How to Cite:
Preethi, C., Sathik, M. M., & Nisha, S. S. (2022). An impact of three dimensional techniques in virtual reality. *International Journal of Health Sciences*, *6*(S4), 1783–1794.
https://doi.org/10.53730/ijhs.v6nS4.6481

An impact of three dimensional techniques in virtual reality

C Preethi
Reg.No 19211192272008, Ph.D Research Scholar, PG & Research Department of Computer Science, Sadakathullah Appa College, Affiliation of Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli-627012, Tamil Nadu, India

M Mohamed Sathik
Principal, Sadakathullah Appa College, Affiliation of Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli-627012, Tamil Nadu, India

S Shajun Nisha
Assistant Professor & Head, PG & Research Department of Computer Science Sadakathullah Appa College, Affiliation of Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli-627012, Tamil Nadu, India

***Abstract*---**Three dimensional (3D) imaging play a prominent role in the diagnosis, treatment planning, and post-therapeutic monitoring of patients with Rheumatic Heart Disease (RHD) or mitral valve disease. More interactive and realistic medical experiences take an advantage of advanced visualization techniques like augmented, mixed, and virtual reality to analyze the 3D models. Further, 3D printed mitral valve model is being used in medical field. All these technologies improve the understanding of the complex morphologies of mitral valve disease. Real-time 3D Echocardiography has attracted much more attention in medical researches because it provides interactive feedback to acquire high-quality images as well as timely spatial information of the scanned area and hence is necessary for intraoperative ultrasound examinations. In this article, three dimensional techniques and its impacts in mitral valve disease are reviewed. Specifically, the data acquisition techniques, reconstruction algorithms with clinical applications are presented. Moreover, the advantages and disadvantages of state-of-the-art approaches are discussed in detail.

***Keywords*---**three dimensional images, virtual reality, echocardiography, reconstruction algorithms.

Manuscript submitted: 18 Feb 2022, Manuscript revised: 9 March 2022, Accepted for publication: 1 April 2022

Introduction

Recently improved three dimensional (3D) cardiac imaging technologies are triggering the medical use of advanced visualization techniques including augmented reality, mixed reality, virtual reality, and 3D printing. Over the past decades, echocardiography has become the essential diagnostic procedure for cardiologists to noninvasively assess cardiac structure, and to make important clinical decisions. The majority of echocardiography studies are performed to investigate left ventricular (LV) chamber dimensions and LV ejection fraction (LVEF) (MR Avendi et.al 2016). Current methods via two-dimensional (2D) echocardiography (2DE) are operator-dependent, relying on the visual interpretation of moving images and poor test–retest reliability. Moreover, LVEF estimation from 2DE is subject to bias and error in the presence of pathology and endocardial visualization. This single perspective 2D views resulting in less accurate and inconsistent geometric measurements, specifically due to incorrect location of the valve (Milgram and Kishino 1994).

Three-dimensional echocardiography (3DE) offers several important advantages. The introduction of fully sampled matrix-array transducers (containing 3,000 piezoelectric elements) allows the measurement of pyramidal volume datasets from a single apical window. Since the mid-1990s, studies have validated that the real-time 3DE accurately quantify LV volumes than other imaging modalities.

Meta-analyses have also supported these findings and found that compared with 2DE, 3DE was more accurate for LV end-systolic volume (ESV), LV end-diastolic volume (EDV) and LVEF. Furthermore, the real-time 3DE produces a volume–time curve which is a reflection of continuous LV volume changes throughout the cardiac cycle allowing more detailed quantitative analysis of LV performance (e.g. LV filling rates). Visualization of cardiac structures and pathology (Seslar et.al 2015) is shown in fig.1 and fig.2

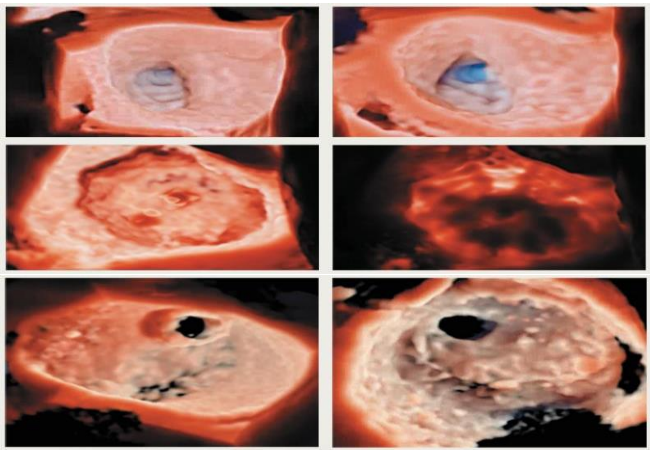

Fig 1: High-resolution photo-realistic 3D echocardiographic images – top row: left atrial appendage occlusion viewed from opposing angles; middle row: Watchman device for left atrial appendage occlusion; bottom row: mitral valve perforation viewed from left atrial and left ventricular views.

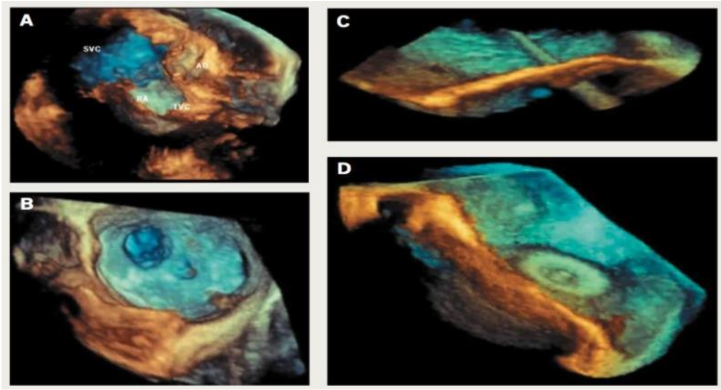

Fig 2: 3D echocardiographic images in closure of atrial septal defects (ASD). A & B: improved identification of size, shape, location, orientation and multiple orifices pre-procedurally. C: delivery catheter view across the defect. D: positioning of the left atrial disc and retraction against the septum.

This page should begin with the introduction of your article and follow the rest of your paper. Wilson (1990), stated that the Introduction explains the scope and objective of the study in the light of current knowledge on the subject. State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Mitral Valve Analysis Using 3DE

3DE offers significant advantages when assessing the mitral valve (MV) and planning MV repair. Since it is free from geometric assumptions (whereas 2DE depends on correct alignment of imaging planes), it measures the non-planar mitral annular geometry and diagnose pathology more accurately, which are critical for surgical planning. Using 3DE prolapsing segments/scallops and associated chordae rupture, perforations, clefts and flail segments are identified.

The use of 3DE to assist in percutaneous mitral valve repair (PMVR) using the MitraClip device has also been shown to overcome significant limitations with 2DE, which provide a limited assessment of anatomy and morphological changes during and after PMVR. Apart from aiding intra-operative guidance and positioning, 3DE is able to accurately visualize the MV and assess morphological and functional changes (Kiraly et.al 2019).

Other studies quantifying the improvement in mitral regurgitation after PMVR have shown 3DE (with colour flow Doppler) is able to characterize the improvements in LV and RV strain (with speckle-tracking), as well as RVEF(Right Ventricular Ejection Fraction). 3DE has also improved the understanding of acute changes in MV morphology after PMVR, namely an increase in annular ellipticity and coaptation area (Farooqi et.al 2016). Full-volume colour Doppler transthoracic 3DE (3D-FVCD) has also recently been shown to quantify mitral regurgitation more accurately.

2.1 Data Acquisition

Ideal 3D probes have an isotropic high spatial resolution by assembling a linear array transducer with handheld instrument. In case of mechanical three dimensional probes, the linear transducer is motored to make rotation, move or translate under the computer control. Multiple two dimensional images are obtained when the motor is activated.

These images have an isotropic high spatial resolution, sharp contrast between blood and myocardium, homogeneous signal distribution across all cardiovascular structures, low image noise, and minimal artifacts. Therefore, obtaining all these features is the gold standard for 3D data acquisition. These features make all post-processing steps and advanced visualization techniques described in the following sections more accurate and less time- consuming.

2.2 Processing

A variety of useful volumetric segmentation tools, such as threshold-based segmentation and 3D region-growing algorithms, are available for processing the 3D cardiac images of RHD. Data in 3D are often presented as a single set of volume-rendered images. Multiple sets of different volumes may be color-coded and spatial relationships with adjacent structures, including the airways and the thoracic cage. Furthermore, 3D threshold- based segmentation is increasingly used for volume measurements of cardiac chambers for evaluating cardiac function in patients with RHD. A new cinematic rendering technique was recently introduced for 3D photorealistic visualization of complex cardiovascular structures by enhancing depth perception. Cinematic rendering may also be used to illustrate intra-cardiac structures by adjusting the opacity to make enhanced blood in cardiac chambers completely transparent (Speggiorin et.al 2016).

2.3 Visualization

3D cardiac models can be viewed using different visualization methods such as augmented reality, virtual reality and printed as a 3D physical replica. In augmented reality, virtual objects are overlaid on the real-world with spatial registration. In virtual reality, a user is immersed in an entirely artificial digital environment. Thus, augmented reality is clearly distinguished from virtual reality in terms of the presence of the ability to visualize the real-world.

On the other hand, the concept of mixed reality, defined as anywhere in the so-called "reality-virtual continuum," ranging from the completely real to a completely virtual environment, which was proposed in 1994 (Milgram and Kishino 1994). Compared to augmented reality, a mixed reality not only overlays but anchors virtual objects to real-world objects and allows the user to interact with combined virtual and real objects. Fig. 3 depicts the 3D model visualization in different techniques

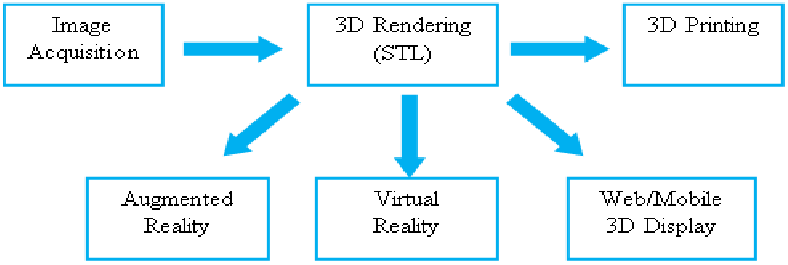

Fig. 3. Workflow of advanced visualization technology.

Segmented and refined 3D model can be visualized using augmented reality, virtual reality, interactive web or mobile 3D displays and also in 3D printing. STL = Standard Tessellation Language.

a) Augmented and Mixed Reality Techniques

Fundamental elements of augmented reality include real objects (such as patients), virtual objects processed from medical images, spatial registration, instrument tracking, and visualization. The combined visualization of spatially registered virtual and real objects in augmented reality allows clinicians to maintain focus and analyze without taking their eyes off their patients. Spatial registration has been applied to rigid organs.

A tracking device is necessary for surgical or interventional navigation. Currently, optical or electromagnetic tracking systems are used, and each of these has its benefits and limitations (Peters TM and Linte CA 2016). In order to overlay virtual objects on real objects, a variety of display methods, such as conventional display monitors, head mounted displays, projection displays, and transparent screens, may be used.

The main barriers to the extensive use of augmented reality in medicine include the initial setup costs, additional time required to prepare virtual data, and unreliable accuracy in spatial registration (Ender et.al 2008; Belhaj Soulami et.al 2016).

Applications: Augmented reality and mixed reality can be used for education, pre-procedural planning, simulation, and procedural guidance. Augmented reality is particularly helpful for minimally invasive cardiac intervention or surgery. It was demonstrated that augmented reality-enhanced trans esophageal echocardiography could help to determine the optimal annuloplasty ring size (particularly for surgeons with limited experience), and for percutaneous mitral valve repair (Opolski et.al 2018).

Another study demonstrated that mixed reality using Echo-gated data facilitated trans catheter heart valve implantation during valve-in-valve procedure (Zimmerman et.al 1987). In a patient with congenitally corrected transposition of the great arteries, augmented reality was used to guide trans catheter pacemaker implantation (Pensieri C and Pennacchini M 2014).

b) Virtual Reality Techniques

Virtual reality (VR) is broadly defined as a three-dimensional (3D) simulation of the real-world, with the ability to interact directly with the simulation (Bao X et.al 2013; Yiannakopoulou et.al 2015). In its earliest applications to biomedicine, VR was largely applied to the behavioral sciences, though the advent of "controllers" or sensors that track hand position and movements in real time and expanded the ability to interact with the virtual space. Presently, VR is widely used in medicine, from stroke rehabilitation to tools for trainees to learn how to perform laparoscopic surgery (Sorensen et.al 2001; Ong CS et.al 2018).

In VR, 3D cardiac models should be generated initially from 2D DICOM (Digital Imaging and Communications in Medicine) images. The patient's imaging data were loaded directly and the volumetric renderings of the data are generated instantaneously by any software (UNITY, Game Engine, Unreal Engine etc.,) without any human intervention.

Inspired by the work of Gavin wheeler (Gavin Wheeler et.al 2019), Table 1 presents the summary of ultrasound datasets for accurate view of cardiac phases in virtual reality.

Table 1. Summary of accurate view of cardiac phases in Virtual Reality.

Cardiac Anatomy	Perspective Views	Cardiac Phases
Posterior and Anterior Leaflet	Parasternal Long Axis	Diastole
Aortic Veins	Short Axis	Systole
Pulmonary Veins	Esophageal	Systole
Mitral Valve Connections	Short Axis	Systole
Aortic Valve Connections	Short Axis	Systole
Aorta	Apical 4 Chamber View	Diastole
Pulmonary Artery	Apical 3 Chamber View	Diastole
Chordea Tendineae	Apical 2 Chamber View	Diastole

Applications: Until now, the medical use of virtual reality in the field of RHD has been quite limited. In 2001, virtual reality was first applied in interactive, real-time visualization of cardiac morphology (Wierzbicki et.al 2004). Its role was recently demonstrated in two infants with RHD (El Beheiry et.al 2019). Virtual reality with hand controller based interactivity allows better interactive viewing of echo models. This serves as a preplanning method in terms of collaborative planning and user defined perspective views.

Three Dimensional Printing Techniques

The workflow of 3D printing comprises several sequential stages: 1) 3D data acquisition, 2) segmentation, 3) conversion of a Digital Imaging and Communication in Medicine (DICOM) file to a 3D mesh file format, 4) computer-aided design (CAD), and 5) 3D printing. Acquisition of high-resolution isotropic 3D image data with excellent image quality is mandatory for creating a quality 3D printed model (Yoo S.J et.al 2015; Hibino 2016; Vukicevic M et.al 2017). Table 2 presents the study of 3D-printing applications in various clinical scenarios.

Table 2. Study of 3D Printing applications in various clinical scenarios.

First author with year	Clinical scenarios	No.of Patients	Study design	Clinical application	Imaging Modality
Hachullaet al. (2019)	Percutaneous LAA occlusion	15	Cross - sectional study	Pre-surgical simulati on	CT
Hosny et al. (2019)	TAVR	30	Retrospective study	Pre-surgical simulati on	CT
Zhang et al. (2019)	Recurrent coronary artery	1	Case report	Preoperat ive plannin g	CT
Misra et al. (2019)	Coronary-pulmonary artery	1	Case report	Preoperat ive plannin g	CT
Fan et al. (2019)	Percutaneous LAA Occlusion	104	Retrospective[72], prospective [32]	Preoperat ive plannin g	TEE
Shijo et al. (2018)	Multiple aneurysms with coarctation	1	case report	Pre-surgical simulati on	CT
Faletti et al. (2018)	TAVR	20	Retrospective study	Preoperat ive plannin g	CT
Lee et al. (2019)	Coronary artery Abnormality	7	Retrospective study	Medic al educat ion	CT
Sun et al. (2018)	HOCM	1	Case report	Preoperativ e planning	CT
Gomes et al. (2018)	Aortic aneurysm/ dissection	6	Case report	Preoperativ e planning	CT
Guo et al. (2018)	HOCM	7	Case report	Preoperativ e planning	CT
Ginty et al. (2018)	Mitral valve repair for MR	10	Cross- sectional study	Pre-surgical simulatio	TEE

				n	
Bagur et al. (2017)	TMV-in-R replacement	1	Case report	Pre-surgical simulation	CT
El Sabbaghet al. (2018)	TMVR	8	Case report	Pre-surgical simulation	CT
Aroney et al. (2019)	Cardiac fistulae	4	Case report	Preoperative planning	CT
Sunet al. (2017)	Kommerell's diverticulum	5	Case report	Preoperative planning	CT
Song et al. (2017)	LAA occlusion	18	Cross- sectional study	Preoperative simulation	TEE

LAA-left atrial appendage; HOCM-hypertrophic obstructive cardiomyopathy; TAVR- transcatheter aortic valve replacement; TMVR- transcatheter mitral valve replacement; AS- aortic stenosis; CT- Computed Tomography; MRI - magnetic resonance imaging; 3D TEE, Three dimensional transesophageal echocardiography.

3D Reconstruction Algorithms

Aside from quality and rate of data acquisition, the speed and accuracy of volume reconstruction are significant for real-time 3D Echo imaging. Various reconstruction algorithms are proposed for visualizing region of interest. The real-time reconstruction algorithms of 3D voxel representation can be classified into three types based on implementation: Voxel Based Methods (VBMs), Pixel-Based Methods (PBMs), and Function-Based Methods (FBMs).

Voxel-Based Methods (VBMs)

In VBMs (C. D. Barry et.al 1997), every voxel in the structured volume is traversed and assigned a value depending on one pixel or more pixels from the acquired B-scans. With this method, three dimensional features are represented and aligned with 3D space.

Pixel-Based Methods (PBMs)

PBM traverses each pixel in the 2D images and assigns a pixel value to the neighboring voxel. If more than one pixel contributes to the same voxel value, then average or the highest value is taken into consideration (R. N. Rankin et.al 1993).

Function-Based Methods (FBMs)

The FBMs estimates the functional interpolation for 3D reconstruction. It chooses a particular function, for example, a polynomial, and utilizes the pixel values and its relative positions to determine the function coefficients (Rohling et.al 1999). Here the functions are evaluated at regular intervals to produce the voxel array.

Unresolved Issues

Several studies have tackled problems of 3D visualization in terms of cost, time, and changeability by comparing it with virtual 3D modeling. For example, the display of virtual 3D cardiac models using a tablet device was effective than expensive 3D printed models in a cardiac intensive care unit (Olivieri et.al 2018). Other limitations of 3D cardiac models are a lack of dynamic representations throughout the entire cardiac cycle and making use of hemodynamic data (Gosnell et.al 2016). Both are crucial for understanding the pathophysiology of RHD. Table 3 depicts the comparison of 3D visualization in terms of various parameters.

Table 3. Comparison of Advanced 3D Visualization Techniques

3D Visualization Techniques	Voxel Information	Depth Perception	CAD	Tangibility	Additional Cost for Hardware	Additional Cost for Printing
Standard 3D Model (DICOM format)	+	±	-	-	-	-
Augmented/mixed reality	±	±	+	±	+	-
Virtual reality	-	+	+	±	+	-
3D printed model	-	+	+	+	+	+

CAD - Computer-Aided Design, DICOM - Digital Imaging and Communication in Medicine, STL - Standard Tessellation Language, 3D - three dimensional.

Conclusion

Virtual and augmented reality visualization technologies have a significant impact in various fields of medicine. It has been used to create virtual anatomical models to train surgeons in complicated surgeries. Merging the virtual reality world with 3D printing together could be a new spin in the field of design and manufacturing. It is probable that in the future, young surgeons and practitioners will be able to practice most complex surgeries on 3D printed models made of actual tissues.

References

Aroney N, Markham R, Putrino A, et al. Threedimensional printed cardiac fistulae: a case series. Eur Heart J Case Rep 2019. doi: 10.1093/ehjcr/ytz060.

Avendi MR, Kheradvar A, Jafarkhani H. A combined deep learning and deformable-model approach to fully automatic segmentation of the left ventricle in cardiac MRI.MedImageAnal2016;30:108-119.

Bagur R, Cheung A, Chu MWA, et al. 3-DimensionalPrinted Model for Planning Transcatheter Mitral Valve Replacement. JACC Cardiovasc Interv 2018;11:812-3.

BaoX ,MaoY, LinQ,etal. Mechanism of Kinect-based virtual reality training for motor functional recovery of upper limb safter subacute stroke.NeuralRegenerRes.2013;8(31):2904–2913.

BelhajSoulami R, Verhoye JP, Nguyen Duc H, Castro M, Auffret V, Anselmi A, et al.Computer-assistedtranscatheterheartvalveimplantationinvalve-in-valveprocedures.Innovations (Phila)2016;11:193-200.

C. D. Barry, C. P. Allott, and N. W. John, “Three-dimensional freehand ultrasound: image reconstruction and volume analysis,” Ultrasound Med. Biol., vol. 23, no. 8, pp. 1209–1224, 1997. (C. D. Barry et.al 1997)

El Beheiry M, Doutreligne S, Caporal C, Ostrertag C, Daham M, Masson JB. Virtualreality:beyond visualization. JMol Biol. 2019; 431:1315-1321.

Ender J, Koncar-Zeh J, Mukherjee C, Jacobs S, Borger MA, Viola C, et al. Value ofaugmentedreality-enhancedtransesophagealechocardiograph (TEE) for determining optimal annul oplastyring size duringmitral valverepair.Ann ThoracSurg2008;86:1473-1478.

Faletti R, Gatti M, Cosentino A, et al. 3D printing of the aortic annulus based on cardiovascular computed tomography: Preliminary experience in pre-procedural planning for aortic valve sizing. J Cardiovasc Comput Tomogr 2018;12:391-7.

Fan Y, Yang F, Cheung GSH, et al. Device Sizing Guided by Echocardiography-Based Three-Dimensional Printing Is Associated with Superior Outcome after Percutaneous Left Atrial Appendage Occlusion. J Am Soc Echocardiogram 2019;32:708-719.e1

Farooqi KM, Uppu SC, Nguyen K, Srivastava S, Ko HH, Choueiter N, et al. Applicationof virtual three-dimensional models for simultaneous visualization of intracardiac anatomicrelationshipsin double outletright ventricle.PediatrCardiol2016;37:90-98.

Gavin Wheeler, Shujie Deng, KuberanPushparajah, Julia A. Schnabel, John M. Simpson, Alberto Gomez, Virtual linear measurement system for accurate quantification of medical images, Healthcare Technology Letters, 2019, Vol. 6, Iss. 6, pp. 220–225 doi: 10.1049/htl.2019.0074.

Ginty OK, Moore JM, Xu Y, et al. Dynamic PatientSpecific Three-Dimensional Simulation of Mitral Repair: Can We Practice Mitral Repair Preoperatively? Innovations (Phila) 2018;13:11-22.

Gomes EN, Dias RR, Rocha BA, et al. Use of 3D Printing in Preoperative Planning and Training for AorticEndovascular Repair and Aortic Valve Disease. Braz J Cardiovasc Surg 2018;33:490-5.

Gosnell J, Pietila T, Samuel BP, Kurup HK, Haw MP, Vettukattil JJ. Integration ofcomputed tomography and threedimensional echocardiography for hybrid

three-dimensionalprintingin congenital heartdisease. JDigitImaging2016;29:665-669.
Guo HC, Wang Y, Dai J, et al. Application of 3D printing in the surgical planning of hypertrophic obstructive cardiomyopathy and physician-patient communication. J Thorac Dis 2018;10:867-73.
Hachulla AL, Noble S, Guglielmi G, et al. 3D-printed heart model to guide LAA closure: useful in clinical practice? Eur Radiol 2019;29:251-8.
HibinoN.Threedimensionalprinting:applicationsinsurgeryforcongenitalheartdisease.WorldJPediatrCongenit Heart Surg. 2016; 7(3):351–352.
Hosny A, Dilley JD, Kelil T, et al. Pre-procedural fittesting of TAVR valves using parametric modeling and 3D printing. J Cardiovasc Comput Tomogr 2019;13:21-30.
Kiraly L, Kiraly B, Szigeti K, Tamas CZ, Daranyi S. Virtual museum of congenital heartdefects: digitization and establishment of a database for cardiac specimens. Quant ImagingMed Surg2019;9:115-126.
Lee M, Moharem-Elgamal S, Beckingham R, et al. Evaluating 3D-printed models of coronary anomalies: a survey among clinicians and researchers at a university hospital in the UK. BMJ Open 2019;9:e025227.
MilgramP, KishinoF. A taxonomyof mixed realityvisual displays.IEICE TransInfSyst 1994;E77-D:1321-1329.
Misra A, Walters HL, Kobayashi D. Utilisation of a three-dimensional printed model for the management of coronary-pulmonary artery fistula from left main coronary artery. Cardiol Young 2019;29:431-4.
Olivieri LJ, Zurakowski D, Ramakrishnan K, Su L, Alfares FA, Irwin MR, et al. Novel,3Ddisplayofheartmodelsinthepostoperativecaresettingimproves CICUcaregiverconfidence.World JPediatrCongenit Heart Surg2018;9:206-213.
Ong CS, Krishnan A, Huang CY, Spevak P,Vricella L, Hibino N,etal. Role of virtual reality in congenital heart disease. Congenit HeartDis2018;13:357-361
Opolski MP, Michałowska IM, Borucki BA, Nicin' ska B, Szumowski Ł, Sterlin' ski M.Augmented-reality computed tomography-guidedtranscatheter pacemaker implantation in dextro cardiaand congenitally corrected trans position of greatarteries. CardiolJ2018;25:412-413.
Pensieri C, Pennacchini M. Overview: virtual reality in medicine.\ J Virtual Worlds Res.2014;7(1):1–34.
Peters TM, Linte CA. Image-guided interventions and computer-integrated therapy: quovadis, Med ImageAnal 2016;33:56-63
R. N. Rankin, A. Fenster, and D. B. Downey, “Three-dimensional sonographic reconstruction: Techniques and diagnostic applications,” Amer. J. Roentgenol., vol. 161, no. 4, pp. 695–702, 1993.
R. Rohling, A. Gee, and L. Berman, “A comparison of freehand three dimensional ultrasound reconstruction techniques,” Med. Image Anal., vol. 3, no. 4, pp. 339–359, 1999.
Sabbagh A, Eleid MF, Matsumoto JM, et al. Threedimensional prototyping for procedural simulation of transcatheter mitral valve replacement in patients with mitral annular calcification. Catheter Cardiovasc Interv 2018;92:E537-E549.
Seslar SP, Shepard CW, Giroud JM, Aiello VD, Cook AC, Spicer DE, et al.; ArchivingWorking Group of The International Society for Nomenclature of Paediatric and Congenital Heart Disease. Losttreasures:aplea for the

systematic preservation of cadaveric heart specimens through three-dimensional digital imaging.CardiolYoung2015;25:1457-1459.

Shijo T, Shirakawa T, Yoshitatsu M, et al. Stent grafting simulation using a three-dimensional printed model for extensive aortic arch repair combined with coarctation. Eur J Cardiothorac Surg 2018;54:593-5.

Song H, Zhou Q, Zhang L, et al. Evaluating the morphology of the left atrial appendage by a transesophageal echocardiographic 3-dimensional printed model. Medicine (Baltimore) 2017;96:e7865.

Sorensen TS, Therkildsen SV, Makowski P, KnudsenJL, PedersenEM. Anew virtual reality approach for planningof cardiacinterventions.ArtifIntellMed 2001;22:193-214.

Speggiorin S, Durairaj S,Mimic B, Corno AF. Virtual 3D modeling of airways in congenital heart defects.Front Pediatr2016;4:116

Sun X, Zhang H, Zhu K, et al. Curved section modeling based three-dimensional printing for guiding septal myectomy. J Thorac Dis 2018;10:E535-E537.

Sun X, Zhang H, Zhu K, et al. Patient-specific threedimensional printing for Kommerell's diverticulum. Int J Cardiol 2018;255:184-7.

Vukicevic M, Mosadegh B, Min JK, Little SH. Cardiac 3D printing and its futuredirections.JACC CardiovascImaging. 2017;10(2): 171–184.

Wierzbicki M, Drangova M, Guiraudon G, Peters T. Validation of dynamic heart modelsobtained using non-linear registration for virtual reality training, planning, and guidance ofminimallyinvasivecardiacsurgeries.MedImage Anal2004;8:387-401.

Yiannakopoulou E, Nikiteas N, Perrea D,Tsigris C.Virtual reality simulators and training in laparo scopic surgery.Int JSurg(Lond, Engl). 2015;13:60–64.

Yoo S-J, Thabit O, Kim EK, et al. 3D printing in medicine of congenital heart diseases.3DPrint Med. 2015;2(1):4.

Zhang J, Ma W, Zhang W, et al. Three-Dimensional Printed Models-Guided Surgical Repair for Recurrent Coronary Artery Fistula. Ann Thorac Surg 2019;107:e161-3.

Zimmerman TG, Lanier J, Blanchard C, Bryson S, Harvill Y. A handgesture interfacedevice.SIGCHIBull. 1987;18(4):189–192.