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

EDITORIAL COMMENT

Roadmap to Success

3D Printing in Pre-Procedural Planning*

Alejandro Jiménez Restrepo, MD, Diljon Chahal, MD, Anuj Gupta, MD

Treatment of patients with severe symptomatic aortic stenosis with transcatheter aortic valve replacement (TAVR) requires adequate arterial access from which the valve delivery system is advanced. As patients with severe aortic stenosis often present with additional ailments, including peripheral arterial disease, selecting the best vascular access approach for patients undergoing TAVR can be challenging. Data from the SOURCE 3 (SAPIEN Aortic Bioprosthesis European Outcome) (1) and FRANCE TAVI (French Transcatheter Aortic Valve Implantation) (2) registries suggests that between 10% and 15% of patients referred for TAVR are not suited to undergo transfemoral (TF) arterial access. Alternative options to the traditional TF approach include transthoracic (transapical and transaortic), transarterial (transcarotid [TC] and transsubclavian [TS]), and transcaval access. Existing data from randomized and observational studies show significantly increased procedural risks for patients undergoing transthoracic TAVR compared to TF TAVR (3-6). By contrast, data recently published by Beurtheret et al. (7) suggests that alternative transarterial access (TC or TS) in patients who are not candidates for TF access produces similar results to TF-TAVR without increased risk of vascular and nonvascular complications. Challenges still remain, and published case reports and series (8-10) highlight how patients' unique aortic root and vascular characteristics may hinder a successful procedure. This has led to the widespread use of imaging modalities to evaluate aortic and vascular anatomy prior to TAVR. Multidetector computed tomography (MDCT) dominates as the imaging modality of choice in most centers because of its widespread availability; relative low costs; and ability to evaluate the aortic root diameter, presence of coronary artery disease, calcification of the aortic cusps, and distance and angulation between the coronary ostia and the aortic annulus (all important factors that can negatively affect the outcome of TAVR). Importantly, it provides a comprehensive evaluation of the aorta and peripheral arteries for the presence of severe peripheral arterial disease or vascular anomalies and allows the operator to plan the optimal access in anticipation of the procedure (11).

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In this issue of *JACC: Case Reports*, Alasnag et al. (12) report a complex case of a 77-year-old woman with severe aortic stenosis due to a bicuspid aortic valve who was referred for TAVR but presented unique challenges in vascular access: severe iliofemoral disease, a tortuous left axillary artery, and coarctation of the aorta. They describe an approach of combined pre-procedural MDCT and 3-dimensional (3D) printing to plan the intervention and successfully deliver a size 23 CoreValve Evolut R aortic prosthesis (Medtronic, Minneapolis, Minnesota). This interesting case presents an opportunity to review unique challenges in structural heart interventions and the potential benefits of enhanced pre-procedural planning. Recognizing the difficulties of this particular case and the fact that surgical aortic valve replacement was considered too risky for the patient, the authors chose to use a MDCT-derived 3D-printed model of the aortic root, arch, and great vessels to perform a simulation of the procedure and

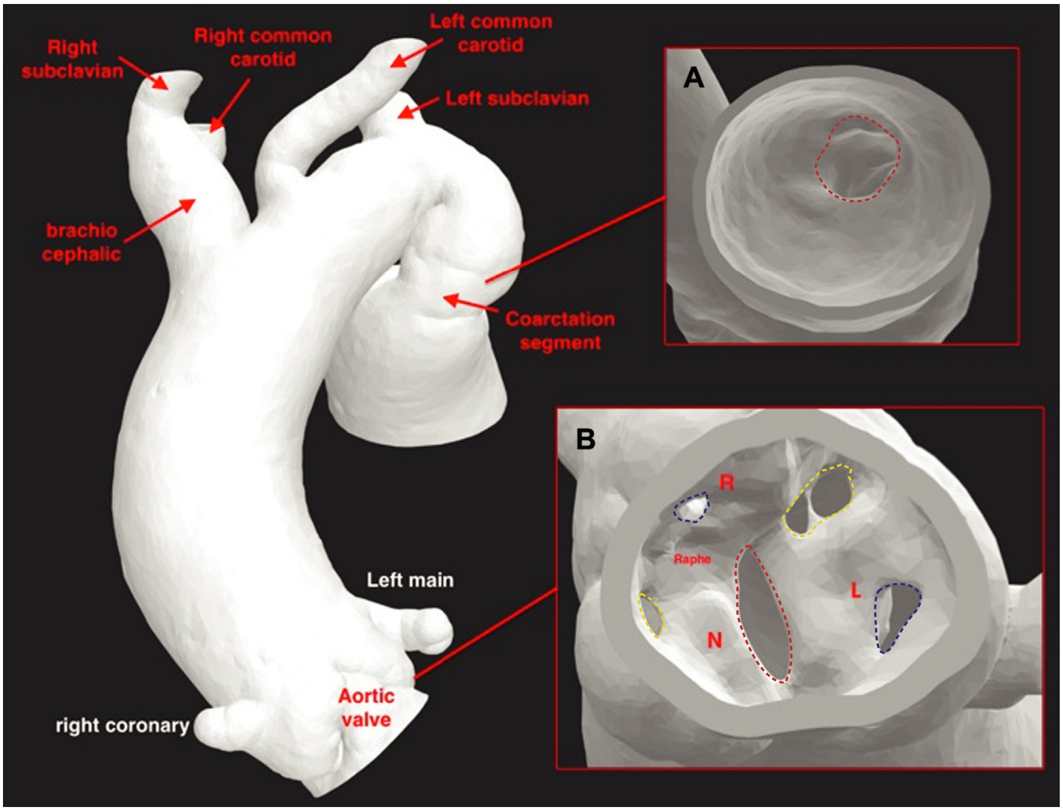
*Editorials published in *JACC: Case Reports* reflect the views of the authors and do not necessarily represent the views of *JACC: Case Reports* or the American College of Cardiology.

From the Division of Cardiovascular Medicine, University of Maryland School of Medicine, Baltimore, Maryland. The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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.

ISSN 2666-0849 https://doi.org/10.1016/j.jaccas.2020.02.003

FIGURE 1 Anterior View of the 3D Virtual Model of the Patient's Ascending Aorta and Aortic Arch Showcasing the Great Vessels and Coarctation Segment



(A) Inferior endoluminal view of the descending aorta with visualization of the narrow coarctation segment **(red dotted line)**. **(B)** Inferior cross-sectional view of the type 1b bicuspid aortic valve based on the morphological classification proposed by Sievers et al. (13), with a raphe between the right and noncoronary cusps. The aortic valve opening (between the R/N fused and L cusps) is highlighted **(red dotted area)**. The ostium of the left main and right coronary arteries is seen **(blue dotted areas)**. Small imperfections in the cusp anatomy related to the 3D printing process are seen **(yellow dotted areas)**. Modified from Alasnag et al. (12) with permission. STL file courtesy of the Cardiac Center, King Fahd Armed Forces Hospital, Jeddah, Saudi Arabia. L = left coronary cusp; N = noncoronary cusp; R = right coronary cusp.

select the optimal access site and the aortic valve size. Their rehearsal proved that a distal transaxillary approach was not recommended based on the left axillary artery having significant tortuosity and narrowing of its distal portion, leading to unfavorable angulation of the guidewire and sheath/delivery system (see Figure 9 in the paper by Alasnag et al. [12]). Conversely, a trans-subclavian access on the 3D model (Figures 6 to 8 in the paper by Alasnag et al. [12]) suggested a more straightforward valve delivery, eventually leading to an uncomplicated TAVR procedure performed using this access approach.

The authors should be commended for their preparedness and detailed planning in anticipation of a potentially complex and risky intervention. Although the MDCT images allowed for planning regarding the aortic annular size, aortic arch diameter, and the diameter and precise location of the coarctation and its post-coarctation dilatation (in the event a transaortic approach was to be considered), we believe that the use of the 3D model to simulate the procedure, and particularly the vascular access entry point, allowed the operators to clearly choose a less-invasive transarterial approach despite an apparent unfavorable anatomy that still allowed for the delivery system to be advanced freely into the aortic annulus; thus, they avoided the risks associated with a more intrusive transthoracic TAVR approach. The STL file provided by the authors permits a detailed view of the reconstructed 3D model showcasing a type 1b bicuspid aortic valve (13), a very tortuous aortic arch, and lumen narrowing at the coarctation segment (**Figure 1**, Supplemental Figure 1). This clearly demonstrates the difficulty in selecting the vascular access best suited for this case.

Other applications within TAVR and the broader field of structural heart disease exist. For example, the last decade has seen a shift toward younger patients getting surgical bioprosthetic valves. As these valves fail, TAVR valve in valve is offered, but concerns regarding coronary artery occlusion and patient prosthesis mismatch increase. Using 3D printing might improve anatomical understanding in this area. In addition, utilizing 3D printing in more complex anatomy, such as mitral annular calcification causing mitral stenosis, or in severe tricuspid regurgitation might allow for better planning for these situations.

Although the utility of 3D printing in pre-procedural planning is evident in this particular case, to this date there are no controlled trials or observational studies proving the superiority of this methodology over conventional image-based pre-procedural planning schemes in reducing complications or improving outcomes. It is unlikely, however, that these studies will ever be conducted. Costs, time investment, availability, and expertise in 3D modeling are additional limitations for its widespread use in routine clinical practice. Currently, the use of 3D models in structural interventions is limited to "niche" indications, but as this technology becomes less expensive and physicians become more familiar with 3D printing workflows, including setting up their own printing laboratories (a less expensive option compared with outsourcing the 3D printing process), we will likely see more operators and centers routinely using 3D-printed models for pre-procedural simulation and planning in the future.

ADDRESS FOR CORRESPONDENCE: Dr. Alejandro Jiménez Restrepo, Division of Cardiovascular Medicine, University of Maryland School of Medicine, 22 South Greene Street, Room N3W77, Baltimore, Maryland 21201. E-mail: arestrepo@som.umaryland.edu. Twitter: @DrAJRestrepo.

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

APPENDIX For a supplemental 3-dimensional figure, please see the online version of this paper.