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CASE REPORT

INTERMEDIATE

CLINICAL CASE

4-Dimensional Velocity Mapping Cardiac Magnetic Resonance of Extracardiac Bypass for Aortic Coarctation Repair

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ABSTRACT

This report describes a case of a young lady who, following extracardiac bypass between ascending and descending aorta for severe aortic coarctation, underwent 4-dimensional flow cardiac magnetic resonance, a technique that, by 3-dimensional flow assessment over time (4-dimensional), allows not only quantification of flows but also wall shear stress. In this case, increased wall shear stress was observed in the conduit's acute angle (kinking) as well as at the distal anastomosis level. The authors postulate that increased wall shear stress could help identify and risk stratify adult congenital heart disease who could develop vascular complications in the future. (**Level of Difficulty: Intermediate.**) (J Am Coll Cardiol Case Rep 2019;1:17-20) © 2019 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

HISTORY OF PRESENTATION

A 21-year-old woman with complex aortic coarctation (Ao-Coa), consisting of a right aortic arch, Kommerell diverticulum, aberrant left subclavian artery, and severe Ao-Coa post-surgical repair, was electively scheduled for cardiac magnetic resonance (CMR) study for anatomic and functional evaluation of the aortic arch and extracardiac bypass. She was completely asymptomatic, with normal blood pressure and a 15 mm Hg difference between right and left arms as a result of a mildly hypoplastic left subclavian artery; she had a systolic 2/6 heart murmur.

LEARNING OBJECTIVES

- 4-dimensional flow CMR may have an important diagnostic value in complex coarctation of the aorta after anatomic extracardiac bypass repair.
- The potential relationship between altered aortic wall shear stress and the risk of aneurysm in this setting require longitudinal studies and further scientific evidence.

PAST SURGICAL HISTORY

At the age of 16 years, she was successfully operated on for complex Ao-Coa and systemic hypertension, through a left thoracotomy, with extracardiac bypass (16-mm Dacron vascular prosthesis) between the ascending and descending aorta. Follow-up confirmed a good surgical result, and antihypertensive therapy was subsequently discontinued.

INVESTIGATIONS

CMR examination was performed on a 3-T scanner (Ingenia, Philips Medical Systems, Amsterdam, the

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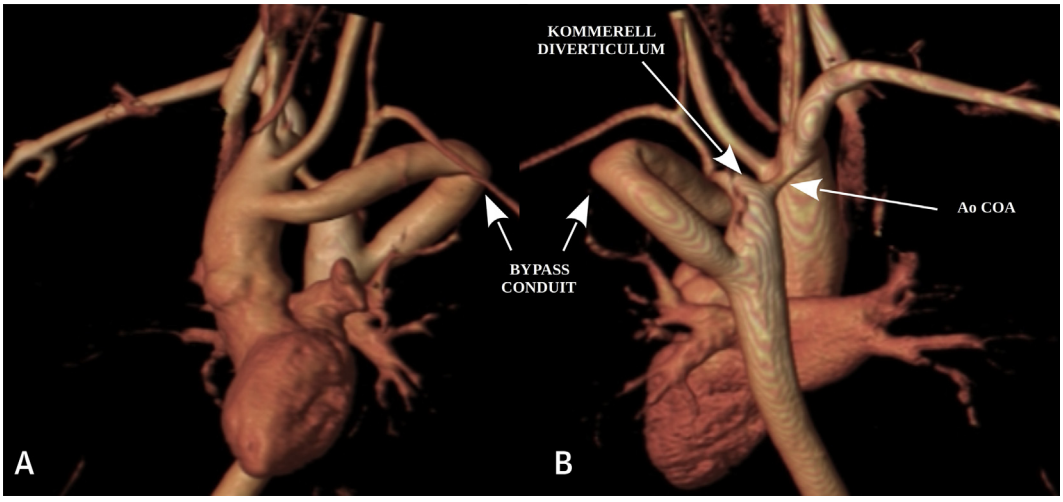
FIGURE 1 Volume-Rendering Reconstruction of Contrast-Enhanced Magnetic Resonance Angiography Showing the Severe Aortic Coarctation and the Bypass Conduit Between Ascending and Descending Aorta



The conduit presents a posterior "kinking." **(A)** Anterior view. **(B)** Posterior view. Also see Video 1. Ao COA = aortic coarctation.

Netherlands) according to standard clinical protocol (1). A 4-dimensional (4D) flow CMR sequence was also performed in a coronal orientation covering the entire aorta with the following parameters: velocity encoding of 200 cm/s in 3 directions, spatial resolution 1.87 × 1.87 × 2.0 mm, flip angle 8°, repetition time/echo time; 4.3/2.1, 23 phases; temporal resolution: 34.4 ms, sensitivity encoding factor: 2. Electrocardiography and respiratory navigator gating were performed to synchronize data acquisition with cardiac motion in end-expiration phase. The total acquisition time was approximately 10 min.

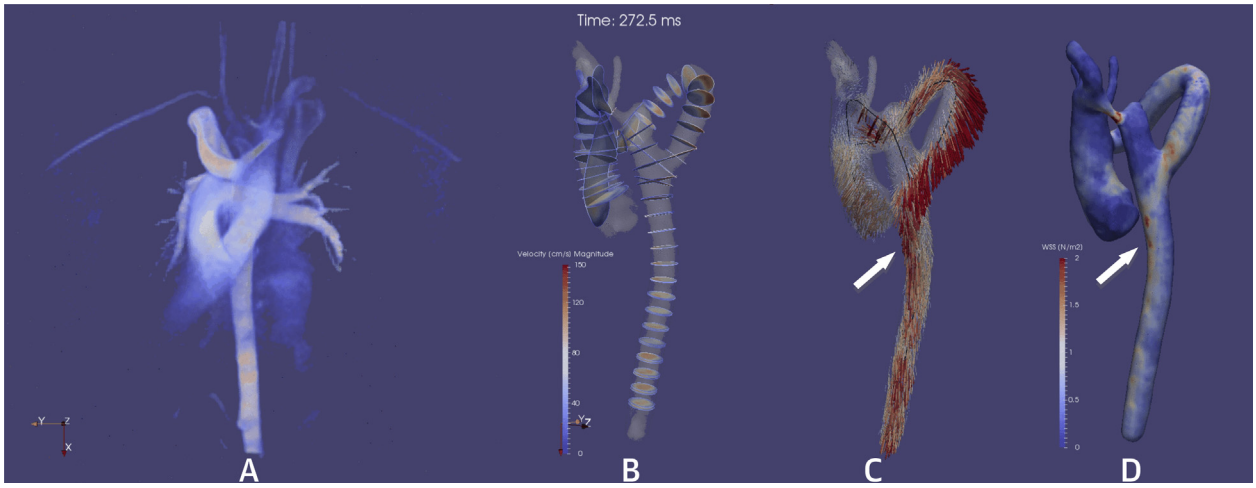
Contrast-enhanced magnetic resonance angiography (MRA) confirmed the extracardiac conduit's patency with posterior kinking and a reduced caliper of the conduit in its posterior portion (**Figure 1**, Video 1) without significant obstruction. 4D flow CMR data were analyzed using the Vascular Modeling Toolkit (VMTK, Orobix, Bergamo, Italy). First, a Phase-Contrast (PC) MRA (PC-MRA) dataset was obtained by the combination of velocity and magnitude images. Then, vessel geometry was extracted with a level set-based segmentation of the PC-MRA. Blood flow quantification was performed by reformatting the 4D velocity data into a plane perpendicular to the ascending and descending aorta below and above the conduit insertion and perpendicular to the extra-anatomic conduit. In particular, flow through the conduit was 60% of the total aortic flow. Multiparametric assessment of post-processed 4D flow CMR revealed accelerated velocities within the coarctation site, as well as at the distal anastomosis level with the descending aorta, where wall shear stress (WSS) was also increased (**Figure 2**, Video 2). Similar findings, with increased velocities (>150 cm/s) and increased WSS (>2 N/m^2), were also documented at the descending aorta, below the distal anastomosis level.

DISCUSSION

Ao-Coa is a common congenital heart disease (2). The choice of treatment, surgical or percutaneous, depends on the patient's age and Ao-Coa anatomy. In complex Ao-Coa, anatomic bypass is a valid surgical option (3). Lifetime follow-up is recommended in post-repaired Ao-Coa because of the increased risk of Ao-Coa recurrence, among other possible complications (2). CMR is required and routinely performed in Ao-Coa follow-up (4). In addition to anatomic details, 2-dimensional phase-contrast sequence is used for aortic flow quantification and flow pattern evaluation. The 4D velocity mapping of flow (4D flow CMR) is a useful tool for the off-line evaluation of flow volumes and velocities in any section of interest of the acquired volume, with the additional advantage of altered fluid mechanics identification in the vessel wall (1).

Hereby, we illustrate feasibility and potential utility of noninvasive 4D flow CMR for the evaluation of post-repair Ao-Coa with extracardiac anatomic bypass. In addition to post hoc quantification of the

FIGURE 2 **Multiparametric Visualization of Post-Processed 4D Flow CMR at End-Systolic Phase**



(A) Maximum intensity projection of the phase contrast cardiac magnetic resonance (CMR) angiography. **(B)** Color-coded velocity distribution in multiple sections of interest. **(C)** Color- and size-coded velocity vector graphs. **(D)** Wall shear stress (WSS) distribution on the whole meshed geometry. Note the unexpected higher velocities and wall shear stress at the level of the descending aorta below the distal anastomosis with the bypass conduit **(arrows in C and D).** Also see Video 2. 4D = 4-dimensional.

aortic flow at any level, 4D flow CMR identified velocity distribution through the aorta and extra-anatomic conduit. Similarly to previous studies (5,6), higher velocities and altered WSS were documented at the descending aorta level. Moreover, we found an impairment of WSS at the level of the descending aorta below the anastomosis with the bypass conduit. The real significance and potential clinical repercussions of these findings cannot be adequately estimated by this anecdotal evaluation, and larger longitudinal studies are warranted to investigate the link between altered velocities and WSS with aortic wall remodeling. Previous studies, however, speculated that unfavorable WSS could contribute to the risk of aneurysm formation (1,7), a potential long-term complication of Ao-Coa repair (7). In complex Ao-Coa, the type and approach of the surgical technique for extracardiac bypass are still rather controversial (3). Several techniques have been described in this setting: subclavian artery-to-descending aorta bypass, ascending aorta-to-descending aorta bypass, ascending-to-infrarenal aorta bypass. ascending aorta-to-subclavian artery bypass. The choice of extra-anatomic bypass and the surgical approach can be complex because they depend on a variety of parameters such as aortic arch and isthmus anatomy and length of the hypoplastic segments, the degree of tissue scarring from previous operations and the presence of an anastomotic aneurysm, type of previous surgery, primary cardiovascular anatomy, type of original repair, and site of the stenosis. It is reasonable to speculate that evaluation of aortic fluid dynamics by 4D flow of different scenarios and treatment strategies for extracardiac anatomy repair could contribute to evaluate the impact of each technique on the aortic wall and identify new imaging biomarkers for risk stratification in this population.

FOLLOW-UP

The patient has regular clinical follow-up in our outpatient clinic. She is doing well and is asymptomatic, with normal blood pressure. Further CMR studies, including 4D flow sequence, will be performed periodically to detect any subclinical changes, with the first study scheduled in the next 18 months.

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KEY WORDS aortic coarctation, cardiac magnetic resonance, 4D flow CMR, 3D imaging

APPENDIX For supplemental videos, please see the online version of this paper.