Four-Dimensional Magnetic Resonance after Ascending Aorta Replacement and Aortic Valve Repair with HAART 300 Internal Annuloplasty Ring

Joshua S. Engel[1], Sandeep Bharadwaj[2], Mohammed Elbaz[1], Michael Markl[1], Bradley D. Allen[1], and S. Malaisrie[2]

[1]Northwestern University Feinberg School of Medicine
[2]Northwestern University Department of Surgery

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Abstract

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 4D flow hemodynamic analysis before and after implementation of the HAART ring in patients undergoing ascending aortic replacement. HAART patients displayed similar or improved flow profiles when compared to a patient undergoing ascending aortic replacement alone.

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Authors and Affiliations:

Joshua S. Engel, BS[1], Sandeep Bharadwaj, MD[2], Mohammed Elbaz, PhD[1,3], Michael Markl, PhD[1,3], Bradley D. Allen, MD[1], S. Chris Malaisrie, MD[2]

1. Department of Radiology, Northwestern University Feinberg School of Medicine, Chicago, IL, USA.

2. Department of Surgery, Division of Cardiac Surgery, Northwestern University, Chicago, IL, USA.

3. Department of Biomedical Engineering, Northwestern University, Chicago, IL, USA.

Short Title: HAART Ring 4D Flow

Corresponding Author:

Joshua Engel

Northwestern University Department of Radiology

737 N Michigan Ave, Suite 1600

Chicago, IL 60611

joshua.engel@northwestern.edu

Phone: (240) 498-6634

Fax: (312) 926-5991

Abstract: 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 4D flow hemodynamic analysis before and after implementation of the HAART ring in patients undergoing ascending aortic replacement. HAART patients displayed similar or improved flow profiles when compared to a patient undergoing ascending aortic replacement alone.

Keywords: annuloplasty, magnetic resonance imaging, aortic valve, valve repair

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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[1]. Valve-sparing aortic root replacement (VSARR) also carries similar to improved morbidity and mortality compared to valve-replacing root replacement; therefore, improving valve repair techniques is of significant interest[2]. AV repair typically includes annuloplasty to reduce annular diameter and prevent later annular dilatation and reintervention[3]. The hemispherical aortic annuloplasty reconstructive technology (HAART) is an internal geometric annuloplasty ring designed to restore a natural elliptical shape to the aortic annulus, unlike other annuloplasty methods (Biostable Science and Engineering, Inc.). Noninvasive 4-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.

Patients and Methods:

Patient 1 was a 66-year-old woman with TAV who presented with a 5.1 cm ascending aortic (AAo) aneurysm extending into a 4.3 cm transverse arch with moderate AI on echocardiography. She underwent AAo and proximal transverse arch replacement using a 24 mm Dacron graft and placement of a 21 mm HAART ring. 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 transverse arch diameter of 4.4 cm. The patient underwent AAo and transverse arch replacement with a 26 mm Dacron graft and placement of a 21 mm HAART ring. 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 post-operatively in patient 1, and post-operatively in patient 2. Post-operative scans were acquired on post-op day 4 and day 2 for patients 1 and 2, respectively. Aortic hemodynamics were visualized using time-resolved 3D pathlines to illustrate blood flow over the cardiac cycle (EnSight, Ansys, USA). 3D velocity streamlines tangent to the time-resolved velocity vector field were used to demonstrate instantaneous hemodynamics in the aorta. All traces were color-coded according to velocity. Peak velocity, forward and retrograde flow, and regurgitant fraction were calculated within planes placed 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 the 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 aortic 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 transverse arch replacement without HAART ring placement as a control.

Results:

Patient 1 demonstrated restoration of cohesive flow and resolution of the large systolic vortex previously present in the aneurysmal portion of her AAo (Figure 1). Patient 2 also showed a cohesive flow pattern in the AAo with some complex flow in the arch. Compared to the control, there was qualitatively less helical flow in patients with HAART ring. 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 2). 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 post-operatively except for at the proximal AAo, where it decreased from 1.53 to 1.24 m/s. The peak velocity gradient across the HAART ring, captured at planes just above in the root and below in the LVOT, was negligible in patient 1 (-0.02 m/s), while in patient 2 there was a 0.34 m/s increase in velocity. 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 post-surgery levels of WSS overall than patient 1 (0.629 and 1.163 Pa). Post-surgery 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 3).

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 and trace to no AI or AS on echocardiogram following surgery.

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, increased area of elevated WSS is associated with 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, post-operative 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. VSARR alone 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.

Our case series demonstrates while HAART patients may still be at elevated risk for abnormal aortic flow and remodeling, there may be a trend towards improved flow dynamics. Sample size and the short interval between surgery date and acquisition of post-surgery scans limit our ability to further characterize HAART ring alterations of flow. It would be worthwhile to analyze flow patterns at a longer interval to definitively rule out AS. Additionally, our work highlights serial 4D flow imaging as a valuable, noninvasive tool with minimal radiation exposure for post-operative evaluation of patients undergoing aortic surgery and for prognostication of need for future reintervention.

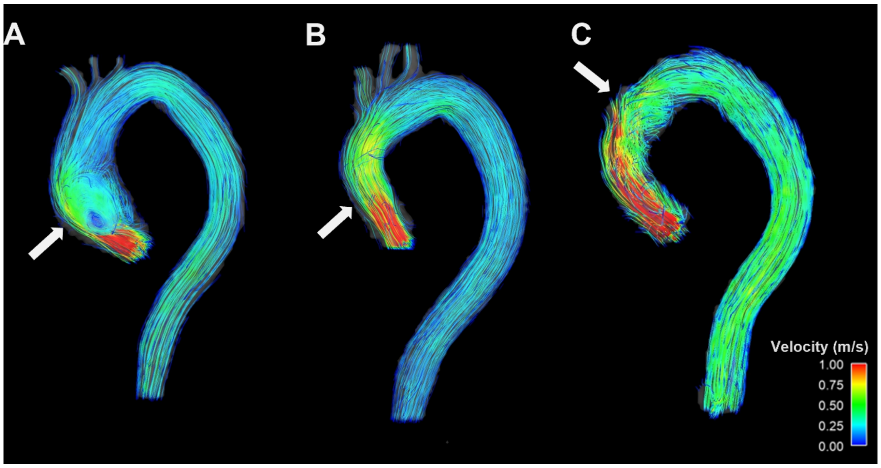

Figure 1. 3D velocity streamlines using 4D Flow MR in Patient 1 before surgery **(A)** , after surgery **(B)** , and in Patient 2 after surgery **(C)** .

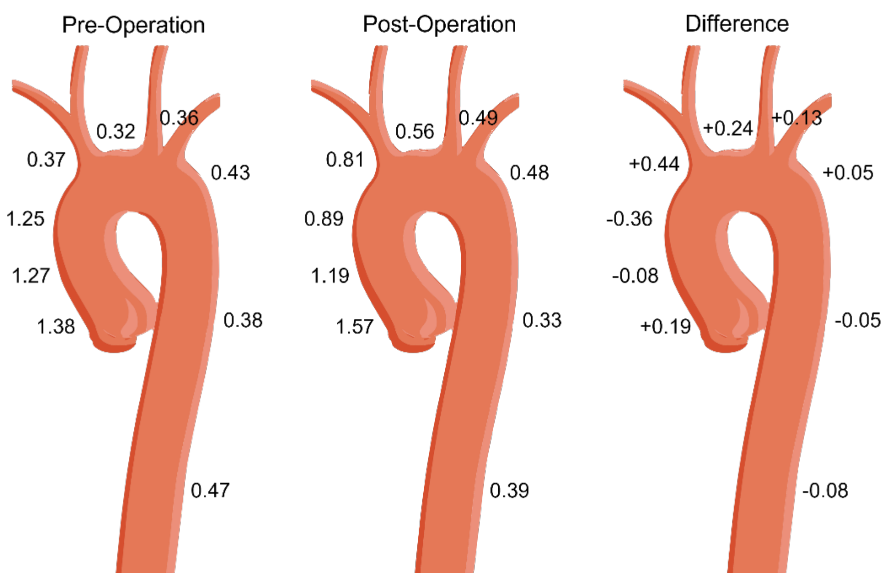

Figure 2. Peak velocities (m/s) in Patient 1 before and after surgery

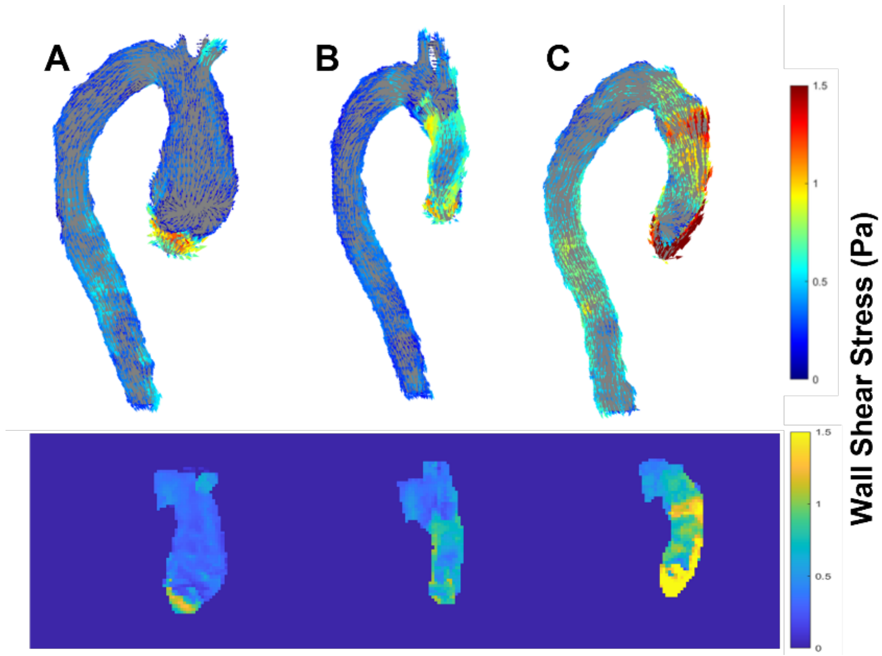

Figure 3. Top: Peak systolic WSS vectors- Patient 1 before surgery **(A)** , after surgery **(B)** , Patient 2 after surgery **(C)** . Bottom: WSS maximal intensity projections in the AAo and arch.

Contributions: JSE- data collection, analysis, and drafting. SB- drafting, critical revision. ME- data collection. SCM, MM, BDA- concept, critical revision, approval.

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