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CASE REPORT
Cardiac imaging

Preoperative planning using virtual reality for percutaneous transseptal valve-in-valve transcatheter mitral valve replacement: a case report

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Background Virtual reality (VR) technology has been implemented as a pre-procedural planning tool for cardiovascular interventions to enable detailed evaluation of patient anatomy from different vantage points. Here, we employed a VR platform to pre-operatively plan for percutaneous valve-in-valve transcatheter mitral replacement (ViV-TMVR) in a prohibitive surgical candidate.

Case summary An 85-year-old male with a history of two prior sternotomies for bioprosthetic aortic valve (AV) and mitral valve (MV) 31 mm Medtronic Mosaic bioprosthesis presented with severe mitral regurgitation from a degenerative bioprosthetic MV. The patient was deemed a prohibitive surgical candidate for a third sternotomy and instead was recommended a percutaneous transseptal ViV-TMVR. An electrocardiogram-gated chest computed tomography (CT) provided a neo-left-ventricular outflow tract (neo-LVOT) of 1.89 cm^2. This CT was reconstructed to create a 360° VR (360VR) model. A 29 mm SAPIEN three bioprosthetic valve, selected based on the already implanted MV, was placed inside the bioprosthetic MV and analysed in VR at different angles to ensure it would not obstruct the LVOT. The neo-LVOT measured in VR was 3.02 cm^2, which would allow for sufficient blood flow without significant obstruction from the new SAPIEN three bioprosthetic valve. The patient tolerated the procedure well.

Discussion This case demonstrates the utility of VR as a pre-procedural planning tool for interventional cardiology procedures. Preoperative planning in VR alleviated concerns regarding obstruction of the neo-LVOT and helped confirm safe implantation by clearly showing the three-dimensional spatial relationship between the implants and surrounding patient anatomy.

Keywords Virtual reality • Transcatheter mitral valve replacement • Valve in valve • Surgical planning • Case report • LVOT obstruction

ESC Curriculum 2.1 Imaging modalities • 4.3 Mitral regurgitation

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Learning points

- Conventional two-dimensional LVOT measurement requires experienced personnel and is limited by the difficulty in appreciating the exact dimensions and spatial relationships of relevant structures.
- In contrast to three-dimensional printing, procedural planning in VR provides depth perception is not labour intensive, and does not have to account for printer and raw material costs and printing time.
- Immersive 360VR technology allows for in-depth visualization of the patient's anatomy to carefully prepare for complex structural heart interventions. This VR surgical planning platform also provides a library of tools and valve implants of various sizes that can interact with the patient-specific model for preoperative planning and rehearsal.

Introduction

Virtual reality (VR) has been utilized as a pre-procedural planning tool for cardiovascular procedures to provide detailed visualization of the three-dimensional (3D) spatial relationship between relevant critical structures that are difficult to appreciate with standard two-dimensional (2D) images.[1] Here, a percutaneous transseptal transcatheter mitral valve-in-valve replacement (ViV-TMVR) was planned using VR for a prohibitive surgical candidate.

Timeline

Data	Events
2003	First bioprosthetic aortic valve (AV) replacement
2014	Tricuspid valve repair with an annuloplasty ring, and a bioprosthetic mitral valve (MV) replacement (31 mm Medtronic Mosaic)
Admission Day 0	Presented with decompensated congestive heart failure and flail of the bioprosthetic MV leaflets resulting in severe mitral regurgitation
Admission Day 1	Percutaneous ViV-TMVR Procedure day
Admission Day 2	Discharge from hospital
1 month after surgery	Follow-up imaging and comparison pre- and post-operative left-ventricular outflow tract (LVOT) gradients using transthoracic echocardiography (TTE), which did not show a significant haemodynamic obstruction
18 months after surgery	No complication or complaints, all examinations are normal

Case presentation

An independent 85-year-old male taking aspirin and apixaban with a history of chronic atrial fibrillation, stroke, ventriculoperitoneal shunt, and two prior sternotomies for bioprosthetic AV and MV (31 mm Medtronic Mosaic bioprosthesis) replacements presented with decompensated congestive heart failure and pulmonary oedema resulting from severe mitral regurgitation from a flail bioprosthetic MV caused by chronic degeneration. His AV was functioning well (no aortic insufficiency, 8 mmHg mean AV gradient). Left-ventricular (LV) ejection fraction was 55% with a normal LV internal end-diastolic diameter of 4.7 cm. With a blood gas PaO_2 of 57 mmHg on room air, he was profoundly dyspnoeic on high-flow nasal cannula with 2+ bilateral lower extremity pitting oedema. Coarse lung sounds were auscultated bilaterally, and jugular venous pressure was elevated. He had a loud holo-systolic murmur at the left lower sternal border radiating to his left axilla. The patient was severely deconditioned and had a calculated 30-day mortality of 20%. He was deemed a prohibitive surgical candidate by the heart team and was recommended ViV-TMVR.

Transoesophageal echocardiography (TEE) demonstrated flail of the bioprosthetic MV leaflets and a small neo-LVOT (*Figure 1*). Vegetation or peri-valvular regurgitation was not evident. His NT-proBNP was elevated at 8200 pg/mL. An electrocardiogram-gated chest computed tomography angiogram (CTA; 0.4 mm slice thickness) was taken during end-systole pressure, and a 1.89 cm^2 neo-LVOT area was measured (*Figure 2*). This CTA was reconstructed to create a 360° VR (360VR) model using a VR surgical planner (SRP; Surgical Theater, Cleveland, OH, USA; *Figure 3*, see Supplementary material online, *Video S1*). Using an Oculus Rift S headset (Meta, Irvine, CA, USA), the model was utilized for procedural planning. A 29 mm SAPIEN 3 valve (Edwards Lifesciences, Irvine, CA, USA), selected based on the already implanted MV, was placed inside the bioprosthetic MV and analysed in VR at different angles (*Figure 3B*). The neo-LVOT area was measured in VR by first selecting a polygon and placing it at exactly where the smallest neo-LVOT area would be. The polygon edges were moved in and out of the tissue and valve planes to ensure correct positioning for accurate neo-LVOT measurement. This was verified by viewing the plane from different angles. A 3.02 cm^2 area was measured.

ViV-TMVR was performed via a transeptal approach from the right common femoral vein under general anaesthesia using fluoroscopic and TEE guidance (Supplementary material online, *Video S2*). The patient was intubated, diuresed with IV furosemide, and started on diltiazem. A transseptal puncture was performed using a standard BRK XS transseptal needle (St Jude Medical, St Paul, MN, USA) from the right femoral vein. A 145 cm pigtail catheter was advanced through the septum and into the LV where it was exchanged for a Confida guidewire (Medtronic, Fridley, MN, USA). A 16 French 36 cm E-sheath (Edwards Lifesciences) was advanced, and an Armada-35 12.0 × 40 mm balloon (Abbott) was used for septostomy. The balloon was withdrawn, and a 29 mm SAPIEN 3 was advanced across the septum and deployed inside the bioprosthetic valve under rapid pacing. Once the valve position was confirmed, the wires and sheath were removed, and excellent haemostasis was achieved using Perclose sutures. The patient tolerated the procedure well, was discharged the following day with furosemide, aspirin, apixaban, and diltiazem, and doing well at 18 months.

Discussion

The patient presented with severe mitral regurgitation secondary to chronic degeneration of a flail bioprosthetic MV leaflet. Given his 30-day mortality was estimate at 20% and his preference for a less invasive approach, ViV-TMVR was recommended by the heart team. However, our initial analysis of the TEE and 2D-CT images (1.89 cm^2 neo-LVOT area) concerned us for potential LVOT obstruction, which could put the patient at a high risk for heart failure[2] (*Figures 1* and *2*). A neo-LVOT area of

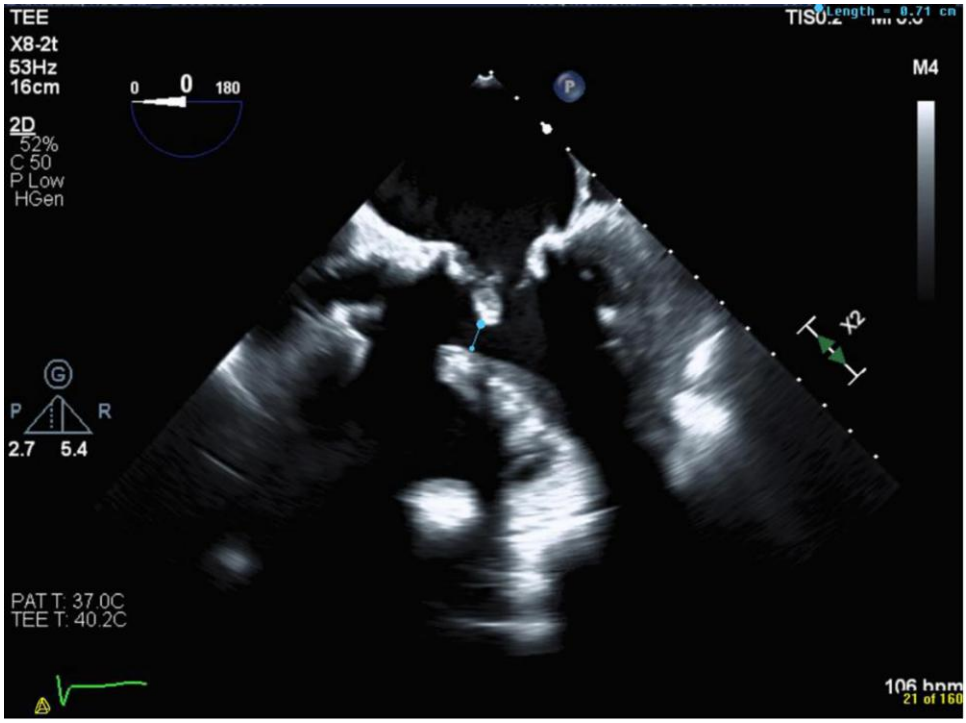


Figure 1 Preoperative transoesophageal echocardiography. Image showing the distance (blue) between the valve and intra-ventricular septum, and small left-ventricular outflow tract.

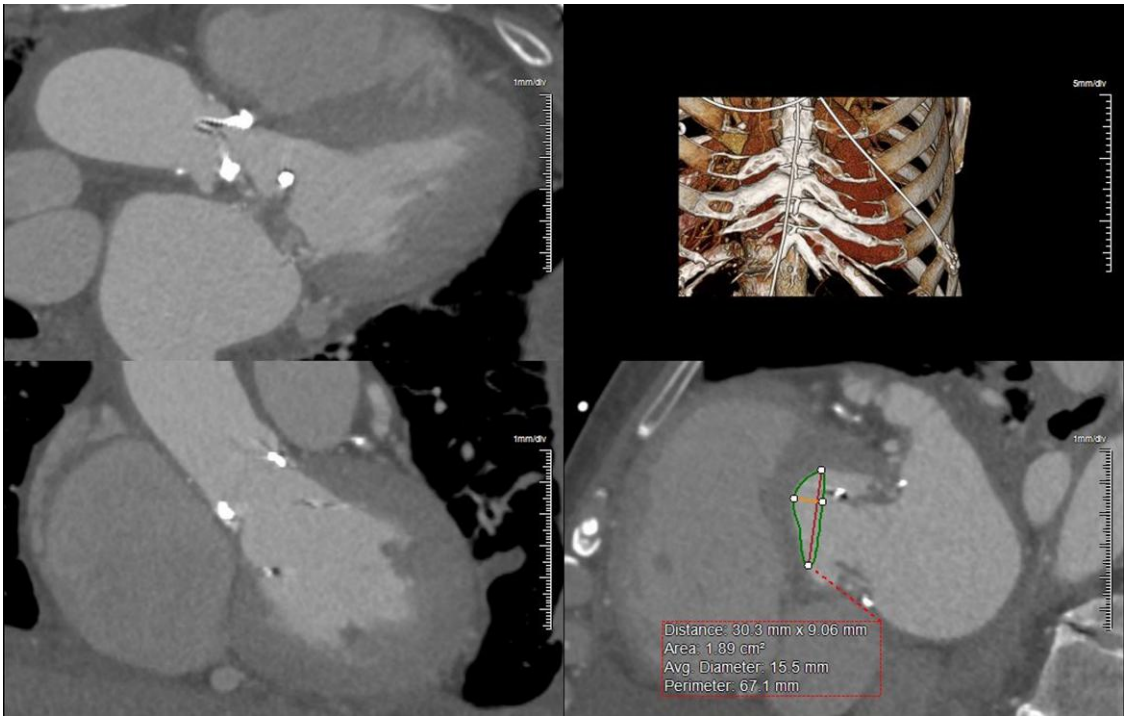


Figure 2 Preoperative electrocardiogram-gated computed tomography angiogram with the neo-left-ventricular outflow tract surface area measurement calculation from an axial plane view (1.89 cm^2).

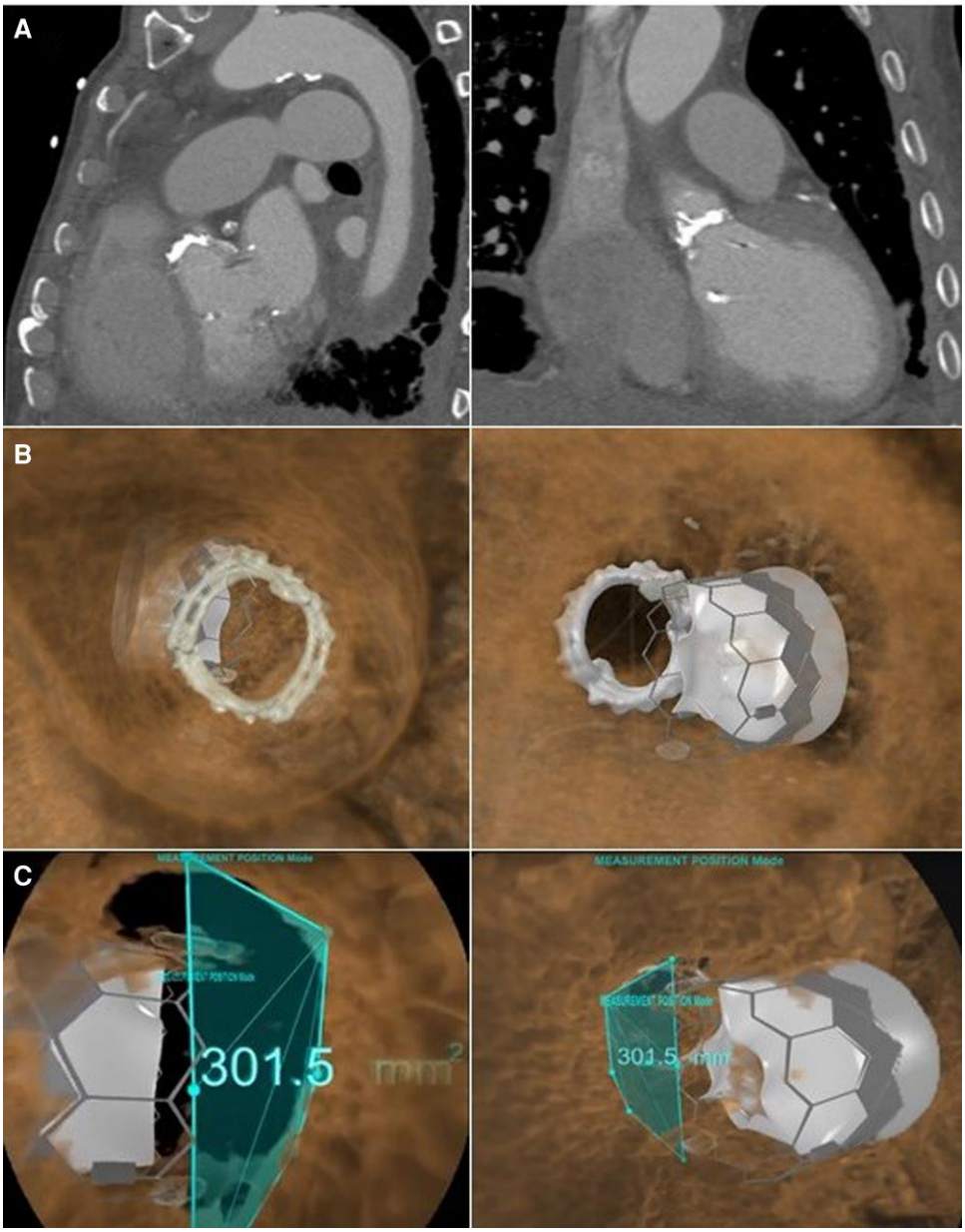
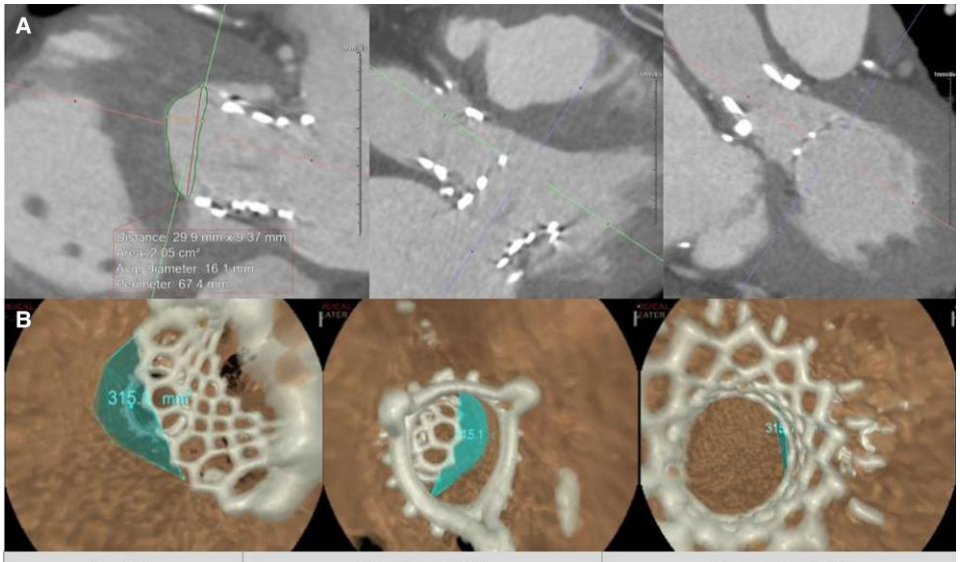


Figure 3 Preoperative computed tomography. (*A*) DICOM images in sagittal and coronal views of the mitral valve and left-ventricular outflow tract. (*B*) Snapshots of the 360° VR model with the virtual 29-mm SAPIEN 3 showing left-ventricular outflow tract opening and neo-left-ventricular outflow tract measurements in virtual reality. (*C*) While the 360° VR snapshots clearly show the left-ventricular outflow tract opening, the evaluation of the model in virtual reality was necessary to better assess its exact surface area due to the lack of depth perception in 2D images.

>2 cm^2 is considered the cutoff value for safe placement without obstruction.[3] Given that a better assessment of the spatial relationship between the bioprosthetic AV, bioprosthetic MV, SAPIEN 3, intraventricular septum, and LVOT was needed, a VR platform was utilized to assess LVOT obstruction risk. This VR platform was recently employed for patient-specific case review and pre-procedural consults for TAVR and LAAO procedures.[4] Here, SAPIEN 3 was virtually placed over the existing bioprosthetic MV in VR (*Figure 3B*, see Supplementary material online, *Video S1*). The interactive 360VR model allowed for pre-procedural planning of the exact location of the valve placement that would not cause LVOT obstruction. The model displayed the MV's exact borders and its 3D relationship to the intraventricular septum. The neo-LVOT area measured in VR was 3.02 cm^2, which would allow for sufficient blood flow without significant obstruction.[2] Neo-LVOT measurements using postoperative 2D-CT and VR were 2.05 and 3.15 cm^2, respectively (*Figure 4*).

A 1-month postoperative 360VR model verified that there was no significant LVOT obstruction from the implanted SAPIEN 3 (*Figure 5*). The model demonstrated how accurate the pre-procedural planning was in predicting where the SAPIEN 3 would land without LVOT obstruction (*Figure 4B*). Further confirmation was done by comparing the pre- and post-operative LVOT gradients using TTE, which did not show a significant haemodynamic gradient (no gradient increase ≥10 mmHg from baseline).[5]



Modality	Pre-Op LVOT	Post-Op LVOT
VR model	3.02 cm^2	3.2 cm^2
CT DICOM	1.89cm^2	2.05 cm^2

Figure 4 Post-operative measurements of (*A*) computed tomography scan in DICOM format and of the (*B*) virtual reality model.

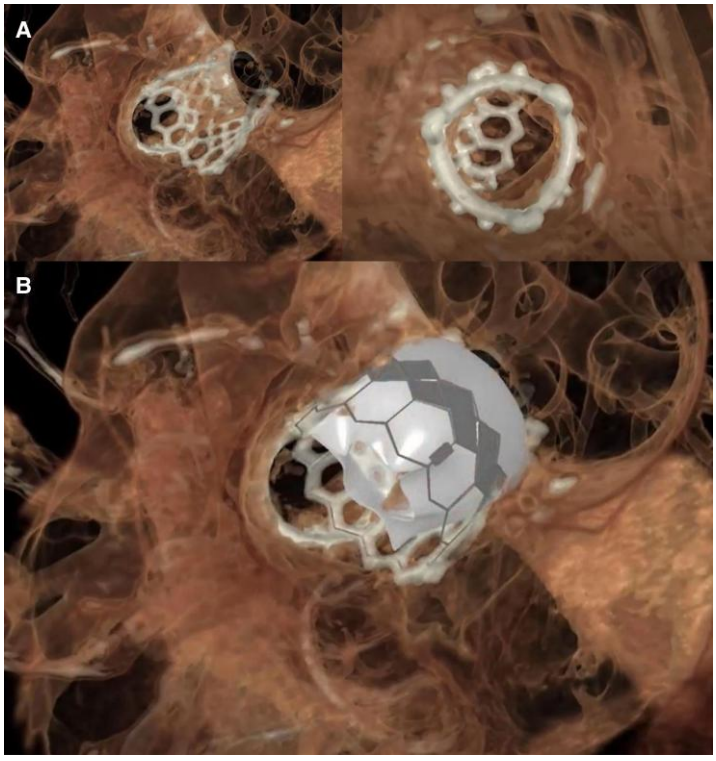


Figure 5 Postoperative 360° VR imaging. (*A*) Snapshots of the 360° VR model with implanted 29-mm SAPIEN 3. (*B*) A 360° VR overlay of the pre-operative virtually placed SAPIEN 3 and the postoperative newly placed valve.

Immediately after the procedure, the peek gradient across the LVOT was 7 mmHg. The 1-month postoperative echocardiogram reported an LVOT peak gradient of 2.6 mmHg, a minimal increase in LVOT gradient that corroborated our 360VR assessment.

The current standard of care, LVOT measurement using CTA, requires experienced personnel and is limited by the difficulty in appreciating the exact dimensions and spatial relationships of relevant structures because the 3D CTA models are examined on a 2D screen. As a result, clinical application of 3D printing for procedural planning in cardiovascular intervention became widespread.[6] However, while 3D printing allows for *ex vivo* device bench testing of patient-specific anatomy to plan the angle and depth of implant deployment,[7] it can be expensive and time-consuming with production needing to be outsourced if a 3D printer is not available. Planning in VR, on the other hand, provides depth perception, is not labour intensive, and does not have to account for printer and raw material costs and printing time. Here, VR provided the in-depth perception needed to accurately evaluate the 3D spatial relationship between the bioprosthetic MV, bioprosthetic AV, intraventricular septum, and newly implanted SAPIEN 3, which was difficult to appreciate in 2D (*Figures 1* and *3A*). VR evaluation allowed for more accurate sizing of the LVOT opening, which would have been difficult with the lack of in-depth perception when viewing on a screen. The platform's library of virtual tools and implants of various sizes that can interact with the patient-specific model allows for precise planning, rehearsal, and prediction modelling for LVOT obstruction, which has proven to be feasible and accurate using other platforms and can be validated for this platform in future studies.[8] Notably, with the assistance of an experienced operator, this 360VR model was created in 5 min, while 3D printing a heart-valve-disease model can range from 30 min to 3 days depending on complexity and technique.[9]

Furthermore, VR can facilitate information sharing with other care team members. Multiple users can gain an understanding of the patient's anatomy from any vantage point.

Conclusion

The presented technology may be a valuable tool in pre-procedural planning for complex structural heart interventions.

Lead author biography

Jorge M. Castellanos, I am currently working in Newport Beach, CA as the founding partner of JMC Medical. I graduated from Harvard Medical School in 2007, completed internal medicine residency in June 2010 at the University of California San Francisco, completed general cardiology fellowship at Cedars-Sinai Medical Center in June 2013, and interventional cardiology at Cedars-Sinai Medical Center in June 2014 with a focus in complex coronary interventions and structural heart disease. I have a particular interest in applying new technologies for improving patient care and procedural planning.

Supplementary material

Supplementary material is available at *European Heart Journal – Case Reports* online.

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Slide sets: A fully edited slide set detailing this case and suitable for local presentation is available online as Supplementary data.

Consent: The authors confirm that written consent for submission and publication of this case report including images and associated text has been obtained from the patient in accordance with COPE guidelines.

Conflict of interest: J.M.C. is a consultant for Surgical Theater and receives compensation for speaking on marketing engagements, for education engagements, and product development feedback. D.B., A.Y., P.N.D. are employees of Surgical Theater. Others: None.

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