Surgical and Radiologic Anatomy
https://doi.org/10.1007/s00276-021-02713-w

ORIGINAL ARTICLE

Real color volume model of cadaver for learning cardiac computed tomographs and echocardiographs

Beom Sun Chung[1] · **Min Suk Chung**[2]

Received: 18 November 2020 / Accepted: 9 February 2021

Abstract

Purpose It is difficult for medical students and novice clinicians to interpret cardiac computed tomographs and echocardiographs. This study was intended to help familiarize them with the clinical images of the heart by providing software to browse the various planes of a heart's volume model with real color and high resolution.

Methods On the sectioned images of a male cadaver, the heart and adjacent structures were segmented to obtain color-filled images. Volume models of the sectioned images and color-filled images were reconstructed and sectioned to obtain three orthogonal planes and five standard oblique planes. The planes were inputted into lab-made browsing software, which was then distributed free of charge.

Results Users of the software would hopefully progress as follows. After experiencing the real color and high resolution, they would become familiar with the grayscale and low resolution. After experiencing the automatic annotation of the basic heart structures, they would become familiar with the detailed structures. After experiencing the designated planes, they would become familiar with the arbitrary planes. After experiencing the still heart, they would become familiar with the moving heart during echocardiography.

Conclusion The software, with a user-friendly interface and realistic features, is expected to properly orient medical novices to cardiac computed tomography and echocardiography images.

Keywords X-ray computed tomography · Echocardiography · Heart · Cadaver · Visible human projects · Volume model

Introduction

Cardiac computed tomography is conducted for diagnosing heart valve disease and coronary artery disease [2, 7, 28]. Echocardiography is also widely carried out as a routine diagnostic procedure because of its safety, low cost, and reliability [9]. Moreover, echocardiography is conducted when performing pericardiocentesis to treat cardiac tamponade and for other procedures [3].

It is not easy for medical students and novice clinicians to interpret cardiac computed tomographs (CTs) that appear in grayscale. Owing to the rotation of the primitive heart during embryological development, the four heart chambers are not symmetric with regard to horizontal and sagittal planes. For instance, the right chambers are anterior to the left chambers. This morphology is the reason why the cardiac CTs are difficult to recognize. The constant beating of the heart may make cardiac CTs blur, despite multi-detector techniques to overcome this problem [13, 18].

Echocardiographs, with much lower resolution as well as grayscale, are even harder to interpret. Moreover, echocardiographs in various oblique planes are more confusing than cardiac CTs in orthogonal planes [10]. The continuous movement of the heart chambers is another factor making the interpretation of echocardiographs difficult.

Existing methods to learn the clinical images and related sectional anatomy of the heart have shortfalls. The three-dimensional (3D) morphology is difficult to comprehend using two-dimensional (2D) atlases of cardiac CTs and echocardiographs [17, 23, 24]. Anatomical models made of plastic are not delicate or realistic compared to the actual human heart and the plastic models cannot be sectioned in the desired direction. A cadaver heart is not readily available

✉ Min Suk Chung
dissect@ajou.ac.kr

[1] Department of Anatomy, Yonsei University Wonju College of Medicine, Wonju, Republic of Korea

[2] Department of Anatomy, Ajou University School of Medicine, Suwon, Republic of Korea

at any time, at any place; it cannot be sectioned repeatedly in diverse planes [8].

To overcome these shortcomings, the corresponding author conducted a trial called the Visible Korean project. A female cadaver was serially sectioned to prepare sectioned images with real color and high resolution [21]. On the sectioned images, the basic heart structures were segmented, and the surface was reconstructed. Using a portable document format (PDF) file, the surface models were freely selected to display and rotated. The surface models were accompanied by orthogonal planes of the heart. However, the orthogonal planes were limited in number [26].

To upgrade the learning tool for the sectional anatomy of the heart, the following image data and computer techniques were prepared in the Visible Korean project. The sectioned images of a male cadaver were acquired [22]. In the sectioned images, the heart structures were segmented as well [26]. A technique to convert the serial 2D color images into volume models and oblique planes on the personal computer was developed [5, 6]. Browsing software that displayed multiple sets of images (e.g., sets of orthogonal planes and oblique planes) was composed [14].

The purpose of this study was to help medical students and clinicians interpret cardiac CTs and echocardiographs by providing free software to visualize the orthogonal and oblique planes of a heart's volume model in real color and high resolution. The 2D and 3D images of this study may suggest a novel approach for interpreting sectional anatomy of the heart to specialists of the field.

Materials and methods

While the previous study employed a female cadaver for making surface models [21, 26], this study employed a male cadaver for making volume models. Horizontal sectioned images (intervals 0.2 mm; pixel size 0.2 mm; color depth 24-bit) of the whole body of a freshly frozen Korean male cadaver (age 33 years old; stature 1.64 m; weight 55 kg) were prepared using a cryomacrotome and digital camera [22]. A personal computer with ordinary performance (CPU 1.80 GHz; memory 16 GBytes) was utilized for the whole image processing. From the 8,505 sectioned images, 691 sectioned images involving the heart and adjacent structures were selected. From the selected images (pixel number 2468 × 1407), outside of the interested region was cropped (pixel number 848 × 773).

The sectioned images in tagged image file format (TIFF) were converted to digital imaging and communications in medicine (DICOM) files using Adobe Photoshop CC (Adobe Systems Inc., San Jose, CA, USA). The DICOM files were aligned using DICOM Browser (http://nrg.wustl.edu/software/dicom-browser). The aligned DICOM files were accumulated to generate a volume model (voxel size 0.2 mm; voxel numbers 848 × 773 × 691) and saved as a neuroimaging informatics technology initiative (NIfTI-1 = NII) file using MRIcroGL (mccauslandcenter.sc.edu/mricrogl/home) [5, 6, 15].

From the volume model of the sectioned images, the three orthogonal planes (intervals 1 mm) were obtained using MRIcroGL (Fig. 1) (Table 1) [15]. From the same volume model, the standard oblique planes simulating echocardiographs were obtained using MRIcroGL too [15]. Five standard oblique planes were as follows: long axis plane that passes the base and apex of the heart and shows the mitral valve and aortic valve. Short axis plane (aorta side) and short-axis plane (apex side) that are right-angled to the long axis plane. Four-chamber plane that shows the tricuspid valve, mitral valve, and aortic valves. Two-chamber plane that shows the left atrium, left ventricle, mitral valve (Fig. 2) [20]. In addition, 20 neighboring parallel images (1 mm intervals) of each standard oblique plane were obtained (Table 1).

The segmented structures included heart structures, blood vessels, bones, and others (Table 2). The segmented structures were assigned different colors to derive the color-filled images [27].

The color-filled images were also stacked to reconstruct another volume model. From the volume model of the color-filled images, the orthogonal and oblique planes were obtained in the same manner.

The various planes made of the sectioned images and corresponding color-filled images were input into the browsing software (Fig. 3) [14].

Results

The browsing software showing orthogonal and oblique planes of the heart (file size 101 MBytes) was downloadable from the homepage (anatomy.co.kr) for free [4] by selecting the link "Browsing software (Male—Sectioned heart)." Once the ZIP file was extracted, the browsing software could be operated on a personal computer without installation.

In the browsing software, the horizontal, coronal, sagittal, and oblique planes of the sectioned images could be chosen with the bottom buttons. Then, a set of planes could be continuously viewed at 1 mm intervals with the scroll bar. The sectional plane could be zoomed in/out and shifted. Any planes could be swapped for the equivalent color-filled planes by using the top-left checkbox. Names of the segmented structures were automatically shown as a tooltip (Fig. 3).

The volume model of the sectioned images had real color and high resolution (voxel size 0.2 mm). Therefore, the minute structures that are not recognizable on cardiac CTs

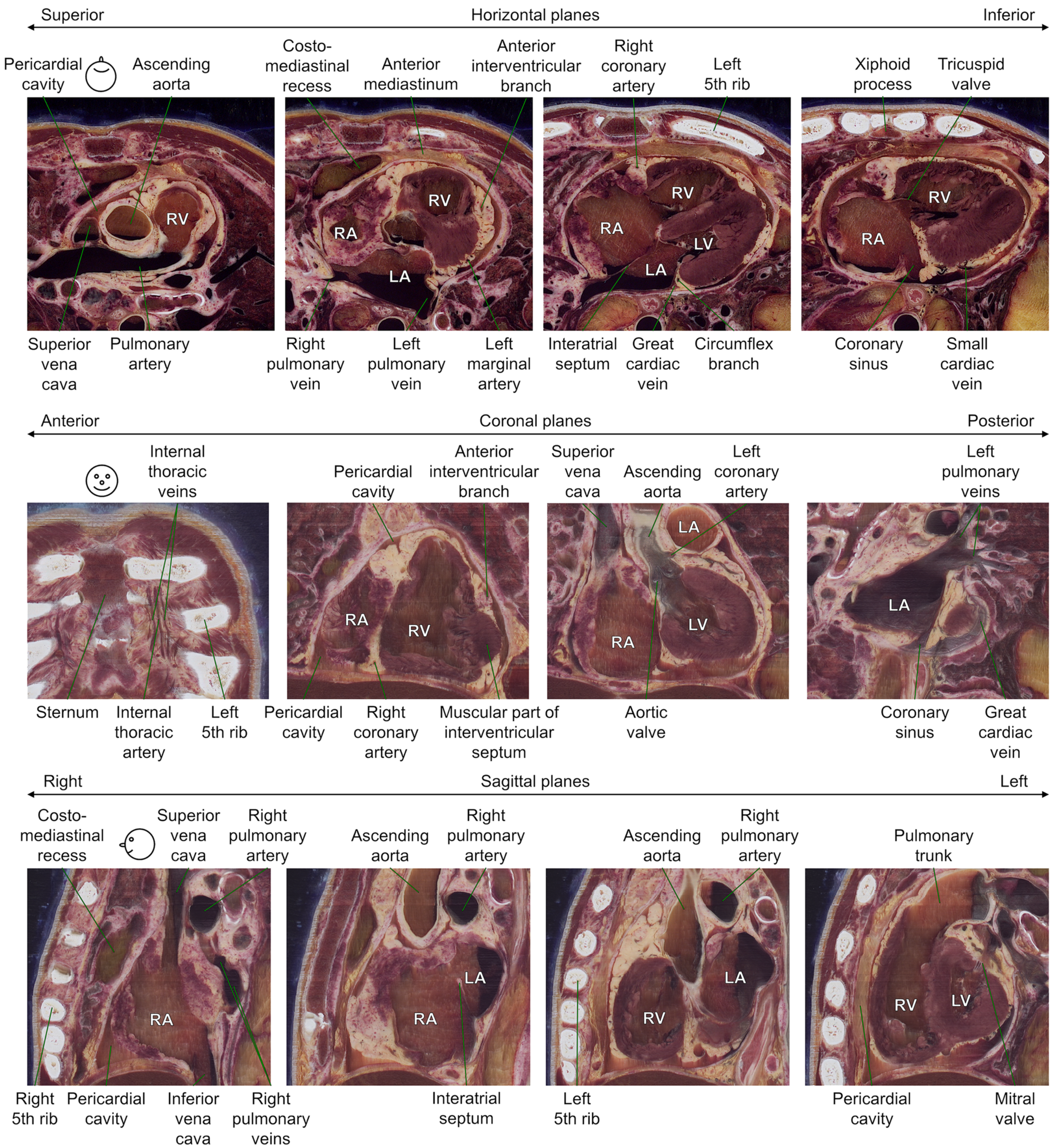

Fig. 1 Three orthogonal planes showing heart structures derived from the volume model of the sectioned images

and echocardiographs could be identified. For instance, the branches of the coronary arteries and cardiac veins were vividly recognized in the images (Fig. 1). Moreover, the layers from the skin to the lumen of the heart and the conducting system of the heart were recognized (Fig. 4).

In addition, the heart's original volume model (file size 1,110 MBytes) and its color-filled volume model (file size 11 MBytes) could be downloaded by clicking the menu "Volume model (Male—Sectioned images of heart)" and "Volume model (Male—Segmented images of heart)" on the same homepage. In MRIcroGL, the volume model could be sectioned either orthogonally or obliquely as the users preferred to display the sectional planes on the volume model (Fig. 5) [15].

Table 1 Three orthogonal planes and five oblique planes of the heart volume model

		Number of planes
Orthogonal planes	Horizontal planes	139
	Coronal planes	154
	Sagittal planes	169
Oblique planes	Long axis planes	21
	Short axis planes (aorta side)	21
	Short axis planes (apex side)	21
	Four-chamber planes	21
	Two-chamber planes	21

Intervals of all planes are 1 mm

Discussion

In this study, software for the sectional anatomy of the heart is presented. The software is equipped with a user-friendly interface and realistic features (Fig. 3) and is expected to aid medical students and clinicians who are compelled to learn the interpretation of cardiac CTs and echocardiographs. Detailed procedure to manipulate the software to produce desired sectional planes is described in a previous article [14]. Different users of the software will hopefully progress as follows.

First, after experiencing the real color and high resolution of the sectioned images (Fig. 4), the users will become familiar with the grayscale and low resolution of the cardiac CTs and echocardiographs. Second, after experiencing the automatic annotation of the basic heart structures (Fig. 3) (Table 2), the users will become familiar with the detailed structures in the clinical images. Third, after experiencing the designated planes (Figs. 1, 2) (Table 1), the users will become familiar with the arbitrary planes of echocardiography. In the learning progression, free sectioning of the volume models would be the intermediate stage (Fig. 5). Fourth, after experiencing the still heart of a cadaver, the users will become familiar with the moving heart of a patient during echocardiography. Fifth, after experiencing the personal computer environment, the users will become familiar with the hospital equipment used for the clinical images.

This type of stepwise knowledge acquisition is currently done in medical learning. Another distinct example is cadaver dissection in the laboratory that is followed by patient surgery in the operation room. The serial and compensatory steps are approved to be important [11, 16].

Images of this study can provide a new perspective of heart sectional anatomy even to specialists of the field. Real color and high resolution of the sectioned images enable the observation of small structures (e.g., conduction system) (Fig. 4), which can be a reference for advanced interpretation of cardiac CTs and echocardiographs. Arbitrary planes produced from the volume model (Fig. 5) can be a link between the sectional anatomy of a cadaver and the clinical images of a patient.

The heart's volume models and surface models of the Visible Korean project complement one another. Even if the surface models, reconstructed from the color-filled images, do not show the heart's details, the surface models can be selected and rotated in real time. For combined learning, the PDF file of the heart's surface models made from the Visible Korean female data can be accessed from the same Internet site [26]. There is no remarkable morphological difference between the male data for volume models and the female data for surface models.

The learning effect of the presented software can be reinforced by 3D printed models. The basic heart structures were segmented (Table 2), so that surface models could be reconstructed and printed in three-dimensions [1, 25]. The equivalent 3D printed models, which are to be cut, would be the best complement to the volume models offered in this research (Fig. 5). The 3D printed models and the volume models can become the source of augmented reality to achieve a more realistic learning experience [12].

In addition, the browsing software of this research is suggested for use with the convenient plastic heart model, even if the cadaver heart including plastination specimen would be a better reference. The software can play a bridging role between the 3D plastic heart model and the 2D medical images.

Clay models may be another learning tool to combine with this browsing software. Clay models of the heart were made and sectioned to obtain the orientation of the heart anatomy [19]. During the manual work to match the clay models and digital images, the students would become familiar with the heart morphology.

The users should aware that the images of this study derived from a single male cadaver. Different individuals can result in different position of heart structures in the orthogonal and standard oblique planes. By understanding this limitation, the users should try to realize fundamental heart anatomy from the clinical images of the various patients.

In conclusion, the software to browse the sectional planes of the heart's volume models, as well as the independent volume models that enable free sectioning, are expected to properly orient the many novices who learn cardiac CTs and echocardiographs. The same technique can be applied to the abdomen to simulate ultrasonography of the liver, gallbladder, kidney, and other organs. The learning effect of these attempts need to be verified and affected by further investigations, such as questionnaire surveys of the users.

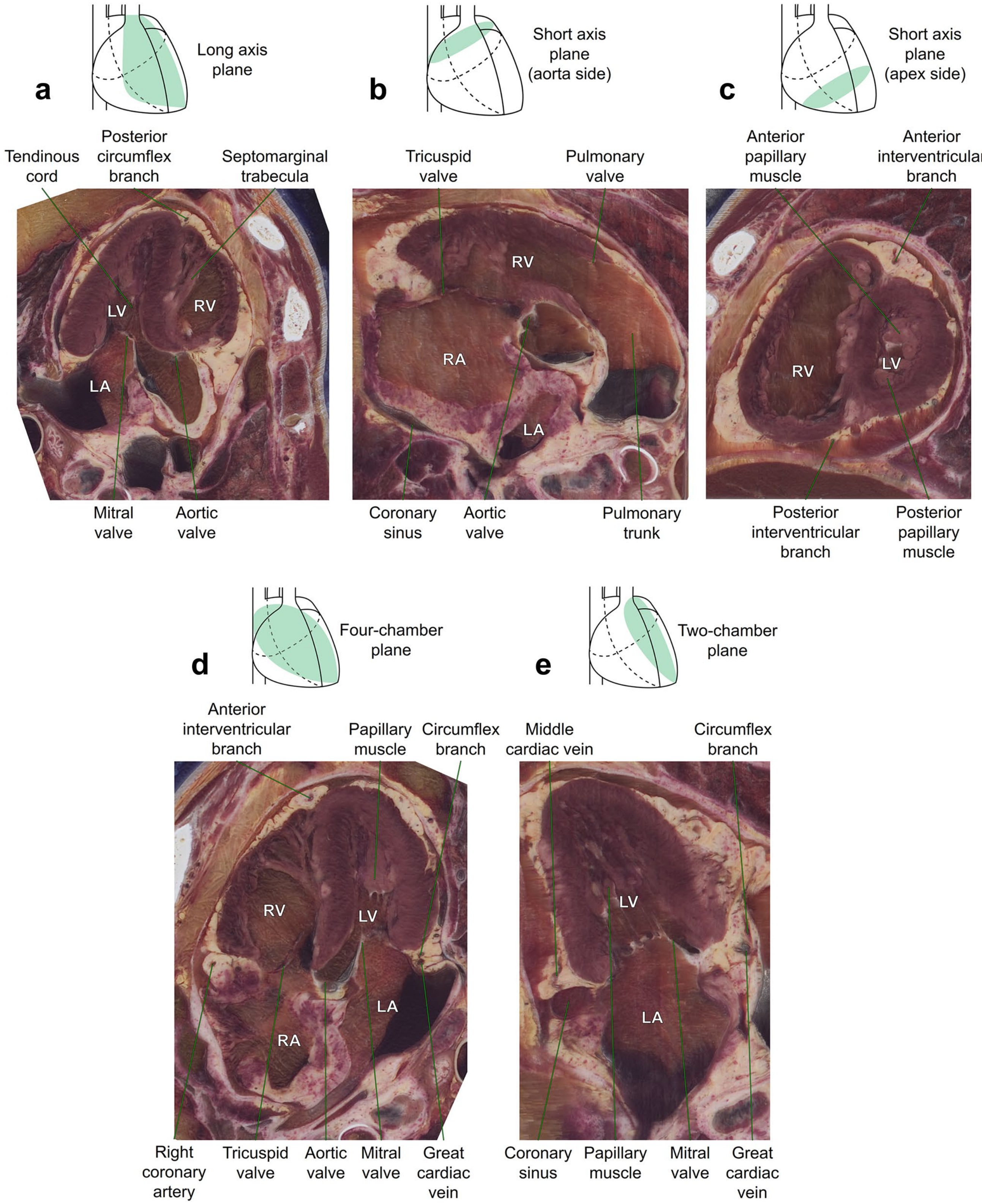

Fig. 2 Standard oblique planes showing heart structures derived from the volume model of the sectioned images. Long axis plane (**a**), short axis plane (aorta side) (**b**), short axis plane (apex side) (**c**), four-chamber plane (**d**), and two-chamber plane (**e**)

Table 2 Structures of the heart and adjacent structures that are segmented

	Number of structures	Structures
Heart	10	Myocardium, pericardial cavity, right ventricle, right atrium, tricuspid valve, pulmonary valve, left ventricle, left atrium, mitral valve, aortic valve
Blood vessels	32	Pulmonary trunk, pulmonary artery, ascending aorta, arch of aorta, brachiocephalic trunk, right coronary artery, sinuatrial nodal branch, posterior interventricular branch, atrioventricular nodal branch, left coronary artery, anterior interventricular branch, circumflex branch, left marginal artery, coronary sinus, great cardiac vein, middle cardiac vein, small cardiac vein, superior pulmonary vein, inferior pulmonary vein, superior vena cava, brachiocephalic vein, inferior vena cava
Bones	13	Sternum, 1st rib, 2nd rib, 3rd rib, 4th rib, 5th rib, 6th rib, 7th rib, 8th rib, 9th rib, 10th rib, 11th rib, 12th rib
Others	9	Skin, pectoralis major, diaphragm, rectus abdominis, trachea, main bronchus, lung, esophagus, liver

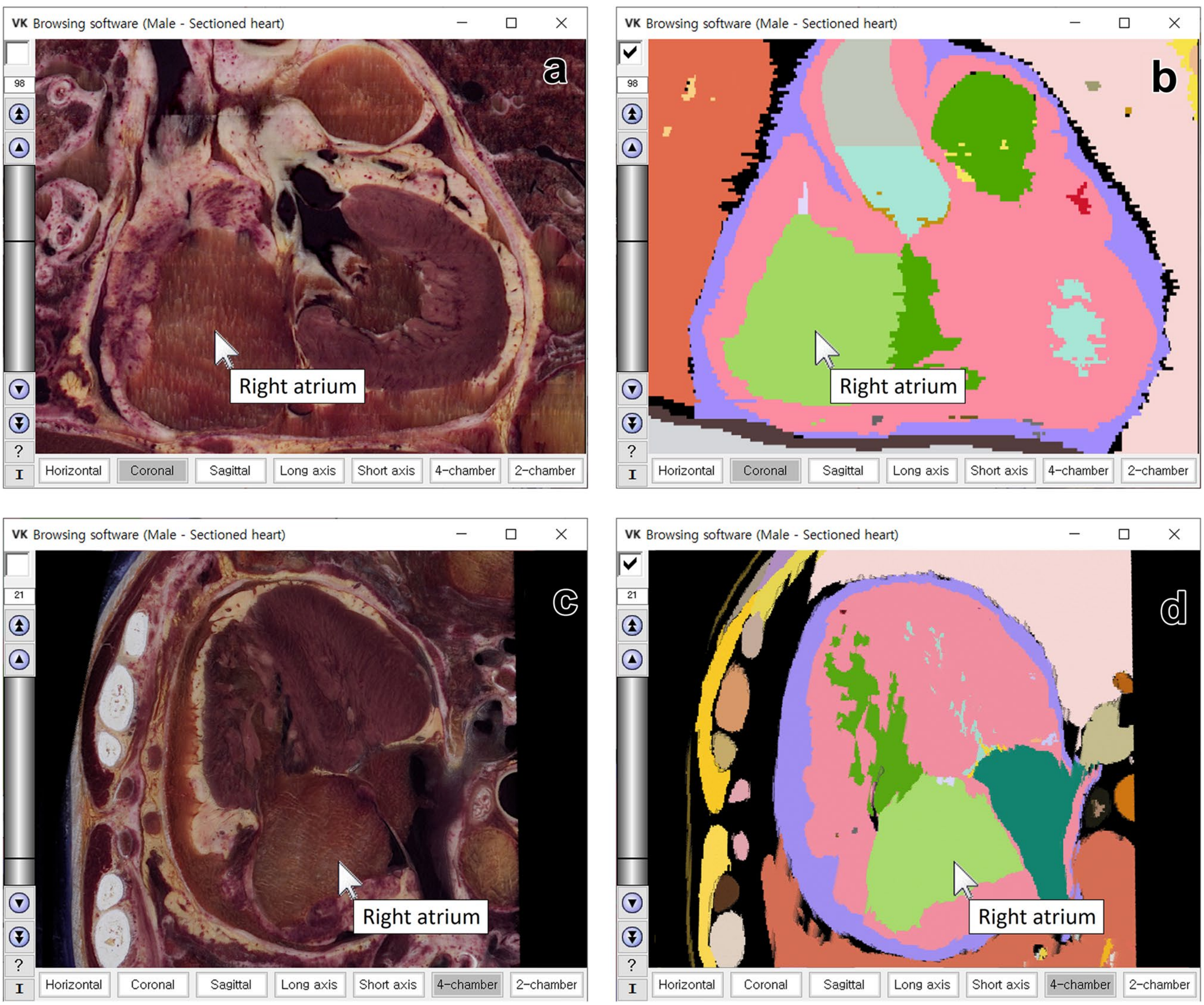

Fig. 3 Browsing software showing the sectional planes. A coronal plane of the sectioned images (**a**) and color-filled images (**b**) and a four-chambered plane of the sectioned images (**c**) and color-filled images (**d**). The name of the segmented structure (right atrium) is shown as a tooltip

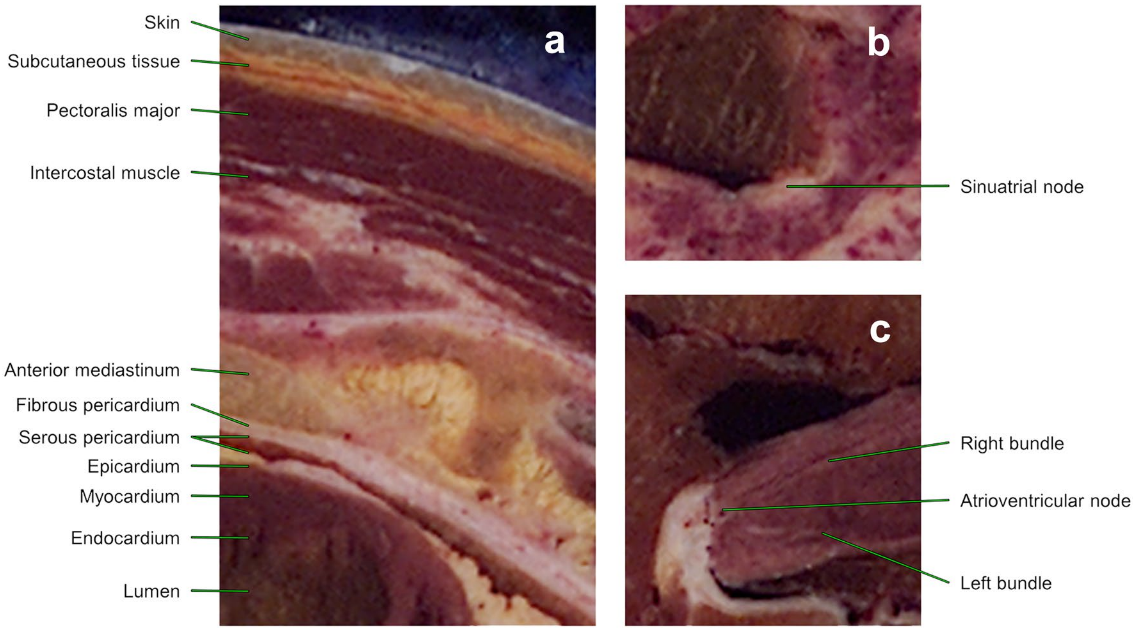

Fig. 4 Sectioned images of heart. Layers from the skin to the lumen of the heart (**a**) and conducting system of the heart (**b**, **c**)

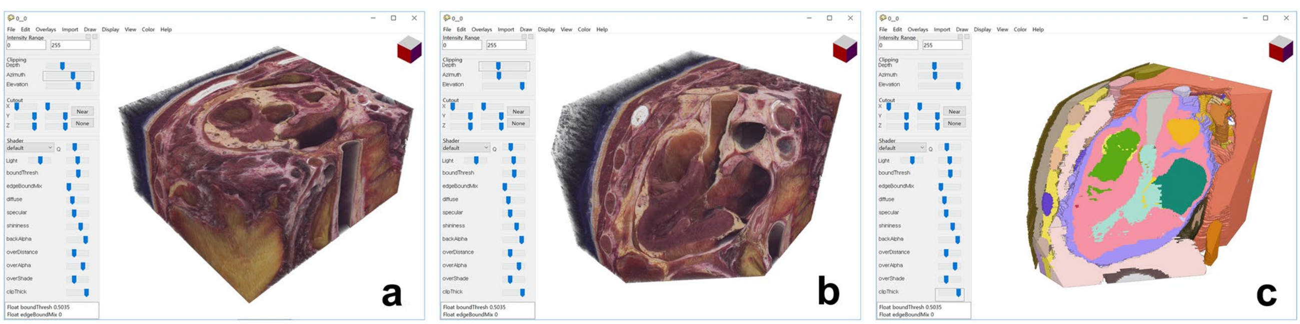

Fig. 5 Manipulation of the volume model of the heart and neighbors on MRIcroGL. The volume model (**a**) is sectioned to display an oblique plane of the sectioned images (**b**). The corresponding oblique plane of the color-filled images is displayed (**c**)

Author contributions BSC data collection, data analysis, manuscript writing and manuscript editing. MSC project development and manuscript writing.

Funding This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2019R1F1A1059842).

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest related to this report.

Ethical approval The whole process for this study was approved by the institutional review board (AJIRB-MED-MDB-18–315). Informed consent to use the cadaver for research and education was acquired from the donor and the families.

References

1. AbouHashem Y, Dayal M, Savanah S, Štrkalj G (2015) The application of 3D printing in anatomy education. Med Educ Online 20:29847
2. Budoff MJ, Shinbane JS (2016) Cardiac CT imaging: diagnosis of cardiovascular disease. Springer, Germany
3. Callahan JA, Seward JB, Tajik AJ (1985) Cardiac tamponade: pericardiocentesis directed by two-dimensional echocardiography. Mayo Clin Proc 60:344–347

4. Chung BS, Chung MS (2018) Homepage to distribute the anatomy learning contents including Visible Korean products comics and books. Anat Cell Biol 51:7–13
5. Chung BS, Chung MS (2019) Four learning tools of the Visible Korean contributing to virtual anatomy. Surg Radiol Anat 41:1211–1216
6. Chung BS, Park JS (2019) Real-color volume models made from real-color sectioned images of Visible Korean. J Korean Med Sci 34:e86
7. Feuchtner GM, Alkadhi H, Karlo C, Sarwar A, Meier A, Dichtl W, Leschka S, Blankstein R, Gruenenfelder J, Stolzmann P, Cury RC (2010) Cardiac CT angiography for the diagnosis of mitral valve prolapse: comparison with echocardiography. Radiol 254:374–383
8. Finn GM, Sawdon M, Griksaitis M (2012) The additive effect of teaching undergraduate cardiac anatomy using cadavers and ultrasound echocardiography. Eur J Anat 16:199–205
9. Gottdiener JS, Bednarz J, Devereux R, Gardin J, Klein A, Manning WJ, Morehead A, Kitzman D, Oh J, Quinones M, Schiller NB (2004) American Society of Echocardiography recommendations for use of echocardiography in clinical trials: a report from the american society of echocardiography's guidelines and standards committee and the task force on echocardiography in clinical trials. J Am Soc Echocardiogr 17:1086–1119
10. Ho SY, Nihoyannopoulos P (2006) Anatomy, echocardiography, and normal right ventricular dimensions. Heart 92:i2–i13
11. Kim SC, Fisher JG, Delman KA (2016) Cadaver-based simulation increases resident confidence initial exposure to fundamental techniques and may augment operative autonomy. J Surg Educ 73:e33–e41
12. Kiourexidou M, Natsis K, Bamidis P (2015) Augmented reality for the study of human heart anatomy. Int J Electr Comm Comput Eng 6:658–663
13. Kondo C, Mori S, Endo M, Kusakabe K, Suzuki N, Hattori A, Kusakabe M (2005) Real-time volumetric imaging of human heart without electrocardiographic gating by 256-detector row computed tomography: initial experience. J Comput Assist Tomogr 29:694–698
14. Kwon K, Chung MS, Park JS, Shin BS, Chung BS (2017) Improved software to browse the serial medical images for learning. J Korean Med Sci 32:1195–1201
15. Li X, Morgan PS, Ashburner J (2016) The first step for neuroimaging data analysis: DICOM to NIfTI conversion. J Neurosci Methods 264:47–56
16. Manning EP, Mishall PL, Weidmann MD (2018) Early and prolonged opportunities to practice suturing increases medical student comfort with suturing during clerkships: suturing during cadaver dissection. Anat Sci Educ 11:605–612
17. Mori S, Anderson RH, Takaya T, Toba T, Ito T, Fujiwara S, Watanabe Y, Nishii T, Kono AK, Hirata KI (2017) The association between wedging of the aorta and cardiac structural anatomy as revealed using multidetector-row computed tomography. J Anat 231:110–120
18. Mori S, Kondo C, Suzuki N (2005) Volumetric cine imaging for cardiovascular circulation using prototype 256-detector row computed tomography scanner (4-dimensional computed tomography): a preliminary study with a porcine model. J Comput Assist Tomogr 29:26–30
19. Oh CS, Kim JY, Choe YH (2009) Learning of cross-sectional anatomy using clay models. Anat Sci Educ 2:156–159
20. Otto CM (2004) Textbook of clinical echocardiography, 3rd edn. WB Saunders, Philadelphia
21. Park HS, Choi DH, Park JS (2015) Improved sectioned images and surface models of the whole female body. Int J Morphol 33:1323–1332
22. Park JS, Chung MS, Hwang SB, Lee YS, Har DH, Park HS (2005) Visible Korean human: improved serially sectioned images of the entire body. IEEE Trans Med Imaging 24:352–360
23. Saremi F, Sánchez-Quintana D, Mori S, Muresian H, Spicer DE, Hassani C, Anderson RH (2017) Fibrous skeleton of the heart: anatomic overview and evaluation of pathologic conditions with CT and MR imaging. Radiographics 37:1330–1351
24. Seward JB, Tajik AJ, Edwards WD, Hagler DJ (2012) Two-dimensional echocardiographic atlas: volume 1 congenital heart disease. Springer, Germany
25. Shin DS, Chung MS, Park JS, Park HS, Lee S, Moon YL, Hang HG (2012) Portable document format file showing the surface models of cadaver whole body. J Korean Med Sci 27:849–856
26. Shin DS, Lee S, Park HS, Lee SB, Chung MS (2015) Segmentation and surface reconstruction of a cadaver heart on Mimics software. Folia Morphol 74:372–377
27. Shin DS, Park JS, Park HS, Hwang SB, Chung MS (2012) Outlining of the detailed structures in sectioned images from Visible Korean. Surg Radiol Anat 34:235–247
28. Yu FF, Lu B, Gao Y, Hou ZH, Schoepf UJ, Spearman JV, Cao HL, Sun ML, Jiang SL (2013) Congenital anomalies of coronary arteries in complex congenital heart disease: diagnosis and analysis with dual-source CT. J Cardiovasc Comput Tomogr 7:383–390