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EDUCATION FORUM

WILEY Congenital Heart Disease

Cardiac morphology for the millennial cardiology fellow: Nomenclature and advances in morphologic imaging

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Abstract

Cardiology fellows-in-training, both in adult and pediatric hospitals, need structured education in regards to congenital heart disease (CHD) nomenclature. With improved survival of patients with CHD, it is not uncommon for these patients to seek care in multiple adult and pediatric hospitals. A deep understanding of CHD nomenclature would aid in providing accurate medical and surgical care for these patients. In this forum, we share our experience with such structured education and also comment on recent advances in morphologic imaging that would aid in understanding the nomenclature.

KEYWORDS
cardiac morphology, cardiac pathology, congenital heart disease, imaging

1 | INTRODUCTION

With an improved survival of patients with complex congenital heart disease (CHD) well into adulthood, a precise understanding of the underlying cardiac morphology is required to deliver care to these patients for all cardiology fellows-in-training (FIT). The nomenclature of cardiac morphology in describing various forms of CHD is inherently complicated and has developed into nonuniform systems of terminology largely based on expert opinion. Although advancements in the fields of cardiac embryology, genetics, and imaging have improved our anatomical understanding of CHD, and form the evidence used for the consensus nomenclature promoted in the upcoming ICD-11 terminology, differing schools of thought persist on the definition and classification of many forms of CHD.[1] It is not uncommon that a variety of terms not completely synonymous are used to describe the same lesion, making it difficult to communicate between providers, trainees, and patients. As an example, a ventricular septal defect opening to the outlet of the right ventricle may be described as doubly committed juxta-arterial, perimembranous outlet, muscular outlet, outlet, conal, supracristal, conal septal hypoplasia or as a subarterial defect, depending on the clinician's understanding and interpretation of the right ventricular geography and borders of the defect, and their preferred terminology. Although some institutions may agree on the general terminology to be used, it is not uncommon for various nomenclature systems to be used within one institution. This clearly has the potential of making the understanding and description of CHD challenging for the early FIT unaccustomed to CHD.[2] Furthermore, an imperative need for fellows to be "multilingual" with an understanding of all major nomenclature systems is arising due to the improved survival of patients with complex CHD well into adulthood, who are not restricted to care in a single institution.

Although cardiac morphology forms the building blocks of training in pediatric cardiology, it is rare to have dedicated time to dwell on the anatomical aspects of CHD. In response to this training deficit, we launched a local initiative with the help of a junior faculty with expertise in cardiac morphology to improve the understanding through the development of an immersive experience given by expert lecturers in cardiac development and anatomy. This was accomplished in the form of a 2-week cardiac morphology elective and consisted of a mixture of traditional didactic lectures in both cardiac development and morphology, lectures applying clinical applicability to this understanding, as well as hands-on investigations of various lesions in our archive of cardiac specimens with CHD. The group was fortunate to have pioneer cardiac morphologist, Professor Robert Anderson, participate in the first week of the elective giving formal lectures and lead several small group sessions. Experts in the cardiology subspecialties provided additional clinical perspectives specific to their fields, including cardiac catheterization, cardiomyopathy, cardiothoracic surgery, electrophysiology, imaging, and pathology. The learners reported satisfaction with the comprehensive experience and cited an improved understanding of key subject areas and corresponding clinical correlates, such as the relative location of the conduction system in various forms of CHD, the important developmental aberrations that lead to the various forms of CHD, and the anatomic changes following surgical repair or palliation of specific lesions.

Upon evaluation of the cardiac morphology course, it became evident that cardiac specimens played a pivotal role in both the understanding of the three-dimensional (3D) anatomical aspects of each lesion and correlation with two-dimensional (2D) imaging, as well as comprehension of the various nomenclature systems. Traditionally preserved cardiac specimens have limitations to their application in widespread education, and complex unrepaired cardiac pathology specimens are scarce in most modern-day cardiology programs.[4] Large collections of cardiac specimens with a wide variety of pathologies, including rare defects, are usually available only in a small number of institutions. Additionally, the information available is oftentimes limited by the dissection windows. Finally, cardiac specimens do not last forever and will eventually be prone to damage. In light of these realities, the Archiving Working Group of The International Society for Nomenclature of Paediatric and Congenital Heart Disease recently made a plea for the preservation of cardiac specimens through the means of creating digital datasets.[3] With recent advances in imaging technology, there are a number of new imaging and postprocessing modalities that have gained attention in the demonstration of cardiac morphology in both the deceased and living patient, which may even surpass pathological inspection as the gold standard for understanding cardiac anatomy.[4]

A thorough understanding of normal and abnormal cardiac anatomy begins with that of cardiac development. With the advent of high-resolution episcopic microscopy, we are now able to accurately explore the changing morphology of the developing heart with the ability of multiplane reformatting and virtual dissection.[5] Microscopic computed tomography (micro-CT) has the ability to demonstrate the high-resolution cardiac anatomy of obtained cadaveric specimens, with the ability of multiplane reformatting, allowing the investigator to virtually dissect the autopsied heart in any plane. Recent use of contrast-enhanced micro-CT may even allow one to study the cardiac conduction tissue relative to this detailed anatomy without employing histological sectioning.[3] Magnetic resonance imaging has also demonstrated the capability of high-resolution anatomical imaging in cadaveric specimens, also with the potential for visualization of the conduction system. Another important advantage of these datasets is their storage in digital format with the capability to seamlessly transfer information between trainees or institutions, with the ultimate goal of many to create a freely accessible digital archive of various forms of CHD from the major institutional archives for educational purposes of all trainees across the world. Institutions that do not have access to a comprehensive cardiac specimen collection could take advantage of these innovative technologies.

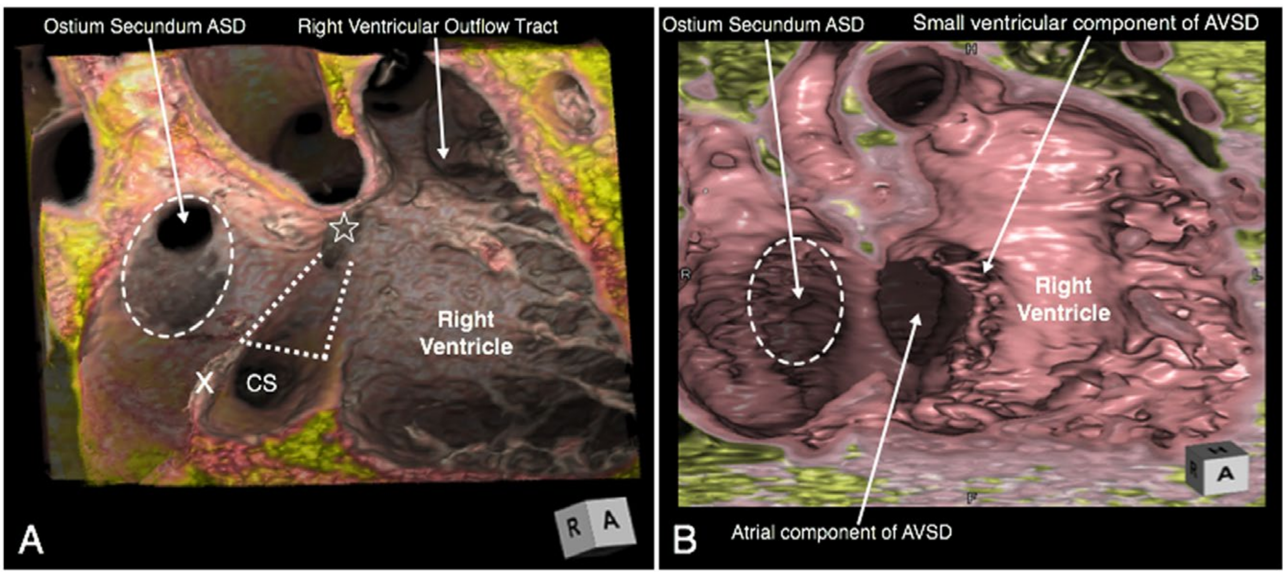

FIGURE 1 Computed tomographic 3D reconstruction. (A) Patient with a moderate-sized ostium secundum atrial septal defect (ASD) with the anterior aspect of the right atrial and right ventricular wall removed. The defect is seen to be a deficiency within the superior aspect of the oval fossa (the oval fossa is outlined with a white dashed line). The components of the triangle of Koch are highlighted (dotted white line) with the apex directed toward the membranous septum (☆) and the base formed by the coronary sinus (CS) that is guarded by the Eustachian valve (X). Panel A is courtesy of Shumpei Mori, Division of Cardiovascular Medicine, Kobe University Graduate School of Medicine, Kobe, Japan. (B) Patient with an atrioventricular septal defect (AVSD) and a small ostium secundum ASD, highlighting the difference between the two types of atrial-level communication. Both the superior and inferior bridging leaflets of the common atrioventricular valve attach to the crest of the muscular ventricular septum allowing only small ventricular-level shunting through the interchordal spaces [Colour figure can be viewed at wileyonlinelibrary.com]

With the desire for not only improved education but also improved anatomical understanding guiding patient care, the field of "living cardiac anatomy" guided by advanced cardiac imaging with 3D reconstruction has emerged. This allows the observer to view the 2D dataset in 3D form, whether virtually or in the printed construct. (Figure 1) Although virtual models are often sufficient, rapid prototyping and the creation of a tangible 3D printed model often enhances the understanding for not only education purposes, but for clinical and surgical understanding and planning in certain forms of CHD, with growing interest in surgical simulation for both purposes.[6] Three-dimensional printed models can be generated in a relatively short period of time at a relatively low cost without jeopardizing the understanding of cardiac anatomy, and is therefore suitable for the education of trainees.[7] Additionally, the functionality of 3D printing allows for the production of different constituents of a specimen with different strength materials and colors, such as valves and muscle tissue. These models can be reproduced from CT, MR, or echocardiographic image datasets of cardiac specimens or living patients, with each imaging modality having relative strengths and weaknesses. While the accuracy of 3D printed models is strongly dependent on not only the equipment used but even more so on the anatomical interpretation and understanding of the segmenting operator, it has been shown that 3D printed models of anatomical structures can be equivalent to the original specimens and therefore are well suited for the education of trainees, as well as for patients and families.[8]

In conclusion, a clear understanding of the nomenclature and morphology of CHD is necessary to effectively care for these patients. The development of an immersive experience in cardiac morphology can be a viable way to address the current knowledge gap within pediatric cardiology fellowship education. While traditional methods for teaching pathology have heavily relied on preserved cardiac specimens, newer technologies such as 3D reconstructions from CT and MR datasets are emerging as promising tools and have the potential to revolutionize education on cardiac morphology and nomenclature in the near future. Future studies are needed to assess the effectiveness of newer technologies in providing an educational experience compared to the traditional teaching with pathologic specimen.

CONFLICT OF INTEREST

None

AUTHOR CONTRIBUTIONS

Drafting article, approval of article, concept/design: Baskar. *Critical revision of article*: Gray. *Drafting article, approval of article*: Del Grippo, Osakwe, Powell. *Concept/design, critical revision of article, approval of article*: Tretter.

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