Direct Identification of Patency Achieved by a Bi-Directional Glenn Shunt Procedure — Images by Volume Rendering Using Electron- Beam Computed Tomography —

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The present study aimed to identify the patency achieved by a bi-directional Glenn shunt procedure by shaded volume rendering (VR) images using electron-beam computed tomography (EBCT). A Damus Kay-Stanzel type procedure was performed on a female with hypoplastic left heart syndrome who later received a bi-directional Glenn shunt to increase pulmonary blood flow. In considering the characteristics of the bi-directional Glenn shunt procedure, in which the superior vena cava is connected to the right pulmonary artery, an early phase acquisition protocol with injection of contrast material from the right cubital vein using the step volume scan mode of EBCT was planned to acquire blood flow information. Excellent spatial resolution volume data of the heart and great vessels was obtained from which 3-dimensional images were made. Bi-directional Glenn shunt flow could be observed directly and the complex morphology and relationships between adjacent structures were revealed by 3-dimensional VR imaging. The combination of EBCT and VR can provide useful information to evaluate congenital heart diseases. (*Jpn Circ J* 2001; 65: 457–461)

Key Words: Bi-directional Glenn shunt; Electron-beam computed tomography (EBCT); Patency; Volume rendering (VR)

There is anatomical variety among the complex congenital heart diseases and a variety of shunt procedures are available for each disease, allowing for selection based on factors specific to the patient's condition. At times, however, it is difficult to get good enhanced images using computed tomography (CT). We describe the utility of 3-dimensional (3-D) shaded volume rendering (VR) images using electron-beam CT (EBCT) to acquire blood flow information on the bi-directional Glenn shunt with an early phase acquisition protocol, as well as its ability to reveal complex morphology and the relationships between adjacent structures.

Methods

The patient was a 23-year-old female with hypoplastic left heart syndrome who, when she was a baby, had undergone a Damus Kay-Stanzel type procedure in which the main pulmonary artery (PA) was directly connected to the aortic arch. Later a bi-directional Glenn shunt procedure was performed. Through this procedure, systemic venous blood from the superior vena cava (SVC) filled the right PA with some filling in the left PA. Systemic venous blood from the inferior vena cava (IVC) filled the right ventricle (RV) and, through the main PA, filled the aortic arch, as allowed by the Damus Kay-Stanzel type procedure. By

injecting contrast material from the right cubital vein using an early phase acquisition protocol and completing the acquisition during injection of the contrast material, we attempted to differentiate systemic venous blood from the SVC that filled the right PA from that which flowed from the IVC into the RV through the main PA and then filled the aortic arch.

An EBCT scan (ImatronC-150XP, Imatron, South San Francisco, CA, USA) was performed in the step volume scan (SVS) mode using 3-mm collimation, 2-mm table incrementation, and triggered to 80% of the R-to-R interval. The acquisition range was set at 70 mm and, as a result, a total of 35 slices were required. In the SVS mode with ECG triggering, if the heart rate is less than 120 beats/min, one slice would be acquired for each heart beat. Therefore, the total acquisition time would equal the time required for 35 heart beats. According to the heart rate (60 beats/min) just before the acquisition, the total acquisition time required approximately 35 s. Following intravenous injection of 120 ml of iodinated contrast material (300 mg I/ml) at 2 ml/s, CT scanning was performed with a 15-s delay time with breath holding. The reconstruction was performed with fields of view of 21×21 cm, with the result that the voxel size of the in-plane became 0.41×0.41 mm with a 512×512 matrix. These data were sent to the work station (M-900, Zio, Tokyo, Japan), and 3-D images were reconstructed by maximum intensity projection (MIP) and shaded VR.

Results

Axial source images of enhanced EBCT are shown in Fig 1. The main PA is directly connected to the aortic arch. The SVC and the right PA apparently have a higher attenuation than the ascending aorta, main PA and the aortic arch

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Fig 1. Axial source images of enhanced electron-beam computed tomography. (A) Level of the aortic arch. The main pulmonary artery (PA) was directly connected to the aortic arch. The superior vena cava (SVC) apparently has a higher attenuation than the ascending aorta, main PA and the aortic arch. (B) Level of the connection of the superior vena cava to the right PA with some filling in the left PA as achieved by the bi-directional Glenn shunt procedure. (C) Upper level of the ventricles. High attenuation blood within the right atrium (RA), right ventricle (RV), and the left ventricle (LV) cavity is seen.

Fig 2. Thin slab maximum intensity projection (MIP) images of the heart and great vessels using electron-beam computed tomography. Right superior frontal view (A) and right superior posterior view (B) are shown. Window level and width were set at 350 and 680 HU, respectively. Systemic venous blood filling the right pulmonary artery (PA) from the superior vena cava (SVC) with CT numbers well above those of the great vessels' lumen (including the aorta and excluding the SVC and right PA) and the cavity of the heart filled with contrast material could be distinguished by MIP. The right pulmonary vein and left atrium (LA) with high CT numbers also can be observed. However, it is difficult to elucidate the complex morphology and its relationship to adjacent structures.

(Fig 1A,B). At the upper level of the ventricles, the cavity of the RV, which is larger than that of the left ventricle (LV), with a large right atrium (RA) can be seen (Fig 1C).

Thin slab MIP images of the heart and great vessels using EBCT from the right superior frontal view and right superior posterior view are shown in Fig 2A and B, respectively. Window level and width were set at 350 and 680 HU, respectively. Systemic venous blood filling the right PA from the SVC with CT numbers well above those of the great vessels' lumen (including the aorta and excluding the SVC and the right PA) and the cavity of the heart filled with contrast material could be distinguished by MIP. The right pulmonary vein and the left atrium with high CT numbers also can be observed. However, it is difficult to elucidate the complex morphology and its relationship to adjacent structures.

The shaded VR images that demonstrated a bi-directional Glenn shunt with high attenuation systemic venous blood filling the right PA from the SVC are shown in Figs 3 and 4 (rendered in red). The VR images also showed the

Damus Kay-Stanzel type procedure in which the main PA was directly connected to the aortic arch, not to the ascending aorta. We could represent the lumen filled with contrast material and could distinguish difference, such as the systemic venous blood in the right PA from that in the SVC and the blood in the cavities of the heart, through selection of the appropriate shape of opacity and color curves.

Discussion

In planning surgical procedures or identifying the outcome of surgical procedures for congenital heart disease in which there are complex anatomical anomalies that require sophisticated surgical correction, the creation of 3-D images is a valuable means of non-invasively revealing complex vascular morphology and the relationships between adjacent structures^{1,2}

Other Imaging Modalities

To construct the 3-D images, we must obtain the entire

Fig 3. (A–D) Three-dimensional shaded volume rendering (VR) images of the heart and the great vessels using enhanced electron-beam computed tomography data. Right superior frontal views are shown. The shape of the opacity curves was set to represent the great vessels' lumen and the cavity of the heart filled with contrast material. The shape of the color curves was also set to represent systemic venous blood filling the right pulmonary artery (PA) from the superior vena cava (SVC) as red and the great vessels' lumen (except the SVC and the PA) and the cavities of the heart as white. (A) Right superior frontal view shows the great vessels' lumen including the SVC, aorta, and the cavity of the heart. VR images demonstrate a bi-directional Glenn shunt with high attenuation systemic venous blood (here rendered in red) filling the right PA from the SVC. VR images also demonstrate the results of the Damus Kay-Stanzel type procedure in which the main PA was directly connected to the aortic arch. Systemic venous blood filling the PA from the SVC with CT numbers well above those of the great vessels' lumen (except the SVC and right PA) and the cavity of the heart filled with contrast material could be distinguished by VR. The right coronary artery (RCA) also can be observed. (B–D) Cut-plane VRs show the same views as Fig 3A. The shapes of the opacity and color curves are also the same as in Fig 3A. (B) Cut-plane VR shows a longitudinal image of the SVC (arrow). (C) Cut-plane VR shows a transverse image of the SVC (arrow). (D) Cut-plane VR shows a longitudinal image of the right PA (arrow).

Fig 4. Three-dimensional shaded volume rendering (VR) images of the heart and the great vessels using enhanced electron-beam computed tomography data. Superior posterior views are shown. The shapes of the opacity and color curves are the same as for Fig 3A. (A) The superior posterior view shows the great vessels' lumen including the superior vena cava (SVC), aorta and the cavity of the heart. (B) Cut-plane VR shows a longitudinal image of the SVC (arrow). (C) Cut-plane VR shows a longitudinal image of the SVC, right pulmonary artery (PA). The lumen of the right pulmonary vein (PV) is also rendered in red.

volumetric data of the heart and great vessels and we can use CT, magnetic resonance imaging (MRI) and echocardiography as the non-invasive modalities to acquire the data.

Echocardiography has greater temporal resolution and spatial resolution than either CT or MRI^{3,4} but is incapable of acquiring the entire volumetric data of the heart and

great vessels.

MRI can be performed in patients with iodinated allergy or renal dysfunction, but the poorer spatial resolution than with CT is a disadvantage and there is artifact from stent graft, wire, turbulent flow or rapid blood flow^{5,6}. Also, MRI cannot be performed in patients with claustrophobia or a

cardiac pacemaker.

Generally, there are 2 kinds of CT scanners: continuous rotation CT and EBCT. Because of the heart's motion, excellent temporal resolution is required. A previous study found that to eliminate the motion artifact of the LV, a 200-ms scan speed was needed in diastole and 20 ms was needed in systole,⁷ but the best temporal resolution (minimum full scan speed) with continuous rotation CT is 500 ms.⁸ With regard to EBCT, the scan speed is 50 ms in cine and flow mode, and 100 ms in SVS mode.⁹ Therefore, in the present study, we used EBCT to obtain volume data of the heart and great vessels free of significant motion degradation.

Three-Dimensional Reconstruction Techniques

There are several 3-D reconstruction techniques: multi-planar reconstruction (MPR), curved-planar reconstruction (CPR), MIP, shaded surface rendering (SSR), and VR.¹⁰ MPR and CPR are image reconstruction methods in which arbitrary cross-sectional and curved surface images, respectively, are generated from data yielded by multislicing. Because there is no threshold setting, we can acquire information from the original CT numbers and there are no overlapping redundant objects that have to be cut. However, all target organs are not always on the same cross-sectional images and it is not always possible to depict the target organs on one MPR image. In addition, the actual 3-D structure is distorted on the CPR images.

MIP is useful for demonstrating vascular structures to evaluate the patency of a graft and vessel diameters, but is not a useful technique for visualizing the heart and great vessels because the anatomic complexity results in substantial overlap of structures.

SSR is very useful for demonstrating the 3-D relationship of morphology, but with a single-threshold setting the information on CT numbers pertaining to the vessel lumen will be lost and so differences in objects can not be distinguished by the CT numbers. The multiple-threshold setting in SSR may be more useful in the differentiation of target objects than the single-threshold setting because different colors can be set for different objects.

With VR, differences in objects can be distinguished through selection of the shape of opacity and color curves for the CT numbers.¹¹ For example, by setting adjacent structures as half transparency and setting target organs as full opacity, the target organs can be observed through the adjacent structures and their relationship to the adjacent structures can be understood using information provided by the CT numbers.

Electron-Beam Computed Tomography

EBCT achieves ultrafast scan speeds by sweeping a steered electron beam on a fixed tungsten target ring, thereby providing a moving X-ray source without mechanical motion.¹²

The SVS mode is used to define static anatomical information with matrix sizes of 512×512 with ECG gating during diastole, which minimizes blurring caused by cardiac motion. Using those volumetric data, 3-D images are reconstructed in a work station and the complex vascular morphology and its relationship to adjacent structures can be elucidated. However, differing from the flow mode, if 3-D images of a graft without any stenosis are obtained in the SVS mode, it cannot be concluded that the blood flow was supplied not from a native vessel but from the graft. Nor can the patency of such a graft be identified in this mode.¹³

To achieve the advantages of both the flow mode and SVS mode (ie, acquiring volume data that include information on local blood flow with high in-plane spatial resolution), the 3-D shaded VR image using EBCT is receiving increasing attention as a potential alternative to conventional 3-D images using SSR for assessing heart diseases. With VR, differences in objects can be distinguished through selection of the shape of opacity and color curves for the CT numbers. The SVS mode is used in VR images with ECG gating during diastole. If there is a difference between the CT numbers among the blood vessels, different settings for opacity and color can be selected.

Usually the scan delay time is determined by administering a small test bolus at the determined rate while sequential scans are obtained at the roof of the great vessels every 2 s. In the present patient, however, to make the degree of enhancement of the SVC to the right PA greater than that of the right atrium, the main PA, RV, LV and the aorta, we injected the contrast material from the right cubital vein and set the delay time at 15 s (earlier than the determined scan delay time); the setting was such that before finishing the injection of the contrast material, the CT scanning would be completed. Actually, we succeeded in making a significant difference between the CT numbers in the blood vessel lumen of the right PA (from the SVC) and the entire cavity of the heart. From the viewpoint of anatomy and physiology, in the normal heart it is impossible for the CT numbers in the vessel of the SVC to be similar to those of the right PA, but different from those of the entire cavity of the heart, unless there is a shunt present. Therefore, we could set color differences among these structures and conclude that the blood flow of the right PA was supplied by the SVC and that the bi-directional Glenn shunt had good patency.

Conversely, as the degree of enhancement of the ventricles and main PA was poorer with the early phase acquisition protocol than that determined by the scan delay phase acquisition protocol, the early phase acquisition protocol would make it more difficult to precisely evaluate the state of the ventricles and main PA. Furthermore, in the present patient, there was a lack of information on the lower one-third to one-half of the heart in the CT images. It is usual in a cardiac study to set the acquisition range to cover the whole heart, considering the breath holding time, but in this study, as we wanted to get information on the SVC, we started the acquisition at a higher level than usual. As a result we failed to get CT images on the lower one-third to one-half of the heart.

Conclusion

Considering the characteristics of the bi-directional Glenn shunt procedure, in which the SVC is connected to the right PA, we planned an early phase acquisition protocol with injection of the contrast material from the right cubital vein in the SVS mode of enhanced EBCT. We acquired excellent spatial resolution volume data of the heart and the great vessels and from this we made 3-D images. The bi-directional Glenn shunt flow could be observed directly in the 3-D shaded VR images. Because of the anatomical variety of congenital heart diseases and the many kinds of shunt procedures available for each disease, it would be desirable to plan a specific acquisition protocol utilizing the anatomical and functional characteristics of each, respectively.

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