Oblique-Angle Tomography:
A Restructuring Algorithm for Transaxial Tomographic Data

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A set of contiguous transaxial tomographic sections obtained with a rotating-camera tomograph represents the full three-dimensional distribution of activity within a volume of the body. Tomographic sections in planes other than the original transverse plane can be produced from these data merely by resorting the data appropriately. The paper presents a simple and efficient algorithm for producing tomograms of the heart oriented either at right angles to the long axis of the left ventricle, or parallel to it. Tomograms in these orientations have specific advantages for imaging the heart and avoid some of the limitations seen in comparable tomograms obtained by the seven-pinhole technique.

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A set of contiguous transaxial tomographic sections is, in effect, a three-dimensional image of the body. It is often advantageous to redisplay such three-dimensional data as two-dimensional tomograms in new orientations. This was recognized by Glenn and coworkers, who first developed a technique for reorganizing the data from a series of transaxial computed tomograms into sections oriented in the coronal and sagittal planes (*1*). More recently, the feasibility and utility of reorganizing the data from rotating-camera emission CT studies into coronal and sagittal sections has been demonstrated (*2,3*). Although such techniques extend the value of computed tomography, there are certain situations, such as myocardial imaging, in which the best tomographic sections would be oriented at an angle that is oblique to the cardinal planes. We present here an algorithm for the restructuring of transaxial tomographic data to provide such oblique angle tomograms.

RATIONALE AND METHOD

Let us define a coordinate system in which the Z axis is the long axis of the body, the X axis is parallel to the side-to-side dimension of the body, and the Y axis is parallel to the front-to-back dimension. The Z axis is then the axis of rotation for a rotating camera tomograph, and the resulting tomograms have X-Y coordinates. Figure 1A illustrates the desired section orientation for myocardial tomography, i.e., planes oriented at right angles to the long axis of the left ventricle. Figure 1B shows the orientation of such planes relative to the data set produced by a rotating camera tomograph oriented in the coordinate system just defined. Note that the desired plane of section is oblique to all three major axes.

The orientation of the heart can be defined by two angles. The long axis of the ventricle is rotated to the left (the horizontal angle) and downward (the vertical angle) relative to the major body axes as defined above.

The restructuring problem can be greatly simplified by reducing the apparent horizontal angle of the heart to zero. This can be accomplished at no cost in time during the initial reconstruction process as illustrated in Fig. 2. In Fig. 2A a midventricular transaxial thallium tomogram is shown in standard body CT format. A computer-generated line corresponding to the long axis of the ventricle is shown, and the angle between this line and the Y axis defines the horizontal angle of the heart. If the backprojection starting angle of the transaxial reconstruction program is offset by a "correction angle" equal to this horizontal angle, the effect is to rotate the heart in the resulting reconstructions so that the long axis of the ventricle is apparently oriented parallel to the midsagittal plane of the body, as shown in Fig. 2B. Once this is done, only the vertical angle of the heart must be considered when the oblique sections are reconstructed. The simplification thus effected is illustrated in Fig. 1C. This correction technique also permits the data to be resorted into "sagittal" sections that actually slice the heart parallel to the long axis of the ventricle and tangentially to the septum. As is discussed below, such "rotated sagittal" sections provide an optimal view of the cardiac apex.

The horizontal correction angle is calculated from a single midventricular transaxial section in standard body CT format, using an interactive program that allows the operator to position a line through the long axis of the ventricle, as in Fig. 2A. Once the

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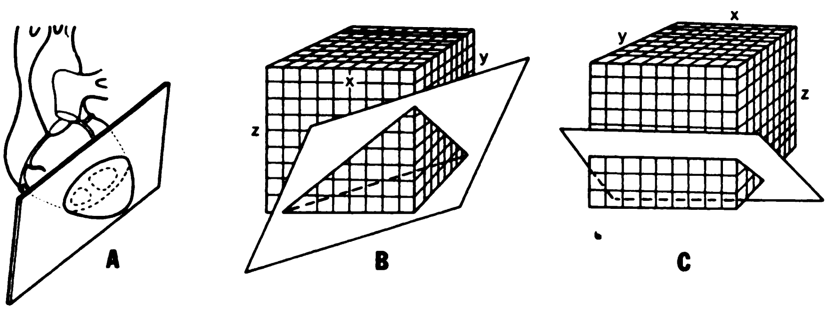

FIG. 1. (A) Schematic representation of optimal tomographic sections in relation to the heart. (B) Orientation of optimum tomographic plane to major axes of standard ECT data set. (C) Orientation of optimum tomographic plane after correction of ECT images for horizontal angle of heart.

correction angle has been determined, a series of contiguous tomograms, one pixel thick, is reconstructed, encompassing the entire volume of the heart. Note that the single-pixel thickness of the slices is important in order to preserve resolution in the Z direction. Once the rotated transaxial tomograms have been reconstructed, a single midventricular "sagittal" plane is produced using standard techniques (*2,3*), and the vertical angle of the heart is determined by a method similar to that used to measure the horizontal angle.

The oblique sections are reconstructed from the transaxial reconstructions by performing a coordinate transformation, with appropriate interpolation where required.

Let x, y, and z be the coordinates after rotation of the transaxial sections to reduce the horizontal angle to zero. Let x′, y′, and z′ be the coordinates in the oblique sections. Then:

$$x = x' \tag{1}$$

$$y = y' \sin \alpha + z' \cos \alpha \tag{2}$$

$$z = y' \cos \alpha + z' \sin \alpha \tag{3}$$

where α is the vertical angle of the heart.

Since these coordinates refer to a discrete matrix of pixels rather than a continuum, the value of each oblique pixel must be interpolated from four surrounding pixels. Note that if the original tomograms were not rotated to eliminate the horizontal angle, the interpolation would involve eight pixels rather than four.

The interpolation is accomplished by fitting the following planar function of two variables to the four surrounding pixels in a least-squares sense:

$$f(y, z) = Ay + Bz + C \tag{4}$$

This fitting is accomplished using the following equations:

$$A = \frac{F(y_0 + 1, z_0 + 1) + F(y_0 + 1, z_0) - F(y_0, z_0) - F(y_0, z_0 + 1)}{2} \tag{5}$$

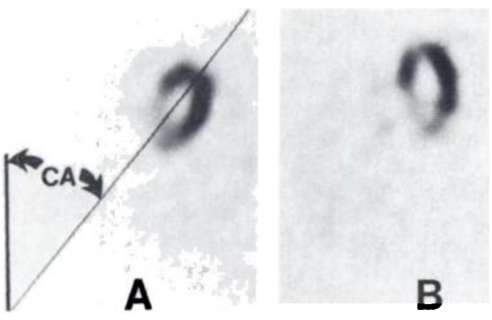

FIG. 2. (A) Transaxial thallium tomogram in standard body ECT format, with computer-generated line defining long axis of ventricle and the horizontal correction angle (CA). (B) Same section reconstructed with offset starting angle to eliminate horizontal angle.

$$B = \frac{F(y_0 + 1, z_0 + 1) + F(y_0, z_0 + 1) - F(y_0, z_0) - F(y_0 + 1, z_0)}{2} \tag{6}$$

$$C = \frac{3F(y_0, z_0) + F(y_0, z_0 + 1) + F(y_0 + 1, z_0) - F(y_0 + 1, z_0 + 1)}{4} \tag{7}$$

where y_0 and z_0 are the truncated values of y and z from Eqs. 2 and 3, and F(a, b) is the value of the pixel at position (a, b) where a and b are integers.

The fractional parts of y and z from Eqs. 2 and 3 are then used in Eq. 4, along with the values of A, B, and C from Eqs. 5, 6, and 7, to obtain the interpolated value of the oblique section pixel.

RESULTS

Table 1 gives the system response functions in three dimensions for a point source imaged in air with a high-resolution collimator. X, Y, and Z are the values for full width at half maximum from the original reconstructions. X′ and Y′ are the in-plane FWHM for a restructured tomogram oriented at 30° to the transaxial plane. The smaller FWHM in the Z direction reflects the fact that the data in this direction have not been convolved with the filter function used during the reconstruction process. The filter used in these reconstructions was a heavily smoothing one of the type used in reconstructing thallium-201 tomograms. A sharper filter would produce values more nearly equal.

Figure 3 shows selected transaxial sections of a thallium-201 myocardial study. The patient had received 2 mCi of Tl-201, and a total of approximately 400,000 counts was acquired from the heart during 22 min of acquisition with an emission tomograph. Although this patient had recently suffered an extensive posterior myocardial infarction, it is not possible to define precisely the location or extent of the perfusion defect from these images. Figure 4 shows the same data restructured into a set of oblique tomograms oriented at right angles to the long axis of the left ventricle. The location and extent of the defect are now readily apparent.

We have studied 70 patients to date with this technique and have been able to obtain oblique-angle tomograms with quality com-

TABLE 1. REPRESENTATIVE FWHM VALUES FOR THE SYSTEM RESPONSE FUNCTION OF THE TOMOGRAPH OBTAINED IN AIR

	X	Y	Z	X′	Y′
FWHM (mm)	25.5	25.5	14.2	24.1	21.2

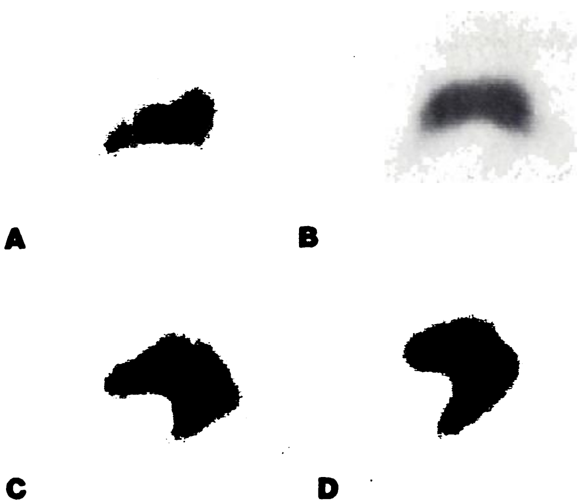

FIG. 3. Transaxial tomograms of Tl-201 distribution in patient who has recently suffered a large, posterior myocardial infarction. Sections are approximately 12 mm thick and are presented in standard ECT format. Sections are contiguous from below upwards.

parable in all to that of the study illustrated. In the implementation of this algorithm in our laboratory, both the rotated sagittal and oblique tomograms are produced by a single program. Using a computer system with 32K of memory, floating-point processor, and hardware multiply/divide functions, this program will produce 29 rotated sagittal and 34 oblique-angle tomograms in 5 min. These are representative figures for a typical thallium study.

DISCUSSION

The practical advantages of oblique-angle tomography stem from its ability to present structure in a more readily perceived form. Although the restructured tomograms represent the *same* data as the original transaxial tomograms, they allow the observer to perceive the structure of the heart better. For example, in Fig. 3 the infarct is located on the inferior surface of the heart, which is cut tangentially in this presentation. Consequently, in some slices there is no viable myocardium on either side of the infarct to outline the extent of the defect. In the oblique tomograms the entire circumference of the ventricle is seen in every section, and thus there is always a clear margin between viable and infarcted myocardium. In the same fashion, the rotated sagittal tomograms permit better delineation of apical defects, which are difficult to appreciate in the oblique sections. In practice, both sets of restructured tomograms are required to present myocardial anatomy fully.

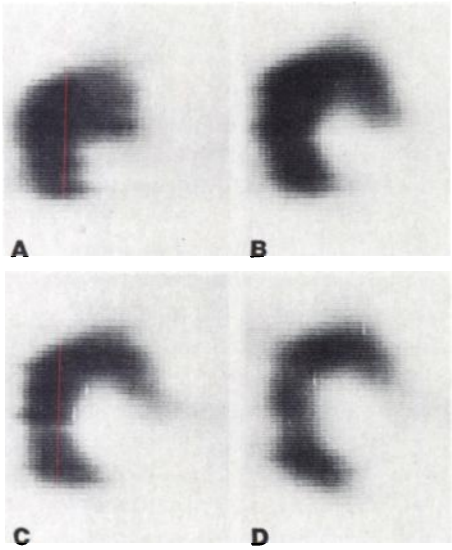

FIG. 4. Oblique tomograms of patient in Fig. 3. Sections are also 12 mm thick but are oriented at right angles to long axis of left ventricle and appear as if viewed from apex of heart, in same orientation as seven-pinhole tomograms. Sections are contiguous from near apex (A) toward the base (D).

The oblique tomograms produced by this technique have certain advantages over the comparable tomograms produced by the seven-pinhole and coded-aperture techniques (*4*,*5*). All of the tomograms have equal thickness, i.e., the tomographic effect is equal at all depths. The x-y resolution is constant in all sections, and so are the relative size relationships. Finally, there is virtually no cross-talk between planes, so there is no ambiguity as to the locations of the apex and valve planes. We believe that these advantages should eliminate some of the problems in image quantification that have been seen in seven-pinhole tomograms (*6*).

The restructuring algorithm presented here is quite simple and efficient. The ploy of correcting for the horizontal angle of the heart during the initial transaxial reconstruction is in large part responsible for this efficiency, since it reduces the computational problem significantly at no cost in computing time. We believe this technique should prove useful in any laboratory studying the heart with ECT techniques.

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