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Editorial

Applications of 3D printing in paediatric cardiology: its potential and the need for gathering evidence

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Three-dimensional (3D) printing holds great promise for applications in paediatric cardiology. From training medical staff to providing insight into complex congenital surgical cases, from acting as communication tools in the delicate dynamics of clinical encounters with parents and children to providing an educational mean to study congenital cases without the need for or complementing the use of specimens (1-4), 3D cardiac models are becoming increasingly used for cases of congenital heart disease (CHD).

A recent paper by the group at The Heart Institute of Cincinnati Children's Hospital (Riggs *et al.* 2018) in this issue of *Translational Pediatrics*, presents a compelling use of 3D patient-specific models in preoperative planning of two cases of paediatric cardiac tumor debulking (5). These cases highlight different features of cardiac 3D models, including: the ability of accurately reconstructing small anatomies (the cases were 12 days and 2 months of age, respectively); the clinical applicability of the technique based on available routinely acquired medical imaging data (CMR images in one case and CT images in the other); and the versatile quality of the models in terms of materials and finishing (in this case mixing white resin and a transparent rubber-like compound to highlight the tumors). The authors also importantly mention the use of models to "engage patients and their families, providing them with a better understanding of their conditions", although in the article it is not explicit how the models were used with the families of the patients and how they impacted on their understanding of the complex procedures that these babies were undergoing.

Case studies like the two presented in this article, and similar cases looking at other congenital scenarios [e.g., conduit replacement in a child with truncus arteriosus, planning complex percutaneous repair of aortic coarctation or repair of a complex double-outlet left ventricle (6-8)] clearly highlight the fact that 3D models are being increasingly used for planning and discussing complex cardiac cases. Small series are also starting to emerge, presenting evidence on a slightly larger scale, e.g., a small series of patients with complex muscular ventricular septal defects or double-outlet right ventricle (9), or a series of 40 patients with complex CHD where it was shown that the use of models helped refining the surgical approach in approximately half of the cases (10). Nevertheless, evidence on a large scale is still lacking. This is in part due to the difficulty in randomizing complex congenital cases, or even to adopt a case-control approach, whereby some cases present such unique features that make it difficult to reliably compare clinical variables across different cases. The number of cases itself can present a limit to gather evidence on a large scale, where complex cases are performed in relatively few centres, and this highlights the need for multicentric endeavors. One good example in this sense is the *Collection*: *Heart Library* as part of the *NIH 3D Print Exchange*, with a focus on CHD (https://3dprint.nih.gov/collections/heart-library). Possible differences in surgical approaches across centres can also impact to some extent on the feasibility of pooling data together from multicentric

studies. But 3D cardiac models may not be necessarily desirable only in complex scenarios, as indeed this would depend on the application of the model itself. If considering, for instance, the use of models for communicating with patients and empowering them in critical moments of their clinical journey, such as transitioning from being a paediatric to an adult patient, patients with less complex defects (e.g., ventricular septal defects or repaired coarctations with no additional comorbidities) would probably also benefit from having a model of their heart presented to them in the context of a clinical appointment, thus broadening the potential population of such a study.

Cost-effectiveness considerations are also important and should be gathered on a large scale, but in this case, they go hand-in-hand also with questions on the possible settings for 3D labs in the paediatric cardiac setting. We are currently witnessing several centres setting up their own 3D labs for in-house manufacturing of 3D models, whilst some still rely on consigning models to external industrial partners. Office-based 3D printing is beginning to be indicated as a cost-effective and efficient solution, with true clinical translation of the technology, e.g., printing skeletal models for repair of facial fractures (11), which indeed reminds us that the technology is successfully used well beyond CHD and cardiovascular medicine, with flourishing applications in urology or craniomaxillofacial procedures.

Streamlining the workflow of clinical 3D printing in the CHD setting is closely linked to advances on the technical side, e.g., accelerating printing times considerably or availability of new materials for printing. The latter point, once again, depends on the application of the model: if the model were used to practice a surgical procedure, a deformable model with realistic mechanical properties and suitable for suturing would be very desirable, whilst this is probably not necessary in the context of clinical encounters with patients and families. Work from focus groups (12) as well as in a creative context (13) begins to highlight different preferences amongst patients, whereby the suitability of showing different heart models to different patients may be discussed with a psychologist or with an adolescent nurse specialist. Another technical issue to be considered is the quality of the input images used for the creation of the 3D models, since the resolution of the printed model will depend mostly on the images used to generate it. As for every imaging modality, also 3D models created for clinical purposes need to address a clinical question, and thus a deep collaboration between a clinical team of cardiovascular imagers and the biomedical engineers is of great importance in the creation of the models. So, the clinical usage of 3D models reiterates the multidisciplinary nature of this field and its players, but it also raises questions on reimbursements and how to potentially, in a not too distant future, integrate the technology in different health systems, if it were to become a service. But the need for evidence remains a priority.

Applications of 3D printing are currently expanding beyond congenital cardiology and cardiac surgery, with 3D models being used in planning other complex procedures such as percutaneous valve procedures or left ventricular myectomy in patients with obstructive hypertrophic cardiomyopathy (14,15). From a purely clinical standpoint, the study by Riggs *et al.* highlights how 3D printing is a versatile tool that can be applicable in any clinical situation in which adequate cross-sectional imaging is performed. Being very rare, pediatric cardiac tumors represent a unique clinical challenge for every cardiac surgeon and, as discussed by the authors, patient-specific 3D models can be of great help in understanding spatial relationships between the neoplastic mass and delicate cardiac structures such as the coronary arteries. Whether the perceived benefit that the 3D models provide to cardiac surgeons translates into a reduction of surgical time is yet to be demonstrated.

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Footnote

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