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CASE REPORT

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Four-dimensional magnetic resonance after ascending aorta replacement and aortic valve repair with HAART 300 internal annuloplasty ring

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Abstract

Background: The hemispherical aortic annuloplasty reconstructive technology (HAART) is an internal geometric annuloplasty ring designed to restore a natural elliptical shape to the aortic annulus as part of aortic valve repair. We present four-dimensional flow hemodynamic analysis before and after implementation of the HAART ring in patients undergoing ascending aortic replacement.

Methods: Aortic hemodynamics over the cardiac cycle were visualized using time-resolved three-dimensional pathlines. Velocity streamlines tangent to the time-resolved velocity vector field were used to demonstrate instantaneous aortic hemodynamics. Peak velocities, forward and retrograde flow were calculated at nine planes placed along the midline of the thoracic aorta. Systolic wall shear stress and peak viscous energy loss over the cardiac cycle were calculated.

Results: HAART patients displayed similar or improved flow profiles after surgery when compared to a patient undergoing ascending aortic replacement alone.

Conclusion: There may be a trend towards improved flow dynamics in patients undergoing HAART ring implantation.

KEYWORDS

annuloplasty, aortic valve, magnetic resonance imaging, valve repair

1 | INTRODUCTION

In patients with aortic insufficiency (AI), preserving the native aortic valve (AV) through valve repair has been shown to reduce valve-related complications and improve survival compared to surgical AV replacement with or without concurrent aorta replacement.[1,2] AV repair typically includes annuloplasty to reduce annular diameter and prevent later annular dilatation.[3] The hemispherical aortic annuloplasty reconstructive technology (HAART) is an internal annuloplasty ring designed to restore a natural elliptical shape to the aortic annulus, unlike other annuloplasty methods (Figure 1; Biostable Science and Engineering, Inc.). Noninvasive four-dimensional (4D) flow magnetic resonance imaging (MRI) is a useful diagnostic tool to characterize the complex hemodynamics present in AV disease.[4] We present the first 4D MR hemodynamic analysis of aortic flow before and after placement of the HAART internal annuloplasty ring.

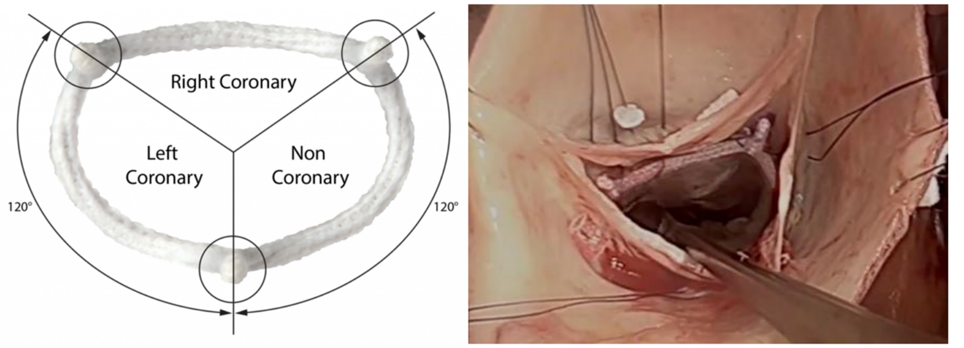

FIGURE 1 Schematic and insertion of HAART 300 Ring. Credit: Biostable Science and Engineering, Inc.

2 | PATIENTS AND METHODS

Patient 1 was a 66-year-old woman with tricuspid AV (TAV) who presented with a 5.1 cm ascending aortic (AAo) aneurysm and a 4.3 cm arch with moderate AI on echocardiography. She underwent AAo and proximal arch replacement using a 24 mm Dacron graft and placement of a 21 mm HAART ring. Intra- and postoperative echocardiography showed trace AI with no aortic stenosis (AS) and a mean gradient of 4 mmHg. Patient 2 was a 62-year-old woman with TAV who presented with an AAo aneurysm and mild-to-moderate AI on echocardiography. Preoperative cardiac MR demonstrated an aortic root diameter of 3.6 cm, an AAo diameter of 5.2 cm, and a proximal arch diameter of 4.4 cm. The patient underwent AAo and proximal arch replacement with a 26 mm Dacron graft and placement of a 21 mm HAART ring. Intraoperative echocardiography showed mild AI with no AS, and postoperative echocardiography showed no AI or AS and a mean gradient of 8 mmHg. No cuspal repair was required for either patient. All patients provided informed consent and the study was approved by the Institutional Review Board of Northwestern University.

To understand the impact of aortic replacement and HAART ring implantation on aortic hemodynamics, 4D flow MRI was performed pre- and postoperatively in Patient 1, and postoperatively in Patient 2. Postoperative scans were acquired on post-op Day 4 and Day 2 for Patients 1 and 2, respectively. Aortic hemodynamics over the cardiac cycle were visualized using time-resolved three-dimensional (3D) pathlines (EnSight). 3D velocity streamlines tangent to the time-resolved velocity vector field were used to demonstrate instantaneous aortic hemodynamics. All traces were color-coded to velocity. Peak velocity, forward and retrograde flow were calculated within planes orthogonal to the aortic midline at the levels of the aortic root 1 cm above the AV, in the proximal AAo 1 cm above the sinotubular junction, in the mid-AAo at the level of the pulmonary artery, in the AAo just proximal to the brachiocephalic trunk, between the brachiocephalic trunk and left common carotid artery, between the left common carotid and left subclavian arteries, in the proximal descending aorta (DAo), in the mid-DAo at the level of the root, and in the distal DAo. 3D systolic wall shear stress (WSS) magnitude at the surface of the aorta, which has been implicated in aortic wall remodeling, was calculated at peak systole and maximal intensity plots were generated for the AAo and arch.[4] Peak viscous energy loss (VEL) over the cardiac cycle, a marker of abnormal flow and ventricular loading, was calculated and normalized to segmented aortic volume.[5] VEL and WSS in HAART patients were compared to an 80-year-old woman with TAV who underwent AAo and proximal arch replacement without HAART ring placement or cuspal repair as a control.

3 | RESULTS

Patient 1 demonstrated restoration of cohesive flow and resolution of the large systolic vortex previously present in her AAo (Figure 2). Patient 2 also showed cohesive flow in the AAo with some complex flow in the arch. Compared to the control, there was qualitatively less helical flow in HAART patients. Flow at the level of the HAART ring was uniform in both patients. In Patient 1, peak velocities were increased in the aortic root and all levels of the arch, but slightly decreased in the proximal and mid-AAo following surgery (Figure 3). The highest velocities occurred just distal to the HAART ring in Patient 1 (1.59 m/s) and in Patient 2 (2.82 m/s). Peak velocities in the control patient increased along her entire aorta postoperatively except for the proximal AAo, where it decreased from 1.53 to 1.24 m/s. The peak velocity gradient across the HAART ring, captured just above in the root and below in the left ventricular outflow tract, was negligible in Patient 1 (−0.02 m/s), while in Patient 2 there was a 0.34 m/s increase. In the control patient there was a 0.3 m/s increase.

Compared to levels before surgery, there was marginally lower WSS in the AAo and arch in Patient 1 after HAART as determined by the mean value of aortic surface with the highest 5% of WSS levels (0.902 and 0.894 Pa), but higher overall mean WSS in the AAo and arch (0.298 and 0.403 Pa). The matched control had a marked increase in WSS after surgery and greater postsurgery levels of WSS

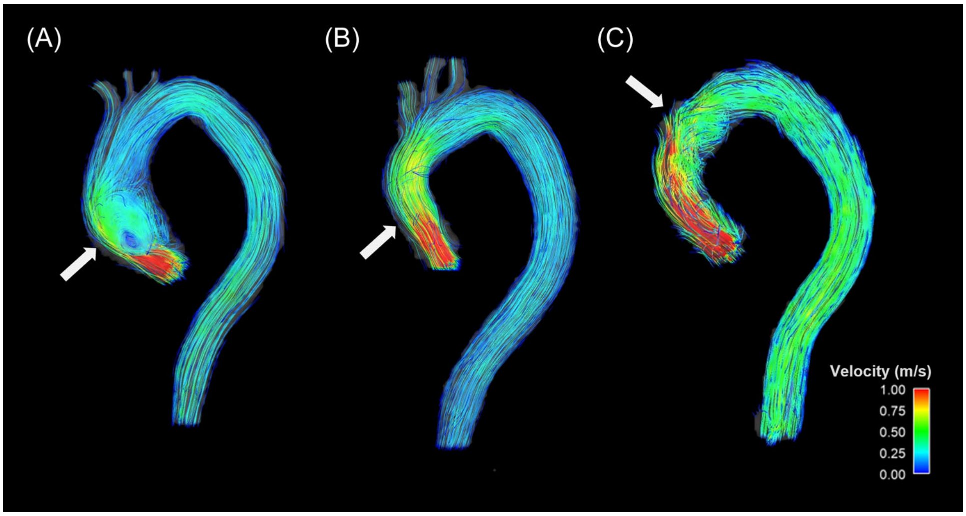

FIGURE 2 Three-dimensional velocity streamlines using 4D Flow MR in Patient 1 before surgery (A), after surgery (B), and in Patient 2 after surgery (C)

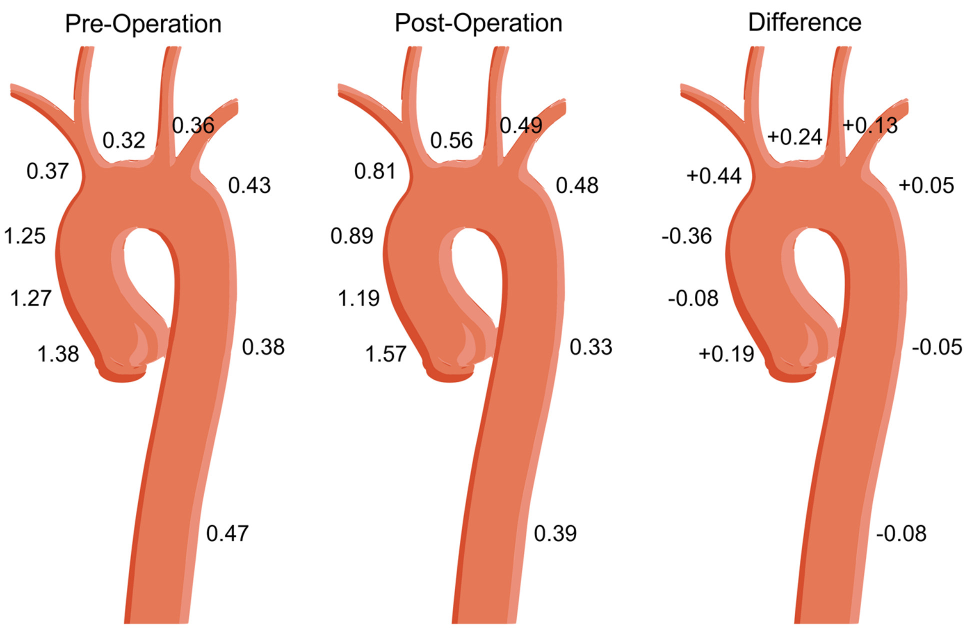

FIGURE 3 Peak velocities (m/s) in Patient 1 before and after surgery

overall than Patient 1 (0.629 and 1.163 Pa). Postsurgery WSS in Patient 2 was elevated in comparison to both Patient 1 and the control (1.995 Pa), with peak WSS occurring in the native aortic root (Figure 4).

Patient 1 demonstrated higher levels of VEL in the AAo and arch after surgery (23.3 and 3.3 W/m^3 vs. 56.6 and 13.1 W/m^3); however, the post-surgery energy loss in Patient 1 was both lower overall and increased to a lesser extent than in the control after surgery (23.4 and 5.0 W/m^3 vs. 73.2 and 30.2 W/m^3). Patient 2 showed modestly greater energy loss in the AAo but less in the arch compared to the control (109.0 and 25.3 W/m^3). All patients presented in this report had no aorta-related complications following surgery.

4 | DISCUSSION

HAART ring implantation has been shown to be a safe and effective valve-sparing approach to restore annular geometry in patients with AI with root or AAo enlargement.[1] To our knowledge, this report is the first to use 4D MRI to characterize flow patterns following HAART ring placement. Our analysis showed that flow velocities, WSS, and VEL increased following aortic repair, regardless of HAART implantation. While still poorly understood, higher flow velocities and VEL likely have adverse effects on ventricular loading and accelerate remodeling.[5,6] Moreover, an increased area of elevated WSS is associated with

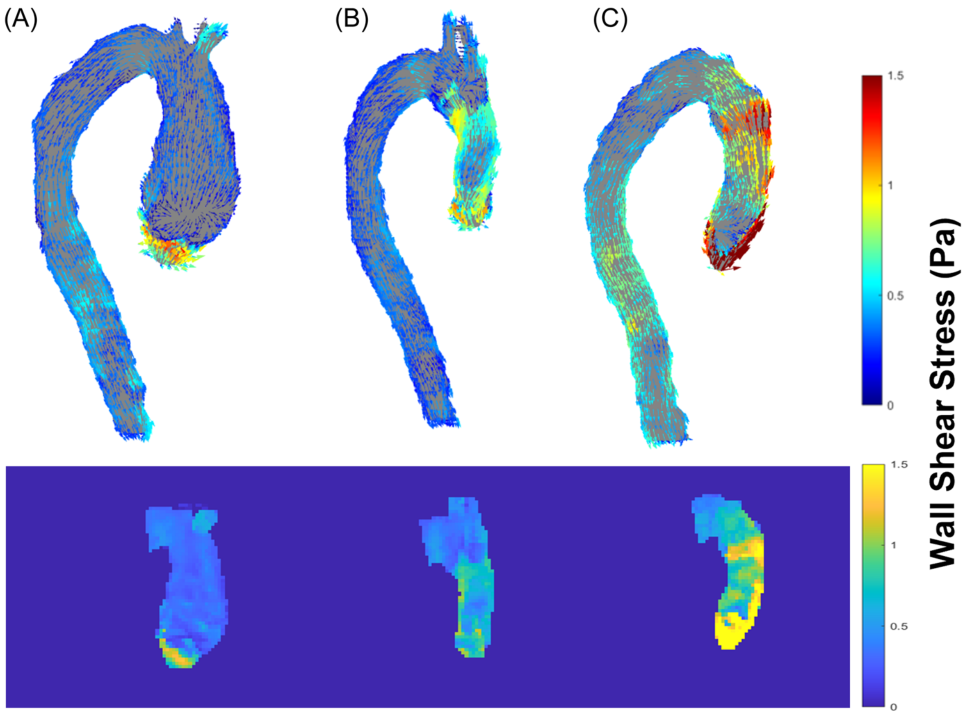

FIGURE 4 Top: Peak systolic WSS vectors—Patient 1 before surgery (A), after surgery (B), Patient 2 after surgery (C). Bottom: wall shear stress maximal intensity projections in the ascending aortic and arch.

greater rates of aortic dilation due to shear stress on native portions of aortic wall.[4]

Our series did demonstrate, however, that patients receiving HAART ring implantation displayed similar or improved WSS, VEL, and peak velocity profiles compared to subjects with aortic replacement alone. But, given the proximity to surgery, postoperative scans may have been acquired in the setting of ventricular ejection patterns before remodeling. It may be of value to study interval changes in flow patterns in the aortic root after allowing ample time for ventricular remodeling. Furthermore, grading of AS can be assessed through the degree of flow acceleration across the valve.[7] Flow acceleration was either reduced or similar in HAART patients when compared to control, suggesting the HAART ring does not contribute to AS.

Importantly, the increases in WSS, VEL, and peak velocity seen in our patients are not unexpected and are multifactorial. Valve-sparing aortic root replacement has previously been associated with increases in complex aortic blood flow, of which VEL is a marker.[8] We have previously speculated that this is, in part, due to the decreased compliance in Dacron grafts relative to physiologic tissue and absence of the Windkessel effect. Isolated valve repair has been shown to decrease peak velocities and WSS in BAV patients but altered aortic geometry in aortic grafts correlates with increased complex flow.[8,9] Given the concomitance of valve repair and aortic replacement in this report, the HAART ring at a minimum did not worsen flow alterations associated with Dacron grafts and may have mitigated them, considering HAART patients showed similar or improved flow profiles when compared to aorta replacement alone.

Our case series demonstrates while HAART patients may still be at elevated risk for abnormal aortic flow and remodeling, there may be a trend toward improved flow dynamics. Sample size, lack of a preoperative MRI for Patient 2, and the short interval between surgery date and acquisition of postsurgery scans limit our ability to further characterize HAART ring flow alterations. Flow patterns at longer intervals should be analyzed to definitively rule out AS. Additionally, our work highlights serial 4D flow imaging as a valuable, noninvasive tool for postoperative evaluation of patients undergoing aortic surgery and for prognostication of need for future reintervention.

AUTHOR CONTRIBUTIONS

Joshua S. Engel: data collection, analysis, and drafting. **Sandeep Bharadwaj**: drafting, critical revision. **Mohammed Elbaz**: data collection. **S. Chris Malaisrie**, **Michael Markl**, and **Bradley D. Allen**: concept, critical revision, approval.

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This study is not part of an ongoing clinical trial.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

1. Papakonstantinou NA, Kogerakis N, Kantidakis G, Athanasopoulos G, Stavridis GT. A modern approach to aortic valve insufficiency: aortic root restoration via Haart 300 internal annuloplasty ring. *J Card Surg*. 2021;36(11):4189-4195.
2. Malaisrie SC, Kislitsina ON, Wilsbacher L, et al. Valve-sparing versus valve-replacing aortic root replacement in patients with aortic root aneurysm. *J Card Surg*. 2022;37:1-10.
3. Youssefi P, El-Hamamsy I, Lansac E. Rationale for aortic annuloplasty to standardise aortic valve repair. *Ann Cardiothorac Surg*. 2019;8(3):322-330.
4. 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(1):33-42.
5. Barker AJ, van Ooij P, Bandi K, et al. Viscous energy loss in the presence of abnormal aortic flow. *Magn Reson Med*. 2013;72(3): 620-628.
6. von Knobelsdorff-Brenkenhoff F, Karunaharamoorthy A, Trauzeddel RF, et al. Evaluation of aortic blood flow and wall shear stress in aortic stenosis and its association with left ventricular remodeling. *Circ Cardiovasc Imaging*. 2016;9(3):e004038.
7. Saikrishnan N, Kumar G, Sawaya FJ, Lerakis S, Yoganathan AP. Accurate assessment of aortic stenosis. *Circulation*. 2014;129(2): 244-253.
8. Oechtering TH, Sieren MM, Hunold P, et al. Time-resolved 3-dimensional magnetic resonance phase contrast imaging (4D flow MRI) reveals altered blood flow patterns in the ascending aorta of patients with valve-sparing aortic root replacement. *J Thorac Cardiovasc Surg*. 2020;159(3):798-810.
9. Lenz A, Petersen J, Riedel C, et al. 4D flow cardiovascular magnetic resonance for monitoring of aortic valve repair in bicuspid aortic valve disease. *J Cardiovasc Magn Reson*. 2020;22:29.

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