JACC: CASE REPORTS VOL. 2, NO. 3, 2020

CASE REPORT

INTERMEDIATE

CLINICAL CASE: DAVINCI CORNER

3D Model Guiding Transcatheter Aortic Valve Replacement in a Patient With Aortic Coarctation

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ABSTRACT

We demonstrate the utility of a printed 3-dimensional model to assist in the vascular access planning for a transcatheter aortic valve replacement in an elderly woman with complicated vascular anatomy including aortic coarctation, severe iliofemoral disease, and a small and tortuous left subclavian artery. (**Level of Difficulty: Intermediate.**) (J Am Coll Cardiol Case Rep 2020;2:352–7) © 2020 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 77-year-old frail female patient was seen in the clinic with progressive dyspnea over a 3-month period. On physical examination, she had a blood pressure of 140/70 mm Hg in both arms and a loud ejection systolic murmur radiating to the carotid arteries.

PAST MEDICAL HISTORY

The past history was significant only for longstanding hypertension and hyperlipidemia.

LEARNING OBJECTIVES

- To understand the importance of pre-planning complex structural interventions
- To explore the utility of 3D modeling and simulation in the planning of complex interventions

DIFFERENTIAL DIAGNOSIS

The only differential diagnosis was degenerative aortic stenosis that warranted an initial workup by echocardiogram.

INVESTIGATIONS

An echocardiogram showed a bicuspid aortic valve with severe stenosis (peak gradient, 120 mm Hg; mean gradient, 75 mm Hg; maximum velocity, 5.5 m/s). The ejection fraction was 60%. Coarctation of the aorta was confirmed by a computed tomography angiography (CTA). This was a type 2A bicuspid valve with a raphe between the right and noncoronary cusps. An invasive coronary angiogram showed mild coronary artery disease with a maximum gradient across the coarctation by direct invasive measurement of only 10 mm Hg (possibly underestimated because of severe aortic stenosis). She was evaluated by the cardiac surgeons for surgical replacement of the aortic valve, and they

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, or patient consent where appropriate. For more information, visit the *JACC: Case Reports* author instructions page.

Manuscript received October 10, 2019; revised manuscript received January 10, 2020, accepted January 23, 2020.

ISSN 2666-0849 https://doi.org/10.1016/j.jaccas.2020.01.021

FIGURE 1 Computed Tomography Angiography of the Coarctation (Lateral Projection)

A 3-dimensional reconstruction of the thoracic aorta in the lateral projection, showing the coarctation and post-stenotic dilation of the descending thoracic aorta.

deemed it too high risk. Accordingly, we evaluated her for percutaneous transcatheter replacement of the aortic valve (TAVR). The CTA measurements obtained were as follows: bicuspid aortic valve annulus area was 291.4 mm^2, and perimeter derived diameter was 19.6 mm. The sinotubular junction diameter was 25.2 mm, ascending thoracic aortic diameter was 29.7 mm, and descending thoracic aortic diameter beyond the coarctation was 31.1 mm. The annulus to left main ostium distance was 13.2 mm, and the annulus to right coronary artery ostium distance was 14.8 mm. The peripheral vessels were diffusely diseased with calcification and tortuosity. The right common iliac artery diameter was 5.9 mm, and the left common iliac artery diameter was 5.8 mm (Figures 1 to 5).

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As such, a transfemoral TAVR was deemed unsuitable, and we explored an alternative access. Upon reviewing the CTA, the distal segment of the left axillary artery was 4.7 mm, and the proximal segment was 7.2 mm. The left subclavian artery was 6.6 mm.

MANAGEMENT (MEDICAL/ INTERVENTIONS)

In view of the small caliber of the distal segment of the axillary artery and the severely angulated take-off of the subclavian artery from the dilated segment of the aortic arch just proximal to the coarctation, we opted to create a 3-dimensional (3D) print of the vasculature. The purpose of an in vitro model was to select the most appropriate access point and assess the ability to track a delivery sheath and valve across this unique anatomy (coarctation with dilatation and tortuous aorta). The 3D printer used was Stratasys J450 Digital Anatomy system. The material used was acrylonitrile butadiene styrene filament, and the 3D modeling software used in converting Digital Imaging and

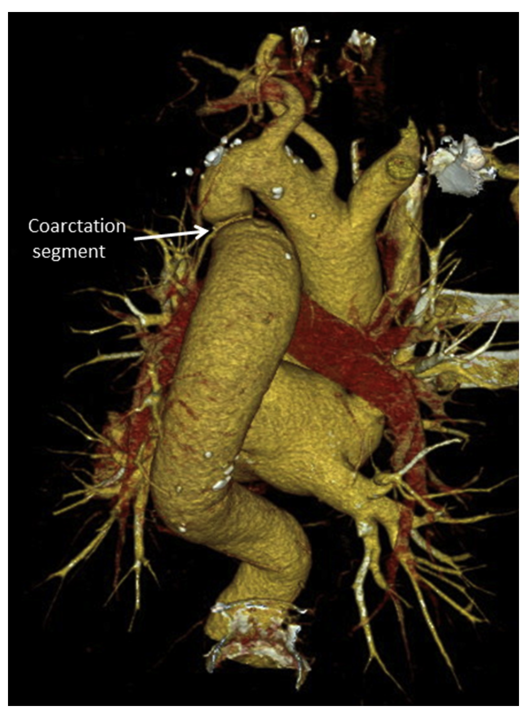
ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional

CTA = computed tomography angiography

TAVR = transcatheter aortic valve replacement

FIGURE 2 Computed Tomography Angiography of the Coarctation (Posterior Projection)



A 3-dimensional reconstruction of the thoracic aorta in the posterior projection, showing the coarctation and post-stenotic dilation of the descending thoracic aorta.

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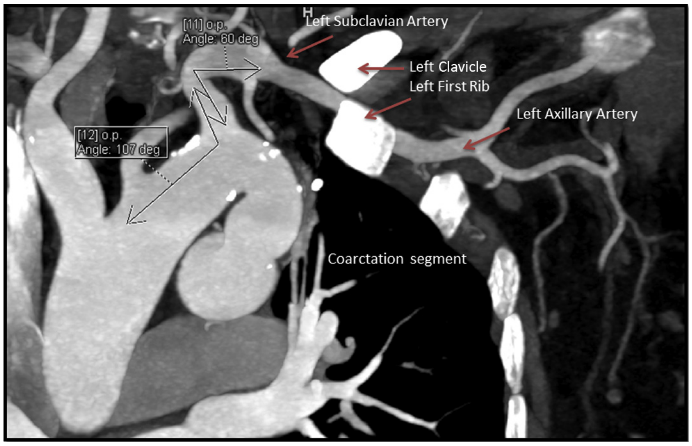
FIGURE 3 **Left Subclavian and Axillary Arteries by Computed Tomography Angiography**



A 2-dimenstional maximum intensity projection image showing the relationship of the arteries to the first rib and the angulation of the vessels.

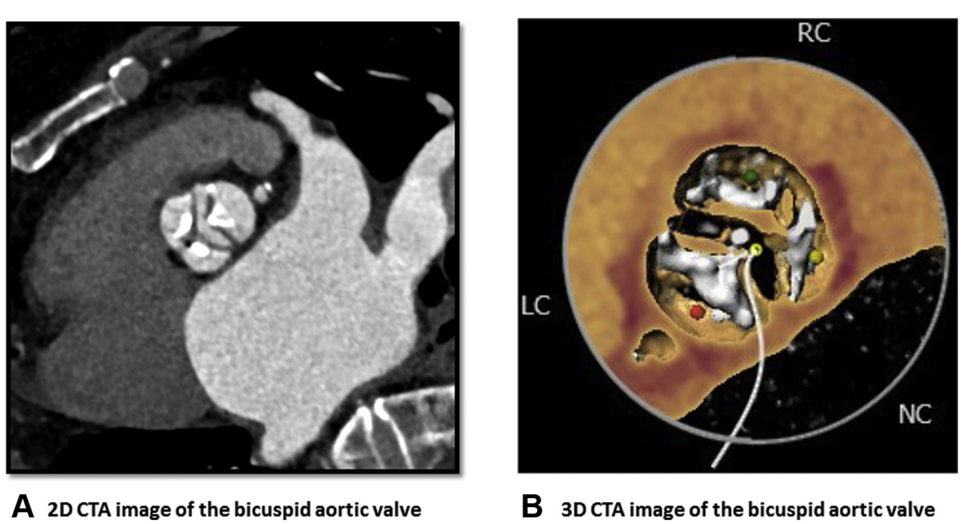
Communications in Medicine (DICOM) to Stereo-Lithography (STL) segmenting and volume rendering was the Mimics inPrint system (Materialise, Leuven, Belgium). Several access points were examined with the 3D model, including the proximal left subclavian artery and distal part of the axillary artery. Based on the model, a surgical cut down of the proximal segment of the left axillary artery was selected. The valve delivery and deployment were also simulated step by step. With the left subclavian access, it was more difficult to negotiate the acute angle of the subclavian artery (60°) and aortic arch compared with the axillary artery approach (**Figures 6 to 9**).

The procedure was performed by using the agreed-on access point and was completed successfully with a CoreValve Evolut R size 23 valve (Medtronic, Santa Rosa, California). The valve was post-dilated with a size 20 NuMED (Brooklyn, New York) balloon. Post-implantation mean gradient across the valve measured by both echocardiography and direct invasive measurement was 5 mm Hg. There was only mild paravalvular regurgitation. Complete hemostasis at the arteriotomy site was obtained after tying the purse-string sutures (**Figures 10 and 11**).

DISCUSSION

Alternate access TAVR has conventionally been through transapical or direct transaortic approaches, both of which are very invasive and require surgical involvement (1-3). More recently, the transaxillary, transcarotid, and transcaval percutaneous approaches have been adopted as less invasive options (4-9). Given the extreme tortuosity and the coarctation of the aorta, the transcaval approach was deemed

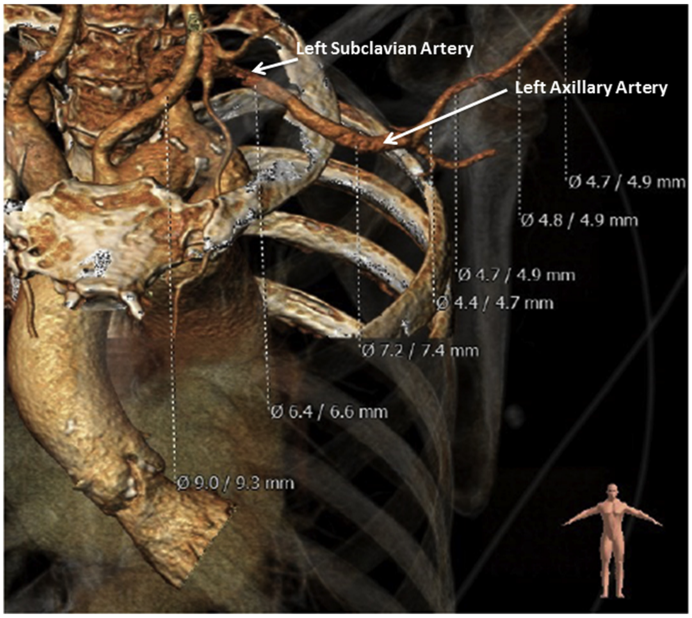
FIGURE 4 **Aortic Valve by Computed Tomography Angiography**



(A) A 2-dimensional (2D) image of type 2A bicuspid valve with a raphe between the right and noncoronary cusps. **(B)** A 3-dimensional (3D) image of the same valve. CTA = computed tomography angiography; LC = left coronary cusp; NC = noncoronary cusp; RC = right coronary cusp.

unsuitable because it would still involve negotiating the coarctation segment with the delivery system. The conventional percutaneous transaxillary was not possible because of the small caliber of the distal axillary artery. Despite limited tactile feedback due to the nature of the model material, 3D modeling and simulation permitted several trials and adjustments that would not have been possible in vivo. A suitable access point in the proximal axillary artery where the delivery sheath could be advanced safely was identified by the simulation. The model included the valve, ascending aorta, coarctation segment, and left subclavian and axillary arteries. The model was also useful for describing the complex anatomy and proposed procedure to the patient and her family. A visual model allowed them to conceptualize the obstacles to conventional access (i.e., transfemoral) and understand the potential vascular complications to a percutaneous transaxillary approach. Resorting to 3D models for structural and congenital heart disease has been described in several reports (10-12). Our case further delineates the practical utility of this technology.

FIGURE 5 Measurements of the Left Subclavian and Axillary Arteries

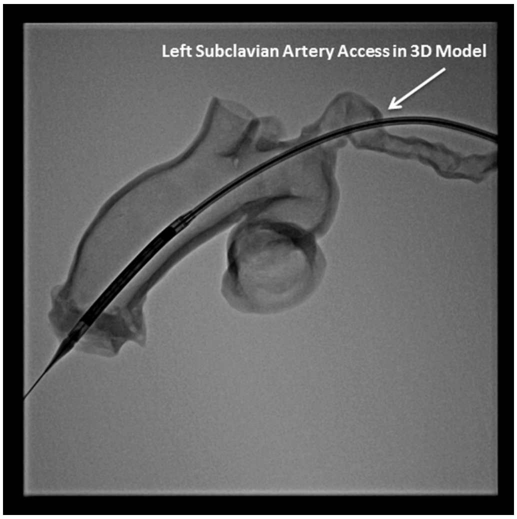


Measurements of the left subclavian and axillary arteries by 3-dimensional reconstructed images on computed tomography-angiography.

FOLLOW-UP

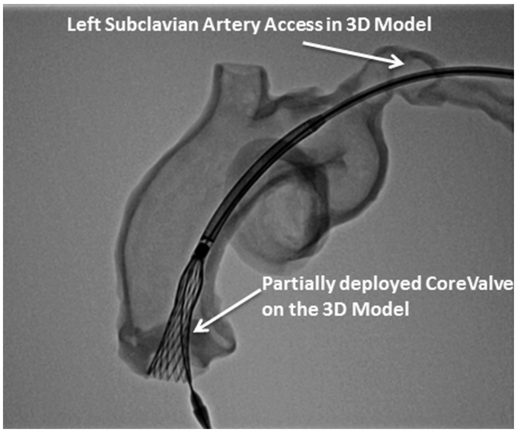
At the patient's 1-month follow-up to the outpatient clinic, she was asymptomatic, with normal function of her left upper limb and intact brachial and radial pulses. She did not require any pacing. The echocardiogram showed a well-seated valve with a mean gradient of 5 mm Hg and mild paravalvular regurgitation; the peak gradient across the coarctation was 14 mm Hg.

FIGURE 6 Delivery Sheath Advancement



Subclavian access in the 3-dimensional (3D) model simulating delivery sheath advancement.

FIGURE 7 Partial Deployment of the CoreValve



Subclavian access in the 3-dimensional (3D) model with partial deployment of the CoreValve.

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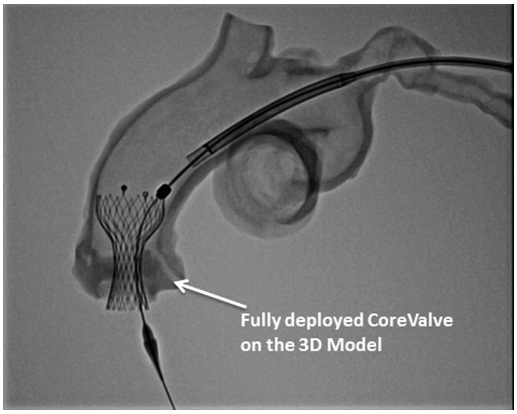
FIGURE 8 **Fully Deployed CoreValve**

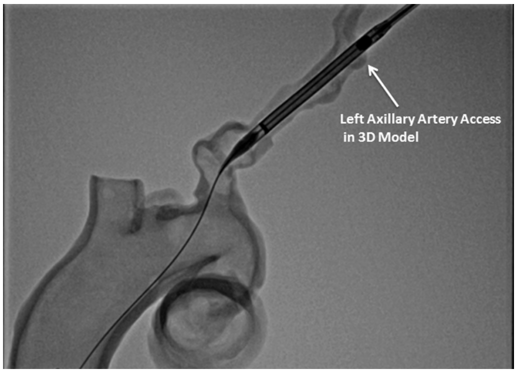


Subclavian access in the 3-dimensional (3D) model with the CoreValve fully deployed.

CONCLUSIONS

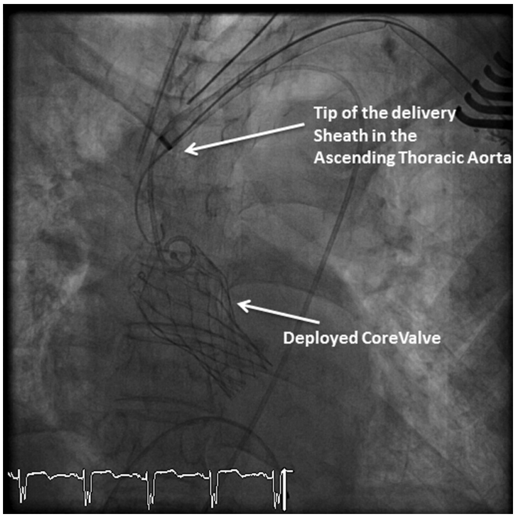
Although 3D modeling remains experimental and is not currently recommended by guidelines, it may have unique applications in complex anatomy, as described in this case. In the future, 3D printing of volumetric datasets obtained by CTA and simulation may serve several purposes, including education (for patients and trainees), further defining complex anatomy, and planning interventions for structural and congenital heart diseases. It may also allow refinement and development of novel devices and techniques.

FIGURE 9 **Axillary Access in the 3-Dimensional Model**



Axillary access in the 3-dimensional (3D) model simulating delivery sheath advancement.

FIGURE 10 **Deployed Transcatheter Aortic Valve Replacement CoreValve**



The deployed transcatheter aortic valve replacement CoreValve in vivo.

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FIGURE 11 **Left Axillary Digital Subtraction Angiography**

Left axillary digital subtraction angiography (DSA) after surgical closure of the arteriotomy in vivo upon completion of the deployment.

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KEY WORDS 3-dimensional model, alternate access, transcatheter aortic valve replacement