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CORONARY, PERIPHERAL, AND STRUCTURAL INTERVENTIONS

HOW WE DID IT

Prediction of Prosthetic Heart Valve Interaction During Transcatheter Double-Valve Replacement Using a Bench Model

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ABSTRACT

Transcatheter aortic valve replacement in the presence of a preexisting bioprosthetic mitral valve can lead to significant interaction of the valves. Simultaneous transcatheter aortic valve and mitral valve deployment using balloon-expandable systems further complicates the interaction. We describe preprocedural computed tomography planning using novel parameters and bench tests to predict these interactions and their clinical significance. On the basis of the available anecdotal evidence, we propose a new classification system for the various types of interactions. (JACC Case Rep. 2025;30:103370) © 2025 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/).

Transcatheter aortic valve replacement (TAVR) with a preexisting bioprosthetic mitral valve (BPMV) is an exclusion criterion in landmark trials because of the possibility of an interaction of the transcatheter aortic valve (TAV) with the BPMV.[1,2] Amat-Santos et al[3] studied the interaction of a mechanical mitral valve and a BPMV while performing TAVR. TAVR device embolization was seen in 6.7% of the procedures as a result of its interaction with BPMV. Here we describe step-by-step procedural planning to predict prosthetic valve interactions by using novel computed tomography (CT) parameters and bench model simulations from 3 patients who underwent simultaneous TAVR and mitral valve-in-valve (M-ViV) implantation.

TAKE-HOME MESSAGES

- Combined transcatheter aortic and mitral valve replacement using the currently available BE platforms may lead to valve interactions.
- CT measurements between the aVBR, the BPMV sewing ring, and its posts are paramount to perform transcatheter left-sided DVR safely.

CASE SUMMARY

All 3 patients with native severe aortic stenosis (AS) and a degenerated BPMV were deemed high risk for open heart surgery (mean European System for Cardiac Operative Risk Evaluation II [EuroSCORE II]: 21.7 ± 15.21) by a heart team and were scheduled for simultaneous TAVR and M-ViV implantation. These patients had NYHA functional class III or IV symptoms. The degenerated BPMV had been implanted 140 ± 60.75 months earlier. All 3 patients had right

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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, including patient consent where appropriate. For more information, visit the Author Center.

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ABBREVIATIONS AND ACRONYMS

aVBR = aortic virtual basal ring

AS = aortic stenosis

BE = balloon-expandable

BPMV = bioprosthetic mitral valve

CT = computed tomography

DVR = double-valve replacement

IVS = interventricular septum

LVOT = left ventricular outflow tract

M-ViV = mitral valve-in-valve

SE = self-expandable

TAV = transcatheter aortic valve

TAVR = transcatheter aortic valve replacement

TMV = transcatheter mitral valve

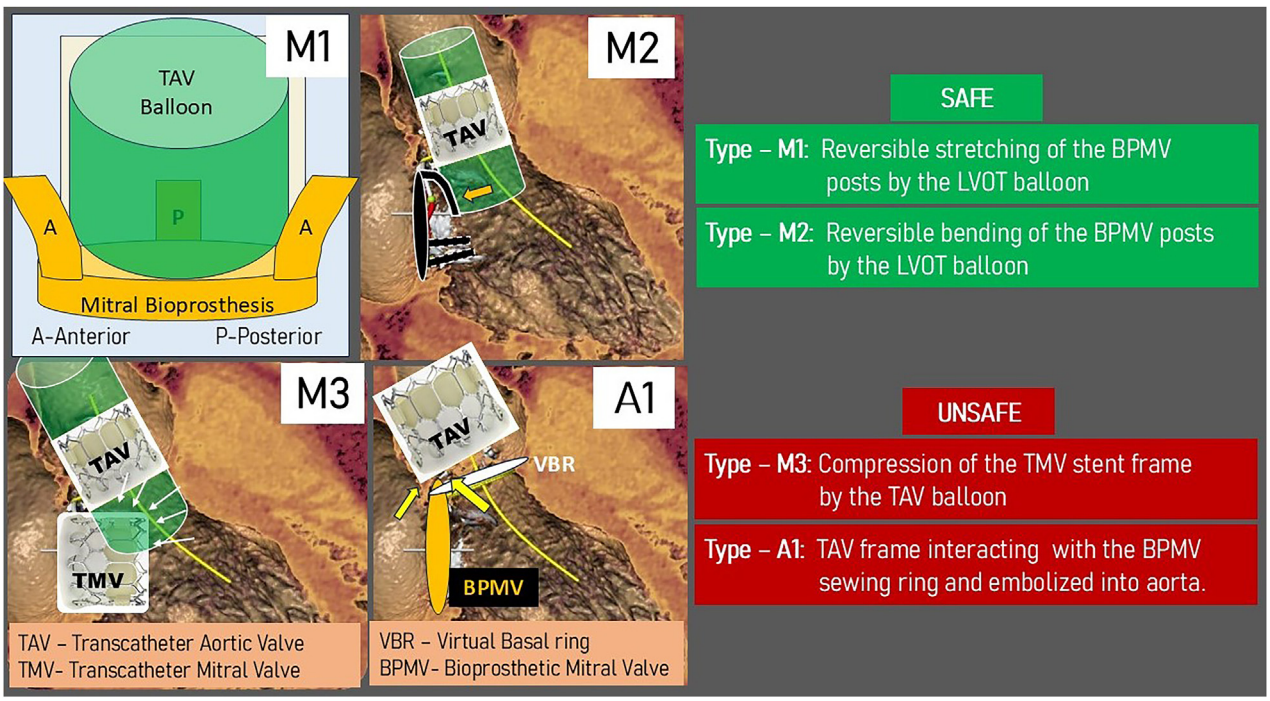
ventricular dysfunction, and 2 of them had additional left ventricular dysfunction. The operators decided to perform a simultaneous double-valve replacement (DVR) rather than taking a sequential approach in all 3 patients because leaving 1 valve unaddressed could lead to potential hemodynamic consequences in the presence of left or right ventricular dysfunction.

PROCEDURAL STEPS

CASE 1. According to the CT assessment, the distance between the aortic virtual basal ring (aVBR) and the degenerated 27-mm Biocor (St Jude Medical) BPMV sewing ring was 3.1 mm, thus mandating TAV deployment with a precise 1- to 3-mm depth to avoid interaction. The operators hence decided to choose the balloon-expandable (BE) platform for TAVR. The M-ViV procedure was planned with a BE platform.

If TAVR is performed after M-ViV implantation, the balloon of the BE TAV will compress the transcatheter mitral valve (TMV) stent frame. If self-expandable (SE) TAV is used after M-ViV, it will not interact with the TMV frame, but if predilation or post-dilatation is required, then the balloon will compress the TMV frame. Hence, a TAVR first and M-ViV second approach is ideal with either of these TAV platforms. During BE TAVR, balloon interaction with the projected BPMV post into the left ventricular outflow tract (LVOT) is possible. To predict this in our cases, the following novel CT parameters (**Table 1**) were measured: the aVBR to BPMV sewing ring distance (3.1 mm) (**Figure 1A**); the distance between aVBR and BPMV near the post (8.3 mm) (**Figure 1B**); the BPMV post to interventricular septum (IVS) distance (13.5 mm) (**Figure 1C**); the BPMV post position,

VISUAL SUMMARY **Classification of Left-Sided Prosthetic Valve Interactions**



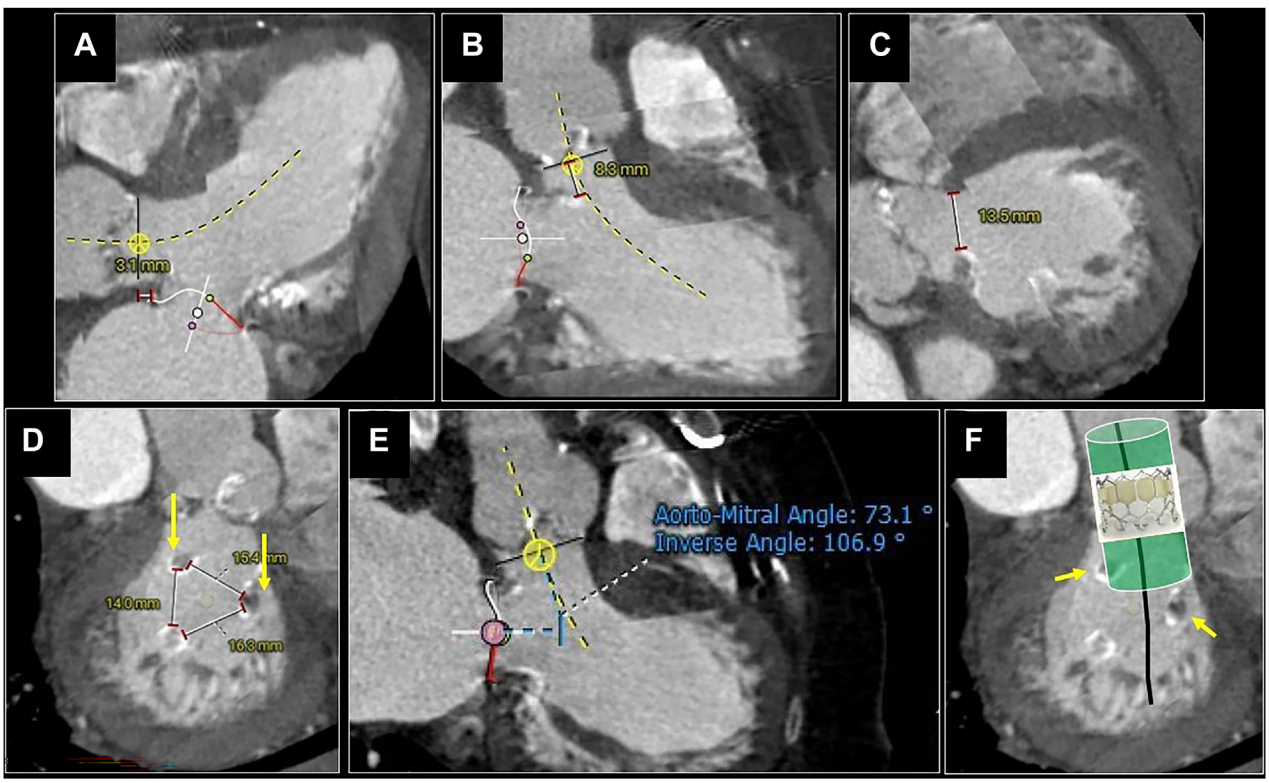
M1: The projected transcatheter aortic valve (TAV) balloon in the left ventricular outflow tract (LVOT) is aligned between the 2 lateral anterior posts (favorable bioprosthetic mitral valve [BPMV] post position) and stretching these posts during the inflation. The stretched posts recover to their original position when deflating the TAV balloon. M2: The projected TAV balloon in the LVOT is bending an unfavorable central anterior post of the BPMV that returns to its original shape when deflating the TAV balloon. M3: The projected TAV balloon in the LVOT irreversibly compresses the transcatheter mitral valve (TMV) stent frame. This can affect TMV function or lead to TMV embolization. A1: The TAV system interacts with the projected anterior part of the BPMV sewing ring at the aortomitral continuity. This may lead to migration of the TAV into the aorta or aortic paravalvular leak.

TABLE 1 CT Analysis for Transcatheter Double-Valve Replacement

	Case 1	Case 2	Case 3
Aortic valve			
Morphology	Tricuspid	Tricuspid	Type 1 bicuspid, R-L
Annulus area, mm^2	374.3	279.1	679.1
Annulus area-derived diameter	22.2	18.9	29.4
Mitral bioprosthetic valve			
Name of valve	Biocor (St Jude Medical)	Mosaic (Medtronic)	Perimount (Edwards Lifesciences)
Labeled size, mm	27	25	27
Inner area, mm^2	460.6	337.4	489.3
Area-derived inner diameter, mm	24.2	20.7	25.0
Aortomitral inverse angle, °	106.9	111	112.3
Neo-LVOT area at end-systole, mm^2 (80:20 simulation)	251.4	268.8	368.6
Novel CT parameters to predict interaction			
aVBR to BPMV near post distance, mm	8.3	6.1	8.6
aVBR to BPMV sewing ring distance, mm	3.1	5.5	3.6
BPMV post position relation to LVOT	Favorable lateral anterior	Unfavorable Central anterior	Favorable lateral anterior
BPMV post-IVS distance, mm	13.5	9.8	10.6
Mean BPMV Interpost distance, mm	15.23	20.73	18.46

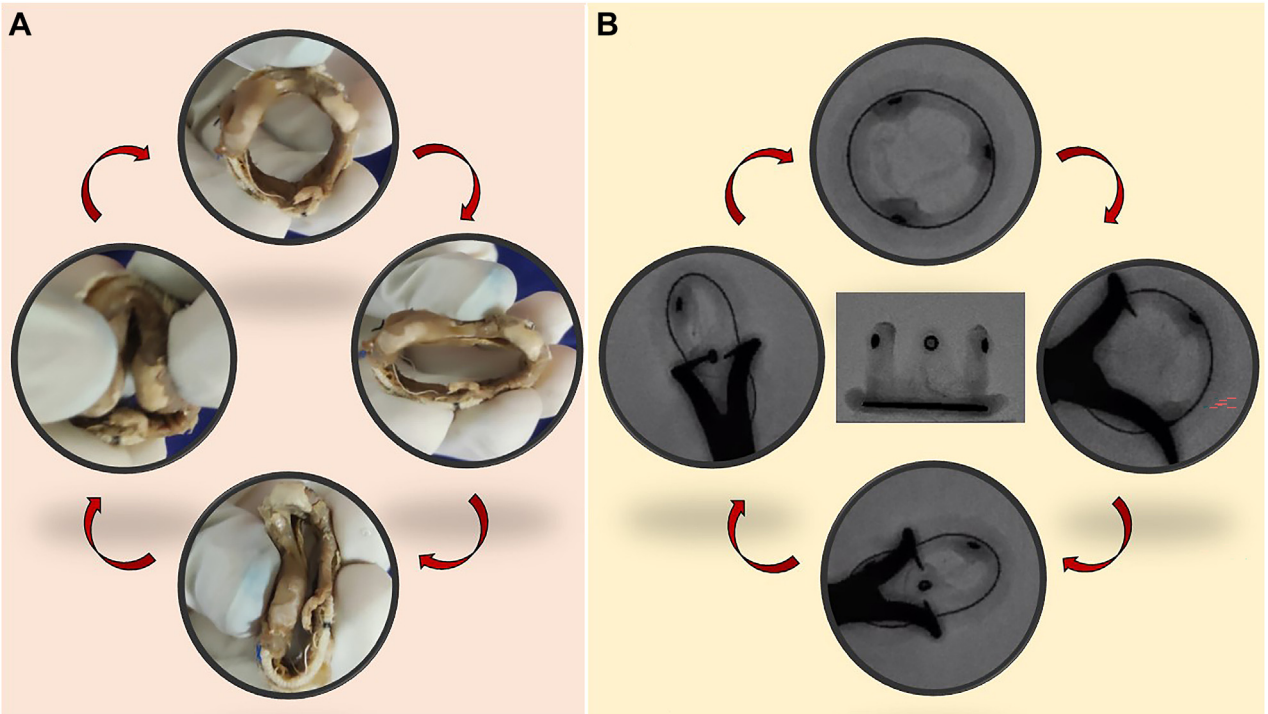
aVBR = aortic virtual basal ring; BPMV = bioprosthetic mitral valve; CT = computed tomography; IVS = interventricular septum; LVOT = left ventricular outflow tract; R-L = raphe between the right and left coronary cusps.

FIGURE 1 Computed Tomography Predictors of Prosthetic Valve Interaction for Case 1



(A) Virtual basal ring to bioprosthetic mitral valve sewing ring distance. (B) Virtual basal ring to bioprosthetic mitral valve near post distance. (C) Bioprosthetic mitral valve post to interventricular septum distance. (D) Bioprosthetic mitral valve interpost distance (arrows). (E) Aortomitral angle. (F) Schematic illustration of a 23-mm Meril Navigator balloon interacting with the anterior bioprosthetic mitral valve posts (arrows).

FIGURE 2 Flexibility and Deflectability of the Sewing Ring and Posts of a Biocor and a Hancock II Valve



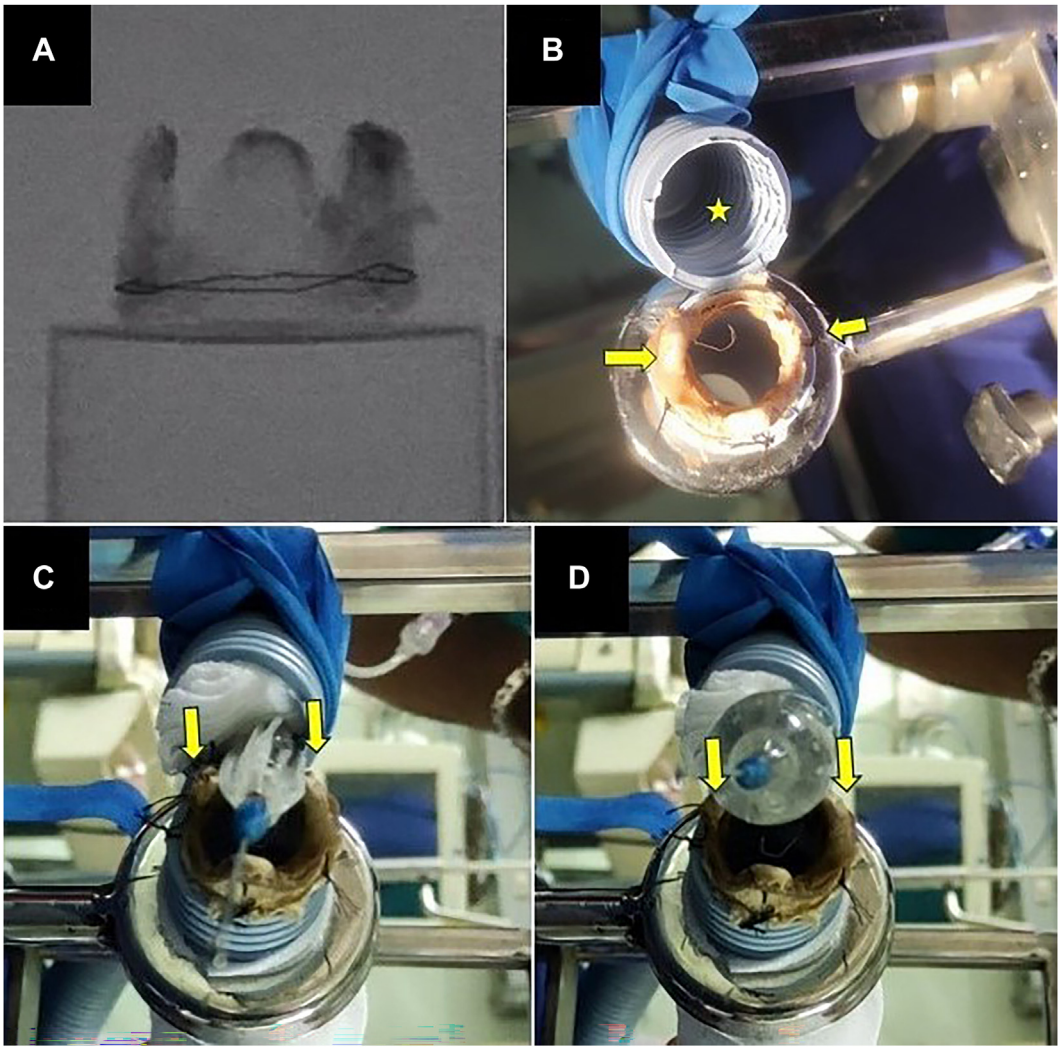
(A) Manual compression test of an explanted 27-mm Biocor valve (St Jude Medical). Clockwise from the 3-o'clock position, horizontal sewing ring compression, vertical sewing ring compression, compression of all 3 posts, and recovery to the normal shape are shown. (B) Compression test by Mayo towel clip forceps of a 27-mm Hancock II valve (Medtronic). Clockwise from the 3-o'clock position, without compression, vertical compression, horizontal compression, and returning to normal shape are shown. The central image shows the coplanar view of the valve.

according to its favorability or not; and the mean BPMV interpost distance (15.23 mm) (**Figure 1D**). The steps for measuring these parameters are elaborated in Supplemental Figures 1 to 4.

We simulated the interaction using a bench model. The bench model was created using the CT aortomitral angle (**Figure 1E**), the aVBR to BPMV near post distance, the aVBR to BPMV sewing ring distance, and favorable lateral anterior BPMV posts (**Figure 1F**). This patient had a 27-mm degenerated Biocor mitral valve. A 27-mm explanted degenerated Biocor valve from a different patient during redo -surgery was used in the bench model. The Biocor valve sewing ring and posts are flexible and deflectable, as are all contemporary surgical bioprosthetic valves (**Figures 2A and 2B**). According to the CT measurements, the operators planned a 23-mm Myval valve (Meril) for AS. Hence a 23-mm Navigator balloon (Meril) was inflated in the bench model's LVOT. It aligned between the 2 lateral anterior posts of the mitral Biocor valve during the initial three-fourths of the inflation. During the final one-fourth of the inflation, it stretched the posts for a moment without damaging them (**Figures 3A to 3D**). The 23-mm balloon stretched the posts during full inflation because the distance between the posts was only 20.8 mm. The posts were back to their position immediately after the deflation.

CASE 2. The CT analysis (**Table 1**) showed an unfavorable central anterior post of a degenerated 25-mm Mosaic (Medtronic) BPMV projecting into the LVOT (**Figure 4A**). With the novel CT parameters as shown in **Figures 4A to 4D**, CT simulation revealed a significant interaction of the balloon of a BE TAV with the unfavorable anterior post. The transthoracic echocardiogram and fluoroscopic images show the projecting central anterior post in the way of the TAV balloon (**Figures 4E and 4F**). A bench model was created in line with the CT measurements as in the previous case, with an explanted 27-mm degenerated Hancock II valve (Medtronic) from a different patient during redo surgery (**Figures 5A and 5B**). At the time

FIGURE 3 **Bench Test for Case 1**

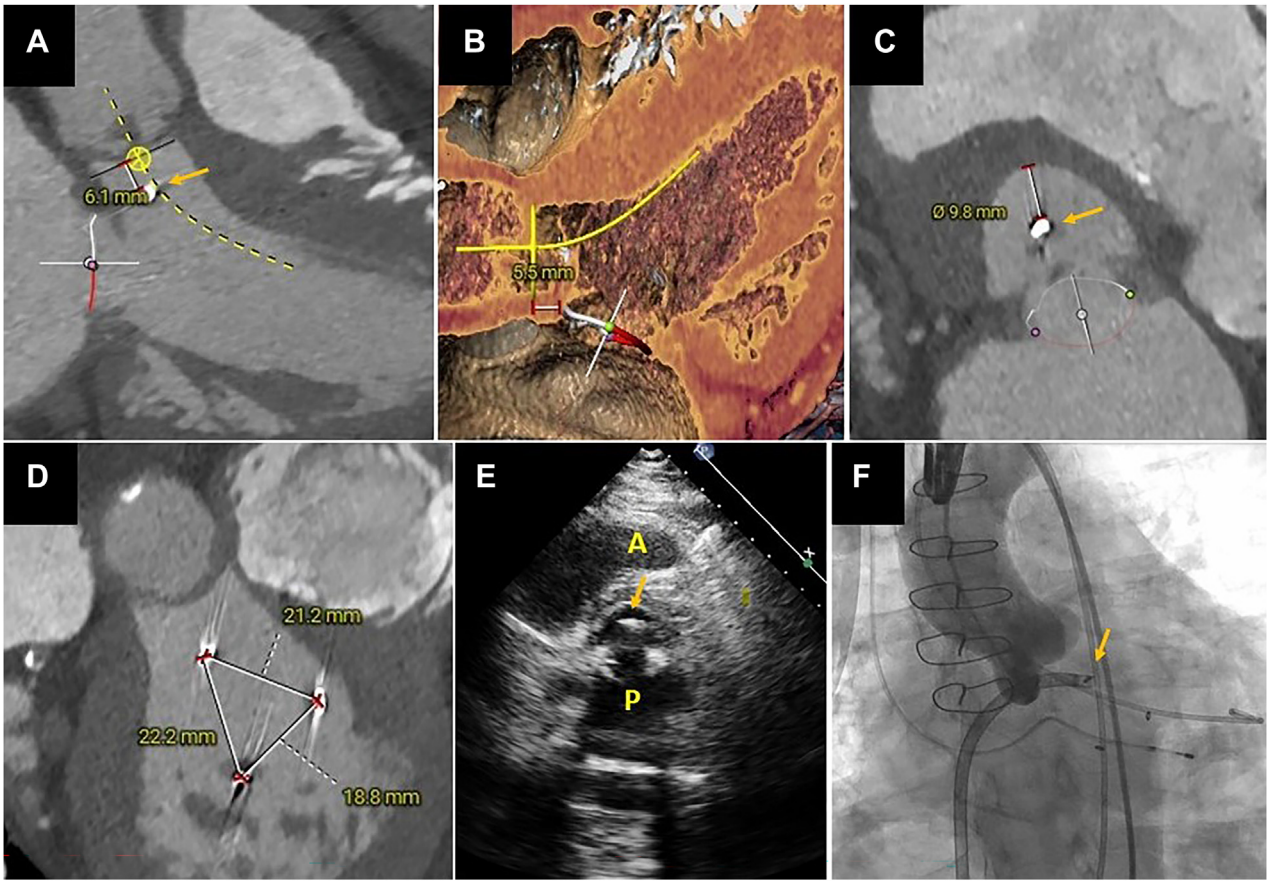


Transcatheter aortic valve balloon interacting with a 27-mm Biocor mitral valve (St Jude Medical) posts in a favorable position. (A) Fluoroscopy image of a 27-mm Biocor valve. (B) Bench model shows a sewn Biocor valve at the mitral position with favorable 2 lateral anterior posts (arrows) on either side of the left ventricular outflow tract (star). This model was created with the computed tomography parameters given in Figure 1. (C) At the beginning of the inflation of a 23-mm transcatheter aortic valve balloon in the left ventricular outflow tract, it was fit between the 2 lateral anterior posts (arrows). (D) At full inflation of the balloon, stretching of the lateral anterior posts was seen (arrows) because the interpost distance between them was 20.8 mm.

of bench testing, an explanted Mosaic valve was unavailable; hence the fluoroscopically closely mimicking Hancock II valve was chosen for the bench test. The planned TAV was a 21.5-mm Myval Octacor valve (Meril). For safety purposes, a 23-mm (1.5-mm higher than the valve size) Navigator balloon was inflated over 20 seconds in the LVOT of the bench model. A clear bending of the central anterior post toward the center of the valve was noted during the second half of inflation; the post returned to its original position immediately after deflation (Figures 5C to 5F).

CASE 3. The CT analysis (Table 1, Figures 6A to 6H) showed favorable lateral anterior posts of a degenerated 27-mm Perimount (Edwards Lifesciences) BPMV in the LVOT. However, the BPMV post to IVS distance was only 10.6 mm, and the mean BPMV interpost distance was 18.46 mm. The operators planned to use a 29-mm Myval valve for TAVR. We

FIGURE 4 Computed Tomography Predictors of Prosthetic Valve Interaction for Case 2



(A) Virtual basal ring to bioprosthetic mitral valve near post distance. (B) Virtual basal ring to bioprosthetic mitral valve sewing ring distance. (C) BPMV post to interventricular septum distance. (D) Bioprosthetic mitral valve interpost distance. (E) Transthoracic echocardiogram shows the unfavorable central anterior post. (F) Fluoroscopy image shows the unfavorable central anterior post projecting into the left ventricular outflow tract. The yellow arrows in panel A,C,E and F denote the tip of the central anterior post of the Mosaic (Medtronic) mitral valve. A = anterior; P = posterior.

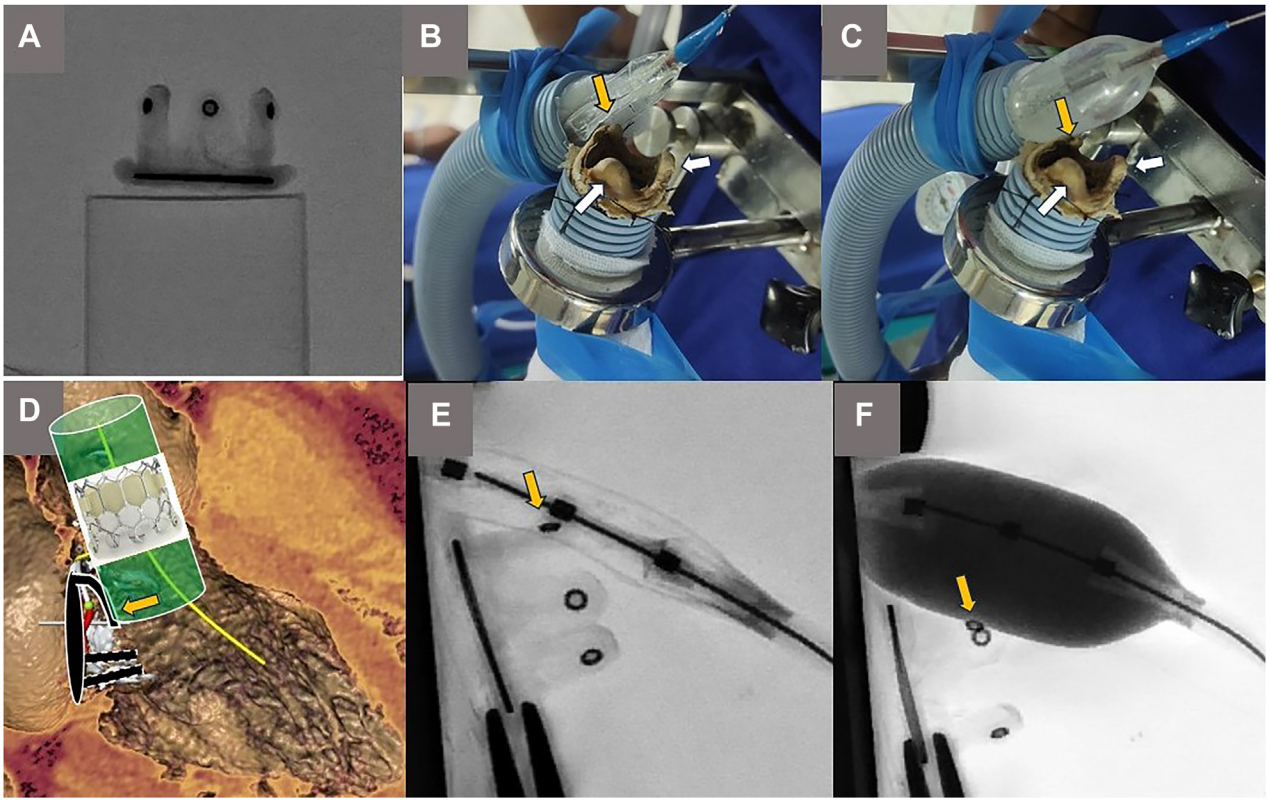
did not conduct a bench test this time. However, from these CT measurements, and on the basis of the previous 2 bench tests, we concluded that a 29-mm TAV balloon would lead to reversible stretching of the posts.

PROSTHETIC VALVE INTERACTION TYPES

We propose a new classification system for prosthetic valve interactions. Two broad types of interactions are possible: type M and type A. A BPMV or TMV affected by a TAV system is proposed as a type M interaction, and a TAV affected by a BPMV or TMV is proposed as a type A interaction. Type M is further subclassified into M1, M2, and M3. Reversible stretching of the BPMV posts by the TAV balloon projecting into the LVOT is type M1. Reversible bending of the BPMV posts by the LVOT balloon is type M2. Compression of the TMV stent frame by the TAV balloon is type M3. Both type M1 and type M2 can be seen during TAVR in the presence of a BPMV and are benign. Type M3 can be seen in a scenario of BE TAVR after the M-ViV procedure. Type M3 can affect TMV function or lead to TMV embolization. If the TAV is affected by the BPMV or TMV, it is a type A interaction. While performing TAVR in the presence of BPMV, aortic embolization or paravalvular leak can manifest from the interaction of the LVOT portion of the TAV stent frame with the BPMV sewing ring.

While performing the DVR in vivo, the BPMV posts were in a favorable lateral anterior position in cases 1 and 3. The BPMV post to IVS distance was less than the TAV balloon diameter in these 2 cases. Hence the TAV balloon expanded between the lateral anterior

FIGURE 5 Bench Test for Case 2



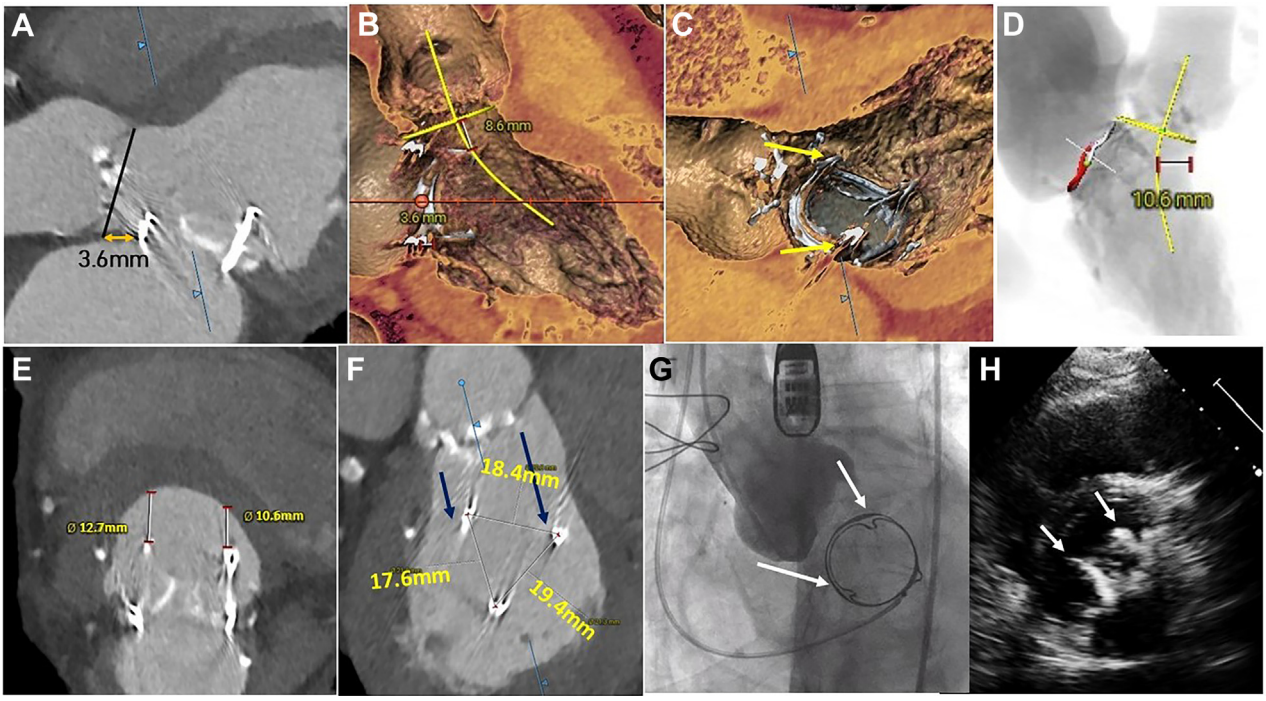
A 23-mm transcatheter aortic valve balloon interacting with 27-mm Hancock II mitral valve (Medtronic) posts in an unfavorable position. (A) Fluoroscopy image of a 27-mm Hancock II valve with a radiopaque ring at the end of each post similar to the Mosaic (Medtronic) valve. (B) Bench model shows a sewn Hancock II valve at the mitral position and a 23-mm Meril Navigator delivery balloon in the anterior left ventricular outflow tract. This model was created with the computed tomography parameters given in Figure 4. The anterior post (yellow arrow) and the posterior posts (white arrows) are shown. (C) On full balloon inflation, we can see the bending of the anterior post. (D) Schematic simulation of (C). Posterior posts are shown as dotted lines. (E) Simultaneous fluoroscopy image of (B) before balloon inflation. (F) Simultaneous fluoroscopy image of (B) during balloon inflation shows bending of the anterior post. The yellow arrows in B, C, D, E, and F indicate the unfavourable central anterior post projecting into the LVOT and that is compressed by the TAV balloon from the LVOT. The white arrows in B and C indicate the posterior posts of BPMV.

posts, and momentary stretching of the posts was noted. We classify this as a type M1 interaction (Figure 7). In case 2, the BPMV post was in an unfavorable central anterior position. The distance between this post and the IVS was less than the TAV balloon diameter; hence we noticed reversible bending of this post by the LVOT part of the TAV balloon. We classify this as a type M2 interaction (Figure 7). In both types, M1 and M2, BPMV function did not worsen.

Bauernschmitt et al[4] reported a simultaneous transcatheter transapical DVR using SAPIEN 3 valves (Edwards Lifesciences) in a 67-year-old woman with degenerative AS and mitral regurgitation. First, a 29-mm SAPIEN 3 valve was deployed inside mitral annular calcium, and then a 23-mm SAPIEN 3 valve was placed in the aortic position. These investigators did not document any valve interaction in their report. However, 5 months later, the patient underwent open heart surgery for LVOT obstruction caused by migration of the TMV into the LVOT. The explanted TMV was compressed on the LVOT side. This is evidence of a type M3 interaction (Figure 7).[4]

Amat-Santos et al[3] studied the outcomes of TAVR in preexisting prosthetic surgical mitral valves. These investigators concluded that the TAV device was embolized only in patients with a prosthetic mitral valve to aortic annulus distance <7 mm. They also observed deformation of the SE TAV prosthesis by the BPMV sewing ring that led to significant paravalvular leaks.[3] We classify this as a type A1 interaction (Figure 7).

FIGURE 6 **Computed Tomography Predictors of Prosthetic Valve Interaction for Case 3**



(A) Virtual basal ring to bioprosthetic mitral valve sewing ring distance. (B) Virtual basal ring to bioprosthetic mitral valve near post distance. (C) Favorable lateral anterior posts of Perimount mitral valve (Edwards Lifesciences) on either side of the left ventricular outflow tract. (D) Bioprosthetic mitral valve post to interventricular septum distance in long axis. (E) Bioprosthetic mitral valve posts to interventricular septum distances in cross-section. (F) Interpost distance. (G) Fluoroscopy image of favorable lateral anterior posts on either side of the left ventricular outflow tract. (H) transthoracic echocardiogram image showing the favorable lateral anterior posts. The double arrows in C, F, G, and H indicate the favourable lateral anterior posts of BPMV on either side of the LVOT.

FIGURE 7 **Transcatheter Valve Interaction Classification During Left-Sided Double Valve Replacement**

Interaction Types	Possible outcomes[a]	CT predictors
Type – M1: Reversible stretching of the BPMV posts by the LVOT balloon	Normal function	1.BPMV interpost distance 2.Favorable lateral anterior posts
Type – M2: Reversible bending of the BPMV posts by the LVOT balloon	Normal function	1.Unfavorable central anterior post 2.BPMV post to IVS distance 3. VBR to nearest BPMV post distance
Type – M3: Compression of the TMV stent frame by the TAV balloon	1. Increased mitral gradient 2. Mitral valvular or paravalvular leak 3. TMV Embolization into LV	1.TMV frame tip to IVS distance 2.VBR to Nearest TMV frame distance
Type – A1: TAV frame interacting with the BPMV sewing ring	1.TAV embolization into Aorta 2. Paravalvular leak	1.VBR to BPMV sewing ring distance

[a]Based on anecdotal reports. BPMV = bioprosthetic mitral valve; IVS = interventricular septum; LV = left ventricle; LVOT = left ventricular outflow tract; TAV = transcatheter aortic valve; TMV = transcatheter mitral valve; VBR = virtual basal ring.

CLINICAL FOLLOW-UP

All patients underwent successful transcatheter DVR and were alive at a mean follow-up of 20.67 ± 10.79 months. The first patient was hospitalized for atrial fibrillation-induced heart failure at 31 months and was in NYHA functional class II at the 33-month follow-up. The other 2 patients were in NYHA functional class I at their latest follow-up.

POTENTIAL PITFALLS

This case series is small. Larger data with these novel CT parameters and cutoffs for these distances should be understood to predict the valve interactions. We did not use a 3-dimensional printout model while performing the bench tests. Bench tests of contemporary bioprosthetic valves, TAVs, and TMVs in a patient-specific 3-dimensional printout model may give a better understanding of these interactions.

CONCLUSIONS

A simultaneous transfemoral TAVR and a transseptal M-ViV implantation can be safely performed in a patient with a degenerated BPMV and native AS. TAVR should be performed first to avoid interaction with the TMV stent frame. Type M1 and type M2 interactions are safe, whereas type M3 and type A1 interactions are not.

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KEY WORDS aortic valve, complication, computed tomography, double-valve replacement, interaction, mitral valve, valve replacement

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