

## 3D printing technique for guiding complicated cardiovascular surgery

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The impressive guidance of three-dimensional (3D) printed model in surgery for a patient with right-sided aortic arch and Kommerell's diverticulum, being presented in our former paper (1), leading to a sound outcome, has been highlighted as well as commented in the editorials which means a big honor for us. Kommerell's diverticulum has been established a rare abnormality in some researches (2,3), even may be seen only once for some surgeons in their career, the medical management varies due to the rarity and complexity of this disease, including surgery, hybrid procedure, and conservative treatment with drugs. The surgical procedure of healing Kommerell's diverticulum is somehow unfamiliar to surgeons, to some extent may be difficult, especially associated with a right-sided aortic arch. The way we introduced in our paper (1) way be a good experience to go by for cardiac surgeons.

As mentioned by all physicians, the novel 3D reconstruction of cross-sectional imaging has been an advanced and ubiquitous technique in assisting diagnosis as well as planning and execution of medical management in many fields, such as orthopedic surgery (4), accounting for the biggest population, neurological surgery (5), plastic surgery (6), and cardiovascular surgery (7), to some degree making the therapy being of better efficiency, accuracy and precision. Compared with the digital reconstruction, the physical one, pointing to the printed model, carries a

preferable vision and more excellent presence of the anatomy which can be graspable as well as obviating the mental manipulation required in analyzing digital objects on a screen after post-processing in various software and printing machines with the computed tomographic angiography (CTA) or magnetic resonance imaging (MRI) data. As described in Treasure's paper, the word 'graspable', meaning an object which surgeons can be grasp and manipulate in hands even simulate surgery on it, makes a dramatic point. The direct touch and advanced vision provided by the model promises a better understanding and more detailed preoperative planning, the same as 'more information means better outcome' wrote by Sundararaghavan (8). It is currently in congenital heart disease where the 3D printing has been most employed for cardiac surgeons, as well has been extended to acquired heart disease. The congenital heart disease is often of great complexity and the hemodynamics are mutable. Utilization of 3D models provide an excellent view of the complexity to the surgeons as well as the simulation of operation before procedure.

With all its numerous advantages and uses of the emerging technique being demonstrated and proofed above, being accompanied by some limitations (7), 3D printing is still some years away from being ubiquitous as CTA reconstruction or MRI in cardiovascular medicine so far. What should be noted is that the rapid prototyping (RP) industry came

to public more than 3 decades ago, but it was just the last decade that RP was used in medical applications and named as '3D printing'. The gap in the initiating moment tells the lack of communication and teamwork between physicians and engineers. Tom Treasure and his team, mainly with John Pepper, have showed us a successful collaboration which can overcome the 'gap' limitation to follow up. Secondly, the 'expensive' issue which has been continuously debated ever since the utilization of 3D printing in medical applications dose restrict the prevalence of this novel technology. The generation of a 3D printed model is such a complex workflow, involving the acquisition of imaging data, the post-processing, the digital reconstruction, the printing procedure and some other related to it, not only expensive but also time-costing, that can't be afforded by some situations. Better would it be if the industry program was simplified and the printing achieved in-hospital. Thirdly, the availability of materials which can reproduce cardiovascular structure holding the most of their characteristics is still limited. Structure delicate as valves and sub-valves, tiny as coronary artery, complex as myocardium, flexible as great vessels, are all difficult to be reproduced with all their properties being remained. Moreover, robust evidence and explicit researches demonstrating 3D printing can significantly improve outcome and patient care is still short-landed.

It is obvious that 3D printing will have an integral role in the multi-disciplinary and collaborative cardiovascular diagnosis and management strategies. The feasibility of this technique has been shown for a broad range of cardiovascular diseases. From perspectives of future progress, some issues should be highlighted, involving some of above and others. First of all, a big progress should be made in the model-generation industry because a simplified and cheaper one will be vital for the prevalence of the 3D print technique as a mainstream with an acceptable costs-outcomes ratio in the imaging division. Furthermore, large patient cohort prospective studies, which can lead to large-scale, randomized, clinical trials, focusing on the specific clinical role that 3D printing plays, the powerful evidence of 3D printing promoting clinical outcomes, and the firm demonstration of effectiveness are urgently required. Lastly, researches on bio-printing procedure involving the bio-ink materials, printing techniques, extracellular matrix (ECM), as well as scaffolds, need to put forward in cardiovascular surgery (9).

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## Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

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