

Identification of the atrioventricular conduction axis and its positional relationship with anatomical landmarks of a heart with tricuspid atresia



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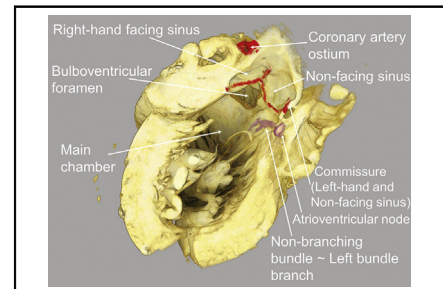
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Conduction axis and anatomical landmarks in a heart with tricuspid atresia.

CENTRAL MESSAGE

During aortic valve operation in patients with tricuspid atresia, identification of the right fibrous trigone is the first step for preventing heart block.

See Commentaries on pages 561 and 563.

▶ Video clip is available online.

Previous reports of the atrioventricular conduction axis (AVCA) in patients with tricuspid atresia (TA) have focused on its anatomical association with the classical Fontan operations and adjunctive procedures, such as enlargement of the bulboventricular foramen and closure of the atrial septal defect.¹ However, surgical techniques for TA have evolved in recent decades, and the total cavopulmonary connection and the Damus–Kaye–Stansel procedure have been widely adopted. Thus, the previous anatomical findings have become less relevant.² Meanwhile, surgeries for late aortic root dilatation and aortic insufficiency in patients with TA have been recently reported.³⁻⁵ However, the anatomical relationship between the aortic valve and the AVCA in patients with TA has not been elucidated. Our group previously reported the 3-dimensional examination method of the cardiac conduction axis using synchrotron radiation-based x-ray phase-contrast computed tomography (PCCT).⁶ The purpose of this study was to reveal the 3-dimensional positional relationship between the AVCA

and the anatomical landmarks associated with the valve operation in patients with TA using PCCT to minimize the risk of a surgical heart block.

METHODS

Institutional review board approval was granted on April 12, 2021 (number R2021011, University of Toyama). This study was approved by the respective ethical committees of the participating hospitals. The institutional review board and the committees waived the need for consent from the family of the deceased. Five human hearts with TA obtained by autopsy were studied using synchrotron radiation-based x-ray PCCT in a SPring-8 synchrotron radiation facility in Hyogo, Japan. The PCCT system (BL20B2) in a SPring-8 uses the Talbot grating interferometer, which has outstanding features compared with other techniques. It is almost 1000 times more sensitive than absorption computed tomography. The precise information about the Talbot grating interferometer was described by Hoshino and colleagues.⁷ The median age at autopsy was 13 days (range, 4-25 days). The hearts were dissected and stored immediately after death. The median time from death to dissection was 1.6 hours (range, 0.75-11 hours; n = 4). The detailed method was described by Shinohara and colleagues.⁶ Briefly, the system specifications were as follows: voxel size, 25.1 μm; target density range, 0.9 to 1.2 g/cm³; and density resolution, 1 mg/cm³. The data obtained were processed and reconstructed using the

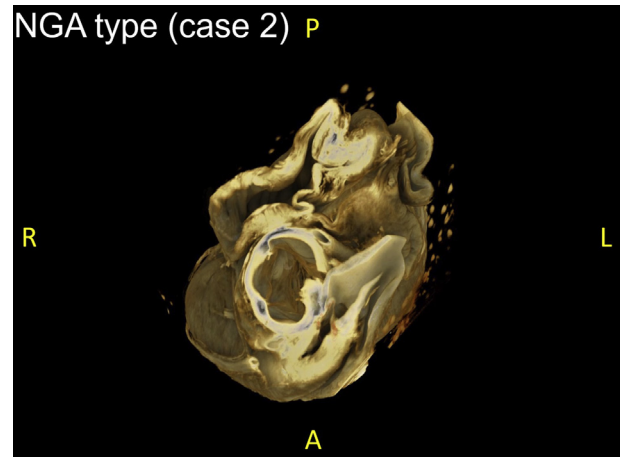
Abbreviations and Acronyms

- AVCA = atrioventricular conduction axis
- AVN = atrioventricular node
- NFS = non-facing sinus
- NGAs = normally related great arteries
- PCCT = phase-contrast computed tomography
- TA = tricuspid atresia

Microscopy Image Browser (<http://mib.helsinki.fi/index.html>) and Drishti (<https://github.com/nci/drishti>). The positional relationship and distance between the AVCA and aortic valve and mitral valve were measured. Each semilunar valve sinus was named as right-facing sinus, left-facing sinus, and non-facing sinus (NFS), according to the modified Leiden Convention, advocated by Gittenberger-de Groot and colleagues.⁸

RESULTS

In all hearts, the AVCA from the atrioventricular node (AVN) to the left bundle branch could be traced as a low-density structure. The AVN was located adjacent to the right fibrous trigone. The median distance from the AVN to the mitral annulus was 2.0 mm (range, 0.9-3.0 mm). In 4 hearts with normally related great arteries (NGAs), the AVCA lay beneath the commissure of the aortic valve between the left-facing sinus and the NFS and extended to the nadir of the NFS (Figure 1 and Video 1). The median distance from the aortic valve to the AVCA was 1.9 mm (range, 1.3-3.1 mm). In 1 heart with malposition of the great arteries, the AVCA lay beneath the commissure of the pulmonary valve between the right-facing sinus and the NFS. The distance from the AVCA to the pulmonary valve was 2.7 mm. Schematic illustrations of the AVCA and the surrounding structures in each heart are shown in Figure 2.



VIDEO 1. The video shows a 3-dimensional image of case 2 (normally related great arteries) and its serial sections. The locations of the atrioventricular conduction axis and its surrounding structures are clearly depicted. Video available at: [https://www.jtcvs.org/article/S2666-2736\(21\)00369-7/fulltext](https://www.jtcvs.org/article/S2666-2736(21)00369-7/fulltext).

DISCUSSION

As previously reported,¹ our study reconfirmed the anatomical proximity of the AVCA and the central fibrous body in all types of TA. However, the most important finding of this study was the posterior location of the AVCA relative to the aortic valve in cases with TA and NGAs. Our results suggested that identification of the aortic sinuses and localization of the AVCA could pose a risk of heart block during an aortic valve operation in patients with TA and NGAs (Figure 3). Dickinson and colleagues¹ suggested the proximity of the AVCA and the acute margin

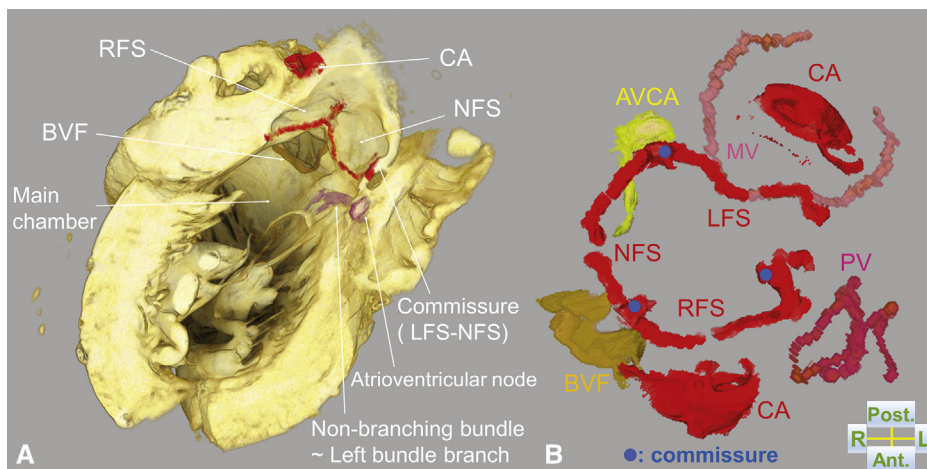


FIGURE 1. Positional relationship between the atrioventricular conduction axis (AVCA) and anatomical landmarks in case 2. A, Volume-rendering image from the posterolateral aspect is shown. The AVCA (light purple) lies beneath the commissure of the aortic valve between the left-facing sinus (LFS) and the non-facing sinus (NFS) and extends to the nadir of the NFS. B, Key anatomical structures are extracted. The AVCA lies beneath the commissure of the aortic valve between the LFS and NFS. RFS, Right-facing sinus; CA, coronary artery ostium; BVF, bulboventricular foramen; MV, mitral valve; PV, pulmonary valve.

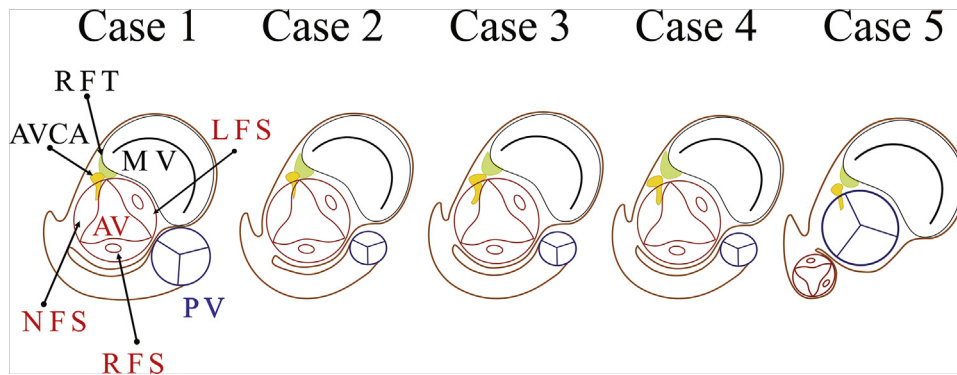


FIGURE 2. Schematic illustrations of the atrioventricular conduction axis (AVCA) and the surrounding structures of the 5 hearts included in the study. In cases with normally related great arteries (cases 1-4), the AVCA (yellow) lies beneath the commissure of the aortic valve (AV) between the left-facing sinus (LFS) and the non-facing sinus (NFS) and extends to the nadir of the NFS. In 1 heart with malposition of the great arteries (case 5), the AVCA lay beneath the commissure of the pulmonary valve between the right-facing sinus (RFS) and NFS. RFT, Right fibrous trigone; MV, mitral valve; PV, pulmonary valve.

in the heart with TA, which implies a right anterior dislocation of the AVCA. Although these 2 findings might be viewed as contradictory, these differences might be because of the difference of anatomical references (aortic valve, whole ventricle). From an embryological viewpoint, the location of the AVCA is correlated with the central fibrous

body. However, it is not correlated with the development of the aortic root nor the aortic root. Although postoperative heart block after aortic root surgery in patients with TA has not been reported, identifying the right fibrous trigone during aortic valve surgery in patients with TA is the first step in preventing surgical heart block. This step is widely

The three-dimensional positional relationship between the atrioventricular conduction axis and anatomical landmarks in patients with tricuspid atresia

<p>Conduction axis</p>	<p>RFS NFS Commissure (between LFS and NFS) AVN</p>	<p>RFT AVCA NFS MV AV LFS PV RFS</p>
<ul style="list-style-type: none"> ✓ Five hearts with tricuspid atresia ✓ phase-contrast CT ✓ 3D reconstruction and tagging of the anatomical landmarks 	<ul style="list-style-type: none"> ✓ In hearts with normally related great arteries, the AVN lay beneath the commissure between the LFS and NFS 	<ul style="list-style-type: none"> ✓ Identifying the aortic sinuses and localization of the AVCA poses a risk of heart block during an aortic valve surgery in patients with tricuspid atresia

FIGURE 3. Five human heart specimens with tricuspid atresia were studied using synchrotron radiation-based x-ray phase-contrast computed tomography. In 4 hearts with normally related great arteries, the AVCA lay beneath the commissure of the aortic valve between the left-facing sinus and the NFS and extended to the nadir of the NFS. Our study revealed that identification of the aortic sinuses and localization of the AVCA could pose a risk of heart block during an aortic valve operation in patients with tricuspid atresia and normally related great arteries. Identifying the right fibrous trigone during aortic valve surgery in patients with tricuspid atresia is the first step in preventing surgical heart block during the aortic valve operation in patients with tricuspid atresia and normally related great arteries. RFS, Right-facing sinus; NFS, non-facing sinus; LFS, left-facing sinus; AVN, atrioventricular node; RFT, right fibrous trigone; AVCA, atrioventricular conduction axis; MV, mitral valve; AV, aortic valve; PV, pulmonary valve; CT, computed tomography.

applicable for other heart diseases, including bicuspid aortic valve.

Limitations

Our study has several important limitations. We only had access to a small number of specimens. A Damus–Kaye–Stansel procedure or Norwood-type operation are frequently required in patients with TA with malposition of the great arteries. However, we could examine only 1 heart with this subtype. In addition, the clinical importance of late aortic root dilatation and progression of aortic valve regurgitation in patients with TA remains to be seen. Furthermore, the right bundle branch passing across the bulboventricular foramen could not be delineated, which could be attributed to postmortem changes. Lastly, the PCCT system was not available for the clinical setting because of its high radiation dose (75 Gy).

CONCLUSIONS

In patients with TA and NGAs, the AVCA was located posterior to the aortic valve. In aortic valve operations, a deep suture or dissection between the left-facing sinus and the NFS and the nadir of the NFS could pose a risk of surgical heart block in patients with TA and NGAs. Further

anatomical studies on the AVCA and aortic root in various types of univentricular hearts are required. In addition, optical technologies that can be used for intraoperative AVCA localization should be developed.

References

1. Dickinson DF, Wilkinson JL, Smith A, Becker AE, Anderson RH. Atrioventricular conduction tissues in univentricular hearts of left ventricular type with absent right atrioventricular connection ('tricuspid atresia'). *Br Heart J*. 1979;42:1-8.
2. Freedom RM, Yoo SJ, Russell J, Perrin D, Williams WG. Designing therapeutic strategies for patients with a dominant left ventricle, discordant ventriculo-arterial connections, and unobstructed flow of blood to the lungs. *Cardiol Young*. 2004;14:630-53.
3. Kanzaki T, Yamagishi M, Miyazaki T, Maeda Y, Yaku H. Valve-sparing neo-aortic root replacement late after the Norwood and Fontan procedures. *Ann Thorac Surg*. 2015;99:309-12.
4. Contreras J, Bannan B, Chaturvedi R, Barron DJ. Bentall procedure for the repair of a neo-aortic aneurysm after the Norwood procedure in a patient with tricuspid atresia and a discordant ventriculo-arterial connection. *Interact Cardiovasc Thorac Surg*. 2020;31:578-9.
5. Koizumi S, Matsuo K, Kabasawa M. Aortic root replacement in a patient with un-operated tricuspid atresia. *Cardiol Young*. 2019;29:1211-3.
6. Shinohara G, Morita K, Hoshino M, Ko Y, Tsukube T, Kaneko Y, et al. Three dimensional visualization of human cardiac conduction tissue in whole heart specimens by high-resolution phase-contrast CT imaging using synchrotron radiation. *World J Pediatr Congenit Heart Surg*. 2016;7:700-5.
7. Hoshino M, Uesugi K, Yagi N. Phase-contrast X-ray microtomography of mouse fetus. *Biol Open*. 2012;1:269-74.
8. Gittenberger-de Groot AC, Koenraadt WMC, Bartelings MM, Bökenkamp R, DeRuiter MC, Hazekamp MG, et al. Coding of coronary arterial origin and branching in congenital heart disease: the modified Leiden Convention. *J Thorac Cardiovasc Surg*. 2018;156:2260-9.