Heart, Lung and Circulation (2019) **28,** 1457–1458
1443-9506/04/$36.00
https://doi.org/10.1016/j.hlc.2019.08.004

EDITORIAL

Medical 3D Printing. Is This Just The Beginning?

Adam El Gamel, MBChB, MD, FRACS [a,b,c*]

[a]Waikato Cardiothoracic Unit, Waikato Hospital, Hamilton, New Zealand
[b]Faculty of Medical and Health Sciences, The University of Auckland, Auckland, New Zealand
[c]University of Waikato Medical Research Centre, The University of Waikato, New Zealand

Oliveira-Santos et al. highlight the rapid expansion of the use of three-dimensional (3D) printing in cardiovascular medicine in this issue of *Heart, Lung and Circulation* [1]. They focus on Non-Congenital Percutaneous Intervention and discuss the potential of 3D printing to facilitate cardiovascular intervention in the problematic but rapidly developing percutaneous treatment of cardiac valve pathologies as well as left atrial appendage closure.

The need for customised devices, as well as realistic models for cardiovascular diseases, is growing. The need for ''the safe road map" and dry run before complicated procedures stems from the fact of endless morphological differences between patients, which make off-the-shelf devices an inaccurate fit for the majority of patients (Figure 1). [2]

Three-dimensional printing involves equipment in which a computer-controlled mechanical device deposits building material, one layer over another, until a 3D model is completed. This process is known as additive manufacturing, compared to subtractive manufacturing in which robots remove the building material, such as by drilling or milling etc. Both techniques can be used at the same time, in a single hybrid process [3].

In recent years, 3D printing technologies have drawn wide fascination in the biomedical field, with a mixture of applications varying from 3D simulation models to bioprinting of organs [2–4]. The sophisticated 3D features of the cardiovascular system can be presented as a full-scale 3D, faithful-to-life replica [4].

Three-dimensional printing has been a useful tool for education and pre-procedural setting up in a variety of cardiovascular diseases. It can serve as a helpful learning device for parents, clinicians, other health care professionals and medical students [4]. Biglino et al. reported the effectiveness of 3D printed models for tutoring adult and paediatric cardiac nurses [5,6]. In a recently published randomised control trial, 3D printed models were demonstrated to

Figure 1 Not all aneurysm are created equal.

noticeably enhance medical students' comprehension in learning cardiac anatomy when compared to the cadaver-based curriculum [7]. Studies based on case reports have also shown that 3D printed models expand surgeons' understanding of complex cardiac disease [8–12].

A systematic review of the application of these new technologies is lacking. Rather, the feasibility of 3D printing in depicting complex cardiovascular and cerebrovascular pathology has been based on individual case reports.

DOI of original article: https://doi.org/10.1016/j.hlc.2019.04.020

*Corresponding author at: Waikato Cardiothoracic Unit, Waikato Hospital, Pembroke St, Hamilton West, 3204, New Zealand.

The potential for customised exo- and endo-stents to treat the complex vascular pathology is extensive, particularly in conditions where complex aneurysmal formation or irregular narrowing of the vessel could lead to the ultimate consequences of the interruption of the organ perfusion or vascular disruption with fatal bleeding [13].

Cardiac computed tomography (CT) is the most common imaging modality used for generating 3D printed models. Other modalities include cardiac magnetic resonance imaging (CMR), 3D digital subtraction angiography, rotational angiography, and 3D echocardiography. Hybrid 3D imaging can also be used to increase the accuracy of the process [14].

Sun and Lee compared measurements taken at six different anatomical sites to confirm the reliability of using 3D printed models for the diagnostic assessment of cardiovascular pathology. The accurate location of disease within the ascending and descending aorta, using pre-3D printing CT images, was established, with measurement differences of less than 0.8 mm [9].

Diverse materials and printers are used for 3D printing, with the mechanical properties of selected materials dependent on the application [15]. During processing, an attempt to match tensile strength and tensile modulus with that of biological structures is the primary goal. The cost associated with manufacturing in 3D is still high but the proposed, if unproven, benefits may become very persuasive [2]. The personalised external aortic root support (PEARS) procedure for Marfan Syndrome pathology—which uses digital imaging to create a model of the patient's aorta around which a supportive mesh is manufactured and then positioned around the patient's own aorta—is gaining acceptance as an alternative to the conventional, higher risk, surgical replacement strategy [13].

Although 3D printing may claim great potential in cardiovascular medicine, its application in clinical practice is still in its initial stages. There are significant limitations with the current technology [3]. The materials used for 3D printing in most of the studies to date, do not match the actual mechanical properties of the cardiovascular system in terms of elasticity comparable to the arterial wall or cardiac chambers. Furthermore, current technology can only produce a static model of a dynamic organ, which makes it challenging to comprehend morphological changes during the cardiac cycle. However, analysis of the flow dynamics of 3D printed models can now be performed using 4D magnetic resonance imaging (MRI) [16].

Future studies should be conducted to generate dynamic 3D printed models. These will replicate both anatomical and physiological changes during the cardiac cycle, and could further improve understanding of the complex cardiovascular and cerebrovascular diseases.

From a clinical standpoint, expected future applications will aim to produce custom-fit 3D printed models for individual patient treatments. Bioprinting represents another major innovation, involving the development of printable biomaterials, 3D printed tissue scaffolds, and 3D stem cells and functional vascular networks [17,18]. The future is bright for the application of 3D printing technologies in medicine.

References

[1] de Oliveira-Santos M, Oliviera-Santos E, Goncalves L, Silva Marques J. Cardiovascular three-dimensional printing in non-congenital percutaneous interventions. Heart Lung Cir 2018;28. xxxx-xxxx.

[2] Vukicevic M, Mosadegh B, Min JK, Little SH. Cardiac 3D printing and its future directions. JACC Cardiovasc Imaging 2017;10(2):171–84.

[3] Giannopoulos AA, Mitsouras D, Yoo SJ, Liu PP, Chatzizisis YS, Rybicki FJ. Applications of 3D printing in cardiovascular diseases. Nat Rev Cardiol 2016;13(12):701–18.

[4] Bartel T, Rivard A, Jimenez A, Mestres CA, Muller S. Medical three-dimensional printing opens up new opportunities in cardiology and cardiac surgery. Eur Heart J 2018;39(15):1246–54.

[5] Biglino G, Capelli C, Wray J, Schievano S, Leaver LK, Khambadkone S, et al. 3D-manufactured patient-specific models of congenital heart defects for communication in clinical practice: feasibility and acceptability. BMJ Open 2015;5(4):e007165.

[6] Biglino G, Capelli C, Leaver LK, Schievano S, Taylor AM, Wray J. Involving patients, families and medical staff in the evaluation of 3D printing models of congenital heart disease. Commun Med 2015;12(2-3):157–69.

[7] Lim KH, Loo ZY, Goldie SJ, Adams JW, McMenamin PG. Use of 3D printed models in medical education: a randomised control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. Anat Sci Educ 2016;9(3):213–21.

[8] Valverde I, Gomez-Ciriza G, Hussain T, Suarez-Mejias C, Velasco-Forte MN, Byrne N, et al. Three-dimensional printed models for surgical planning of complex congenital heart defects: an international multicentre study. Eur J Cardiothorac Surg 2017;52(6):1139–48.

[9] Sun Z, Lee SY. A systematic review of 3-D printing in cardiovascular and cerebrovascular diseases. Anatol J Cardiol 2017;17(6):423–35.

[10] Perica E, Sun Z. Patient-specific three-dimensional printing for pre-surgical planning in hepatocellular carcinoma treatment. Quant Imaging Med Surg 2017;7(6):668–77.

[11] Oshiro Y, Mitani J, Okada T, Ohkohchi N. A novel three-dimensional print of liver vessels and tumors in hepatectomy. Surg Today 2017;47(4):521–4.

[12] Olejnik P, Nosal M, Havran T, Furdova A, Cizmar M, Slabej M, et al. Utilisation of three-dimensional printed heart models for operative planning of complex congenital heart defects. Kardiol Pol 2017;75(5):495–501.

[13] Treasure T, Takkenberg JJ, Golesworthy T, Rega F, Petrou M, Rosendahl U, et al. Personalised external aortic root support (PEARS) in Marfan syndrome: analysis of 1-9 year outcomes by intention-to-treat in a cohort of the first 30 consecutive patients to receive a novel tissue and valve-conserving procedure, compared with the published results of aortic root replacement. Heart 2014;100(12):969–75.

[14] Gosnell J, Pietila T, Samuel BP, Kurup HK, Haw MP, Vettukattil JJ. Integration of computed tomography and three-dimensional echocardiography for hybrid three-dimensional printing in congenital heart disease. J Digit Imaging 2016;29(6):665–9.

[15] Schmauss D, Haeberle S, Hagl C, Sodian R. Three-dimensional printing in cardiac surgery and interventional cardiology: a single-centre experience. Eur J Cardiothorac Surg 2015;47(6):1044–52.

[16] Canstein C, Cachot P, Faust A, Stalder AF, Bock J, Frydrychowicz A, et al. 3D MR flow analysis in realistic rapid-prototyping model systems of the thoracic aorta: comparison with in vivo data and computational fluid dynamics in identical vessel geometries. Magn Reson Med 2008;59(3):535–46.

[17] Jang J, Park HJ, Kim SW, Kim H, Park JY, Na SJ, et al. 3D printed complex tissue construct using stem cell-laden decellularised extracellular matrix bioinks for cardiac repair. Biomaterials 2017;112:264–74.

[18] Tricomi BJ, Dias AD, Corr DT. Stem cell bioprinting for applications in regenerative medicine. Ann N Y Acad Sci 2016;1383(1):115–24.