An Improved Computer Method to Prepare 3D Magnetic Resonance Images of Thoracic Structures

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The mediastinal and cardiovascular anatomy is complex. We have developed a three-dimensional (3D) reconstruction system for the major mediastinal structures using magnetic resonance imaging data on a NeXT workstation. The program uses a combination of automatic and manual procedures to determine the contours of the cardiac structures. The geometric centers of the contours are connected by a 3D space curve, and the central axis of each cardiac structures is determined. The contours are projected on the perpendicular plane to the central axis and semiautomatically processed until the contours of one pixel are obtained. Then the surface rendering with transparency is performed. Compositing combines two images so that both appear in the composite, superimposed on each other. Demonstration of the various mediastinal lines and cardiovascular diseases by the composits of the partly transparent 3D images has promoted a better understanding of the complex mediastinal and cardiovascular anatomy and diseases.

KEY WORDS: MRI, 3D, reconstruction image, mediastinal line, cardiovascular, anomaly

THE MEDIASTINAL and cardiovascular anatomy is complex. To evaluate the anatomy of the heart and great vessels, we have developed a three-dimensional (3D) reconstruction system using magnetic resonance (MR) imaging data.[1-3] The 3D presentation clearly showed the complex anatomy of cardiovascular disease and helped elucidate the misconceptions in the interpretation of plain chest radiographs. Although the system was applied to the heart and great vessels in the previous report, it is also applicable to other anatomical structures.

For beginners in the reading of the plain chest radiographs, it is sometimes difficult to understand the fundamental concepts of the mediastinal lines of the films. The purposes of this study were to refine the modeling technique, to add the half-transparency technique to the 3D reconstruction system, and to apply the 3D image technique not only to the heart and great vessels, but also to the mediastinal structures to understand the overall mediastinal and cardiac anatomy and diseases.

MATERIALS AND METHODS

The operating system of NeXTSTEP (Next Computer, Inc, Redwood City, CA) was chosen as the platform for software development because of its object-oriented user interface. The system hardware was a NeXT workstation and compatible personal computer (PC). The former was NeXT dimension (Next Computer) with a central processing unit (CPU) (model 68040; Motorola, Austin, TX), 64 Mb of random access memory (RAM), an internal 512-Mb hard disk drive and a 17-in video graphics array (VGA) color display. The minimum requirements of the PC-based NeXT system for operating the program included an 486-based or Pentium-based compatible PC, industrial standard architecture or extended industry standard architecture bus, 400 Mb of hard-disk and 24 Mb of RAM. The software was developed using the system's built-in interface builder software and a 3D kit, and the programming language was objective-C.

ECG-gated MR images of multisection, multiphase, and spin echo techniques were used for the reconstruction. The image data were transferred from the scanner to the NeXT system using the Digital Imaging and Communications in Medicine (DICOM) protocol, and further work on the reconstruction was performed.

RESULTS

Technical Improvement of the 3D Modeling

The 3D reconstruction system consisted of 3D modeling and 3D surface rendering, has been described.[1] Figs 1A to E show the process images of the extraction of the contours of multiple components of the mediastinum. In the previous version,

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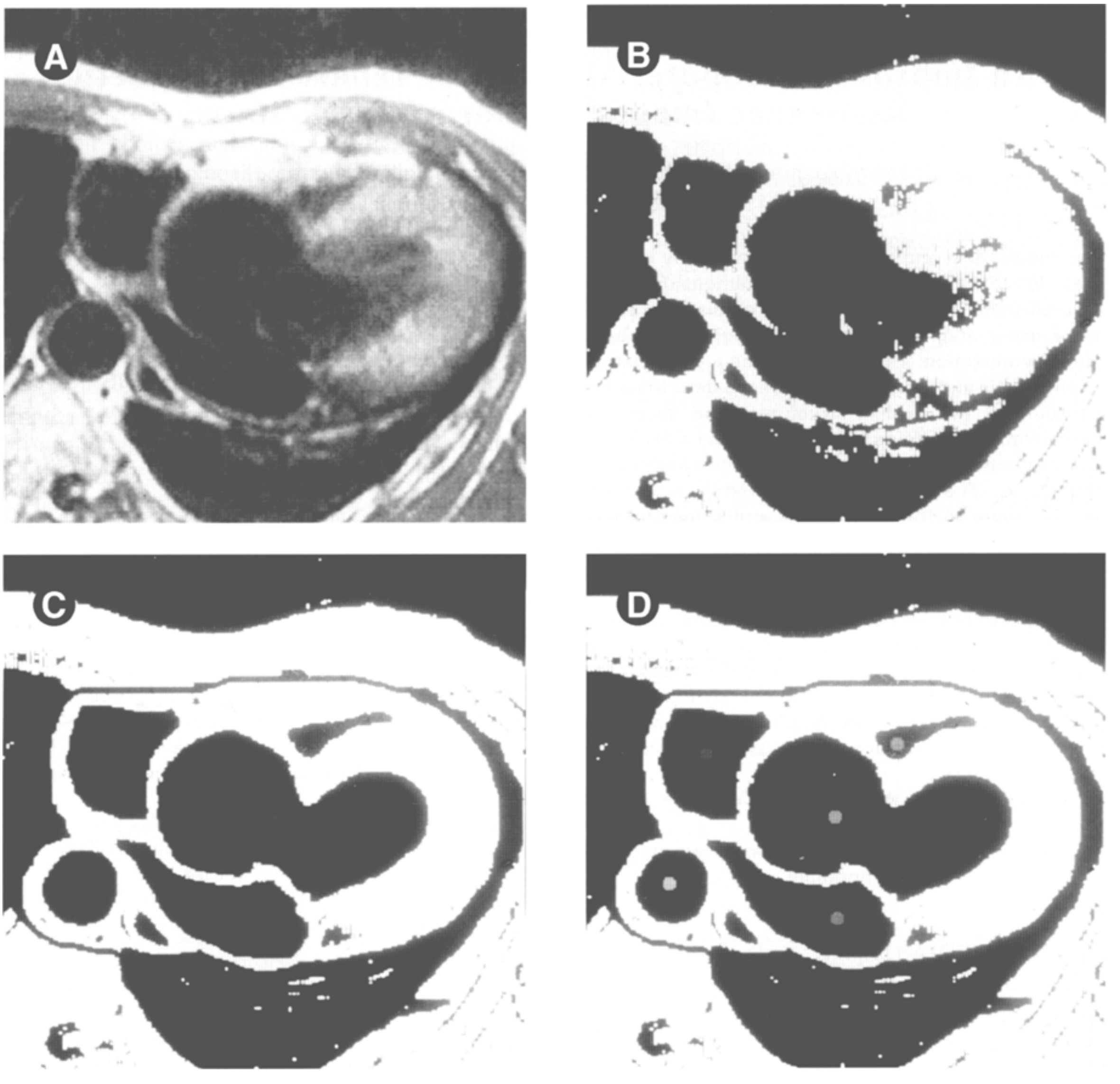
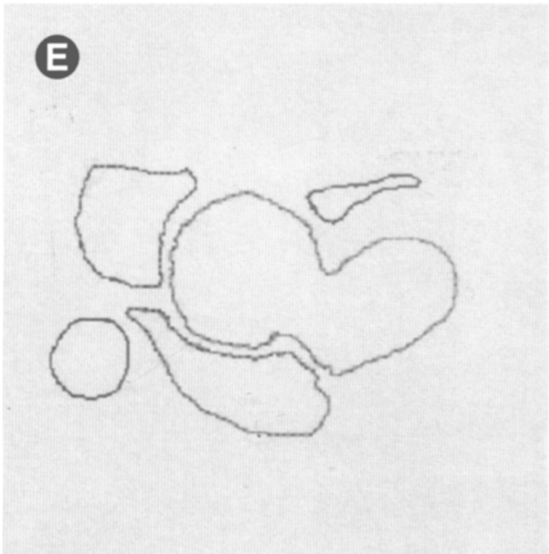
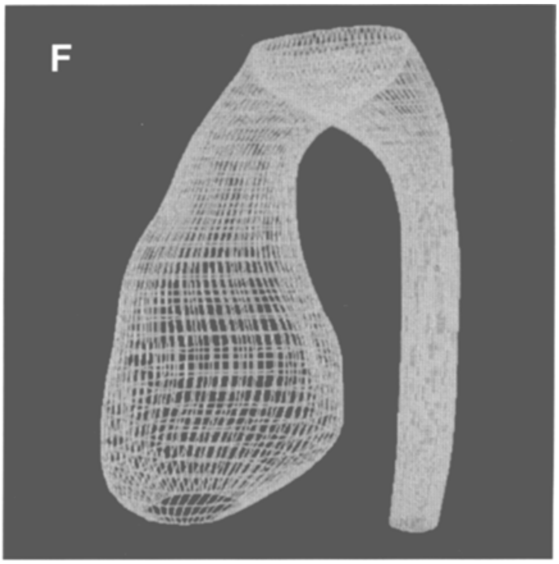


Fig 1. Processed images during 3D modeling of the extraction of the contour (A to E) and the surface-rendered reconstructed image in the previous version (F, G). (A) original trimmed image, (B) thresholding, (C) edited image, (D) starting point, and (E) extracted contour. (F) Wireframe presentation of the ventricle and aorta. (G) Surface rendering of the ventricle and aorta.

the contours of the structures were connected in the manner shown in Fig 1F and Fig 1G. Forming a surface using a trapezoidal patch[4] and rendering done in automatic fashion are not visually acceptable because of the artifact caused by the surfaces of the ascending and descending aorta, which cross over each other.

The technical improvement of the modeling in the reconstruction system is shown in Fig 2. Fig 2A shows the main frame of the program, which circumvents these conditions. The gravities of the contours shown in Fig 2A are connected by the 3D space curve using natural spline function and the central axis of the cardiac structures is obtained (Fig 2B). The contours are projected to the plane that is perpendicular to the central axis and semiautomatically processed until the contours of one pixel are obtained (Fig 2C). Then surface rendering is performed. The two separate structures of the ascending and descending aorta are connected continuously through the aortic arch, and the artifact is illuminated (Figs 2D, 2E).





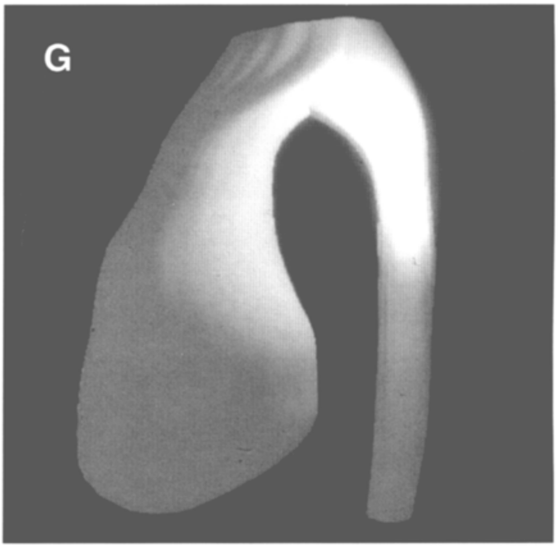


Fig 1. (Cont'd).

Half-transparency for 3D Presentation

Compositing is a NeXT extension of the Display PostScript system that enables separately rendered images to be combined into a final image.[4] It adds two images together so that both appear in the composite, superimposed on each other. Figure 3 shows the program that we developed for applying this technique in the presentation of the mediastinal lines and complicated cardiac anomalies and diseases. The main frame of the compositing program shows the source image of the left ventricle and the aorta in brown on the left side of the frame, the destination image of the right ventricle and the pulmonary artery in blue in the middle of the frame, and the resultant image of the composite of the half-transparent source and destination image on the right side of the frame (Fig 3A). When the source and the destination images are composited, the transparency of one image can let parts of the other show through, as shown in the resultant image.

Compositing defines a number of operations that can achieve different effects when the images are drawn with partial transparency.[5] The composite operations can be selected by clicking the radio buttons in the row of the right part of the main

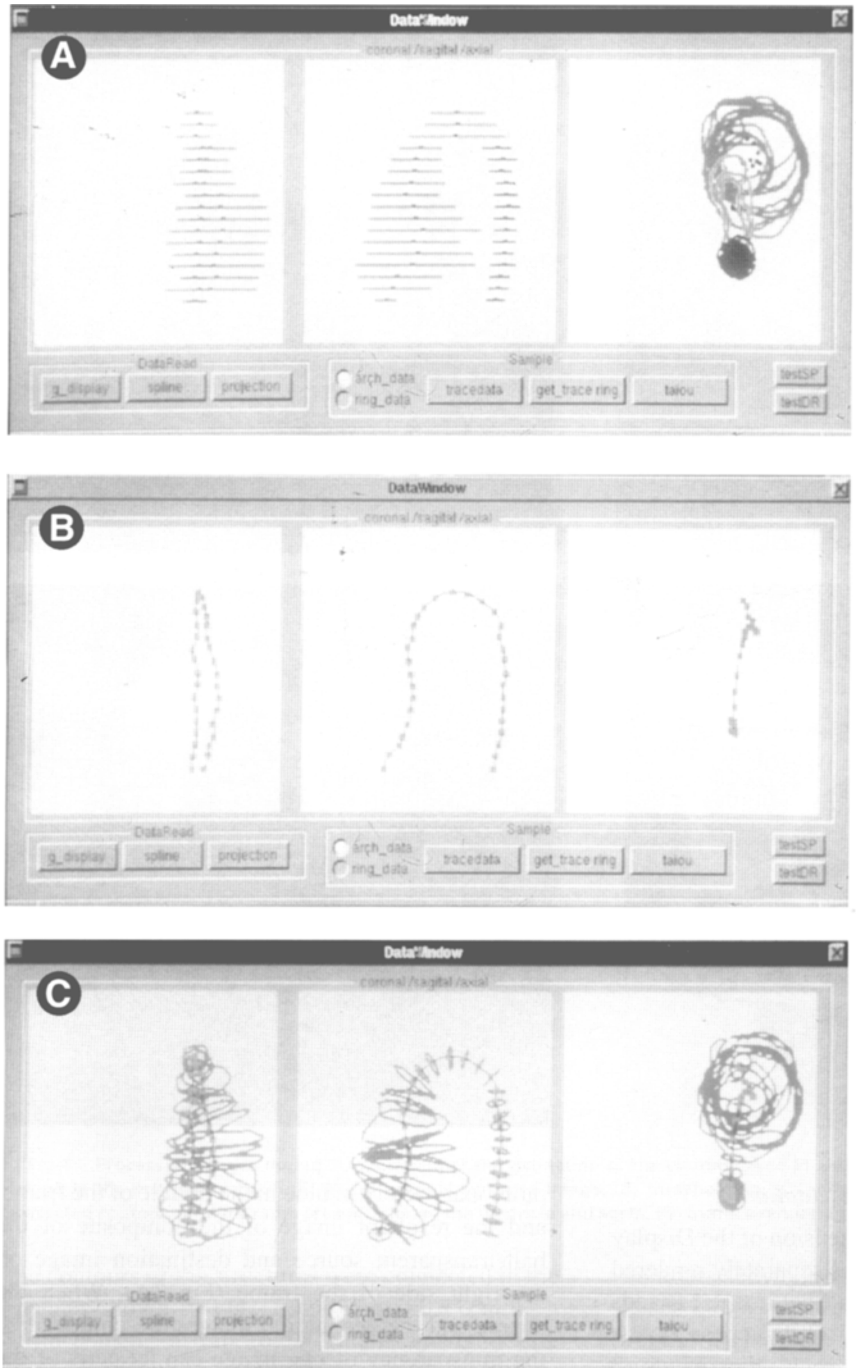


Fig 2. Processed images during the projection of the contours on the perpendicular plane to the central axis. (A) Main frame of the program shows the contours are projected to the coronal, sagital, and axial planes, from left to right. The geometric centers are shown as dots on the contour. (B) The line of the central axis, which is the connection of the geometric centers using the 3D space curve, is shown. (C) Projected contours on the perpendicular plane to the central axis are shown. The geometric centers are shown as dots on the line of the central axis. (D) Wireframe presentation of the ventricle and aorta. (E) Surface rendering of the ventricle and aorta.

frame in Fig 3A. Fig 3B-D show the effects of the different composite operations. The left ventricle and aorta in the source image are accentuated by the composite operation of S-over, which is the source image whenever the source is opaque and the destination image is elsewhere (Fig 3B). The right ventricle and pulmonary artery in the destination image are accentuated by the composite operation of D-over, which is the destination image whenever the destination is opaque and the source image is elsewhere (Fig 3C). Both structures are equally accentuated by the composite operation of

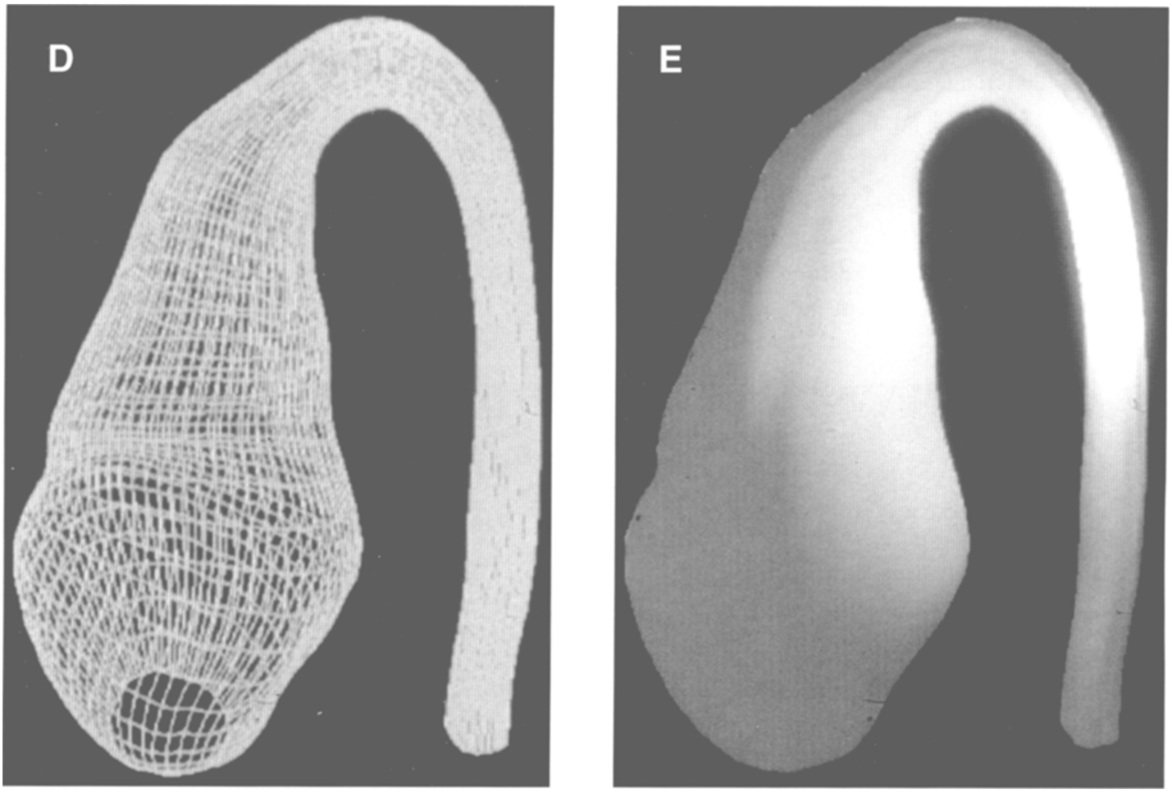


Fig 2. (Cont'd).

Plus-L, which is the sum of source and destination images (Fig 3D).

The degree of transparency of the source and destination images is controlled by the color well in the middle part of the main frame in Fig 3A. The dissolving ratio is another compositing parameter that is controlled by the sliders in the lower part of the main frame. The effect of the parameter of the dissolving ratio is shown in Figs 3E and 3F. The left ventricle and aorta in the source image are more

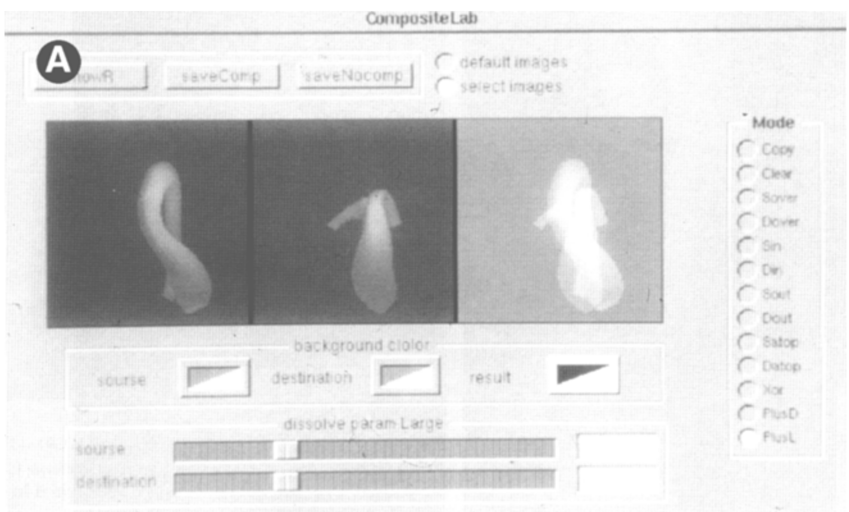


Fig 3. Control of half-transparency. (A) The main frame of the compositing program. (B) Composite operation is S-over. (C) Composite operation is D-over. (D) Composite operation is Plus-L. (E) Composite operation is Plus-L. The dissolving ratio of the source and the destination image is 8:2. (F) Composite operation is Plus-L. The dissolving ratio of the source and the destination image is 2:8.

accentuated in Fig 3E than by S-over in Fig 3B, whereas the right ventricle and pulmonary artery in the destination image is more accentuated in Fig 3F than by D-over in Fig 3C.

Application of 3D Images to Mediastinal Lines and to Cardiac Anomalies

The effect of the composition of the partly transparent image is shown in illustrating the mediastinal lines, and cardiac disease and anomalies.

The most anterior and medial margins of the right lung cast discernible shadows as they contact the mediastinum. Frequently detectable is the anterior junction line, which represents the approximation of the anterior tongues of the right and left lungs (Fig 4A). The composite of the partly transparent image of the mediastinum (Fig 4B) and the lung and mediastinum (Fig 4C) show the pleural

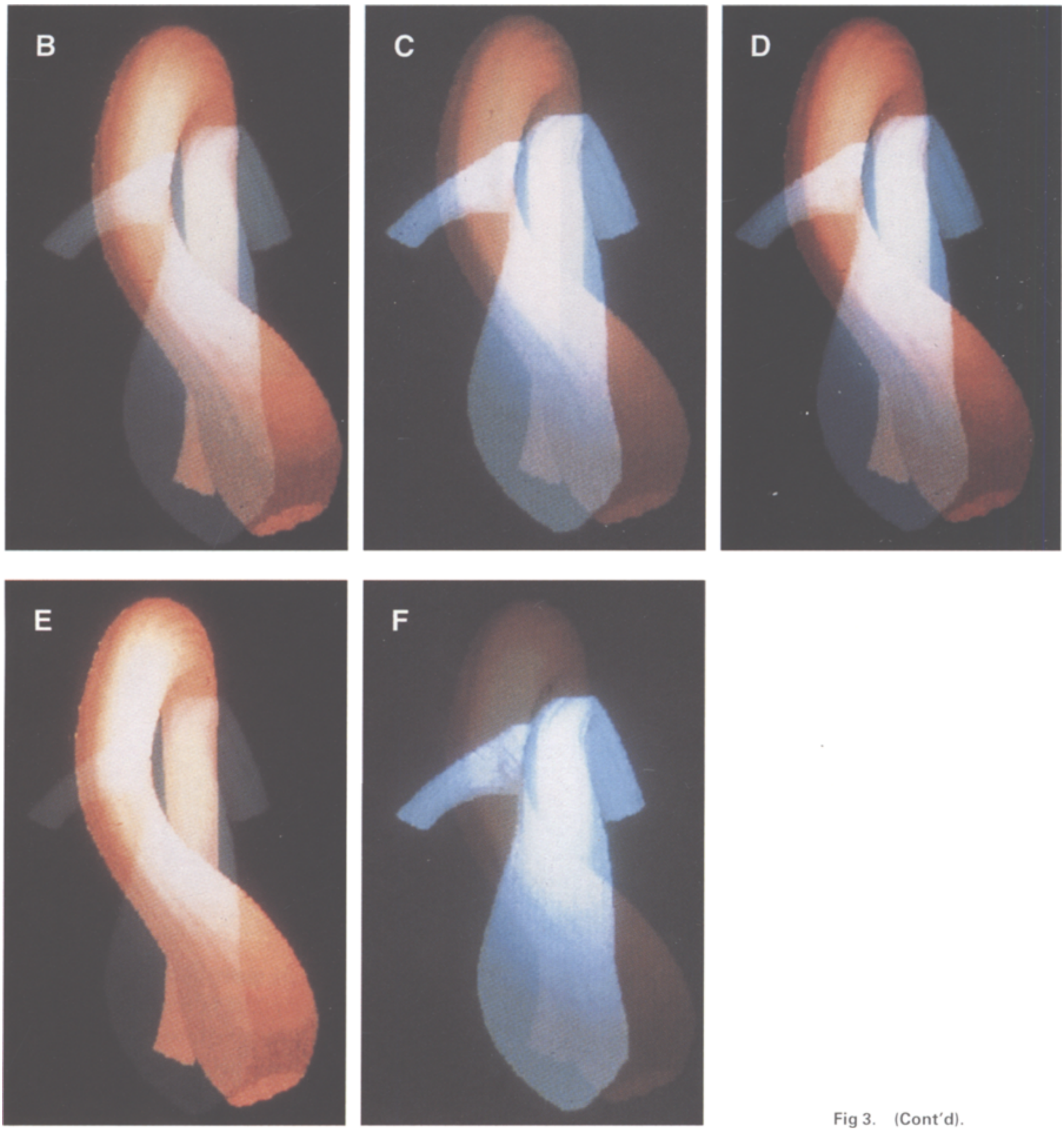


Fig 3. (Cont'd).

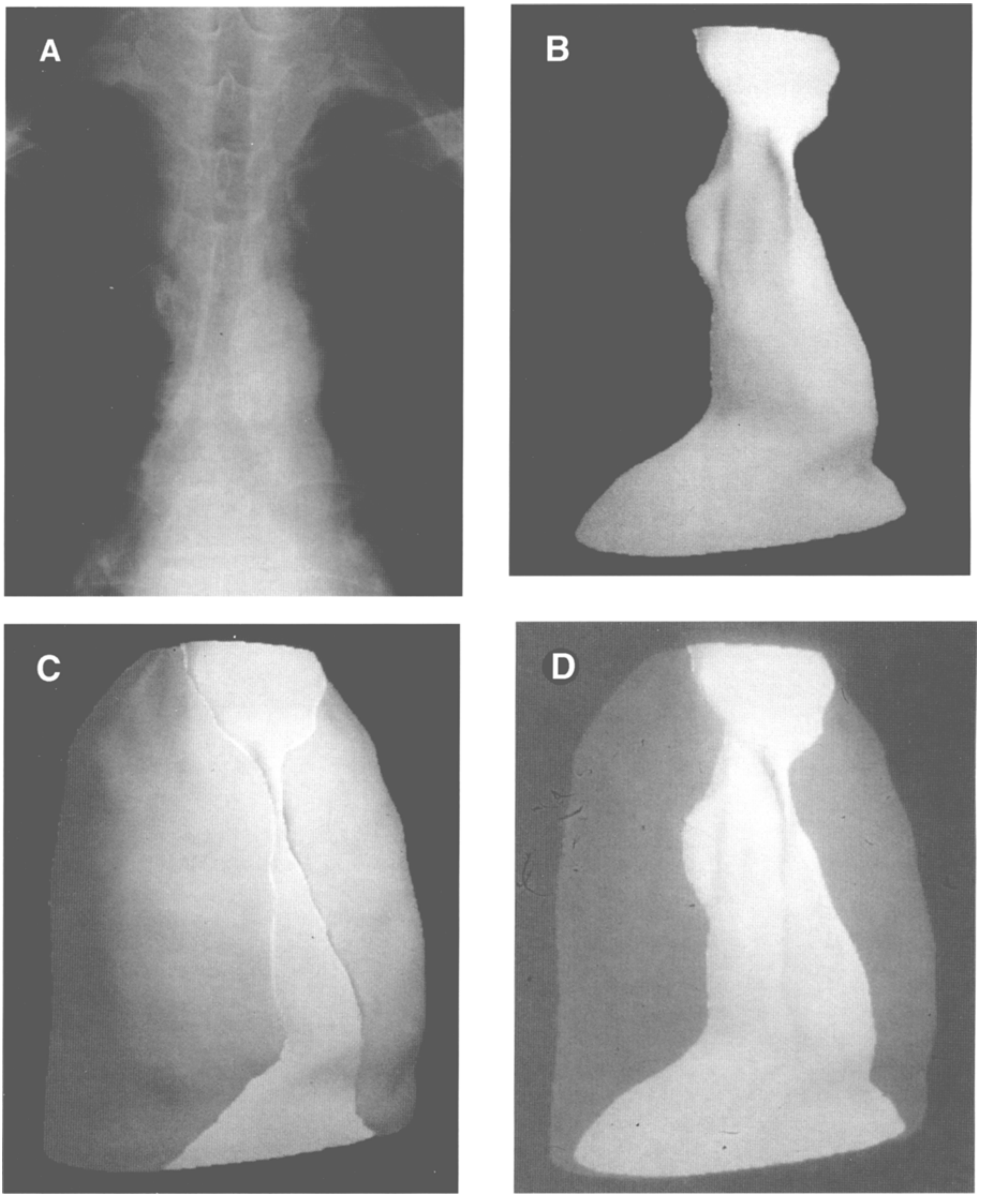


Fig 4. Anterior junction line (AJL). (A) AJL (arrowheads) and the first and second parts of the subclavian artery (arrows) can frequently be visualized on posterior-anterior chest radiographs. (B) 3D image of the mediastinum. (C) 3D image of the lung and mediastinum. (D) Composite image of B and C.

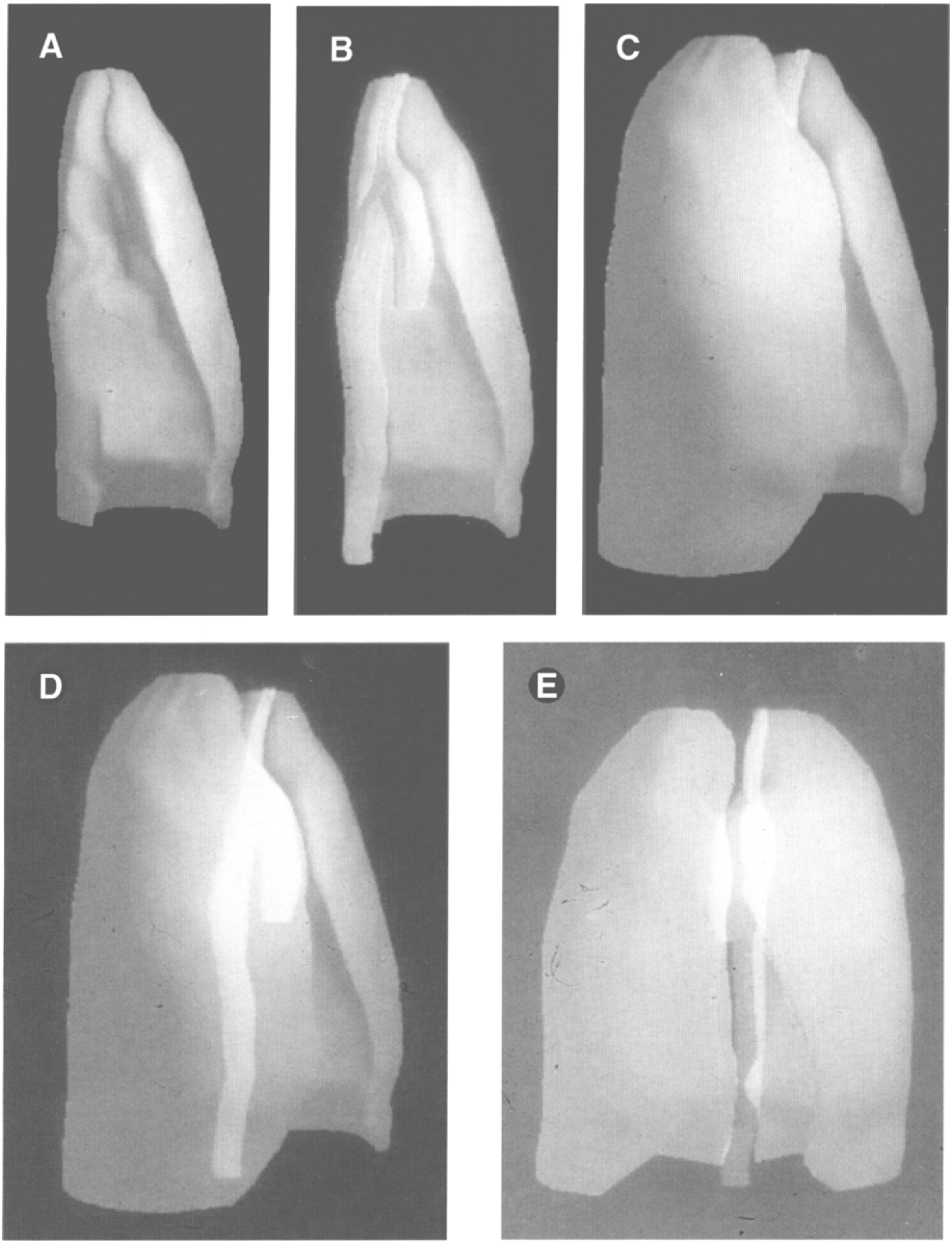


Fig 5. Left subclavian artery. (A) 3D image of the left lung with the groove for the left subclavian artery. (B) 3D image of the left lung with aortic arch and subclavian artery. (C) 3D image of both lungs and vessels. (D) Right anterior oblique view of the composite image of bilateral lungs and vessels. (E) Frontal view of the compositie image of the bilateral lungs and vessels.

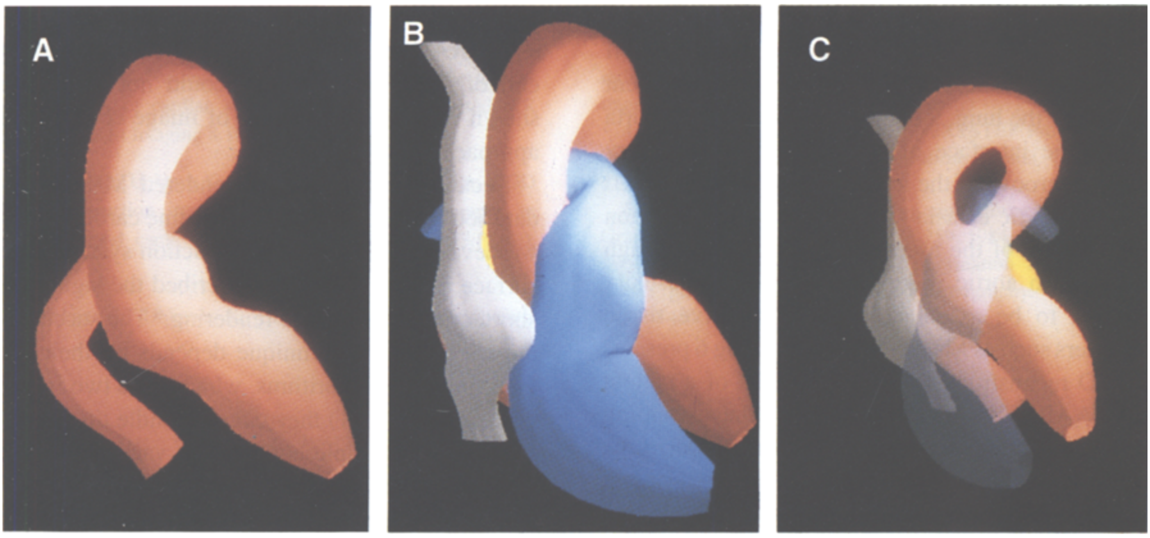


Fig 6. 3D reconstruction of anuloaortic ectasia (AAE) is shown. (A) Frontal view of the left ventricle and aortic arch in brown. (B) Frontal view of all of the cardiac component, the left ventricle, and the aorta in brown, the right ventricle and the pulmonary artery in blue, and the vena cava and the right atrium in white. (C) Left anterior oblique view. Because the right ventricle and pulmonary artery are partly transparent, the dilatation of the ascending aorta of AAE is shown.

reflections, which contact one another in the anterior mediastinum, forming the anterior junction line (Fig 4D).

The left subclavian artery almost invariably projects laterally from the left side of the superior mediastinum to indent the medial aspect of the lung. It thereby casts a distinct shadow because of the radiograph beam striking it tangentially (Fig 4A). The groove for the left subclavian artery is shown in the reconstruction image of the left lung (Fig 5A). The aortic arch and subclavian artery have been added in Fig 5B. The right lung has been

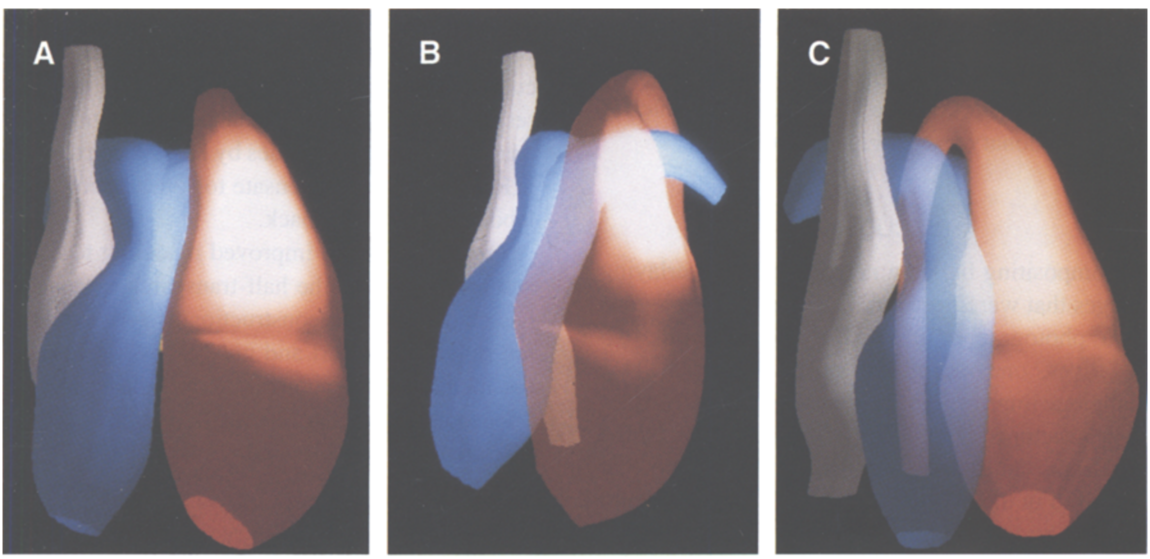


Fig 7. 3D reconstruction of corrected transposition of great arteries is shown. The left atrium is removed. The 3D relationship of the pulmonary artery and ascending aorta is shown by the half-transparent 3D images. The morphologic right ventricle-aorta is shown in brown, and the morphologic left ventricle-main pulmonary artery in blue. (A) Frontal view of the 3D image. (B) Left anterior oblique view of the half transparent 3D image. (C) Right anterior oblique view of the half-transparent 3D image.

added in Fig 5C, in which the cardiovascular silhouette is hidden by the opaque right and left lungs. The composite of the partly transparent images of the lung, left subclavian artery, and aorta shows the interface of the left subclavian artery with the groove of the left lung (Figs 5D and 5E).

Anuloaortic ectasia (AAE) is the most common abnormality of the ascending aorta severe enough to result in aortic regurgitation, and it is usually thought to be associated with connective tissue disorders such as Marfan's syndrome. Fig 6 presents the 3D reconstruction images of MRI of a patient with AAE. The dilated portion of the ascending aorta is confined predominantly to the region of the aortic valve and the proximal ascending aorta (Fig 6A), each of which is situated within the cardiovascular silhouette (Fig 6B). The composits of the partly transparent 3D reconstructed images show the dilated portion of the ascending aorta through the infundibulm of the right ventricle (Fig 6C).

Corrected transposition of the great arteries (TGA) is characterized by transposition of the great vessels and ventricular inversion (Fig 7). Fig 7A is the 3D image of a patient with corrected TGA and shows the morphologic right ventricle-aorta and the morphologic left ventricle-main pulmonary artery connections. The composite of the partly transparent 3D reconstructed images of the right and left oblique views shows the aorta and the pulmonary artery are in a near side-by-side relationship, with the aorta to the left and slightly anterior to the pulmonary artery (Fig 7B and 7C).

DISCUSSION

Compositing builds a new image by overlaying images that were previously drawn. It is analogous to a photographer printing a picture from two negatives, one placed on top of the other. This technique improved the presentation of the overlapping structures more clearly than the combined the wireframe and surface-rendered presentation that was used in the previous system. The composite of the partly transparent 3D reconstructed images shows the mediastinal lines and has promoted a better understanding of what is seen on the conventional radiograph, and it also visualizes the complicated vascular anatomy more clearly by showing the inner structure through the overlapping outer structures. Several of the clinical examples at the end of the Results section could not have been shown well without the use of image compositing approach we used.

Because neither volume-rendered MR nor CT data sets are available for the routine cardiac scans, we developed this 3D reconstruction system using surface rendering. Udupa described the significant shortcomings of surface rendering.[6] The success of the slice-by-slice technique depends on their surface formation algorithms, which have two important drawbacks: (1) they cannot handle the general situation of multiple contours on various slices in an automatic fashion, and (2) even for a given pair of contours, there is no guarantee that the connection of the contour done in an automatic fashion will produce a visually acceptable surface. We used interactive techniques supported by a graphical user interface to solve the above problems. The 3D reconstructed images reveal that even complex structures, such as the aorta or the pulmonary artery with multiple contours in one slice of MR, show visually acceptable surfaces.

Because contouring of anatomic structures on a section-by-section basis by manual or automatic edge tracing is still both time-consuming and labor-intensive, the major potential use of 3D images seems to be educational to facilitate understanding of the anatomy and pathology of cardiovascular disease by medical students and radiology residents. However, the enhanced evaluation of the anatomy and abnormalities by 3D reconstruction of MR image may compensate to some extent for the labor-intensive drawback.

In conclusion, an improved modeling technique and application of the half-transparency technique has made our 3D reconstruction system applicable not only to the heart and great vessels, but also to the mediastinal structures, thereby allowing better understanding of the overall mediastinal and cardiac anatomy and diseases.

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