Impact of Ascending to Descending Aortic Bypass for Aortic Coarctation on 3-Dimensional Hemodynamics

Varun Chowdhary, MD; Michael Rose, BS; Gillian Murtagh, MD; Susanne Schnell, PhD; Alex Barker, PhD; Hyde Russell, MD; Michael Markl, PhD; James Carr, MD

In the management of aortic coarctation, endovascular techniques and surgical repair have been shown to have similar short-term morbidity. However, further studies have shown that, in patients with coarctation that are complex or have previously undergone surgical repair, an ascending-descending aortic bypass surgery is effective in decreasing future interventions. We present postoperative findings in a 67-year-old female patient after ascending-descending aortic bypass surgery for recurrent aortic coarctation. The patient has a history of aortic coarctation for which she underwent 2 separate surgical corrections via thoracotomies as a child (at 5 and 16 years of age). Her preoperative computed tomography scan revealed a stenotic segment with an aneurysmal dilated area between the left common carotid artery to just distal of the left subclavian artery. Cardiac catheterization demonstrated a 40 mm Hg peak gradient across the stenotic segment, and aneurysmal degeneration of the proximal descending thoracic aorta, as well. Because of the complex anatomy from the recurrent coarctation and associated aneurysm, repair via endovascular stenting was not favored. The 2 operative approaches considered included (1) resection with interposed graft reconstruction and (2) ascending to descending aortic bypass. Given the expected dense adhesions, and the concern for the inability to gain proximal control of the aorta from a thoracotomy, as well, in this particular patient, the bypass operation was chosen. A 16×30 mm Gelweave Dacron graft bypass was used between the ascending (AAo) and descending aorta (DAo).

To assess the postinterventional aortic geometry and patency of the bypass graft, a computed tomography angiogram was performed postsurgery. The large saccular aneurysm measured 3.9×5.7×3.9 cm, which was unchanged from presurgery. The Dacron graft extended from the right proximal AAo, wrapping rightward and posteriorly around the heart to anastomose with the descending thoracic aorta (Figure 1B). Although computed tomography data cannot provide information on the changes in aortic hemodynamics (intended reduction of systolic gradient at the site of the coarctation, bypass function, and aneurysmal flow patterns) by using the simplified Bernoulli equation $dP_{\text{max}} = 4V_{\text{max}}^2$, it is possible to estimate a presurgical peak velocity of 3.16 m/s at the stenotic site.

To better understand these complex postsurgical hemodynamics within the aorta, aneurysm, coarctation, and the AAo-to-DAo bypass graft, time-resolved 3-dimensional phase contrast (4D flow) MRI was performed (spatial resolution=3×2.13×3.5 mm, temporal resolution=38.4 ms, echo time=2.41 ms, velocity sensitivity=150 cm/s) to measure in vivo 3-dimensional blood flow velocities. The 4D flow data were acquired with full volumetric coverage of the aorta during free breathing by using ECG gating and navigator respiration control. Blood flow patterns within the thoracic aorta and bypass graft were visualized (EnSight, CEI) by using time-resolved 3-dimensional path lines (Figure 2). In addition, 4D flow MRI allowed for the retrospective quantification of blood flow parameters at any location inside the data volume. Analysis included the assessment of peak systolic velocity, net flow, and retrograde fraction in analysis planes placed at the following locations: AAo, proximal bypass, AAo poststenosis, poststenosis, DAo superior to bypass distal anastomoses, distal bypass, and DAo inferior to bypass anastomoses (Figure 3, Table).

Three-dimensional path line visualization (Figure 2) illustrates the complex aortic hemodynamics in this case with several unique patterns in different segments of the aorta (the full extent of complex changes in aortic flow is best viewed in the online-only Data Supplement Movie). The AAo demonstrates normal cohesive systolic outflow but pronounced early diastolic vortex and retrograde flow (see analysis plane 1 in Table). At the site of the coarctation, a systolic peak velocity of 2.49 m/s and Bernoulli pressure gradient of 24.8 mm Hg was measured, thereby demonstrating successful pressure gradient reduction by the surgical intervention. The aneurysm illustrated a high complex in- and out-flow pattern with marked helix and vortex flow throughout the entire aneurysm. The bypass exhibited good function and cohesive flow. Analysis showed that 43% of the net flow was directed through the bypass graft, whereas 57% was routed through the AAo. The DAo showed marked helical flow below the bypass anastomosis as a result of the redirection of the momentum.

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The online-only Data Supplement is available with this article at http://circ.ahajournals.org/lookup/suppl/doi:10.1161/CIRCULATIONAHA.114.014382/-/DC1.
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Circulation is available at http://circ.ahajournals.org DOI: 10.1161/CIRCULATIONAHA.114.014382

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of the blood flow reentering the DAo from the bypass with a high speed of 1.29 m/s.

Helical and vortex blood flow is suspected to alter wall shear forces, and this may lead to vascular remodeling and progressive aortic dilation. For this patient, the last surgery for her aortic arch coarctation and aneurysm had been performed 51 years earlier. It is difficult to assess the growth rate of her aneurysm, because she had no serial imaging. However, given her presurgical anatomy and cardiac catheterization findings, an intervention was indicated to relieve her high gradient across the stenosis and to increase her lower-body blood flow. This case indicates that 4D flow MRI could help better understand and predict pathologies secondary to surgical intervention. Furthermore, it provides clinicians with non-invasive pre- and postintervention information such as flow patterns and peak velocities. Therefore, our findings indicate a role for 4D flow MRI in both surveillance and surgical planning in patients with aortic coarctation.

Disclosures

None.

References


Figure 1. Three-dimensional renderings of the patient's chest computed tomography from an upright anterior left oblique view. A, Presurgical. B, Postsurgical with bypass indicated in the image. AAo indicates ascending aorta; An, aneurysm; Coarc, coarctation; and DAo, descending aorta.

Figure 2. Blood flow visualization based on time-resolved path lines during early systole (A), midsystole (B), and late systole (C). The cardiac outflow tract and aorta are viewed from the posterior view to better visualize the bypass graft (white arrows). The most posterior aspect of the bypass graft was not captured during cardiac MRI, and therefore is not seen in these images (see also online-only Data Supplement Movie). AAo indicates ascending aorta; and DAo, descending aorta.
Figure 3. Viewed from a posterior aspect. Placement of 8 planes for quantitative analysis of blood flow: 1, AAo; 2, proximal bypass; 3, AAo postbypass; 4, prestenosis; 5, poststenosis; 6, DAo superior to bypass distal anastomoses; 7, distal bypass; 8, DAo inferior to bypass anastomoses. AAo indicates ascending aorta; BCA, brachiocephalic artery; DAo, descending aorta; LCCA, left common carotid artery; and LSA, left subclavian artery.

Table. Summary of Hemodynamic Data Collected at the Planes Designated in Figure 3

<table>
<thead>
<tr>
<th>Plane</th>
<th>Peak Velocity, m/s</th>
<th>Net Flow, mL/cycle</th>
<th>Regurgitation, %</th>
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_Circulation_. 2015;131:1036-1038
doi: 10.1161/CIRCULATIONAHA.114.014382

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/131/11/1036

Data Supplement (unedited) at:
http://circ.ahajournals.org/content/suppl/2015/03/27/CIRCULATIONAHA.114.014382.DC1

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