Redo Aortic Root Operations in Patients with Marfan Syndrome

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Abstract

Aortic root aneurysm is the most common cardiovascular manifestation requiring surgical intervention in patients with Marfan syndrome (MFS), a heritable thoracic aortic disease. Elective replacement of the aortic root is the treatment of choice for patients with aneurysmal complications of the aortic root and ascending aorta. There are two basic approaches to aortic root replacement: valve-sparing (VS) and valve-replacing (VR) techniques. After successful aortic root replacement surgery, several patients with MFS may develop a late complication related to their aortic disease process, such as developing a pseudoaneurysm of the coronary artery reattachment buttons, aneurysmal expansion, or aortic dissection in the remaining native aorta. These patients may also develop other late complications that are not specifically related to the heritable thoracic aortic disease, such as infections that can lead to dehiscence of some or all of the distal or proximal anastomosis. Because these complications are rare, the clinical volume of reoperations of the aortic root in patients with MFS is low, making it difficult to assess contemporary experiences with these procedures. Only a few published reports have examined reoperative aortic root surgery in patients with MFS, each of which had only a small series of patients. Herein, we describe our contemporary experience with reoperative aortic root replacement in patients with MFS and provide our operative approach for these uncommon procedures.

Keywords

- Marfan syndrome
- redo aortic root operation
- remodeling
- valve-sparing aortic root replacement
- Yacoub
- reoperation
- heritable thoracic aortic disease

Marfan syndrome (MFS) is the most common heritable thoracic aortic disease, with a reported incidence of 1 in 5,000 to 1 in 10,000 individuals. It results from an autosomal dominant mutation in the fibrillin-1 gene located on chromosome 15q21, which leads to an alteration of the transforming growth factor β signaling pathway.[1] Patients with MFS have many cardinal features in the skeletal, ocular, and cardiovascular systems. A grossly dilated aortic root is the most common cardiovascular manifestation in patients with MFS,[2] and replacement of the aortic root is eventually required in many to avoid catastrophic aortic dissection or rupture.

Cardiovascular Complications of MFS and Surgical Repair Options

In a case report published in 1968, Bentall and De Bono described the approach they used to perform the first aortic root replacement, which involved using a Teflon graft and Starr valve to simultaneously replace the aortic valve, root, and ascending aorta.[3] Improvements to this approach were made by Cabrol and Kouchoukos.[4,5] Later, Vince Gott at Johns Hopkins introduced the concept of prophylactic aortic root surgery in patients with MFS, by demonstrating a very low

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risk of operative death after elective repair (3%).[6] The introduction of this surgical approach changed the prognosis of patients with MFS who typically had prematurely shortened lifespans when only nonoperative treatments were available.[7] Building on this legacy, Duke Cameron demonstrated the durability of aortic root replacement in such patients.[8] Currently, elective aortic root replacement is indicated for asymptomatic patients with MFS who have one of the following criteria: an aortic root aneurysm $\geq$50 mm in diameter or an aortic root aneurysm $\geq$45 mm and a family history of aortic dissection, rapid aneurysm expansion (>3 mm per year), severe aortic or mitral valve regurgitation, or plans for future pregnancy.[9]

There are two competing approaches to aortic root replacement in patients with MFS: valve-replacing (VR) surgery with either a mechanical or tissue prosthetic aortic valve and valve-sparing (VS) surgery with a remodeling or reimplantation technique. Aortic root replacement using a mechanical valve necessitates lifelong anticoagulation; replacement with a bioprosthetic (tissue) valve has uncertain durability—such issues spurred interest in developing VS approaches. Some of the VS remodeling techniques used include those introduced by Yacoub and colleagues,[10] several iterations introduced by David and colleagues,[11,12] and, most recently, the Florida sleeve,[13] which has failed to pass the test of long-term durability. One concern regarding the use of remodeling techniques during VS operations in patients with MFS is that during these repair procedures, portions of compromised aortic root sinus tissue are left behind and are, thus, further prone to annular dilation over time, resulting in reoperation rates around 60%, as reported by Carrel's experience.[14] A modified remodeling approach in which isolated sinus tissue is replaced has been proposed by Urbanski and colleagues.[15] Today, reimplantation approaches, as led by David,[12] are the commonly preferred VS approach; notably, there is often considerable variation in technique between experienced centers.[16,17] Often the choice between VS and VR aortic root replacement is made intraoperatively and based on the quality of the native aortic valve. Surgeons must be mindful to avoid using this procedure in patients with leaflet fenestration, tissue redundancy, annular dilation, or elongation of the free margin,[18] which will ultimately determine if VS aortic root replacement is feasible and durable.

Clinicians at our institutions and others have compared the outcomes of MFS patients after VS and VR procedures. In 2011, Benedetto et al[19] conducted a meta-analysis of 11 retrospective studies on this topic; they found that the need for aortic valve reintervention was increased in patients who underwent VS aortic root replacement. In 2014, Hu et al[20] conducted a meta-analysis of six observational comparative studies. Their analysis showed no difference in the rates of reoperation after VS and VR procedures, which ranged from a low of 0% when David reimplantation approaches were used to a high of 24% when Yacoub remodeling approaches were used. In 2017, Flynn[21] performed a systematic review and found that reoperation rates for patients who underwent VS versus VR approaches were not statistically different. Early results from the Aortic Valve Operative Outcomes in Marfan Patients (AVOMP) study group, a prospective, multicenter, international registry comparing the details of VS and VR aortic root procedures (for which we are the coordinating center),[22] found similar rates of reintervention between VS ($n = 239$) and VR ($n = 77$) techniques. In time, this registry may help identify the relative advantages and disadvantages of the VS and VR approaches.

After successful VS or VR aortic root replacement, some patients with MFS may develop a late complication related to their aortic disease process, such as developing a pseudoaneurysm of the coronary artery reattachment buttons, aneurysmal expansion, or aortic dissection in the remaining native aorta. Additionally, patients with MFS may also develop other late complications that are not specifically related to the heritable thoracic aortic disease, such as infections that can lead to dehiscence of some or all of the distal or proximal anastomosis (or both). Because these complications are rare, the clinical volume of reoperations of the aortic root in patients with MFS is low, making it difficult to assess contemporary experiences with these procedures. Only a few published reports have presented data on reoperative aortic root surgery in patients with MFS, each of which had only a small number of reoperative patients.[12,15,23–26] ►**Table 1** shows possible indications for reoperations after aortic root replacement surgery in patients with MFS.

Another difficult question is which procedure to perform if reoperation is necessary. The answer differs and is often determined by the index procedure that the patient underwent. When the prior aortic root operation was performed with a mechanical composite valve graft (CVG) and the patient develops a "coronary button pseudoaneurysm," the choice of reoperation could vary widely. One option would be to remove and replace the prior composite root using either direct reimplantation of the coronary buttons directly or by using a small-diameter graft to apply the

Table 1 Indications for redo aortic root replacement in patients with Marfan syndrome

Coronary button aneurysm
Pseudoaneurysm
Dilation of aortic root after VSARR
Infection of graft or pseudoaneurysm
Anastomotic dehiscence
Endocarditis of native or prosthetic aortic valve
Valve thrombosis (mechanical valve)
Perivalvular leak
Degeneration or calcification of bioprosthetic aortic valve or homograft
Aneurysm of prior homograft
Progressive aortic valve regurgitation after VSARR
Other failure of native, mechanical, or bioprosthetic aortic valve

Abbreviation: VSARR, valve-sparing aortic root replacement.

"Cabrol technique."[27] However, the simplest approach would be to leave the root unaltered and plicate the "aneurysmal tissue" around the coronary buttons. Oftentimes, because of adhesions from prior operations, mobilization of the coronary buttons is not feasible, in which case, attachment of the coronary buttons to a saphenous vein graft (usually for the right coronary button) or to an 8- or 10-mm Dacron graft (usually for the left coronary button) is an option (this includes Cabrol and other modifications relying on the use of a small-diameter graft). If the proximal arch or full arch is dilated, then a hemiarch or total arch replacement operation is warranted as well, with the repair performed under hypothermic circulatory arrest. Herein, we describe our contemporary experience with reoperative aortic root replacement in patients with MFS and provide our operative approach for these uncommon procedures.

Table 2 Description of reoperative aortic root replacement procedures in 13 patients with Marfan syndrome

Time interval between procedures (y)	Age at reoperation (y)	Index aortic root replacement	Reason for redo operation	Redo aortic root replacement procedure
0.2	28	Valve-replacing ARR (mechanical CVG)	Graft infection	Homograft replacement of the aortic root, ascending aorta, and hemiarch
0.2	30	Valve-replacing ARR (mechanical CVG)	Graft infection with infected pseudoaneurysm, dehiscence at the annulus, and perivalvular leak	Homograft replacement of the aortic root, ascending aorta, and hemiarch[a]
0.7	25	Valve-replacing ARR (mechanical CVG)	Presumed infection, dehiscence at the annulus, and large pseudoaneurysm	Homograft replacement of the aortic root, ascending aorta, and hemiarch
1.1	55	Valve-sparing ARR	Endocarditis of the native aortic valve with regurgitation and graft infection	Homograft replacement of the aortic root and ascending aorta
1.3	37	Valve-replacing ARR (mechanical CVG)	Graft infection, dehiscence at the distal suture line, and pseudoaneurysm	Bioprosthetic porcine root and graft replacement of the ascending aorta and hemiarch[a]
3.3	33	Valve-replacing ARR (mechanical CVG)	Graft infection, dehiscence at the annulus, and pseudoaneurysm	Homograft replacement of the aortic root, ascending aorta, and hemiarch
7.8	20	Valve-sparing ARR	Dilated aortic root	Mechanical CVG replacement of the aortic root, ascending aorta, and total arch (reverse ET)
7.9	61	Valve-replacing ARR (mechanical CVG)	Endocarditis of the prosthetic aortic valve, graft infection, pseudoaneurysm, and perivalvular leak	Bioprosthetic porcine root and homograft replacement of the ascending aorta
8.7	52	Valve-replacing ARR (bioprosthetic porcine root)	Aortic valve regurgitation, dehiscence of the proximal suture line, and pseudoaneurysm	Bioprosthetic porcine root and graft replacement of the ascending aorta and hemiarch[a]
11.3	38	Valve-replacing ARR (bioprosthetic porcine root)	Severely calcified and degenerated bioprosthetic aortic root, aortic valve stenosis and regurgitation	Mechanical CVG replacement of the aortic root
13.7	59	Valve-replacing ARR (mechanical CVG)	Endocarditis of the prosthetic aortic and mitral valves	Homograft replacement of the aortic root and ascending aorta, mitral valve replacement (tissue)
18.4	59	Valve-replacing ARR (mechanical CVG)	Pseudoaneurysm and aortic valve regurgitation	Mechanical CVG replacement of the aortic root, ascending aorta, and hemiarch
20.3	49	Valve-replacing ARR (homograft)	Aneurysm of the prior homograft and aortic valve regurgitation	Bioprosthetic porcine root and graft replacement of the ascending aorta and total arch, mitral valve repair

Abbreviations: ARR, aortic root replacement; CVG, composite valve graft; ET, elephant trunk.
[a]Resulted in operative death.

Single-Center Experience with Aortic Root Reoperation

In our prospectively maintained database, we identified 13 patients with confirmed MFS and a prior aortic root operation who subsequently underwent reoperation for aortic root replacement at our institution between June 2000 and February 2017 (procedures shown in ►**Table 2**). The majority of these patients were referred from outside facilities to our tertiary aortic center. Approval for this study was obtained from Baylor College of Medicine's institutional review board. The patients' preoperative characteristics and demographics are provided in ►**Table 3**, and a summary of the operative details is provided in ►**Table 4**.

Operative Technique

Preoperative Evaluation

For all the patients studied, a preoperative echocardiogram and a computerized tomographic scan were obtained, which were used to determine the proximity of the previous grafts to the chest wall. It is not uncommon for patients with MFS to have undergone a prior pectus excavatum repair as part of their initial operation. Having this knowledge before the reoperation helps clinicians decide what method to use for chest reentry: redo midline sternotomy or an alternative approach, such as a left-sided thoracotomy.[28] An updated coronary angiogram was obtained for all patients before the operation using the appropriate injections to define the relevant coronary sinus and arterial anatomy, as well as to determine the patency of previous bypass grafts. If there were preoperative signs suggestive of a preexisting infection (e.g., dehiscence or presence of a pseudoaneurysm), blood cultures were obtained and intravenous antibiotics were given preoperatively.

Table 3 Preoperative characteristics

Variable	Distribution
Age	38 [30–55]
Gender, male	4 (30.8)
Prior type A aortic dissection	5 (38.5)
Coronary artery disease	3 (23.1)
Previous CABG	2 (15.4)
COPD/emphysema	1 (7.7)
History of stroke	4 (30.8)
History of smoking	10 (76.9)
Ejection fraction	47 [35–55]
FEV1 (percent predicted)	58.7 [58.3–77.6]

Abbreviations: CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; FEV1, forced expiratory volume in 1 second.
Note: Values are presented as *n* (%) or median [interquartile range].

Table 4 Operative details

Variable	Distribution
Elective repair	6 (46.2)
Urgent repair	7 (53.9)
Redo aortic root replacement	
CVG, mechanical	3 (23.1)
Homograft	6 (46.2)
Bioprosthetic porcine root	4 (30.8)
Reattachment of left coronary artery	
Button	10 (76.9)
Cabrol or hemi-Cabrol	2 (15.4)
Saphenous vein interposition or bypass	1 (7.7)
Reattachment of right coronary artery	
Button	10 (76.9)
Cabrol or hemi-Cabrol	2 (15.4)
Saphenous vein interposition or bypass	1 (7.7)
Concomitant procedures	
Aortic arch replacement	9 (69.2)
Total transverse arch	2 (15.4)
Hemiarch	7 (53.9)
Reverse ET completion	1 (7.7)
CABG	2 (15.4)
Mitral valve repair or replacement	2 (15.4)
CPB	13 (100)
HCA	9 (69.2)
ACP	6 (46.2)
CPB time (minutes)	217 [173–298]
HCA time (minutes)	34 [25–60]
ACP time (minutes)	37 [20–57]
Cannulation site	
Aortic arch	1 (7.7)
Axillary artery	6 (46.2)
Femoral artery	4 (30.8)
Innominate artery	1 (7.7)
Other	1 (7.7)

Abbreviations: ACP, antegrade cerebral perfusion; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; CVG, composite valve graft; ET, elephant trunk; HCA, hypothermic circulatory arrest.
Note: Values are presented as *n* (%) or median [interquartile range].

Surgical Technique

During reoperative aortic root replacement procedures in patients with MFS, a variety of cannulation sites may be used. Most commonly, we used the right axillary artery ($n = 6$, 46.2%) or the femoral artery ($n = 4$, 30.8%). During the redo aortic root operations, the decision of whether to replace the hemiarch or total transverse arch versus solely the ascending aorta was based on the diameter of the distal ascending aorta. However, within our practice, when treating patients with MFS, we pursue reoperations in a more aggressive manner because further reoperations add great complexity to these challenging cases involving patients with heritable thoracic aortic disease. Although we do adhere to aortic-diameter thresholds in general, in these redo operations, we are more liberal about replacing the distal ascending aorta and the proximal arch if the diameter is more than 4 cm because there is a well-established risk in these patients of continued late aortic expansion in any residual native aortic tissue. Another determining factor in whether we proceed with a redo hemiarch or total arch replacement or redo aortic root operation is if the aortic diameter growth rate is more than 0.5 cm/year, as determined using the preoperative images.

If the patient's aortic disease necessitated concomitant hemiarch or total arch reconstruction, during the cooling period, we tried to dissect the aortic root. Multiple times, this was not feasible because of the presence of multiple adhesions and our inability to cross-clamp the ascending aorta. Once the patient's temperature reached ~24°C, flows were decreased on the pump to 10–12 mL/kg/min, and the ascending aorta was divided. The flow rate was dictated by monitoring cerebral perfusion using near-infrared spectroscopy. Commonly, antegrade cerebral perfusion was first initiated unilaterally via the right common carotid artery and then bilaterally via the left common carotid artery by using a 9 Fr Pruitt catheter attached in a Y configuration with the arterial inflow line used for establishing cardiopulmonary bypass. Various reconstruction techniques may be employed for total arch operations in MFS patients, such as using a prefabricated or custom-made bifurcated (Y), trifurcated (double-Y), or single graft (Vascutek Ltd., Renfrewshire, Scotland) or an island patch technique with implantation of two or all three head vessels.

After the distal reconstruction was completed, we started reconstruction of the aortic root. Several patients had an infection with concomitant dehiscence of a suture line. For these patients, an aortic homograft was selected for the reconstruction. The aortic annulus was aggressively debrided during the operation, and all infected and devitalized tissue was removed and sent for microbiologic analysis. Specific attention was paid to removing all residual prosthetic material, including the previously placed pledgets, the Dacron graft, and the cloth on the annular sewing ring of the index prosthetic valve replacement. Any structural cardiac defects resulting from extension of an infected process or from necessary thorough debridement were repaired with bovine pericardium, which was used to patch residual periannular abscess cavities. Debridement of all infected tissue was the most important part of the reoperation for patients with an infected aortic root.

When aortic root homograft conduits were implanted, the proximal suture line of the trimmed cryopreserved homograft was constructed with continuous 2-0 or 3-0 prolene sutures and, when necessary, reinforced with pericardial pledgets. Whenever possible, the coronary ostia were reimplanted as buttons with 5-0 or 6-0 running prolene sutures. In patients in whom the coronary buttons could not be mobilized because of extensive scar tissue, an interposition graft of autologous saphenous vein was placed between the homograft and the coronary artery (left or right) origin. When no adequate vein graft was available, either an 8-mm or 10-mm Dacron graft was used as an interposition graft, a technique described by Cabrol and colleagues.[4]

In patients who did not have an infection, typically a modified Bentall operation was performed with a Valsalva mechanical CVG (St Jude Medical, Inc., St. Paul, MN) or a bioprosthetic porcine root (Freestyle aortic root bioprosthesis; Medtronic Inc., Minneapolis, MN). When implanting a mechanical CVG, we commonly used interrupted horizontal mattress pledgeted valve sutures to secure the CVG into the aortic annulus. For the Medtronic Freestyle bioprosthetic root, we used a 2-0 or 3-0 polypropylene continuous suture to secure the porcine root into the annulus.

After de-airing of the aorta and root had been achieved, the aortic cross-clamp was released. The patients were weaned from cardiopulmonary bypass when their body temperature reached 36.5°C.

Outcomes

For our series of 13 MFS patients who underwent aortic root reoperation, we assessed several postoperative outcomes, including early neurologic events, renal insufficiency necessitating hemodialysis, hospital length of stay, early and late reinfection rate, early and midterm survival, and operative mortality (►**Table 5**). Operative death occurred in three of these patients; two of these patients had evidence of gross infection, and all had dehiscence of a suture line. No patients in our series had postoperative stroke, renal failure, or paraplegia, and there were no reoperations for bleeding. The median length of stay for all patients was 14 days [interquartile range 13–20].

Table 5 Early outcomes

Variable	Distribution
Operative (early) death	3 (23.1)
30-day death	3 (23.1)
Persistent stroke	0
Persistent renal failure	0
Persistent paraplegia	0
Cardiac complications, all	8 (61.5)
Cardiac failure	4 (30.8)
Atrial arrhythmia	3 (23.1)
Heart block/pacemaker	1 (7.7)
Pulmonary complications, all	5 (38.5)
Bleeding requiring reoperation	0
Failure requiring reoperation	1 (7.7)
Postoperative ICU LOS (days)	11 [9–11]
Postoperative overall LOS (days)	14 [13–20]

Abbreviations: ICU, intensive care unit; LOS, length of stay.
Note: Values are presented as *n* (%) or median [interquartile range].

Conclusion

Reoperation in patients with MFS and prior aortic root replacement is uncommon. However, when such redo root reoperation is necessary, it is technically difficult to perform. Often, the coronary artery buttons may be salvaged. Redo root procedures are prompted by pseudoaneurysm formation, coronary button aneurysm, aortic valve regurgitation (if the valve is preserved), endocarditis, infection with and without dehiscence, thrombosis-related valve dysfunction (if a mechanical valve is used), and aortic valve degeneration (if a bioprosthetic valve or homograft is used). Because there is very limited data regarding reoperation in such patients, it is not yet clear how to best prevent reoperation of the aortic root.

Conflict of Interest
None.

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