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CASE REPORT
Valvular heart disease

Transcatheter mitral valve replacement to treat severe calcified rheumatic native mitral stenosis: role of three-dimensional printing—a case report

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Background Rheumatic heart disease is a major disease that seriously affects human health and survival worldwide. Rheumatic mitral stenosis often has relatively complex pathological changes, and its progression leads to various manifestations of mitral valve dysfunction and adverse clinical events.

Case summary We present a 60-year-old patient who developed chest tightness, shortness of breath, and bilateral lower limb oedema in 2018 (New York Heart Association functional class III). Systolic and diastolic murmurs could be heard in the mitral auscultation area. In December 2021, the patient was admitted to the hospital with stroke. Thereafter, transthoracic echocardiography and computed tomography were performed, and the progress of rheumatic mitral stenosis was recorded. Due to the patient's high surgical risk, a patient-specific three-dimensional printed model was used to observe anatomical structures and simulate main procedures, and the surgeons finally chose to perform transcatheter mitral valve replacement. The balloon-expandable bioprothesis was released from the right femoral artery to treat the rheumatic mitral stenosis. The patient remained asymptomatic at the 6-month follow-up.

Discussion For patients with rheumatic mitral stenosis with high surgical risk, it is feasible to conduct transcatheter mitral valve replacement under the guidance of three-dimensional printing.

Keywords Case report • Mitral valve • Rheumatic mitral stenosis • Transcatheter mitral valve replacement • Calcification • Three-dimensional printing

ESC curriculum 2.1 Imaging modalities • 2.4 Cardiac computed tomography • 4.4 Mitral stenosis

Learning points

- Rheumatic mitral stenosis is one of the main causes of mitral valve disease, especially in developing countries with a large patient base.
- Treatment decisions for rheumatic mitral stenosis should always be made on an individual basis, taking into account surgical risk and the complexity of the status of the mitral valve.
- Transcatheter mitral valve replacement is feasible for the treatment of rheumatic mitral stenosis but may require three-dimensional printing guidance due to the procedural challenges.

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Introduction

Rheumatic mitral stenosis (RMS) is one of the main causes of mitral valve (MV) disease. Rheumatic heart disease has been reported to affect more than 33 million people worldwide.[1] Previous treatments include surgical MV repair and surgical MV replacement. However, for patients with RMS who have a high surgical risk, transcatheter therapy is feasible and promising but presents many procedural challenges.[2] This case report addresses a clinical case of transcatheter mitral valve replacement (TMVR) for RMS under the guidance of 3D printing.

Summary figure

Time	Events
November 2018	The patient presented with chest tightness and shortness of breath.
December 2021	Stroke
16 July 2022	Hospitalization
17 July 2022	Assessment of computed tomography and transthoracic echocardiography
18 July 2022	The three-dimensional printed model was constructed and followed with main procedural simulations.
20 July 2022	Transcatheter mitral valve replacement
25 July 2022	The patient was in stable condition, discharged without complications.

Case report

A 60-year-old man presented with chest tightness and shortness of breath in 2018. He presented to the outpatient department with worsening symptoms and bilateral lower extremity oedema (New York Heart Association functional class III). Systolic and diastolic murmurs could be heard in the mitral auscultation area. Echocardiography showed severe calcified mitral stenosis (MS) (heart rate = 83 b.p.m.; anatomical area = 0.5 cm^2; mean pressure gradient = 18 mmHg) with moderate mitral regurgitation (volume = 57 mL) (*Figure 1A*; *Movie I in the Data Supplement*). Severe tricuspid regurgitation (volume = 140 mL) and pulmonary hypertension (pulmonary artery systolic pressure = 91 mmHg) were suggestive of rheumatic MS. The patient was at extremely high surgical risk (Society of Thoracic Surgery score, 17.1%; European System for Cardiac Operative Risk Evaluation Score, 8.3%). In addition, the patient had had a stroke in December 2021, with Wilkins score of 12.

The possibility of TMVR was assessed by transoesophageal echocardiography (TEE) (*Figure 1B*; *Movie II in the Data Supplement*) and computed tomography angiography (CTA) (*Figure 1C–E*). Meanwhile, CTA data in the Digital Imaging and Communication of Medicine format were imported into the software of Materialise Mimics version 21.0 (Leven, Belgium) for three-dimensional (3D) reconstruction. The Standard Tessellation Language format file of the 3D reconstructed model was exported to a Stratasys Polyjet 850 multimaterial full-colour 3D printer (*Figure 1F*). Then, the main procedural steps were simulated during the bench test. After it was released, the unfolded bioprosthetic valve was clearly observed to assist in the evaluation and prediction of major intraoperative complications (*Figure 2A–D*; *Movie III in the Data Supplement*).

After the team conducted a comprehensive evaluation, they decided to proceed with TMVR. The transfemoral access was chosen as the puncture point and was used to cross the atrial septum. After the anaesthesia was infiltrated locally, a 5 Fr arterial sheath was inserted, and the atrial septum was punctured with the Brockenbrough needle. A Lunderquist wire was placed into the left atrium, and a 16 mm balloon was selected to dilate the atrial septum. Afterward, an 8 Fr adjustable bent catheter was delivered to the left atrium along the guide wire, and another 6 Fr pigtail catheter was delivered to the left ventricle under the guidance of the loach guide wire. After digital subtraction angiography was used to determine the position of the mitral annulus, the guide wire was delivered to the left ventricle by the trans-septal approach (*Figure 2E*; *Movie IV in the Data Supplement*). Then, a 26 mm balloon-expandable PrizValve (NewMed Medical Inc., Shanghai, China) was implanted via a transatrial septal approach (*Figure 2F–H*; *Movies V and VI in the Data Supplement*). After the balloon was released, digital subtraction angiography (*Movie VII in the Data Supplement*) and transoesophageal echocardiography (*Figure 2I and J*; *Movie VIII in the Data Supplement*) both showed that the bioprosthetic valve was in a stable position and functioning well [mean pressure gradient (PG_{mean}) = 1 mmHg] without paravalvular regurgitation; bioprosthesis morphology was intact with normal blood flow in the left/right coronary artery. The stability and function of the bioprosthesis were confirmed by a post-operative 3D printed model before discharge. Furthermore, echocardiography showed that the bioprosthetic valve was properly fixed with the leaflets opening and closing normally (maximum velocity = 0.7 m/s; PG_{mean} = 1 mmHg). Tricuspid regurgitation volume was reduced to 5.7 mL, and pulmonary artery systolic pressure was decreased to 65 mmHg (see *Movie IX in the Data Supplement*).

Discussion

Rheumatic mitral stenosis is characterized by simultaneous pathophysiological changes in the MV annulus, leaflets, joint junction area, chordae tendineae, and papillary muscle, leading to MV complex dysfunction, LV remodelling, arrhythmia, pulmonary hypertension, and eventually to heart failure. Surgical repair or replacement is the main method to treat rheumatic MV disease. However, for some patients, the high surgical risk results in unacceptable surgical burden and complications. Transcatheter aortic valve replacement has changed the treatment pattern of severe aortic stenosis and also led to the rise and progress of transcatheter techniques in rheumatic MV disease. Unlike aortic stenosis, the MV has a complex subvalvular anatomy, which further increases the difficulty of an operation. In addition, surgical management of severe MS due to extensive calcification remains a challenge. Therefore a balloon-expandable bioprosthesis anchored by radial force may offer patients a new approach.

According to reported studies, patients with high risk after surgical MV repair/replacement can consider having valve-in-valve TMVR.[3] However, severe bleeding after TMVR and left ventricular outflow tract obstruction prevent further promotion of the technique. The reason is that the bioprothesis is overlarge, and the implant depth is often inappropriate. Echocardiography is the preferred imaging approach for diagnosing MV disease and assessing its severity. Traditionally, TEE was adequate for routine evaluation of MV and left cardiac system. However, due to the complex structures of patient-specific MV complex, it may not be sufficient of TEE to formulate surgical strategies, determine implantation depth, select the device size, and accurately predict potential complications.

Cardiovascular 3D printing provides important support for TMVR simulation. The 3D printed MV model with complete functional structures including annulus, leaflets, chordae tendineae, and papillary muscle can be used not only to observe and understand complex anatomical structures but also to provide guidance for further pre-operative evaluation and surgical simulation. Vukicevic *et al.*[4] developed a multimaterial 3D printed MV model that is suitable for simulation and planning of transcatheter mitral valve repair (TMVr). Ginty *et al.*[5] also made a dynamic MV model to simulate TMVr; the results showed that the model had

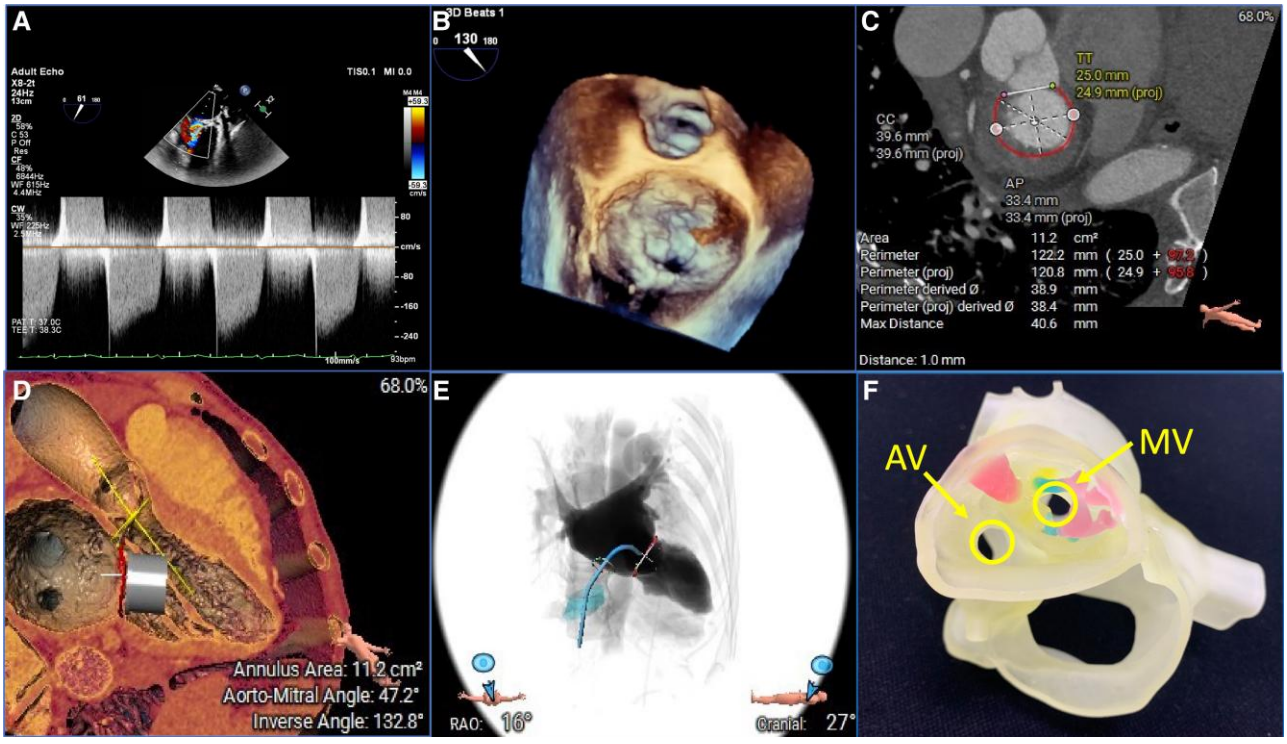

Figure 1 Pre-operative imaging assessments and three-dimensional printed model reconstructions were used to formulate the comprehensive transcatheter mitral valve replacement procedure used to treat a patient with severe rheumatic native mitral stenosis. (*A*, *B*) Pre-operative TEE measurements showed the severity of the mitral stenosis; mean pressure gradient = 18 mmHg at a heart rate of 83 b.p.m. (*C*–*E*) Pre-operative computed tomography angiography was used to access the mitral valve annulus and the left ventricular outflow tract. (*C*) The area of the mitral valve annulus was 11.2 cm^2. (*D*) The aortomitral angle was 47.2°. (*E*) The projection angle of the released implanted valve was RAO16, CAU27. (*F*) The pre-operative three-dimensional printed model in the left ventricular view. The chordae tendineae, calcifications, and papillary muscle could be clearly observed. TEE, transoesophageal echocardiography; MV, mitral valve; AV, aortic valve.

anatomical accuracy and the ability to reflect regurgitation. Daemen *et al.* used 3D-transoesophageal echocardiographic data to print 3D MV models made with rigid plastic and silicone. The models could play a positive role in enhancing the understanding of MV anatomy and in promoting the planning, simulation, and training of complex operations.[6]

We present a patient who underwent TMVR to treat severe calcified rheumatic native MS. We believe that for RMS patients combined with MR, pre-operative planning using 3D printing simulation has the following advantages: (i) through pre-operative simulation, the 3D printed model could help surgeons test different sizes of bioprosthetic valves to determine the most appropriate bioprosthesis; (ii) after the bioprosthetic valve was implanted in the 3D printed model, the surgeon could intuitively observe whether the LVOT size and the sub-mitral valve structures have significant anatomical changes; (iii) after the simulated implantation completed, the surgeon may intuitively observe the fit between the bioprosthetic valve and the native mitral valve, so as to avoid the occurrence of post-operative paravalvular leakage (PVL); and (iv) through the simulation using 3D printed model before TMVR, the operator could be guided to determine the anchoring position and implantation depth of the device. Overall, several key preparatory steps and assessments contributed to the success of the procedure as follows: (i) a multidisciplinary team whose members had extensive experience with surgical/transcatheter aortic valve replacement and valve-in-valve TMVR reviewed the feasibility of TMVR. (ii) The evaluation of pre-operative images was of great importance. Computed tomography angiography can be used to determine aortomitral valve angulation, bioprosthesis size, and expected valve deployment position. Transoesophageal echocardiography is critical for evaluating the optimal deployment position and preventing complications (including left ventricular outflow tract obstruction, paravalvular leakage, and eccentric calcification impingement). (iii) The 3D printed model may be used for comprehensive pre-operative evaluation, patient selection, formulation of surgical strategy, bioprosthesis sizing, and determination of implant depth, all of which may improve the success rate of TMVR and reduce the possibility of perioperative complications. (iv) The 3D printed model can help surgeons to enhance visual spatial understanding and decide the device selection. (v) Last but not least, the 3D printed model may improve the communication quality between doctors and patients, and shorten the learning curve for trainees. However, cardiovascular 3D printing has several limitations. In recent years, though cardiovascular 3D printing technology has made great progress, the materials used for 3D printed models have not been able to fully match human tissue until now; and the time-consuming and relatively high-cost nature may constrict the development of 3D printing. Furthermore, the pre-operative 3D printing simulations for this patient were carried out under static conditions, and the realistic cardiovascular haemodynamics environment could not be completely reproduced. In addition, further multicentre studies are needed to evaluate the effectiveness and risks of this novel intervention. Overall, we introduced a reliable method for surgeons to access RMS patients before TMVR, and it is believable that cardiovascular 3D printing will have a bright prospect in the future of treating valvular heart disease.

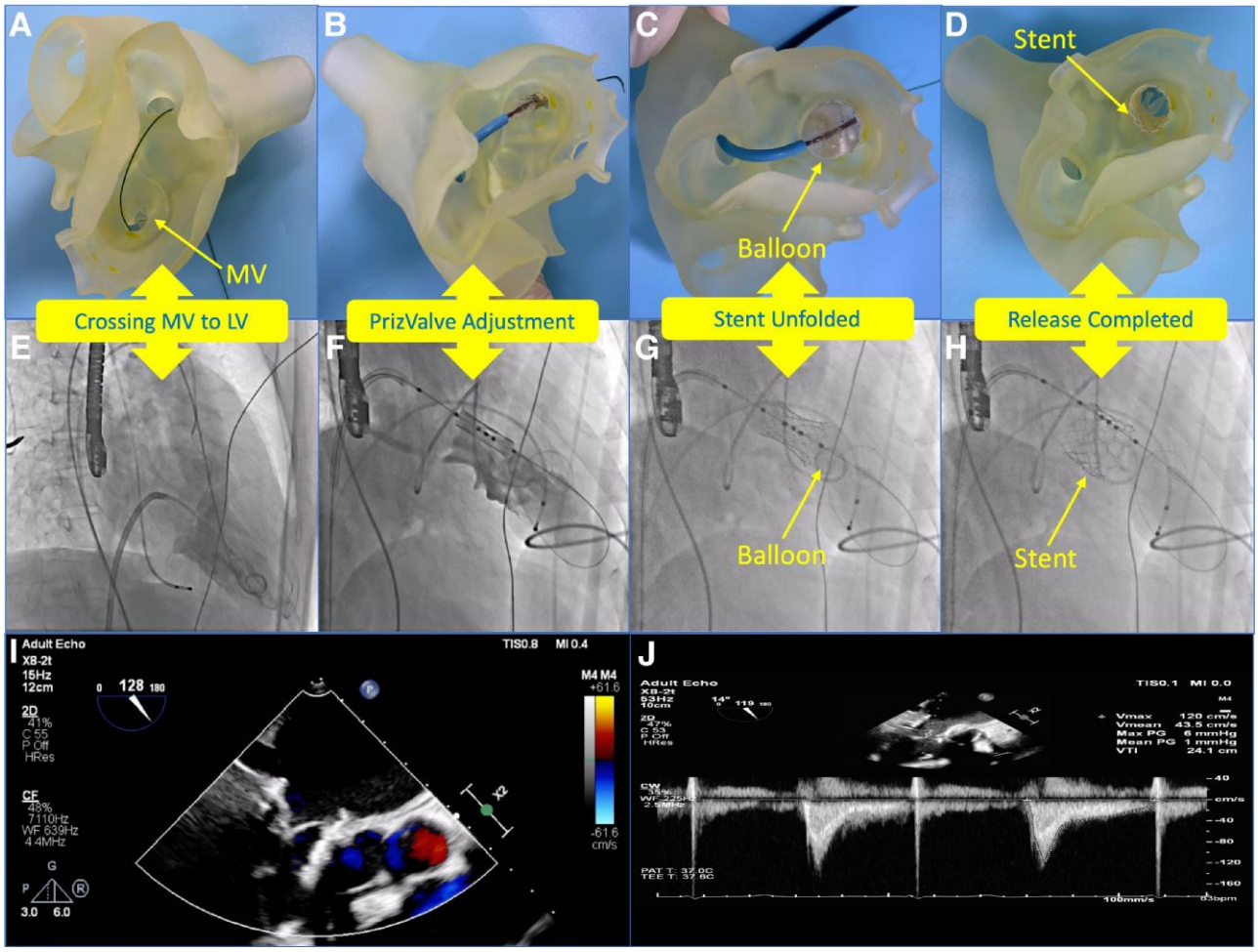

Figure 2 Perioperative main steps of transcatheter mitral valve replacement. (*A–D*) Pre-operative simulation with a three-dimensional printed model was used to practice and formulate a surgical plan. (*A*) The guide wire was delivered to the left ventricle. (*B*) The coaxiality and the release position were adjusted. (*C*) The balloon was expanded. (*D*) The fully unfolded valve. (*E–H*) The main steps of the procedure, which correspond to *A–D*. (*I* and *J*) Post-operative and follow-up transoesophageal echocardiography showed a well-functioning valve without paravalvular leakage.

Lead author biography

Meng-En Zhai is an associate professor in the Department of Cardiovascular Surgery, Xijing Hospital of Air Force Medical University. He is engaged in the diagnosis and treatment of various difficult and severe cardiovascular diseases and interventional treatment of valvular heart disease.

Supplementary material

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

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Consent: Signed consent has been obtained from the patients in accordance with COPE guidelines.

Conflict of interest: None declared.

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Data availability

The data underlying this article are available in the article and in its online *supplementary material*.

Ethics approval: The studies involving human participants were reviewed and approved by the ClinicalTrials Organization: Xijing Hospital, Air Force Medical University.

Consent to participate: The patient provided written informed consent to participate in this study. This study complies with COPE guidelines.

Consent for publication: Written informed consent was obtained from the patient to publish any potentially identifiable images or data included in this article.

Clinical trial registration

ClinicalTrials.gov Protocol Registration System (NCT02917980).

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