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Procedural Vignettes in Structural Heart Disease

Computed Tomography-Guided Computational Modeling to Guide Treatment in Aortic Stenosis With Extremely Large Aortic Annulus

Abdul Rahman Ihdayhid, MBBS, PhD [a,b,*], Breandan Yeats, BS [c], Michael Vernon, BEng [d,e], Janarthanan Sathananthan, MD [f], John Webb, MD [f], Jonathon Leipsic, MD [f], Sharad Shetty, MBBS [a,b], Vinod H. Thourani, MD [g], Gerald Yong, MBBS [a,b], Elena De-Juan-Pardo, BEng, PhD [d,e], Lakshmi P. Dasi, PhD [c]

[a] *Department of Cardiology, Fiona Stanley Hospital, Perth, Australia*
[b] *Harry Perkins Institute of Medical Research, Curtin University, Perth, Australia*
[c] *Department of Biomedical Engineering, Georgia Institute of Technology and Emory University, Atlanta, Georgia, USA*
[d] *T3mPLATE, Harry Perkins Institute of Medical Research, QEII Medical Centre and UWA Centre for Medical Research, The University of Western Australia, Perth, Australia*
[e] *School of Engineering, The University of Western Australia, Perth, Australia*
[f] *Centre for Cardiovascular Innovation, St. Paul's Hospital, Vancouver, Canada*
[g] *Department of Cardiovascular Surgery, Marcus Valve Center, Piedmont Heart Institute, Atlanta, Georgia, USA*

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A 78-year-old male with severe symptomatic aortic stenosis was assessed by the heart-team as inoperable given the presence of a porcelain ascending aorta. Preprocedural cardiac computed tomography (CT) demonstrated a type-1 Sievers bicuspid aortic valve with a very large annular area at 1021 mm^2, perimeter 115 mm, dimensions 37.1 × 36.0 mm and severe raphe and leaflet calcification. (Figure 1a and b). The inter-commissural distance at 4 mm above the annulus was 39.2 mm representing a flared anatomical configuration. Percutaneous implantation of a significantly overfilled balloon-expandable transcatheter heart valve (THV) was considered; however, in the setting of an extremely large aortic annulus beyond the manufacturer recommendations, questions remained regarding procedural safety and feasibility.

A combination of CT-guided computational modeling and bench testing was performed to predict valve anchoring, frame expansion, THV leaflet coaptation, and paravalvular regurgitation (PVR). A 29 mm SAPIEN-3 device (Edwards Lifesciences, Irvine, CA) was overfilled by 8 ml and expanded on the bench with high-definition video documenting kinetics of THV expansion and relaxation (Supplemental Video 1). THV frame expansion and height were recorded using digital calipers (Figure 2a and b). The overexpanded THV was placed in a sealed 3D-printed static flow loop with physiological mass pressure (50 mmHg) to simulate leaflet coaptation in diastole. Visual assessment demonstrated complete leaflet coaptation with no leak within the flow loop (Figure 2c).

The cardiac CT was analyzed for predictive computational modeling of the SAPIEN-3 balloon-expandable THV. The aortic root and left ventricle were segmented and meshed in Materialize Mimics (Leuven, Belgium). The 29 mm SAPIEN-3 geometry was created from micro-CT measurements with additional data from bench testing (Figure 2). Finite element analysis was performed using Abaqus 2020 (Johnston, USA). Material properties were defined as hyperelastic for native soft tissues, elastic for calcium nodules, and elastic for the stent and balloon which were extracted from previous studies.[1-3] The balloon was filled to +8 cc's above nominal volume to simulate overexpansion of the THV followed by a balloon deflation step to account for tissue recoil (Figure 1c and Supplemental Video 2). CT simulation demonstrated an eccentrically expanded THV with average diameter of 30.4 mm and evidence of anchoring on the leaflet calcification (Figure 3a). PVR was evaluated

Abbreviations: CT, computed tomography; PVR, paravalvular regurgitation; TAVR, transcatheter aortic valve replacement; THV, transcatheter heart valve.

* Address correspondence to: Abdul Rahman Ihdayhid, MBBS, PhD, Harry Perkins Institute of Medical Research, Fiona Stanley Hospital, Perth, Australia, 11 Robin Warren Drive, Murdoch, Western Australia 6150, Australia.

E-mail address: abdul.ihdayhid@perkins.org.au (A.R. Ihdayhid).

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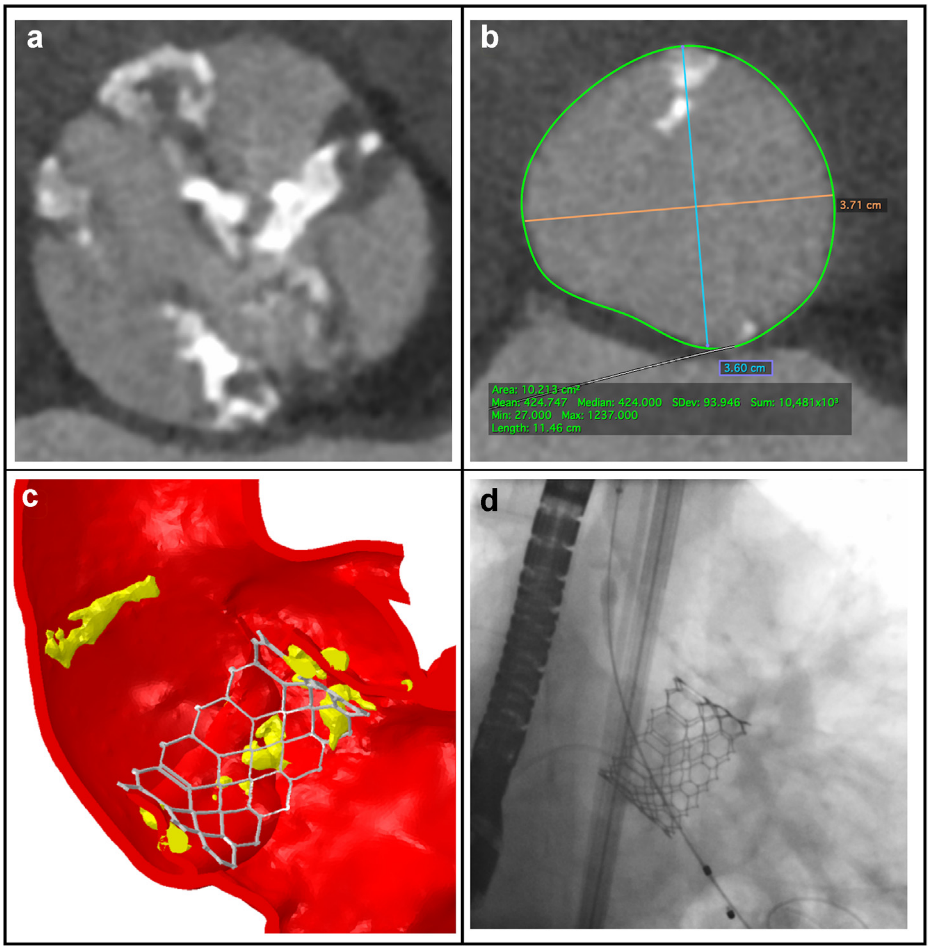

Figure 1. CT-guided treatment of extremely large aortic annulus. (a and b) Preprocedural cardiac CT demonstrating type-1 Sievers bicuspid aortic valve with calcified raphe and measuring an annular area of 1021 mm^2 and perimeter of 115 mm. (c) Computational modeling with finite mesh analysis simulating a 29 mm SAPIEN 3 deployment overfilled by 8 ml anchoring on leaflet calcification. (d) Successful procedural deployment of overfilled (+8 ml) 29 mm SAPIEN 3 valve.
Abbreviation: CT, computed tomography.

following the stent deployment using computational fluid dynamics in Ansys Fluent (Canonsburg, USA). A nominal pressure in the aorta of 80 mmHg and 0 mmHg in the ventricle was applied to represent physiological diastolic conditions. The highest velocity PVR jets were predicted to originate anterolaterally (Figure 3b).

The patient was successfully treated with a 29 mm SAPIEN-3 THV deployed with 8 ml of additional volume (Figure 1d). Post-dilatation was performed with the same overfilled balloon volume to optimize frame expansion. Intraprocedural transoesophageal echocardiography demonstrated trivial valvular and mild PVR predominately located at the anterolateral aspect of the frame (Figure 3d and Supplemental Video 3). Post-transcatheter aortic valve replacement (TAVR) CT highlighted an eccentrically expanded frame with comparable dimensions to CT modeling (Figure 3c).

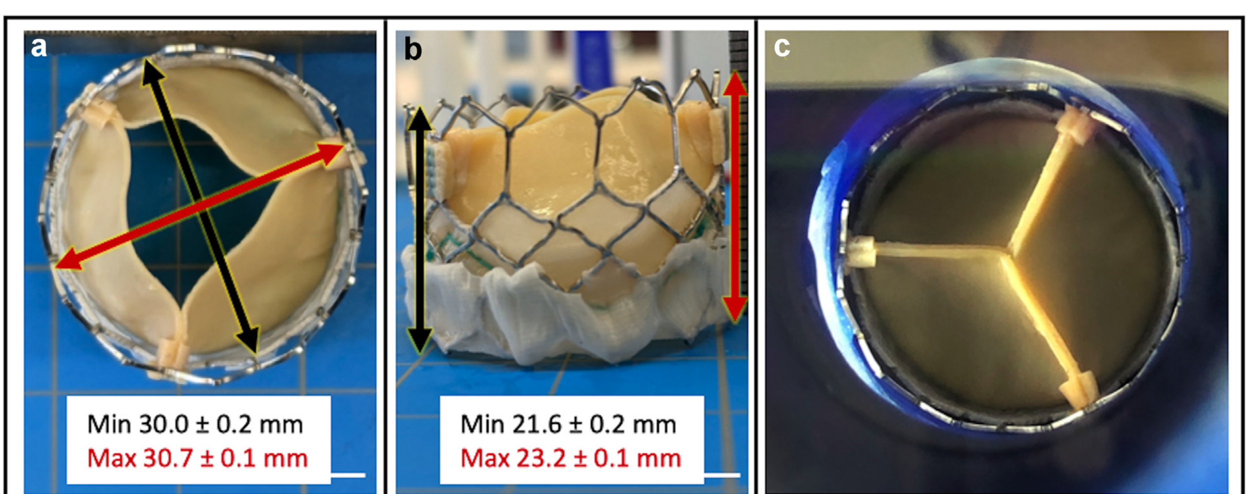

Figure 2. Bench measurements and testing of overexpanded SAPIEN 3 valve. (a and b) Digital caliper measurements of valve expansion and height of overexpanded (+8 ml) 29 mm SAPIEN 3 THV. (c) Leaflet coaptation of overexpanded valve fixed in static flow loop with physiological mass pressure applied.
Abbreviation: THV, transcatheter heart valve.

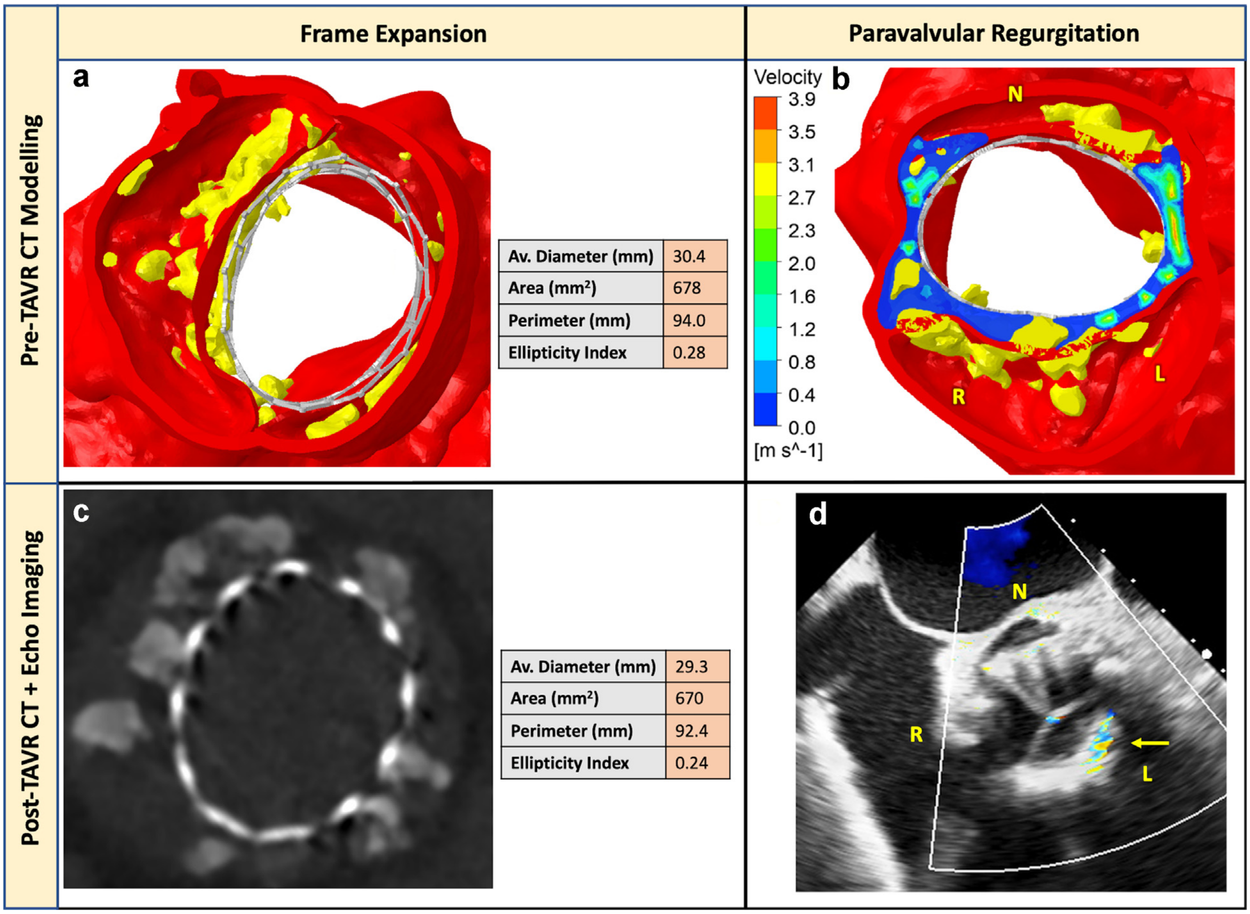

Figure 3. Comparison of CT modeling with post-TAVR CT and echocardiography. (a and b) CT modeling of frame expansion and location of paravalvular regurgitation. (c) Post-TAVR CT dimensions. (d) Transoesophageal echocardiography assessment of paravalvular regurgitation.
Abbreviation: CT, computed tomography; TAVR, transcatheter aortic valve replacement.

To our knowledge, this is the largest aortic annulus successfully treated with a THV. It should be emphasized that this single report does not support the routine treatment of extremely large annuli with TAVR, which requires further clinical evaluation. Our case provides new insight into the potential role of CT-guided computational modeling to predict and optimize outcomes in patients undergoing TAVR for complex aortic valve disease. Future studies are needed to assess the ability of CT-guided computational modeling to guide TAVR procedural strategy across the spectrum of annuli size, THV devices, and procedural endpoints.

ORCIDs

Abdul Rahman Ihdayhid https://orcid.org/0000-0003-0501-0980
Breandan Yeats https://orcid.org/0000-0002-7333-041X
Michael Vernon https://orcid.org/0000-0003-0370-3652
Elena De-Juan-Pardo https://orcid.org/0000-0001-9005-7497
Lakshmi P. Dasi https://orcid.org/0000-0003-3776-0073

Consent Statement

Consent given by the patient for publication of this case.

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Disclosure Statement

Breandan Yeats: Has a patent pending as coinventor of patents related to computational predictive modeling of heart valves. Lakshmi Dasi: Stakeholder in Dasi Simulations and has a patent pending as coinventor of patents related to computational predictive modeling of heart valves. Vinod H. Thoruani: Consultant for Abbott Vascular, Boston Scientific, Cryolife, and Edwards Lifesciences. Abdul Ihdayhid has received consulting honorarium from Boston Scientific and Artrya. Dr Webb has been a consultant to, and has received research funding from Edwards Lifesciences, Abbott, and Boston Scientific. Dr Sathananthan has been a consultant to Edwards Lifesciences and Medtronic; and has received speaking fees from Edwards Lifesciences and NVT.

Review Statement

Given his role as an editor, Jonathon Leipsic, MD, had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Paul Schoenhagen, MD.

Supplementary Material

Supplemental data for this article can be accessed on the publisher's website.

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