickening and retraction of their free margin.

2. Preparation for Surgery

NOTE: Preparation for surgery follows the institutional guidelines and recommendations for adult cardiac surgery patients.

1. Prepare the surgical suite and patient for surgery as previously described[13].

3. Surgery

1. Access to the heart through a median sternotomy, as previously described[13] (**Figure 1A**).
2. **Prepare the aortic root for replacement.**
    1. Grab the ascending aorta at the sino-tubular junction with Carpentier dissection forceps. Make a horizontal opening with a #11-blade knife.
    2. Complete the aortotomy circumferentially and horizontally with Metzenbaum scissors.
    3. After having transected the aorta, verify the absence of calcifications of the cusps and/or thickening and retraction of their free margin. Check the coronary ostia.
    4. Dissect free from the surrounding tissue the outer aspect of the non-coronary sinus down to the roof of the left atrium.
    5. Detach the right coronary ostium from the aortic wall with a generous circular patch, leaving 5 mm of the aortic wall remnant attached to the insertion of the cusp (**Figure 1B**).
    6. Free the commissure between the non-coronary and right coronary sinus from the surrounding tissue.
    7. Dissect free the outer aspect of the aortic wall remnant of the right coronary sinus from the outflow tract of the right ventricle.
    8. Free the outer aspect of the commissure between the non-coronary and left coronary sinus down to the roof of the left atrium.
    9. Excise the aortic wall of the non-coronary sinus leaving 5 mm of the aortic wall remnant attached to the insertion of the cusp.
    10. Separate the outer aspect of the commissure between the right and left coronary sinus from the surrounding tissue. Take care not to injure the pulmonary artery.
    11. Detach the left coronary ostium from the aortic wall with a generous circular patch, leaving 5 mm of the aortic wall remnant attached to the insertion of the cusp (**Figure 1B**). Mobilize the left main coronary artery over its first 10 mm.
    12. Dissect free the outer aspect of the aortic wall remnant of the left coronary sinus from the roof of the left atrium.
    13. Put a mattress 4/0 polypropylene stay suture on top of each commissure.
3. **Start the proximal implantation of the prosthesis.**
    1. Perform the first row of the proximal anastomosis by 12 mattress non-pledgeted 2/0 braided polyester sutures. Put these sutures circumferentially in a horizontal plane 1 - 2 mm below the insertion of the cusps and at the base of the commissural triangles except for the commissure between the non-coronary and right coronary sinus (**Figure 2A**).
    2. Put the first mattress suture at the base of the commissural triangle between the non-coronary and left coronary sinus. Put the second and third sutures 1 - 2 mm below the insertion of the non-coronary cusp, in the direction of the commissure between the non-coronary and right coronary sinus.
    3. Place the forth suture next to the third one in the direction of the commissure between the non-coronary and right coronary sinus by avoiding the base of the commissural triangle between the non-coronary and right coronary sinus and thus not compromising the membranous septum.
    4. Start the first suture of the right coronary sinus 2 mm away from the base of the commissural triangle of the commissure between the non-coronary and right coronary sinus, thus skipping the membranous septum (**Figure 2B**).
    5. Put the following sutures of the right coronary sinus in the direction of the commissure between the left and right coronary sinus.
    6. Place the forth suture of the right coronary sinus at the base of the commissural triangle of the commissure between the left and right coronary sinus.
    7. Next, pass 4 equidistant mattress sutures 1 - 2 mm below the insertion of the left coronary cusp for fixation of the left coronary sinus.

8. To choose the size of the prosthesis, add 4 to 6 mm to the size of a commercially available biological valve sizer which passes comfortably through the left ventricular-aortic valve junction.
9. Determine the commissural height between the commissural stay suture and the mattress suture at the basis of the commissural triangle. To adjust the commissural heights of the patient to the pre-shaped sinuses of the prosthesis, pass the 4/0 polypropylene commissural stay sutures inside-outside of the prosthesis in the vicinity of its sino-tubular junction.
10. Be aware that the height of the commissure between the left and right coronary sinus is often slightly less than that of the other two. Trim circumferentially the lower neck of the prosthesis 2 mm below the measured commissural height to adapt the height of the sinuses of the prosthesis to that of the commissures and to be able to pass the first row of the mattress sutures through the prosthesis.
11. Now pass the mattress sutures inside-out into the prosthesis. Slide down the prosthesis thus placing the valve inside it (**Figure 3A**). Tie the mattress sutures gently and cut them.
12. Start the second row of the proximal anastomosis by three 5/0 polypropylene running sutures, one for each sinus.
13. Begin the first 5/0 polypropylene running suture at the nadir of the left coronary sinus to fix the remnant of the aortic wall inside the prosthesis by following in parallel the insertion of the cusp up to the commissure between the left and right coronary and then up to the commissure between the left and non-coronary sinus. Put the 2 ends under slight tension.
14. Continue with the second 5/0 polypropylene running suture at the nadir of the right coronary sinus to fix the remnant of the aortic wall inside the prosthesis by following in parallel the insertion of the cusp up to the commissure between the right and left coronary and then up to the commissure between the right and non-coronary sinus. Put the 2 ends under slight tension.
15. Place the third 5/0 polypropylene running suture at the nadir of the non-coronary sinus to fix the remnant of the aortic wall inside the prosthesis by following in parallel the insertion of the cusp up to the commissure between the non-coronary and left coronary sinus.
16. Finish the second row of the proximal anastomosis by fixing the remnant of the aortic wall in parallel to the insertion of the cusp up to the commissure between the non-coronary and right coronary sinus. Tie at each commissure the two suture-ends together (**Figure 3B**).
17. Check the absence of aortic regurgitation by filling the prosthesis with saline and applying suction to the vent placed through the right pulmonary vein and the mitral valve into the left ventricle.

4. **Reconnect the coronary ostia to the prosthesis (Figure 4).**
    1. Create a button hole in the left sinus of the prosthesis adjusted to the size of the left coronary ostium patch.
    2. Begin the anastomosis at the nadir of the button hole in the prosthesis from inside out and to the left coronary ostium from outside in by a 6/0 polypropylene running suture.
    3. Place the second stitch 2 mm to the right of the first one from inside out of the prosthesis and outside in of the left coronary ostium up to the mid-height of the right ridge of the anastomosis. Put the suture end under light tension.
    4. Continue the running suture on the left ridge of the anastomosis from outside in the prosthesis and from inside out of the left coronary ostium to meet the other end. Tie the two ends together.
    5. Create a button hole in the right sinus of the prosthesis adjusted to the size of the right coronary ostium patch.
    6. Connect the right coronary ostium to the prosthesis by a 6/0 polypropylene running suture, starting at the nadir of the right coronary ostium from inside out and into the prosthesis from outside in.
    7. Continue the suture to the mid-height of the right ridge of the anastomosis and put the end under light tension.
    8. Complete the anastomosis by running the left ridge of the anastomosis to meet the other end. Tie the two ends together.

5. **Perform the distal anastomosis (Figure 4).**
    1. Start the anastomosis at the nadir of the distal end of the prosthesis from inside out and into the distal ascending aorta from outside in by a 5/0 polypropylene running suture. Run up the suture first to the mid-height of the right ridge of the anastomosis.
    2. Complete the distal anastomosis by running the suture on the left ridge to meet the other end. Tie the ends together.
    3. Tilt the operating table in the Trendelenburg position. Let the pump flow reduce to 50% of the full flow and slowly remove the aortic cross-clamp under gentle aspiration of the left ventricular vent.
    4. Resume the full flow of the cardio-pulmonary bypass. Check the operative field for undue surgical bleeding.
    5. Rewarm the patient to 37 °C and separate the patient from the cardio-pulmonary bypass. Stabilize blood pressure, neutralize heparin by protamine infused IV in a 1:1 ratio (3 mg/kg corresponding to 300 U/kg of heparin).
    6. Check for hemostasis and put the chest drainage as needed. Close the chest in standard fashion by reapproximating the sternum with sternal wires and the soft tissue with absorbable sutures in two layers[13].

4. Post-operative Patient Care

1. Following the transfer to the intensive care unit, provide the patient with standard post-operative care for cardiac surgical operation on aortic root[13].

Representative Results

Statistical Analysis:

Continuous variables are presented as mean ± standard deviation and categorical variables as percentages. Kaplan-Meier curves are calculated for survival, freedom from aortic valve reoperation, and freedom from recurrent moderate regurgitation using a commercially available software package.

Patient Population:

VSRR according to the present protocol was performed in 54 consecutive patients with aortic root aneurysm ≤60 mm and normal or near-normal appearing aortic valve (**Table 1**). The majority of patients were adult males in stable clinical condition (**Table 1**). Thirty-two patients underwent isolated VSRR whereas twenty-two had a VSRR combined with other cardiac surgical procedures (**Table 2**). For patients undergoing isolated VSRR, cross-clamp and cardiopulmonary bypass times were shorter than for those having combined operations (**Table 2**).

Early Outcomes:

Thirty-day mortality, re-sternotomy for bleeding, re-sternotomy for mediastinitis, and the incidence of stroke were very low, 1.8% for each (1 of 54). No patient required permanent pace-maker implantation.

Mid-term Survival:

There were 2 deaths during the follow-up period. One patient died 4 years after the operation of sudden death. The echocardiographic study one year before had shown trivial aortic regurgitation and normal ejection fraction. A second patient died 6 years after the operation following a car accident. This patient had stable moderate aortic regurgitation with stable left ventricular dimensions and without impairment of the left ventricular function on successive follow-up echocardiographic examinations. Thus, the 5 year and 10 year survival in this series were 97.5% and 92.5%, respectively (**Figure 5A**).

Mid-term Freedom from Reoperation on Aortic Valve:

Mid-term Freedom from Reoperation on Aortic Valve: Two of the four patients with recurrent moderate aortic regurgitation underwent reoperation because of progredient left ventricular dilatation. One of these two patients had been reoperated early on after one week for mediastinitis. At reoperation for valve replacement 36 months later, the plication of the right coronary cusp was torn, presumably due to accompanying bacteremia during his mediastinitis. At the second valve operation, he received a full-root stentless aortic valve replacement and survived. The second patient was reoperated for aortic valve replacement 49 months after the initial operation. At reoperation, the free edge of the plicated left and right coronary cusps was fibrotic and considerably retracted. He received a mechanical aortic valve replacement through the synthetic prosthesis and survived. Thus, the freedom reoperation for aortic valve replacement at 5 years and 10 years was 95.2% and 93%, respectively (**Figure 5B**).

Mid-term Freedom from Moderate Aortic Regurgitation:

Four patients developed moderate (2+) aortic regurgitation[14] during the follow-up period. All these patients had tricuspid aortic valves. Only one of these four patients left the operating room with mild insufficiency at the end of the operation. Because of his stable asymptomatic clinical status and echocardiographic surveillance parameters (left ventricular function and dimensions) he is being followed-up without reoperation. Two of the four patients underwent reoperation on the aortic valve. The fourth patient was the one who died following a car accident. Thus, the freedom from moderate aortic regurgitation at 5 years and 10 years were 91.6% and 90%, respectively (**Figure 5C**).

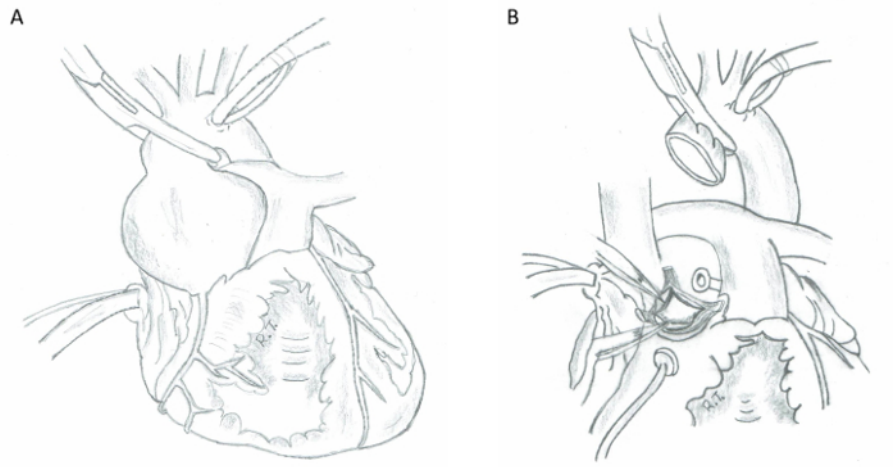

Figure 1: Schematic view of the heart after establishment of the cardiopulmonary bypass. (**A**) The ascending aorta is cross-clamped below the origin of the innominate artery. (**B**) Coronary buttons are detached from the aortic wall and the sinuses are excised. Please click here to view a larger version of this figure.

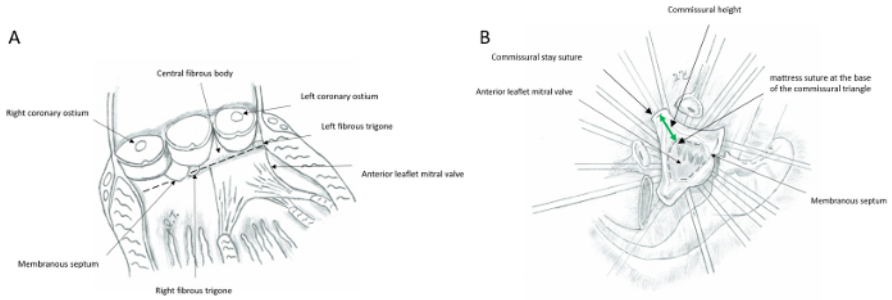

Figure 2: Distribution of the first row of mattress sutures for the proximal anastomosis. (**A**) Mattress sutures are passed circumferentially through the aorto-ventricular junction in a horizontal plane 1 - 2 mm under the nadir of the aortic valve. (**B**) Care is taken to avoid passing sutures through the membranous septum. Please click here to view a larger version of this figure.

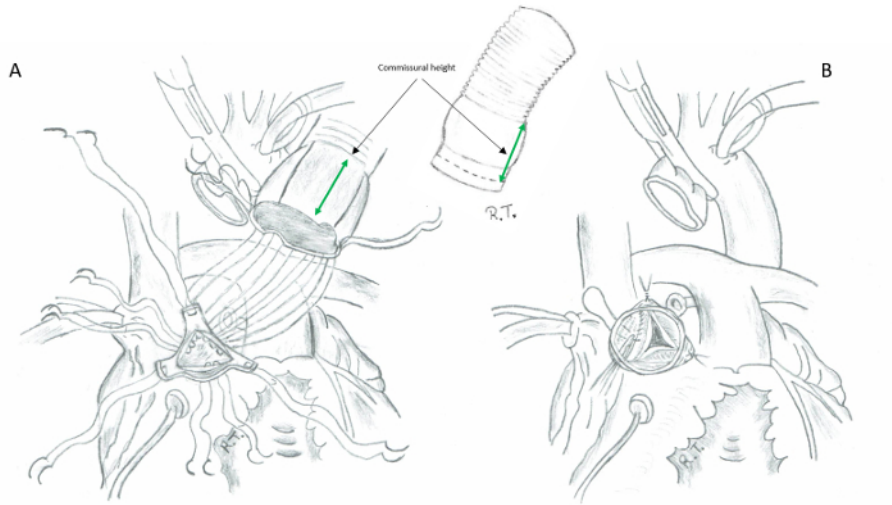

Figure 3: Implantation of the pre-shaped sinus graft. (**A**) The mattress sutures of the first row of the proximal anastomosis are then passed through the tailored proximal skirt of the graft. (**B**) The second row of sutures fixes the remnants of the aortic wall inside the graft. Please click here to view a larger version of this figure.

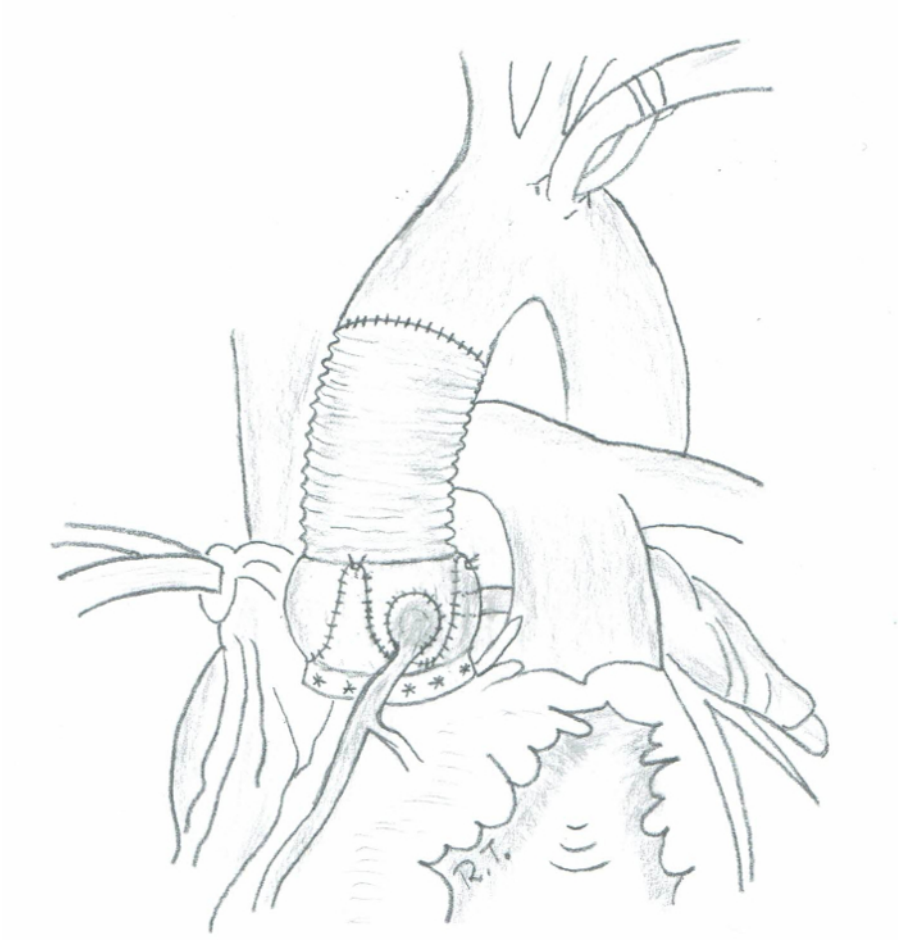

Figure 4: Completion of the implantation of the graft. The coronary ostia are connected to the graft and the distal anastomosis completed. Please click here to view a larger version of this figure.

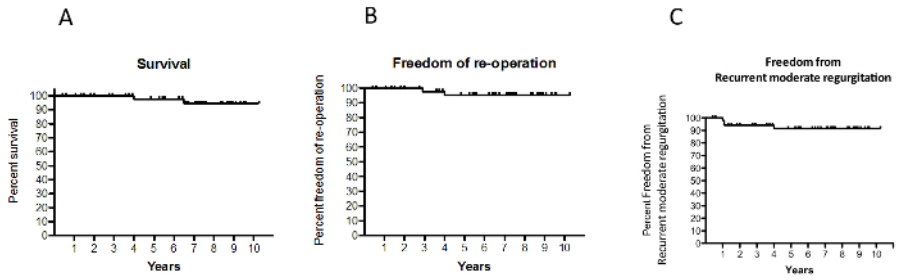

Figure 5: Kaplan-Meier curves at 10 years. (**A**) Survival. (**B**) Freedom from reoperation on the aortic valve. (**C**) Freedom from recurrent moderate aortic regurgitation Please click here to view a larger version of this figure.

	Age (years)	61 ±11
	Male sex	46 (85%)
Diagnosis		
	Aneurysm	48 (89%)
	Type A Dissection	6 (11%)
NYHA class		
	I	31 (57%)
	II	7 (13%)
	III	10 (19%)
	IV	6 (11%)
	Emergency	7 (13%)
EF		
	≥50%	45 (83%)
	>35%, <50%	6 (11%)
	≤35%	3 (6%)
Pre-operative aortic regurgitation		
	0	10 (19%)
	1+	9 (17%)
	2+	18 (33%)
	3+	17 (31%)
	Aorto-ventricular junction (mm)	26.2 ±1.3
	Valsalva sinus (mm)	49.2 ±9.2

Table 1: Patients' characteristics. Patients' characteristics are depicted in this table. The decision to consider a valve sparing root replacement is based on the diameter of the aorto-ventricular junction less than 28 mm and sinuses of Valsalva less than 60 mm.

	Isolated VSRR	**VSRR associated with other operations**	**Total**
N (%)	32 (59%)	22 (41%)	54
cusp repair	3	11	14
Graft size			
28	2	2	4
30	5	9	14
32	25	11	36
Cross-clamp time (min)	159 ±14	192 ±41	
Cardiopulmonary bypass time (min)	217 ±24	258 ±55	
VSRR = valve-sparing root replacement			

Table 2: Intra-operative data in patients undergoing isolated or combined valve sparing root replacement. Cross-clamp and cardio-pulmonary bypass times are shorter for isolated valve sparing root replacement.

Discussion

In patients presenting with aortic root aneurysm with normal or near-normal aortic cusps, valve-sparing aortic root replacement is a more physiological and hence attractive alternative to composite graft replacement of the aorta and the aortic valve with mechanical or tissue valve. In this protocol, we describe a simplified technique of valve-sparing aortic root replacement by re-implantation of the aortic valve. In contrast to the majority of the previously reported techniques[3,8], in this protocol the mattress sutures of the first row are distributed asymmetrically in order to avoid injury to the membranous septum. Moreover, in the protocol these mattress sutures are not reinforced over pledgets. The rationale to omit pledgets for these sutures is based on the intention to reduce the risk of interference with the normal movements of the valve not only by direct disturbance at an early stage but also by potential granuloma formation around them at a later stage[15]. This simplified technique can also be done in patients with thin and pliable bicuspid valves with creation of two corresponding sinuses. In type 0 bicuspid aortic valves, root

reimplantation is performed at 180°/180° circumferential orientation[16]. In type 1 bicuspid aortic valves the 210°/150° circumferential orientation of conjoint and non-conjoint leaflets is respected while reimplanting the valve into the neosinuses[16].

Two distinct procedures, known as remodeling and re-implantation techniques, have been devised by pioneer cardiac surgeons to address VSRR procedures[1,2]. Controversies around the role of the Valsalva sinuses and the long-term fate of the aortic annulus have resulted in several modifications of both techniques, including hand-tailored or fabric creation of neo-sinuses in the synthetic tube[1,3,4,6] and various techniques of supporting the aortic annulus[10,11,12]. In a very recent study[17] the pioneer of the re-implantation technique expressed uncertainty about the rationale for hand-tailored creation of neo-sinuses, which he himself had introduced and performed over a long period. As this, his historical series of 333 valve-sparing aortic root replacement procedures includes an initial cohort of patients with tubular grafts without neo-sinuses, an intermediate cohort of patients with hand-tailored neo-sinuses, and a last cohort of patients similar to the first one with tubular grafts without neo-sinuses. In his recent study, creation of neo-sinuses was even associated with the late development of moderate or severe aortic regurgitation in univariate but not on multivariate analysis[17]. Thus, the wealth of technical modifications of the valve-sparing procedures reported by not only different surgeons but also by the pioneer of the re-implantation technique do not facilitate the decision-making for other cardiac surgeons, having the skills to perform these procedures and to embark in performing this operation[7].

Bearing these considerations in mind, we have opted for a simplified and standardized approach to valve-sparing operation. We agree with authors considering that preservation of the aortic sinuses is more physiological and potentially favors the durability of the aortic valve[18]. We find also that supporting the aortic annulus in all patients may be advantageous since the dynamic of dilatation of the aorto-ventricular junction remains uncertain[19]. For these reasons, we use a commercially available synthetic graft with pre-shaped, uncrimped sinus portion for re-implantation of the aortic valve in all patients in whom the aortic valve is judged suitable for preservation. Contrary to the opinion that the sinus portion of this graft is spherical and deforms the aorto-ventricular junction[17] we find the uncrimped sinus portion of this graft rather conical and suitable for re-implantation of the commissures inside it.

In the protocol, the proximal suture line is performed in standardized fashion in all patients with 12 polyester 2/0 mattress sutures without pledgets, 4 under each cusp. The distribution of these mattress sutures is asymmetric and slightly different from that described by other surgeons[1,3]. In the present protocol, each sinus is secured with 4 mattress sutures with particular attention not to place any stitch through the membranous septum (**Figure 3A, B**). Following this concept and staying 1 - 2 mm under the nadir of each sinus in a horizontal plan, we did not have to deplore any injury to the anterior leaflet of the mitral valve, membranous septum, or AV-node. In the largest series of patients undergoing VSRR, the incidence of implantation of permanent pacemaker for complete heart block was 1.5%[17].

In some studies, the choice of the graft size has been done by application of complex formulas based on theoretical assumptions of relationship between the diameter of aorto-ventricular junction, height of the cusps, and sinus diameter[8,20,21]. This complexity is an additional factor contributing to the limited propagation of the re-implantation technique reported by experienced surgeons. It is noteworthy that by applying his formula, David *et al.* use a narrow range of graft sizes with a mean of 30.7 ±2.8 mm[22]. Another technical aspect of the technique resides in the pragmatic simplification of the choice of the size of the synthetic graft by using commercially available valve sizers. To choose the size of the graft in this technique, 4 - 6 mm are added to the diameter of the valve sizer that comfortably fits through the aorto-ventricular junction. De Paulis *et al.* use a similar approach by adding 5 mm to the diameter of the aortic annulus measured by a Hegar dilator[19]. By this simplification, the mean diameter of the grafts implanted in the series was 31.2 ±1.3 mm, which is very close to 30.4 ±1.4 mm reported by De Paulis[19] and to that reported by David[22].

It has been claimed that the height of the sinuses of patients may vary and not coincide with the height of the pre-shaped sinus grafts and that this discrepancy could potentially create technical and anatomical difficulties[17]. In standardized technique presented here, this issue is addressed by tailoring the proximal skirt of the graft following apposition of the commissures at the sino-tubular junction inside of the graft. The proximal sutures are then passed through the tailored proximal skirt of the graft.

The mean diameter of the implanted prosthesis was 31.2 ±1.3 mm in the patients which is 5 - 6 mm larger than the measured mean aortic annulus diameter. However, in the case of aortic annulus dilation beyond 28 mm, the choice of prosthesis size may be done by addition of less than 4-6 mm to the measured aortic annulus and associated to commissural annuloplasty in order to enhance cusp coaptation.

Because of the small numbers and limited follow-up of the present series, the results should be regarded expectantly. Nevertheless, early and mid-term mortalities and morbidities are low and encouraging. Early and late mortalities of 1.8 and 3.8% in our patients compare favorably with those reported by larger series with longer follow-up[17,19,23]. Likewise, freedom from reoperation and from moderate to severe recurring aortic regurgitation including the patients who underwent reoperation are very good and similar to those observed by the same authors[17,19,23]. The good results of the presented series are to be ascribed to the simplified technique in selected patients. Ideally, good candidates for re-implantation have moderate dilatation of the sinuses (<55 mm), no or trace aortic regurgitation, and normal or near normal cusp anatomy[17]. The majority of the patients in this study fell into this description.

As mentioned above, small numbers of patients and limited follow-up period are the main limitations of this study. Nevertheless, following technical considerations of this protocol would allow a greater number of cardiac surgeons to perform VSRR.

Disclosures

The authors have nothing to disclose.

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