Three-dimensional printing in cardiology: current status and future challenges in China

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Abstract: Three-dimensional (3D) printing has been employed as a potentially useful aid for the guidance of complex surgical procedures in recent years. Many clinical practitioners have preliminarily investigated its effect on improving the patients' outcomes. As one of developing country, China has put forward a series of national plans to advance the development of this relatively new field. In this perspective article, we briefly summarize and discuss the current status and future challenges of cardiovascular three-dimensional printing in China.

Keywords: Three-dimensional printing; cardiology; China; current status; challenge

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Three-dimensional (3D) printing has emerged in recent years as a promising tool to visualize the traditional two-dimensional medical images in a new way (1). It generally refers to the technology that converts a predesigned computerized model to a touchable model. In clinical medicine, it allows the transformation of a series of medical images obtained through computed tomography (CT), magnetic resonance imaging (MRI) or echocardiography to a tactile one, enabling preoperative simulation, postoperative assessment and device design (2). Currently, the application of 3D printing to cardiology is in its infancy, with both opportunities and challenges lying ahead. The development of 3D printing in China has been boosted by the national policies such as the *National Program on the Advancement of Additive Manufacturing* [2015–2016] and the *Made-in-China Project* 2025 (3,4). We aim to review the current status of 3D printing in cardiology in China and to discuss the challenges to be resolved in the future.

Current status of 3D printing in cardiology in China: preoperative, intraoperative and postoperative evaluations

In 2014, Yang *et al.* (5) reported the first patient who was evaluated by a 3D printing model preoperatively for the transcatheter occlusion of rupture of aortic sinusal aneurysm in China. The patient was examined by CT, after which a virtual cardiac model was generated for 3D printing. Then they tried different sizes of occluders on the 3D printing model to choose the most appropriate one for intraoperative placement. Their study built up a nearly standard protocol for the application of 3D printing to clinical cardiology in China. Many case reports on the utility of 3D printing in the preoperative evaluation of transcatheter occlusion have followed the similar steps (6-13). 3D printing has also been applied to the preoperative evaluation of open heart surgeries (10,14). In 2015, Ma *et al.* (15) reported the largest ever case series on the application of 3D printing model to clinical practice in China. They also presented for the first time the value of 3D printing in intraoperative orientation. Our group has recently reported the use of 3D printing for the postoperative evaluation of atrial septal defect occlusion (16). We further proposed an ecosystem for the applications of 3D printing in cardiology, which encompassed three parts, namely preoperative simulation, intraoperative orientation and postoperative evaluation (16). However, this ecosystem has not been fully built in China nowadays, with most

Table 1 Summary of 3D printing in cardiology in China

Category	First author, year	Sample size	Disease	Imaging modality	Application
Preoperative evaluation	Yang *et al.* [2014] (5)	1	Rupture of aortic sinusal aneurysm	CT	Transcatheter occlusion
	Yang *et al.* [2015] (8)	1	Atrial septal defect	CT	Transcatheter occlusion
	Liu *et al.* [2015] (9)	1	Severe aortic valve stenosis and mild regurgitation	CT	TAVI
	Wei *et al.* [2015] (17)	1	Severe aortic valve stenosis and regurgitation	CT	TAVI
	Yang *et al.* [2016] (6)	25	Atrial septal defect	CT	Transcatheter occlusion
	Hua *et al.* [2016] (14)	12	Double outlet right ventricle	CT	Open heart surgery
	Liu *et al.* [2016] (18)	8	Persistent atrial fibrillation	3D TEE	LAAO
	Wang *et al.* [2016] (7)	6	Atrial septal defect	CT	Transcatheter occlusion
	Hu *et al.* [2016] (10)	1	Ventricular septal defect, aortic stenosis	CT	Open heart surgery
	Yan *et al.* [2016] (11)	1	Atrial septal defect	CT	Transcatheter occlusion
	Fan *et al.* [2016] (19)	1	Atrial fibrillation	3D TEE	LAAO
	Pang *et al.* [2016] (12)	1	Atrial septal defect	CT	Transcatheter occlusion
	Luo *et al.* [2016] (13)*	1	Atrial septal defect	CT	Transcatheter occlusion
Intraoperative orientation	Ma *et al.* [2015] (15)	35	Tetralogy of Fallot	CT	Radical surgery of TOF
Postoperative evaluation	Wang *et al.* [2016] (16)	1	Atrial septal defect	CT	Transcatheter occlusion

*, unpublished data. TAVI, transcatheter aortic valve implantation; LAAO, left atrial appendage occlusion; CT, computed tomography; 3D TEE, three-dimensional transesophageal echocardiography.

studies focusing on preoperative simulation and few on intraoperative orientation or postoperative evaluation. *Table 1* summarizes the current utilities of 3D printing in cardiovascular diseases in China.

What are the challenges in the future?

To develop a uniform consensus for 3D printing in cardiology

Currently, there are no uniform consensuses on the application of 3D printing to cardiology. This may undermine the quality of researches in this field since many potential factors may affect the quality of 3D printing cardiac model. A uniform consensus encompassing 3D data acquisition, virtual reconstruction, rapid manufacturing and post processing method is important for a newly emerged technology because it can not only provide a standardized reference for making a 3D cardiac model in different hospitals, but also allow better comparison and validation of study results in the future. However, the development of such a uniform consensus is not an easy task since different types of participants including clinicians, researchers, entrepreneurs and government may be involved in this project.

CT, MRI, or 3D echocardiography?

CT has been commonly used to acquire source datasets for 3D printing, but it is not required for most cases with heart diseases because transthoracic echocardiography can provide enough information for clinicians, even in complicated cases (7). Besides, CT brings additional radiation exposure to the patients. In contrast, MRI brings no radiation to the patients, but it is more commonly used to detect the pathological changes of great vessels and myocardia (20). Compared with CT and MRI, 3D echocardiography is more widely used in cardiology and possibly serves as an ideal tool for the acquisition of raw data for 3D printing. By far, in China, two studies that used 3D transesophageal echocardiography to acquire raw data for 3D printing have included the patients with atrial fibrillation who planned to undergo left atrial appendage occlusion (LAAO) (18,19). However, they only printed the left atrial appendage rather than the whole heart for preoperative evaluation, indicating that 3D echocardiography may not be appropriate for atrial septal defect, ventricular septal defect or tetralogy of Fallot. Also, they did not specify the technical details on the generation of a virtual 3D model from raw data, a critical step for the subsequent 3D printing, thus their study results may not be easily duplicated. The choice of the most appropriate imaging modality for the acquisition of raw data for 3D printing can be based on the patient's disease, willingness and economic affordability.

The call for a better collaboration in clinical trials

The cardiovascular studies of 3D printing are sparse in China. Many groups have conducted very similar clinical studies using the similar study protocols and drawn on the similar conclusions (6-8,11,12). Why not pool up all these studies and draw on a much safer conclusion? Nowadays, 3D printing is still expensive and generally used for the preoperative evaluation of rare diseases. Therefore, the alignment of different hospitals is essentially critical to enlarge the sample size. Although a few studies with relatively large sample sizes have been published, only 1 clinical trial (ChiCTR-DOD-15007533, see on the website: www.chictr.org.cn) has been officially registered (18). The trial registration may be improved in the future with better research collaboration in China.

In conclusion, 3D printing has been preliminarily investigated in cardiology in China, yet a few problems remain unanswered and should be addressed in the future.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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