Effect of Variable Left Ventricular Vertical Orientation on Planar Myocardial Perfusion Images

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Differences in vertical orientation of the left ventricle within the chest cavity cannot be corrected by gamma camera positioning. The effect of variations in vertical angulation on the appearance of the diagnostically important left anterior oblique (LAO) view has not been previously evaluated. In the current study, a computer simulation of a normal left ventricle was created and "imaged," varying only the degree of vertical rotation. The effect of six vertical positions on the LAO image was assessed visually and with horizontal and circumferential profile analysis. Results indicate a homogenous distribution of counts in the horizontal views. With increasing verticality, there are fewer counts in the valve plane, while the inferoapex initially increases in count density, and then progressively decreases. Quantification revealed count variations of up to 37% in the valve plane and 45% in the inferoapex due entirely to differences in vertical orientation of the left ventricular simulation. A survey of 167 patients who underwent routine stress thallium imaging showed a vertical angulation that varied from 7° to 64° (mean = 37°) as determined from the anterior view. Clinical images were similar in appearance to computer generated images after correction for anterior view foreshortening. The present study suggests that the accuracy of current quantitative thallium methods to detect coronary artery disease might be enhanced by the use of a revised set of normal standards corrected for vertical orientation of the left ventricle.

J Nucl Med 27:694–700, 1986

Myocardial perfusion imaging with thallium-201 has been widely used as a diagnostic test for obstructive coronary artery disease. Subjective readings by one or more experienced physicians has been the standard method of test interpretation for this radionuclide technique (*1,2*). More recently, quantitative analysis of thallium images has offered a more objective alternative to visual assessment of images, but evidence for enhanced sensitivity and specificity of quantification to detect coronary disease has been variable (*3–7*). A potential pitfall in the development of quantitative methodology using standardized normal limits is the variability of left ventricular position within the chest cavity. This variability may manifest itself as a difference in rotation along either the horizontal or vertical axis. The left anterior oblique (LAO) position is of primary importance because it allows for separation of the coronary vascular beds, and serves as a main view for the various quantitative methods (*8–10*). Variation in the horizontal plane in this view can be easily corrected by rotating the camera to obtain a "best septal" LAO view (*11*), regardless of the degree of obliquity required. Vertical orientation variability cannot be fully corrected, however, and its impact on interpretation of planar thallium images has not been previously investigated.

The purpose of the present study was to evaluate the effect of differences in degree of left ventricular verticality on the appearance and quantification of planar thallium images. To do this, a computer simulation of planar myocardial perfusion images was created producing anterior and LAO views with varying degrees of left ventricular long axis tilt. Standard quantitative techniques were then applied to the LAO view.

In addition, in order to estimate the potential clinical impact of vertical orientation variability on test results, the range of verticality in the population was assessed in a group of consecutive patients undergoing routine myocardial perfusion imaging.

Received May 31, 1985; revision accepted Dec. 13, 1985.

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MATERIALS AND METHODS

Computer Simulation

The computer model for the present study was developed using a microprocessor* fitted with a Winchester hard disk and array processor. Programs were written in BASIC, and data stored on flexible disks. The left ventricular myocardium was simulated by a parabolloid shell changing in size during the various stages of the cardiac cycle. The model was constructed based on the dimensions of a normal heart with an ejection fraction (EF) of 55% and a heart rate (HR) of 80 bpm. Data derived from the literature (*7*) were used to determine wall thickness and ventricular cavity changes at end-systole and end-diastole (*12*). The timing and duration of wall thickness and cavity size alterations throughout the simulated cardiac cycle were determined by extrapolation from the volumetric changes occurring in a representative normal gated blood-pool time-activity curve obtained at a similar heart rate. Total myocardial mass was held constant throughout the cardiac cycle. The computer-simulated myocardial perfusion image was created in paired anterior and LAO views at seven different angles from the horizon: 0°, 5°, 15°, 25°, 35°, 45°, and 55° (Fig. 1). These angles were chosen based on the results of the clinical survey (described in "clinical study"). The mathematic representation of the thallium myocardial distribution was convolved with a set of experimentally obtained point spread functions to account for attenuation, scatter, and camera spatial resolution. This was performed in a manner similar to the previously described method of Vos et al. (*13*).

The seven computer generated LAO images were analyzed using two previously described methods of quantification. One method† employs four profiles placed at equal intervals horizontally through the left ventricle similar to the method of Watson et al. (*9*). The second method uses circumferential analysis of multiple radians emanating from a central point within the ventricle, the results expressed as a 0° to 360° graphic representation of counts similar to the methods of Meade et al. and Burow et al. (*4,10,14*). The program‡ assigns 0° to the 3 o'clock position and proceeds counter-clockwise, so the valve plane appears at ~90° and the inferopex at 270°.

Patient Study

The survey of patients was performed to determine the distribution of vertical angles encountered in our patient population. The results were used to guide the choice of planar thallium projections subsequently produced by the computer simulation after correction for foreshortening in the anterior view.

One hundred and seventy-five consecutive patients were retrospectively identified who underwent routine, clinically indicated exercise myocardial perfusion imaging between January 13 and October 2, 1984, and who had test data recorded on flexible disks. Postexercise and delayed rest images were acquired in the anterior, 45° (or best septal) LAO, and left lateral views. Eight patients were excluded from the group because of large myocardial perfusion defects interfering with the determination of the long axis of the left ventricle in the anterior view. All patients were referred for stress myocardial perfusion imaging for clinical indications (e.g., suspected or known coronary artery disease) unrelated to the present study. The postexercise image was chosen because of the more favorable target to background count ratio.

The left ventricular long axis was determined by drawing a line from the middle of the valve plane through the apex of the left ventricle in the postexercise anterior myocardial perfusion image. The junction formed by the long axis of the left ventricle and a horizontal line was called the vertical angle and measured in degrees for each of the patients (Fig. 2).

In the anterior view, the long axis of the left ventricle forms an angle of ~45° with a line perpendicular to the face of the detector. Thus, the vertical angle as measured by the current method was expected to overestimate the true vertical angle because of foreshortening in the anterior view. Therefore, the simulated angles of 0°, 5°, 15°, 25°, 35°, 45°, and 55° generated within the computer model are perceived in anterior view patient studies as 0°, 7°, 21°, 33°, 44°, 55°, and 64°, respectively (see Appendix). This correction factor was used when com-

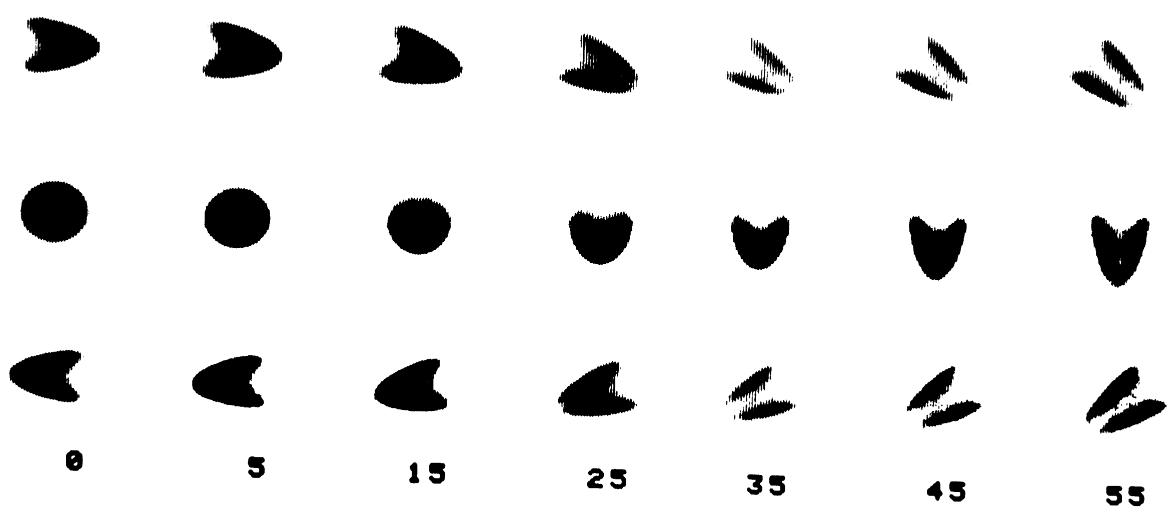

FIGURE 1
Anterior (above), LAO (middle, and lateral (below)) computer simulations of ^{201}Tl myocardial perfusion images tilted to seven different vertical angles from horizon

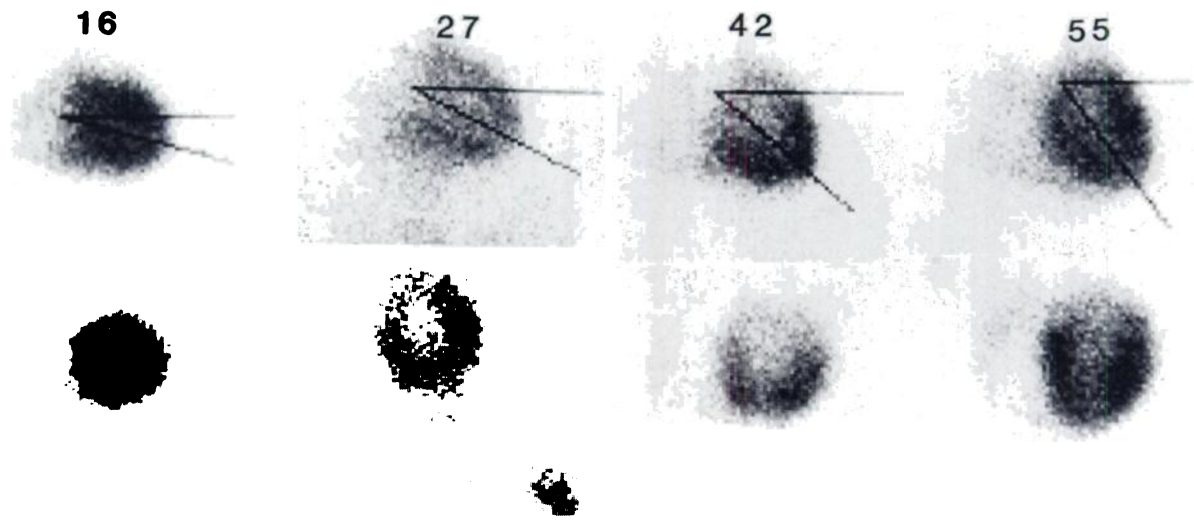

FIGURE 2
Examples of normal patient studies demonstrating measured (uncorrected) vertical angle in anterior (above) and LAO views

paring images from the computer simulation with those of the patient studies.

RESULTS

Quantitative Analysis

Quantification of the computer simulated LAO views was performed using the two previously described methods. For the first method, differences in each profile for the seven images are shown in Fig. 3. Circumferential analysis differences are shown in Fig. 4. Both techniques reveal the homogenous distribution of counts in the most horizontal of the LAO views. The more vertical left ventricular images reveal a more asymmetric distribution of counts, with fewer counts in the upper valve plane and lower interoapical regions. The region corresponding to the valve plane (first line of the profile method, Fig. 3, and ~90° for the circumferential analysis, Fig.

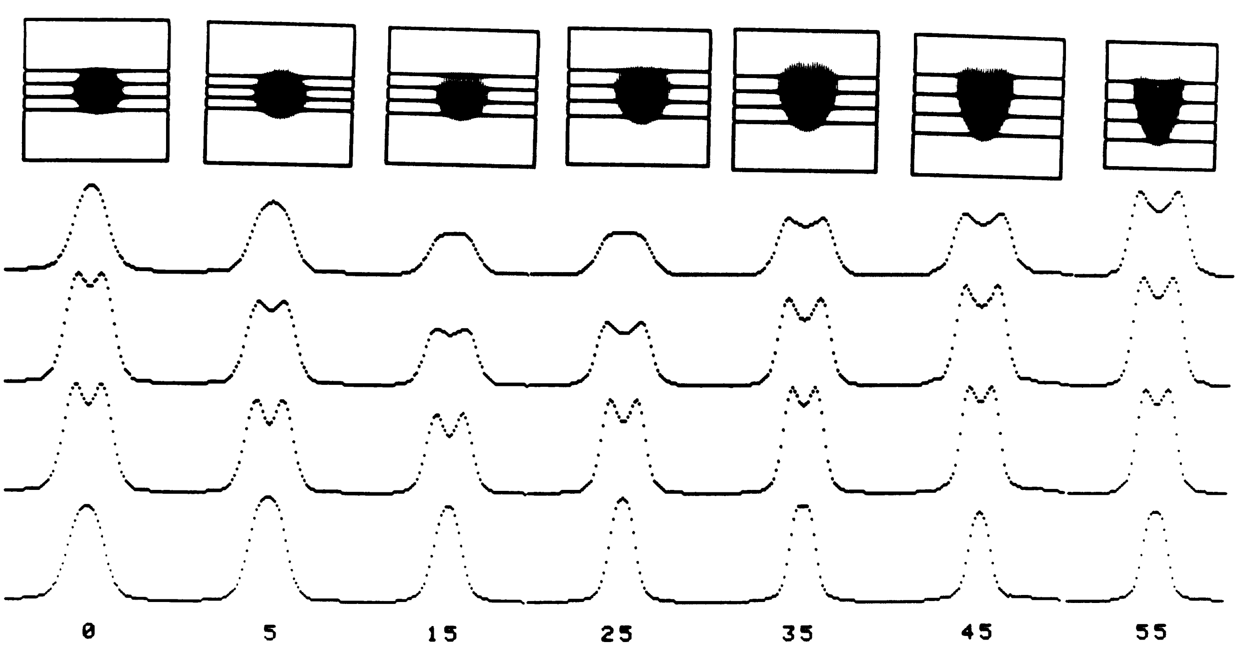

FIGURE 3
Horizontal profile analysis for the seven images seen in Fig. 1. Horizontal lines through images above correspond to profiles below each image

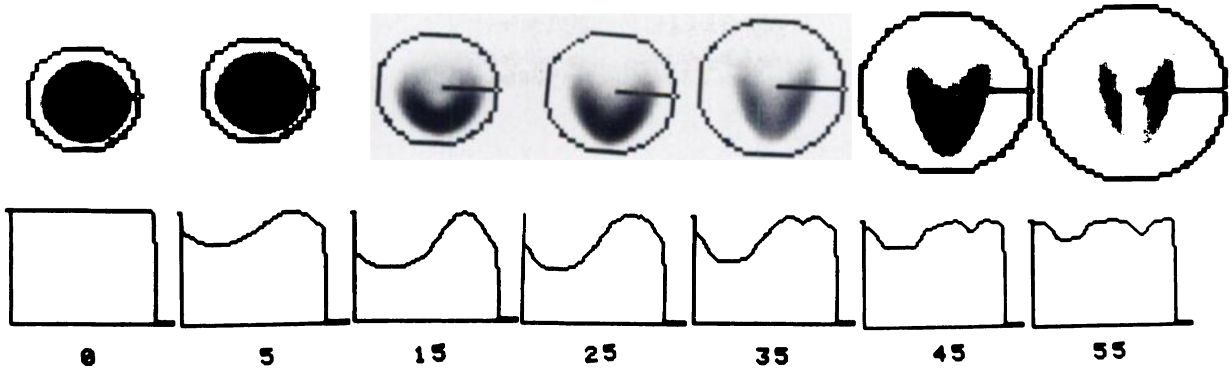

FIGURE 4
Circumferential profile analysis of computer model at the seven angles displayed in Fig. 1. Specific profile for each image is shown below

4), progressively loses counts with increasing vertical angulation. Interestingly, the inferoapical region (bottom line, Fig. 3 and 270°, Fig. 4) progressively increases in count density at 5°, 15°, and 25°, but then decreases at 35°, 45°, and 55°. Superimposition of the circumferential profiles on the same absolute scale (Fig. 5), graphically demonstrates the regional variation in counts observed with increasing angulation. Maximal differences of 37% in absolute counts in the valve plane and 45% in the inferoapex were demonstrated. On a relative scale, maximal count differences ranged from 0% for all segments in a perfectly horizontal heart, to 52% at 25° for the valve plane, and 19% at 55% for the inferoapex (maximal counts normalized to 100% for each profile).

Subjective Assessment

The progression from horizontal to vertical configuration of the left ventricle in the computer model produced a striking change in appearance of the simulated left anterior oblique views. A homogenous ring of thallium was apparent in the horizontal heart. With increasing vertical angulation, the valve plane became progressively more apparent. Interestingly, the inferoapex initially became hotter with increased angulation, producing an appearance of increased uptake in the region of the papillary muscles. This was due entirely to overlap of simulated myocardial segments, since no attempt was made to program papillary muscles into the present computer model.

With further increases in angulation, the inferoapex progressively decreased in counts and the apical cleft became more apparent as the image appeared similar to a long axis view. The images obtained closely resembled the patient studies, matching the images after correction for foreshortening (Figs. 1 and 2).

Patient Study

Results of the vertical angle determination for the 167 consecutive patients are shown in Fig. 6. The distribution closely resembles a normal Gaussian distribution. The mean (uncorrected) vertical angle for the group was 37.3° ± 12.1 (s.d.), with a range of 7° to 64°. Thus, 95% of patients (mean ± 2 s.d.) are expected to fall within the range of 13° to 62°, (equivalent to 9° and 54° of the model, respectively) yet the simulation suggests a wide disparity of quantitative results within this normally encountered range.

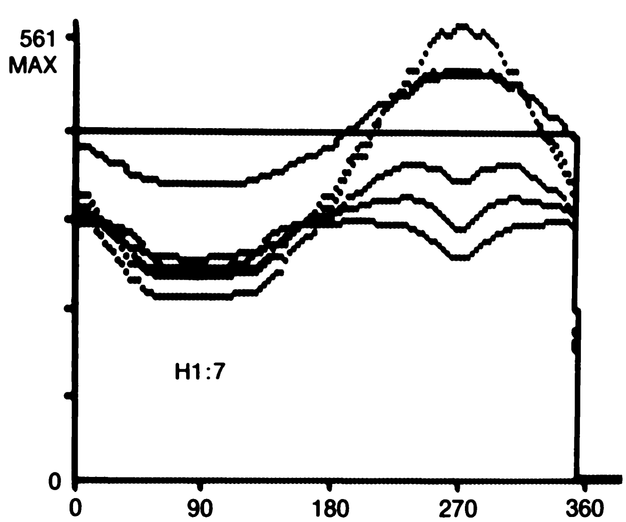

FIGURE 5
Superimposition of seven circumferential profile analysis curves showing range of count distribution for each myocardial segment seen in LAO view

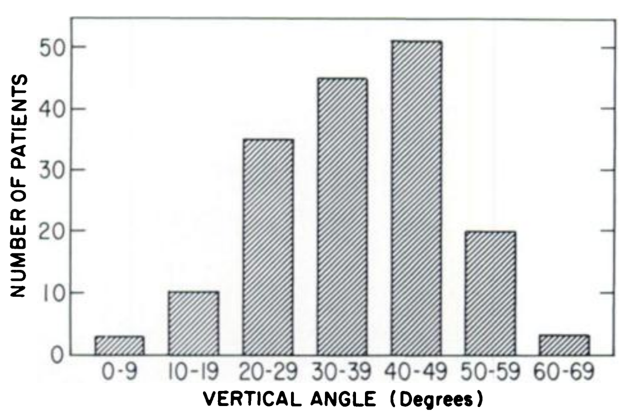

FIGURE 6
Distribution of measured (uncorrected) vertical angles in 167 patients

DISCUSSION

To date, there has been little available information concerning the effect of individual variations in left ventricular orientation on the appearance of planar thallium images. The physician experienced in subjective image interpretation intuitively "corrects" for malpositioned, rotated, or angulated cardiac images. However, the introduction of quantitative methods of analysis and attempts at standardization of normal values for each myocardial segment requires further clarification of the normal range and influence of anatomic variability on perfusion images. The current study indicates that both the appearance and quantification of left anterior oblique myocardial perfusion images are heavily influenced by the degree of vertical tilt of the left ventricle. Unlike horizontal plane rotation, variations in vertical left ventricular orientation cannot be corrected by camera repositioning.

The present computer simulation of a normal myocardial perfusion image indicates that in the LAO view, very vertical hearts appear to have areas of decreased isotope both in the upper valve plane and inferoapical region. This can be demonstrated quantitatively with both profile and circumferential methods of analysis. Although these images are familar to experienced readers, their quantitative patterns are quite different and distinctive compared with the horizontally oriented hearts. This difference is not taken into account by automatic methods of analysis currently in use.

A survey of patients referred for stress myocardial perfusion imaging indicates a large variation of left ventricular vertical axis orientation, including patients with very horizontal hearts and those with vertical hearts. For patients with extremes of vertical orientation, the computer simulation used in the present study suggests that standard quantitative values for upper and lower segments may be expected to be significantly different from the "average" patient. The composite graph of circumferential curves in Fig. 5 demonstrates maximal differences in absolute counts of 37% in the valve plane and 45% in the inferoapical region of the computer simulation. Results from the present study may explain the wide range of normal limits previously reported for thallium uptake in the inferoapical region (*3,15*). This wide range of normal values limits the ability of the quantitative method to accurately detect abnormalities in this particular region. Additionally, at the present time most methods of thallium analysis omit evaluation of the valve plane in the LAO view. The extreme variability of appearance of the valve plane depending on vertical angle of the left ventricle is apparent from the present study. It is theoretically possible to establish normal values for this segment taking into account individual variations in configuration.

The range of vertical angles in the present study may not necessarily be representative of all patient groups. Assuming a general relationship exists between orientation of the heart and body habitus, the distribution of degree of vertical orientation in a particular population may parallel geographic differences in height and weight. For instance, males over the age of 35 tend to be taller in the southern United States than in the northeast, while midwestern males and females are heavier (*16*). Economic, sex, and racial differences in height and weight have also been reported, suggesting the potential for differences in subpopulations even within the same region or city. Therefore, normal quantitative segmental values derived from a group of patients in one area of the country may not necessarily apply to patients tested in other regions. This may in part explain conflicting published data concerning the value of thallium quantification versus subjective interpretation for the diagnosis of coronary artery disease.

Limitations

The computer model employed in the current study has assumed the left ventricle to be perfectly symmetrical in contour. Globular or so-called "banana-shaped" ventricles might be expected to have very different configurations and profiles with varying degrees of vertical tilt. Concentric or regional hypertrophy and hypertrophic papillary muscles would also be expected to significantly alter perfusion image appearance. The assessment of vertical axis angulation obtained from patient images in the current study was presented as a relatively rough survey rather than a highly accurate technique. Since the survey was retrospective, no special care was taken to insure that patient positioning was precisely perpendicular to the camera. Difficulties in defining the long axis were not unusual, most often seen in very foreshortened or unusually shaped ventri-

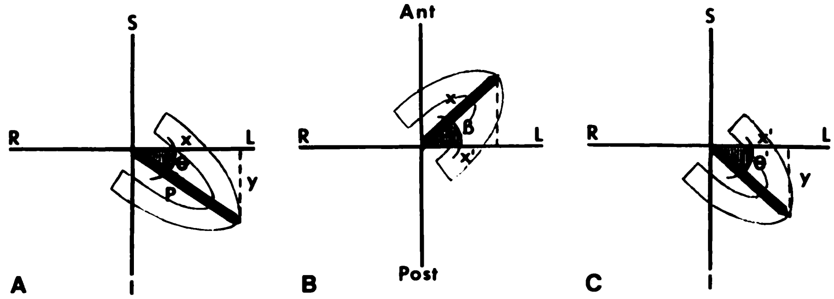

FIGURE 7
Schematic of left vertical (A) long axis (RAO) view, (B) transverse view and (C) foreshortened (anterior) view. θ, P, X, Y, β and θ' are defined in Appendix. R = right, L = left, S = superior, I = inferior, Ant = anterior, Post = posterior

cles, or ventricles with large perfusion defects. The illustrative images selected for Fig. 2 were obtained from patients with low probability of coronary disease who did not manifest any of these problems. Additionally, the varying degrees of foreshortening encountered cannot be precisely corrected by a single formula applied to all patients. It is possible that routine use of a right anterior oblique view adjusted according to position based on the best septal left anterior oblique view (as is performed in some institutions) might produce a true long axis view that does not require correction for foreshortening.

CONCLUSION

This study suggests that the accuracy of current methods of planar thallium image quantification for the detection of coronary artery disease might be enhanced by the inclusion of a correction factor for vertical orientation of the left ventricle in the left anterior oblique view. Although potential clinical significance may be inferred from the present computer simulation and clinical survey, further cardiac catheterization and radionuclide studies are required for confirmation. This would involve the determination of the degree of verticality estimated from the anterior (or right anterior oblique) thallium view, followed by a comparison of quantitative results with a set of revised normal standards. These new normal limits would be derived from a large group of normal controls separated by degrees of vertical orientation. Thus, a vertical heart would have a very different set of normal values for segmental analysis than an "average" or horizontally oriented heart.

FOOTNOTES

* Technicare, Solon, OH (Technicare 560).

† Technicare, Solon, OH (THALQ, Technicare).

‡ Technicare, Solon, OH (CIRSECT, Technicare).

ACKNOWLEDGMENTS

The authors wish to thank Mr. Greg Reiser for his technical assistance, and Ms. Lyris Skinner for her help in the preparation of the manuscript.

This work was supported in part by Bernard and Josephine Chaus through the Heart Research Foundation.

APPENDIX

Definitions

θ = Angle of vertical rotation (0° for a horizontal heart);
P = Length of left ventricular long axis;
X = Horizontal projection of P;
Y = Vertical projection of P;
β = Angle of horizontal rotation (assumed to be 45°), and
θ' = Perceived angle of vertical rotation after horizontal rotation (foreshortened view)

EQUATIONS

$$X = P \cos \theta$$

$$Y = P \sin \theta \quad \text{(Fig. 7A)}$$

$$X' = X \cos \beta \quad \text{(Fig. 7B)}$$

Substituting,

$$X' = P \cos \theta \cos \beta$$

Since Y does not change with horizontal rotation

$$\tan \theta' = \frac{Y}{X'}$$

Substituting for Y and X′

$$\tan \theta' = \frac{P \sin \theta}{P \cos \theta \cos \beta}$$

$$\tan \theta' = \frac{\tan \theta}{\cos \beta}$$

rearranging,

$$\tan \theta = \tan \theta' \cos \beta$$

$$\theta = \text{Atn} (\tan \theta' \cos \beta)$$

$$= \text{true vertical angle.}$$

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