Perioperative evaluation of regional aortic wall shear stress patterns in patients undergoing aortic valve and/or proximal thoracic aortic replacement

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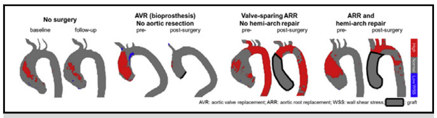
ABSTRACT

Objectives: To assess in patients with aortopathy perioperative changes in thoracic aortic wall shear stress (WSS), which is known to affect arterial remodeling, and the effects of specific surgical interventions.

Methods: Presurgical and postsurgical aortic 4D flow MRI were performed in 33 patients with aortopathy (54 ± 14 years; 5 women; sinus of Valsalva (d_SOV)/midascending aortic (d_MAA) diameters = 44 ± 5/45 ± 6 mm) scheduled for aortic valve (AVR) and/or root (ARR) replacement. Control patients with aortopathy who did not have surgery were matched for age, sex, body size, and d_MAA (n = 20: 52 ± 14 years; 3 women; d_SOV/d_MAA = 42 ± 4/42 ± 4 mm). Regional aortic 3D systolic peak WSS was calculated. An atlas of WSS normal values was used to quantify the percentage of at-risk tissue area with abnormally high WSS, excluding the area to be resected/graft.

Results: Peak WSS and at-risk area showed low interobserver variability (≤0.09 [−0.3; 0.5] Pa and 1.1% [−7%; 9%], respectively). In control patients, WSS was stable over time (follow-up–baseline differences ≤0.02 Pa and 0.0%, respectively). Proximal aortic WSS decreased after AVR (n = 5; peak WSS difference ≤−0.41 Pa and at-risk area ≤−10%, $P < .05$ vs controls). WSS was increased after ARR in regions distal to the graft (peak WSS difference ≥0.16 Pa and at-risk area ≥4%, $P < .05$ vs AVR). Follow-up duration had no significant effects on these WSS changes, except when comparing ascending aortic peak WSS between ARR and AVR ($P = .006$).

Conclusions: Serial perioperative 4D flow MRI investigations showed distinct patterns of postsurgical changes in aortic WSS, which included both reductions and translocations. Larger longitudinal studies are warranted to validate these findings with clinical outcomes and prediction of risk of future aortic events. (J Thorac Cardiovasc Surg 2017;■:1-10)



Changes in at-risk tissue (*red*) for control (no surgery) and aortic surgery patients.

Central Message

Differing proximal aorta interventions induced distinct changes in wall shear stress (WSS). Further research is needed to validate 4D flow MRI WSS to predict outcome and inform surgical practice.

Perspective

Changes between presurgical and postsurgical aortic wall shear stress in the face of different interventions (valve and/or root replacement with or without hemiarch repair) are reported herein for the first time. Given the potential role of hemodynamics on the progression of aortopathy, this noninvasive imaging biomarker may identify patients at high risk for future events and optimize operative strategies.

See Editorial Commentary page XXX.

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Patients with thoracic aortic disease are often asymptomatic before acute critical events such as dissection or rupture occur. Early detection and management are necessary to minimize risk. When necessary, prophylactic surgical repair or replacement of the aorta and/or aortic valve is recommended. Risk for these events is assessed from diameter

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Abbreviations and Acronyms

2D	= two-dimensional
3D	= three-dimensional
4D flow MRI	= three-dimensional time-resolved phase-contrast magnetic resonance imaging with three-directional velocity encoding
AA	= ascending aorta
ARR	= aortic root replacement
AVR	= aortic valve replacement
BAV	= bicuspid aortic valve
CE-MRA	= contrast-enhanced magnetic resonance angiography
DA	= descending aorta
ECG	= electrocardiogram
HA	= hemiarch repair
LV	= left ventricle
LVEF	= left ventricular ejection fraction
LVSV	= left ventricular stroke volume
MRI	= magnetic resonance imaging
PC	= phase-contrast
SOV	= sinus of Valsalva
VS-ARR	= valve-sparing ARR
WSS	= wall shear stress

measurements provided by computed tomography, magnetic resonance imaging (MRI) or echocardiography.[1] However, efforts to use advanced noninvasive imaging to risk-stratify these patients have been proposed.[2] For example, the measurement of three-dimensional (3D) cine (time-resolved) blood flow with three-directional velocity encoding (known as 4D flow MRI) has enabled the use of noninvasive MRI to investigate complex hemodynamics and 3D blood flow patterns.

Previous quantitative in vivo evaluations of postoperative aortic hemodynamics in the literature have mostly focused on transvalvular gradients,[3-8] valvular regurgitation,[3,4,9-11] or peak velocity.[9,12,13] In addition, wall shear stress (WSS), defined as the tangential viscous force exerted by blood flow on the arterial wall, is an important potential biomarker, because it plays a major role in the regulation of cellular function and remodeling via endothelial mechanotransduction.[14] For example, aortic WSS has been studied using 4D flow MRI after valve-sparing aortic root replacement (VS-ARR) in patients with Marfan syndrome[15] or bicuspid aortic valve (BAV).[16] It has also been used to compare different types of valve prosthesis after aortic valve replacement (AVR)[17] or in the evaluation of the impact of surgical and transcatheter AVR procedures.[18] A 4D flow MRI study in patients with BAV has shown that aortic regions with abnormally increased WSS had significant alterations of elastin fibers and extracellular matrix proteins implicated in aortic wall degeneration.[19]

Studies have also investigated perioperative findings of aortic hemodynamics, but they primarily focused on valvular regurgitation,[10,20] pressure gradient,[7,10] or peak velocity,[20] mainly in the setting of AVR. Two studies have reported on WSS changes between preintervention and after surgical[21] or transcatheter[22] AVR, with a focus on investigating carotid and brachial WSS, respectively. However, no comprehensive study has investigated preoperative and postoperative aortic hemodynamic WSS data beyond that of AVR alone. Thus, the purpose of this study is to compare presurgical and postsurgical aortic WSS patterns in patients with aortopathy who underwent replacement of the aortic valve and/or the aorta, using 4D flow MRI. Follow-up 4D flow MRI data of patients with aortopathy who did not have surgery were also investigated as controls. Our hypothesis is that surgery affects WSS, with different changes according to the performed intervention.

METHODS

Study Population

All patients were identified, via institutional review board–approved retrospective chart review with a waiver of consent, from a 4D flow MRI database with 1673 patients (ie phase-contrast MRI with velocity encoding in all 3 spatial directions that is resolved relative to all 3 dimensions of space [3D] and to the dimension of time [cine] along the cardiac cycle). We selected all patients with aortic and/or valve disease ($n = 1128$). Among them, we included the 244 who had undergone aortic valve and/or aorta replacement as well as postoperative clinically ordered standard-of-care cardiothoracic MRI, including 4D flow. We further identified patients who also had undergone a 4D flow examination before surgery ($n = 55$). We excluded those with a history of aortic dissection or previous aortic interventions ($n = 21$), as well as a single patient who underwent a modified Ross pulmonary autograft procedure, resulting in 33 patients and 66 MRI data sets. A consort flow diagram is provided in the Figure E1. In addition, 20 control patients with aortopathy matched for age, gender, height, and weight, who underwent baseline and follow-up routine surveillance MRI ($n = 40$ data sets) but no surgery in between, were included.

Surgical Procedures

All operations were performed between 2012 and 2016.

VS-ARR was performed using a modified reimplantation technique, with a 34-mm Dacron graft. Coronary reconstruction was achieved with reimplantation of left and right coronary arteries as buttons, with a concomitant valve repair for all cases. A second smaller 24-mm to 28-mm graft was used to replace the tubular segment of the ascending aorta (AA). A large straight graft was used for the sinus portion.

ARR with concomitant AVR was performed using a modified Bentall procedure. The valve was sewn into a 7-mm larger Gelweave Dacron graft (VASCUTEK, Inchinnan, United Kingdom). The annular sutures were passed through the valve conduit. The left main and right coronary ostia were anastomosed as buttons to the side of the conduit.

Further hemiarch repair (HA), involving resection of the aorta up to its distal end from the base of the innominate artery to the lesser curve,[23] was performed when the diameter of the proximal aortic arch was >4 cm.

In ARR combined with AVR as well as AVR alone procedures, different valve prostheses were used: bioprosthesis (23-mm to 29-mm Carpentier-Edwards pericardial PERIMOUNT or 23-mm to 27-mm Carpentier-Edwards pericardial Magna Ease or 27-mm to 29-mm Edwards INTUITY bovine pericardial valve [Edwards Lifesciences, Irvine, Calif]) or a mechanical valve (23-mm to 27-mm On-X valve; CryoLife Inc, Kennesaw, Ga).