

Three-Dimensional-Printed Heart Prototype for Application in Pediatric Cardiology: An Initial Experiment

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Introduction

Three-dimensional (3D) prototyping technology is developing rapidly in medicine, and recent studies have shown its important applicability in pediatric cardiology.

Clinicians and surgeons use two-dimensional technologies, such as echocardiography, computed tomography (CT) angiography, and magnetic resonance imaging, to characterize structures and understand complex diseases. Because these images are often projected and extended on a flat screen, they may not represent the actual size of the structures, depth perception, or the proximity between them.¹

The prevalence of congenital heart disease is estimated at 9.1 per 1000 live births.² It causes significant hemodynamic and functional consequences and accounts for 6% of all infant deaths in the first year of life in Brazil.³ The diversity and complexity of heart diseases require surgeons to have a detailed understanding of anatomy for proper treatment planning and management and for providing a didactic explanation of the disease to family members.^{4,5}

This study produced 3D-printed prototypes of congenital heart diseases from CT angiography image files as an initial experiment to increase scientific evidence.

Methods

We conducted a descriptive observational study without the application of a numerical comparison tool. The study aimed to present our initial experience based on current evidence of the use of 3D technology and its benefits in understanding congenital heart diseases and their importance in our setting. Representative images of heart diseases were obtained from CT angiography image files and chosen among those of greater anatomical complexity in order to obtain better structural information with 3D printing. The selected

heart diseases were pulmonary atresia with ventricular septal defect (PA-VSD) and systemic-to-pulmonary collaterals, and left ventricular hypoplasia (LVH) after ductus arteriosus stenting and cerclage of the branch pulmonary arteries. The images were obtained with a GE Revolution 512-slice CT scanner with electrocardiographic modulation and imported into Slic3r for structural segmentation. The prototypes were printed in a ZMorph VX/E 3D printer using 0.2-mm-thick polylactic acid thermoplastic filaments and PVA support. After printing, the 3D prototypes were visually compared with the CT angiography images by the authors.

Results

Visual comparison of the CT angiography images with 3D-printed prototypes showed anatomical compatibility between them, and important anatomical details could be observed from different perspectives in the 3D prototypes. In the PA-VSD case, the 3D-printed prototype facilitated the understanding of the spatial relationship between the systemic-to-pulmonary collaterals originating from the aorta and the branch pulmonary arteries, as well as the comparative observation of the ventricular cavities (Figure 1). In the LVH case, we could observe the degree of hypoplasia of the ascending aorta and the presence of branch pulmonary artery stenosis, in addition to the spatial relationships between them (Figure 2). The size of the 3D models corresponded to the anatomy of the patients, enabling a comparative study of the dimensions between the structures, which may contribute to the surgical treatment strategy. The possibility of having a hands-on 3D prototype to observe the anatomy from different angles allowed an easier and clearer understanding of heart diseases.

Discussion

Three-dimensional printing is a technology that aims to complement conventional tests, since it provides greater understanding of cardiac malformation. It allows a detailed study of the location, length, extension, and relationship between the malformed structures, thus assisting in surgical planning and in identifying anatomical details of patients who have undergone previous interventions.⁶ Consequently, it benefits surgeons by increasing their knowledge of the heart disease and by providing a greater degree of safety when choosing the surgical technique.⁷ Studies of patients with PA-VSD have shown that 3D prototypes enable the visualization of 96% of the major aortopulmonary collateral arteries compared with intraoperative assessment. Thus, it focuses

Keywords

Heart Defects Congenital; Coronary Angiography/methods; TomographyX-Ray Computed/methods; PrintingThree-Dimensional/trends.

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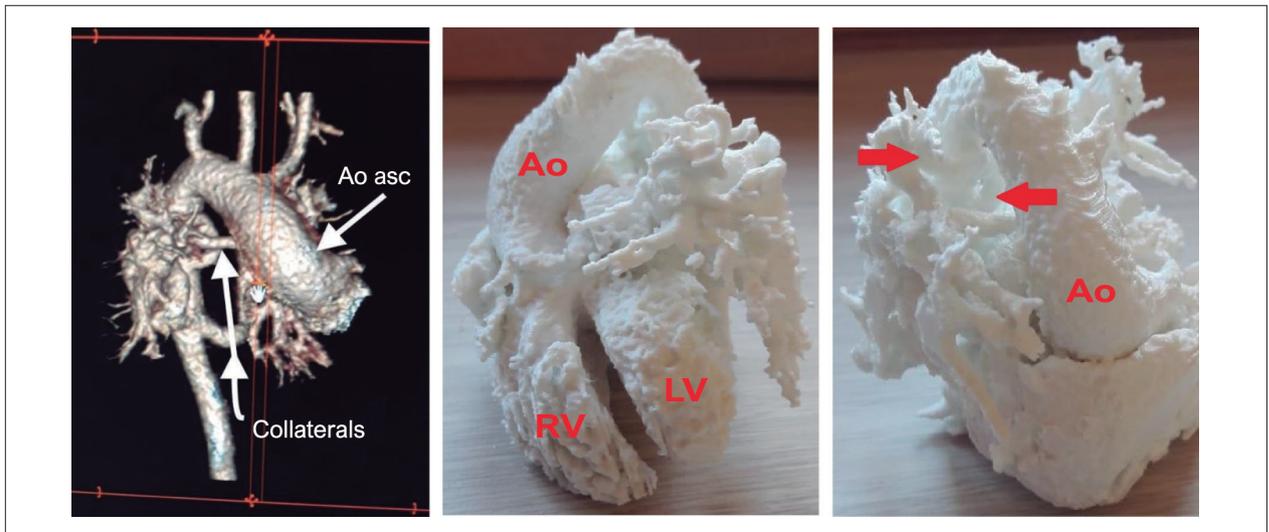


Figure 1 - PA-VSD case. Left: CT angiography: arrows indicate the aorta and the presence of systemic-to-pulmonary collateral arteries emerging from the ascending aorta. Right: 3D prototype – front and right-side view. Ao: aorta; LV: left ventricle; RV: right ventricle.

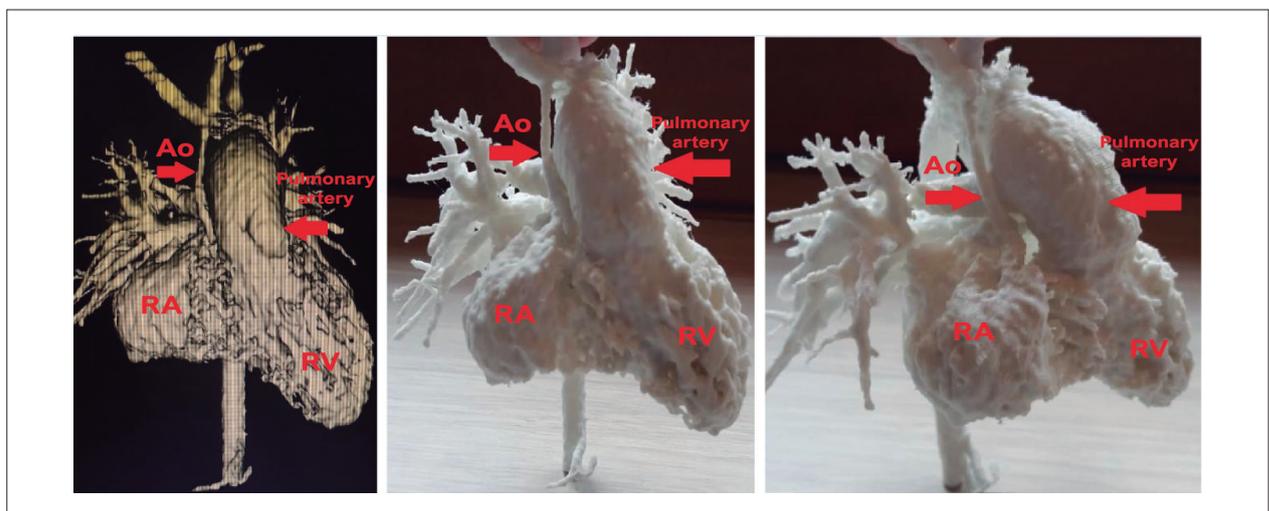


Figure 2 – LVH case. Left: CT angiography – arrows indicate the aorta and pulmonary artery. Right: 3D prototype – lateral view. Ao: aorta; RA: right atrium; RV: right ventricle.

on catheterization and reduces operative time, exposure to anesthesia, fluid therapy time, and the use of contrast agents in hemodynamic procedures.⁶⁻⁸

The 3D prototypes can also be used for surgical simulations, aiming to anticipate the need for adjustments to the surgical plan, to reduce complications, to obtain good postoperative results, and to train students and physicians.¹ Some 3D prototypes are highly flexible and do not require special handling; therefore, they can be used both before and during surgery.⁹

In medical education, 3D printing allows medical students and residents to better understand the pathology and spatial orientation of the structures. With the growing difficulties in obtaining cadavers for study, the use of 3D prototypes is an important option for the teaching of human anatomy in medical schools.¹⁰

In the context of the doctor-patient relationship, the possibility that parents may hold the prototype in their own hands and visualize the anatomical details described by the physician provides a better understanding both of the pathophysiology related to the patient's symptoms and of the proposed treatment. The literature shows that 3D prototypes help to strengthen the doctor-patient relationship, are useful in understanding information, and increase the knowledge and engagement of patients and families in relation to the disease.¹¹

Three-dimensional printing is a developing technology that has limitations and challenges to ensure a better-quality product, including assembly accuracy, construction of models with the same mechanical properties of the tissues, shorter preparation time, and lower economic cost. The possibility of printing different colors would facilitate the identification of different types of structures, such as ventricles, pulmonary

artery and branches, and aorta, especially in undergraduate medical education.

The heart diseases represented by our 3D prototypes provided reliable 3D representations of the CT angiography images used as a basis for the study. Producing 3D-printed heart prototypes is feasible and can be a useful tool in our setting, as they can be used to assist clinicians and surgical teams in treatment decision-making, students' learning in undergraduate and graduate medical education, and surgical-skill education and to provide explanations to family members about the child's heart disease.

Note: in the publication of this manuscript, it must be taken into account that the visual effect of the 3D prototypes is reduced on photographs, compared with the direct, actual handling of the product.

Author contributions

Conception and design of the research and Critical revision of the manuscript for intellectual content: Basso ML, Farah MCK; Data acquisition, Analysis and interpretation of the

data and Writing of the manuscript: Gebran AM, Oliveira JD, Gebran KM, Bonatto LC.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Sundararaghavan S. Three-dimensional-printed cardiac prototypes in complex congenital cardiac defects: new technology with exciting possibilities. *Ann Pediatr Card.* 2017;10(2):114-6.
2. Sodian R, Stefan W, Markert M, Rassouljian D, Kaczmarek I, Lueth TC et al. Stereolithographic models for surgical planning in congenital heart surgery. *Ann Thorac Surg.* 2007;83:1854-7.
3. Lodziński P, Balsam P, Peller M, Cawalko M, Opolski G, Grabowski M. Three-dimensional print facilitated ventricular tachycardia ablation in patient with corrected congenital heart disease. *Cardiology J.* 2017; 24(6):684-85.
4. van der Linde D, Konings EEM, Slager MA, Witsenburg M, Helbing WA, Takkenberg JJM et al. Birth prevalence of congenital heart disease worldwide. A systematic review and meta-analysis. *J Am Coll Cardiol.* 2011;58(21):2241-7.
5. Pinto Jr VC. Avaliação da política nacional de atenção cardiovascular de alta complexidade com foco na cirurgia cardiovascular pediátrica [dissertação]. Fortaleza: Universidade Federal do Ceará; 2010.
6. Valverde I. Impresión tridimensional de modelos cardiacos: aplicaciones en el campo de la educación médica, la cirugía cardíaca y el intervencionismo estructural. *Rev Esp Cardiol.* 2017; 70(4):282-91.
7. Kappanayil M, Koneti NR, Kannan RR, Kottayil B, Kumar K. Three-dimensional printed cardiac prototypes aid surgical decisionmaking and preoperative planning in selected cases of complex congenital heart diseases: early experience and proof of concept in a resource limited environment. *Ann Pediatr Card.* 2017;10(2):117-125.
8. Ngan EM, Rebeyka IM, Ross DB, Hirji M, Wolfaardt JF, Seelaus R et al. The rapid prototyping of anatomic models in pulmonary atresia. *J Thorac Cardiovasc Surg.* 2006; 132(2):264-269.
9. Abudayyeh I, Gordon B, Ansari MM, Jutzy K, Stoletniy L, Hilliard A. A practical guide to cardiovascular 3d printing in clinical practice: overview and examples. *J Interv Cardiol.* 2018;31:375-383.
10. Luo H, Meyer-Szary J, Wang Z, Sabiniewicz R, Liu Y. Three-dimensional printing in cardiology: Current applications and future challenges. *Cardiol J.* 2017;24(4):436-44.
11. Biglino G, Koniordou D, Gasparini M, Capelli C, Leaver LK, Khambadkone S et al. Piloting the use of patient-specific cardiac models as a novel tool to facilitate communication during clinical consultations. *pediatr cardiol.* 2017; 38(4):813-8.



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