2772-9931
https://doi.org/10.1016/j.atssr.2023.05.001

Aorta: Case Report

Four-Dimensional Flow Magnetic Resonance Imaging Evaluation of Post–Ross David Procedure With Valve Repair

Benjamin Thomae, BA,[1] Anthony Maroun, MD,[2] Paul Devlin, MD,[1] David Drullinsky, MD,[3] Michael Markl, PhD,[2] and S. Chris Malaisrie, MD[1]

Valve-sparing aortic root replacements have acceptable reintervention rates in patients with failed pulmonary autografts after a Ross procedure. In our 50-year-old patient with post-Ross valve-sparing aortic root replacement, we report preoperative and postoperative 4-dimensional flow magnetic resonance imaging capturing changes in peak systolic velocity, 3-dimensional systolic flow profiles, and aortic wall shear stress that may predict a decreased risk of aortic dilation, a common complication in repeated Ross procedures.

(Ann Thorac Surg Short Reports 2023;1:392-394)

Up to 25% of patients require reoperation within 15 years of the Ross procedure; neoaortic insufficiency and autograft dilation are the commonly cited concerns requiring intervention.[1] Patients with fenestrations and leaflet prolapse were once thought to be poor candidates for valve-sparing aortic root replacement (VSARR), but high-experience centers currently perform successful post-Ross VSARRs with concurrent valve repair.

Noninvasive 4-dimensional (4D) flow magnetic resonance imaging (MRI) is a useful diagnostic tool in determining complex hemodynamic patterns in the ascending aorta and aortic root after VSARR.[2] Previous studies have shown that elevated aortic wall shear stress (WSS) detected on 4D flow MRI is associated with aortic wall degeneration on histopathologic evaluation, which may help identify patients at risk for progressive aortic dilation.[3]

We report an intraoperative video assessment of autograft salvageability with 4D flow MRI showing favorable postoperative hemodynamic changes in a patient who underwent VSARR for a failing pulmonary autograft.

A 50-year-old man who previously underwent a Ross procedure at the age of 33 years presented with severe aortic valve regurgitation that originated centrally along the coaptation of the noncoronary and left coronary cusps. A short right coronary cusp resulted in an anteriorly directed regurgitant jet into the left ventricular outflow tract and significant flow reversal in the proximal descending aorta. The pulmonary autograft dilated to 5.5 cm, and ejection fraction was 45%.

In the operating room, an examination of the autograft showed prolapse and fenestrations of only the left coronary cusp, which was determined to be repairable with triangular resection and fenestration closure (Video). The right and noncoronary cusps were repaired by central free margin plication, and all cusps had an effective height of 10 mm after repair to reduce the risk of prolapse. The aortic annulus measured 27 mm before repair and 23 mm after repair by St Jude sizer. At the end of the case, there was no observed aortic insufficiency. The patient was discharged on postoperative day 4.

At 4 weeks after intervention, we performed follow-up 4D flow MRI, allowing us to compare flow, peak systolic 3-dimensional (3D) WSS patterns, and systolic peak velocities in the aorta before and after surgical intervention. Preoperative 4D flow MRI showed an aberrant flow profile with a posteriorly directed flow jet in the ascending aorta and a right-handed helix formation (Figure 1). Conversely, postoperative 4D flow MRI demonstrated restored hemodynamics consistent with those from previous successful VSARRs.[4]

The WSS quantification (Figure 2) demonstrated a marked reduction in mean aortic WSS after VSARR by

Accepted for publication May 16, 2023.

[1]Division of Cardiac Surgery, Department of Surgery, Northwestern University Feinberg School of Medicine, Chicago, Illinois; [2]Department of Radiology, Northwestern University Feinberg School of Medicine, Chicago, Illinois; and [3]Division of Cardiac Surgery, Department of Surgery, London Health Sciences Centre, Western University, London, Ontario, Canada

Address correspondence to Dr Malaisrie, Division of Cardiac Surgery, Northwestern Medicine, Arkes Family Pavilion Ste 730, 676 N Saint Clair St, Chicago, IL 60611; email: chris.malaisrie@nm.org.

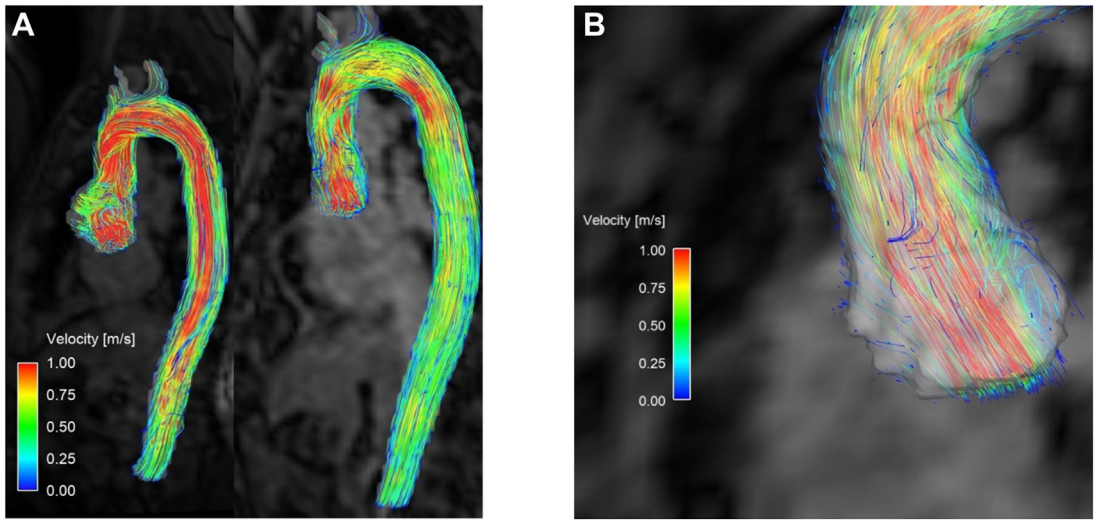

FIGURE 1 Four-dimensional flow magnetic resonance imaging. (A) Side-to-side comparison of peak systolic 3-dimensional streamlines in the aorta before (left) and after (right) the surgical procedure. (B) Flow velocities in the aortic root and ascending aorta after valve-sparing aortic root replacement.

33% (mean preoperative aortic WSS, 1.2 Pa; mean postoperative aortic WSS, 0.8 Pa), indicating a reduced risk for aortic remodeling and progressive dilation. Flow velocities throughout the aorta decreased after intervention (Figure 3). Flow through the pulmonary homograft did not change significantly after the procedure. Preoperative peak systolic gradients in the pulmonary homograft were 40 mm Hg, and 10-month postoperative peak gradients were 38 mm Hg.

Notably, at 10 months after intervention, our patient showed favorable clinical status. He had an aortic valve peak gradient of 12 mm Hg, a mean gradient of 7 mm Hg, and an ejection fraction of 56% with trivial aortic insufficiency.

COMMENT

Our report and video provide a comprehensive example of assessing pulmonary autograft valve salvageability and concurrent 4D flow MRI assessment of a post-Ross procedure VSARR with concurrent valve repair. We prefer the David procedure in Ross reoperations over the Yacoub procedure because of its ability to stabilize or to reduce (as in this case) the autograft annulus and allow reproducibility in concomitant cusp repair.

The 4D flow MRI analysis demonstrated a shift toward physiologic hemodynamics after intervention. Preintervention 3D systolic flow streamlines in the aorta showed a pronounced right-handed helix formation, an eccentric flow profile seen in severe valve insufficiency. Postintervention 3D systolic flow streamlines demonstrated qualitatively less helical flow and reduced eccentric flow in the ascending aorta, which indicate a normalization of valve flow and aortic root volume consistent with previous successful VSARR procedures (Figure 1).[4]

WSS has been extensively studied and associated with increased progressive dilation of the aorta, a common complication requiring reoperation. Our patient's marked decrease in global aortic WSS may contribute to lower rates of adverse remodeling throughout the aortic wall and explain the favorable 10-month postoperative echocardiographic findings in the report.[3,5] We hypothesize that the residual postoperative WSS in the sinotubular junction and ascending aorta proximal to the innominate artery seen in Figure 2 is likely to be

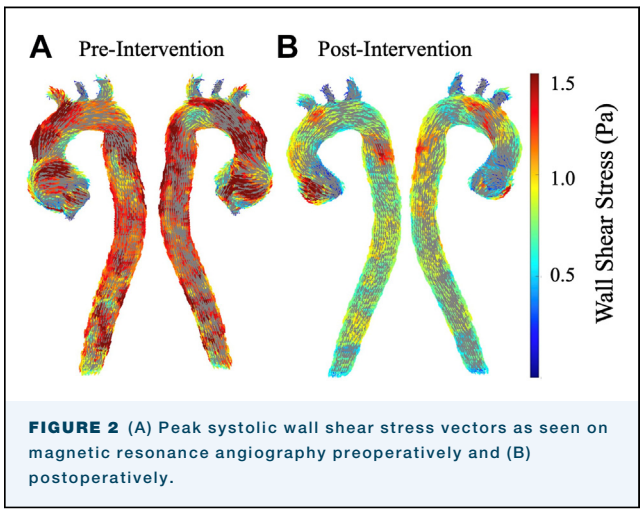

FIGURE 2 (A) Peak systolic wall shear stress vectors as seen on magnetic resonance angiography preoperatively and (B) postoperatively.

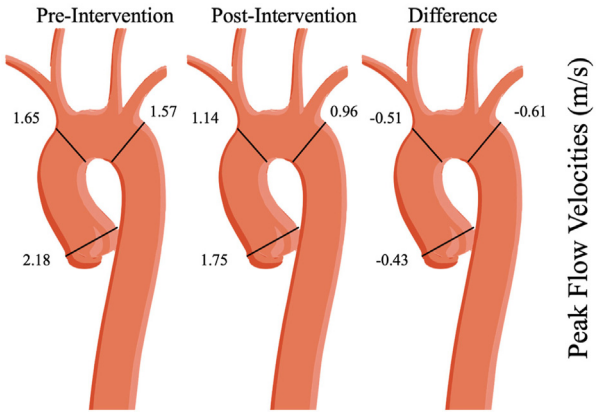

FIGURE 3 Peak velocities in the nontubular junction, ascending aorta proximal to the innominate artery, and distal to the left subclavian artery before and after intervention.

due to the mismatch in the biochemical properties of the less-compliant Dacron graft and the aortic tissue.[6] Our team is not concerned with progressive dilation of the ascending aorta because of the marked decreases in postoperative WSS stress and the well-documented successes of Dacron grafts in resisting dilation.[7]

Postoperative 4D flow imaging demonstrated decreased peak velocities throughout the aorta (Figure 3). Lower velocities and acceleration throughout the aorta are hypothesized to reduce energy loss at the aortic wall and to enhance long-term protection of the ventricle. Interestingly, our findings differ from typical post-VSARR findings on 4D MRI, which have been documented to have increased velocities throughout the aorta compared with preoperative findings.[4] These reported increases in velocity are likely to be due to the absence of the Windkessel effect in the Dacron graft. However, our patient achieved lower postoperative velocities throughout the aorta, indicating successful valvular hemodynamics that overcame the expected unfavorable increase in velocity.

Last, there was no significant change in peak velocities through the pulmonary homograft that demonstrated concern for complications. Increased velocity through the body of the pulmonary homograft (as in this case) is typical after the initial Ross procedure and rarely leads to severe complications after 6 months of follow-up.[8]

Noninvasive 4D flow MRI analysis of WSS, peak velocities, and helical flow profiles in the aortic wall may become a novel, accurate, and reliable tool to plan procedures and to guide follow-up care.

The Video can be viewed in the online version of this article [https://doi.org/10.1016/j.atssr.2023.05.001] on http://www.annalsthoracicsurgery.org.

FUNDING SOURCES
The authors have no funding sources to disclose.

DISCLOSURES
The authors have no conflicts of interest to disclose.

PATIENT CONSENT
Obtained.

REFERENCES

1. Mastrobuoni S, de Kerchove L, Solari S, et al. The Ross procedure in young adults: over 20 years of experience in our institution. *Eur J Cardiothorac Surg*. 2016;49:507-512 [discussion: 512-513].

2. Bollache E, Fedak PW, van Ooij P, et al. Perioperative evaluation of regional aortic wall shear stress patterns in patients undergoing aortic valve and/or proximal thoracic aortic replacement. *J Thorac Cardiovasc Surg*. 2018;155:2277-2286.e2.

3. Soulat G, Scott MB, Allen BD, et al. Association of regional wall shear stress and progressive ascending aorta dilation in bicuspid aortic valve. *JACC Cardiovasc Imaging*. 2022;15:33-42.

4. Semaan E, Markl M, Malaisrie SC, et al. Haemodynamic outcome at four-dimensional flow magnetic resonance imaging following valve-sparing aortic root replacement with tricuspid and bicuspid valve morphology. *Eur J Cardiothorac Surg*. 2014;45:818-825.

5. Guzzardi DG, Barker AJ, van Ooij P, et al. Valve-related hemodynamics mediate human bicuspid aortopathy: insights from wall shear stress mapping. *J Am Coll Cardiol*. 2015;66:892-900.

6. Ballyk PD, Walsh C, Butany J, Ojha M. Compliance mismatch may promote graft-artery intimal hyperplasia by altering suture-line stresses. *J Biomech*. 1998;31:229-237.

7. Spadaccio C, Rainer A, Barbato R, Trombetta M, Chello M, Meyns B. The long-term follow-up of large-diameter Dacron vascular grafts in surgical practice: a review. *J Cardiovasc Surg (Torino)*. 2019;60:501-513.

8. Aranda Granados PJ, Concha Ruiz M, Casares Mediavilla J, et al. Incidence and clinical impact of pulmonary homograft dysfunction after the Ross procedure. *Rev Esp Cardiol*. 2004;57:29-36.