A Method for Determining Left Ventricular Mass in Man

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VARIOUS methods have been devised by others for estimating the weight of the normal heart in man by relating heart weight to body size and age. In other studies the weight of the left ventricle has been compared to total heart weight in postmortem hearts. Smith’s method for estimating the normal left ventricular mass has been utilized by Bing for determining left ventricular efficiency. Friedman, in radiographic studies of heart volume, demonstrated a relationship between the total heart volume, myocardial volume, and the volume of the heart chambers. Furthermore, he demonstrated that the relation between these volumes differed in patients with different types of heart disease, but he did not attempt to relate the volume or muscle mass of individual cardiac chambers to the total heart volume. Amundsen, in extensive studies of total heart volume, has discussed the difficulty in detecting dilatation and hypertrophy of individual cardiac chambers from conventional x-ray films of the heart. The present study is concerned with the development and clinical application of a method for determining left ventricular mass in man.

Methods

Twenty-three postmortem human hearts were prepared by suturing together the leaflets of the mitral valve, inserting a large-bore needle into the ventricular cavity through the aortic valves, and clamping the aorta just above the aortic valves. The hearts were suspended over a Schonander-biplane angiocardioangiographic unit so that the heart position and distances with respect to films and x-ray tubes simulated those present during angiography in vivo when films are taken in the anteroposterior (a-p) and left lateral projections. Barium sulfate paste was injected into the left ventricular chamber to an initial known volume of 80 ml., followed by added known increments of 20 to 25 ml., until contrast material leaked at the mitral valve, or the left ventricle ruptured. Biplane films were taken at each known volume over an 80- to 300-ml. volume range, as indicated in figure 1.

On each film the image of the left ventricular chamber was traced, the enclosed area (A) was determined by planimetry, and the long axis (l) of the ventricular chamber was directly measured. It was assumed that the left ventricular chamber could be represented by an ellipsoid reference figure. The transverse diameters (d) were calculated from the a-p and lateral films by use of the formula for the area of an ellipse: $d = \frac{4A}{\pi l}$. Each of the axes was corrected for distortion due to nonparallel x-rays from knowledge of x-ray tube-to-film distances and left ventricle-to-film distances. This method for correcting for x-ray distortion has been described previously.

Left ventricular chamber volumes were calculated by use of the formula for the volume of an ellipsoid as described earlier:

$$V = \frac{4}{3} \pi \frac{d_n}{2} \times \frac{d_l}{2} \times \frac{1}{2},$$

where $d_n$ = transverse diameter calculated from the a-p film; $d_l$ = transverse diameter calculated from the lateral film; $l$ = maximum measured chamber length whether on the a-p or lateral film. The calculated volumes were corrected by a regression equation obtained from previous studies: $V' = 0.928V - 3.8$ ml., where $V'$ is the adjusted volume and $V$ is the volume calculated by the previous equation.

On each a-p film the outer margin of the free left ventricular wall was outlined, as illustrated in figure 2. A 4-cm. segment of the free left ventricular wall at approximately the junction of the

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Figure 1
Calculated left ventricular chamber volumes of human postmortem hearts are related to known volumes.

The wall thickness was corrected for distortion from nonparallel x-rays as follows. The distance of the portion of the left ventricular wall selected for the measurement of thickness to the plane of the central x-ray beam, as identified by a lead marker, was directly measured on each a-p film. On the lateral film it was assumed that this portion of the left ventricular wall was at approximately the level of the center of the opacified left ventricle. The distance of the center of the opacified left ventricle to the plane of the central x-ray beam, as indicated by a lead marker, was measured on the lateral film. These measurements from the a-p and lateral films and the known x-ray tube-to-film distances were used to calculate the correction factors, which were applied to correct wall thickness for distortion due to nonparallel x-ray beams, as previously described.7

The corrected wall thickness was added to each semi-diameter that was used for calculating the left ventricular chamber volume, and the volume of the left ventricular chamber plus muscle wall was determined by the following formula:

\[ V_{c+w} = \frac{4}{3} \pi \left[ \frac{d_2}{2} + h \right] \times \left[ \frac{d_1}{2} + h \right] \times \left[ \frac{1}{2} + h \right] \]

where \( V_{c+w} \) equals volume of the left ventricular chamber plus wall, \( h \) equals wall thickness, and \( d_2, d_1, \) and 1 are axes as defined in the previous equations.

Left ventricular mass was calculated as follows:

Left ventricular mass equals \((V_{c+w} - V') 1.050\), where \( V_{c+w} \) and \( V' \) are volumes as previously defined. The value 1.050 is the specific gravity of heart muscle as determined in studies by Bardeen.8 This same value for specific gravity for heart muscle was obtained for one heart in the present study.

The left ventricular mass as defined in this study is represented by the weight of the free wall of the left ventricle and the interventricular septum. The actual weight of the postmortem left ventricle was determined after removing the free right ventricular wall, the atria, the aortic and mitral valves, trabeculae from the right ventricu-

Figure 2
An anteroposterior film of a human postmortem heart distended with contrast material. A segment of the free wall used for determining wall thickness is illustrated.
lar side of the interventricular septum, and the epicardial fat.

In six subjects left ventricular mass as calculated from angiocardiograms, which were performed 1 to 15 months prior to death, was compared with left ventricular weight determined at postmortem examination. The method used for calculating left ventricular mass was the same as that described for the postmortem hearts. The time of film exposure within the heart cycle was recorded as described elsewhere. Films recorded near end-diastole were used to calculate ventricular mass because the lateral wall thickness is more clearly defined on films taken during the late diastolic phase of the heart cycle. Films taken during ventricular systole often show considerable irregularity of the inner wall of the ventricle, and prominent papillary muscles that project into the ventricular chamber make the wall thickness difficult to define and measure clearly.

Results

There were 97 individual determinations of left ventricular chamber volume and mass on 23 postmortem hearts. Measurement of left ventricular mass by this method is dependent upon calculation of chamber volume and the volume of the chamber plus the ventricular wall. In figure 1, calculated left ventricular chamber volume is related to the known volume of contrast material injected into the chamber over a range of 80 to 300 ml. The regression equation that expresses the relation between the known and calculated volumes and the standard error of estimate (15 ml.) is shown in the figure.

The relation between the 97 calculated left ventricular mass values and the measured left ventricular weights is illustrated in figure 3. The left ventricular mass was calculated at each chamber volume so that there were one to nine individual calculations of mass on the 23 postmortem hearts. In figure 3, each calculated mass value is indicated by a horizontal line and the individual values for each ventricle are connected with a vertical line. The measured left ventricular weights were 121 to 453 Gm. The regression equation that related the measured and calculated values and the standard error of estimate (23 Gm.) is shown in figure 3.

Figure 4 contains a comparison of the postmortem left ventricular weight and left ventricular mass as calculated from angiocardiograms performed during life in the six subjects. Figure 5 demonstrates an in vivo angiocardiogram with the calculated values for chamber volume, wall thickness, and mass. The segment of the free left ventricular wall

![Figure 4](image)

A comparison of postmortem left ventricular weights and values for left ventricular weight calculated during life in six subjects.

![Figure 3](image)

The 97 determinations of left ventricular mass in the 23 postmortem hearts are compared to the known mass values.
that was used for the determination of wall thickness is outlined. Films taken during the end-diastolic portion of the heart cycle were used for the calculations of ventricular mass as described. There were three to six calculated mass values on each subject as indicated by the horizontal lines in figure 4. The observations in each subject are connected by a vertical line. The averages of the individual calculated values for mass in each subject are indicated by the longer horizontal lines. As shown in figure 4, the calculated and measured values for ventricular mass agreed closely, except in one subject. This subject had pulmonary vascular disease, marked pulmonary hypertension, and right ventricular dilatation and hypertrophy. The erroneously large calculated ventricular mass values were due to an enlarged right ventricle that projected to the left, beyond the free margin of the left ventricle, and resulted in the appearance of an erroneously thick free wall of the left ventricle on the anteroposterior x-ray films (fig. 6). This was evident from angiocardiograms of the right heart and from postmortem examination of the heart.

Discussion
In the method described here, for determining left ventricular chamber volume and mass, it is assumed that the left ventricular chamber and chamber plus wall can be represented by an ellipsoid reference figure. Furthermore, it is assumed that the chamber volume can be calculated from the projections of the ventricular chamber on biplane films after correction for distortion due to nonparallel x-rays, but without correction for distortion due to rotation or position of the chamber. These assumptions were tested in earlier studies of methods for determining the volume of the left ventricular chamber of postmortem hearts. In these earlier studies, left ventricular chamber volumes calculated by the method used in this study were compared to known volumes and volumes calculated by more tedious methods, which permit correction for distortion due to ventricular rotation or position. Volumes calculated by these various methods were similar. The comparison of known volumes and calculated volumes in the present study demonstrated a

Figure 5
An anteroposterior film of the opacified left ventricle at end-diastole from one of the subjects in figure 4. The chamber volume, wall thickness, portion of the ventricular wall used to determine wall thickness, and calculated left ventricular mass are illustrated. Catheters are positioned in the pulmonary artery, left atrium, and left ventricle.

Figure 6
Anteroposterior film of the opacified left ventricle in the subject with marked right ventricular enlargement. There is the erroneous appearance of an increased thickness of the lateral left ventricular wall.
somewhat higher standard error of estimate than was observed for this method for calculating volume in the earlier study.

To calculate left ventricular mass by the method described here, it is necessary to determine a left ventricular wall thickness that is representative or has a relatively constant relation to the thickness of the ventricle as a whole. A segment of the free left ventricular wall as visualized on the anteroposterior film was selected, because this is the portion of the ventricular wall that is most often clearly seen and can be measured on angiocardiograms. There is evidence from postmortem studies by others that there is a relatively fixed and close relation between the thickness of the lateral left ventricular wall and interventricular septum. The results of this study demonstrate a close relation between thickness of the lateral left ventricular wall, dimensions of the left ventricular chamber, and the left ventricular mass.

Left ventricular mass as determined in this study included the free wall of the left ventricle and the entire thickness of the interventricular septum. Others have dissected the septum into a right and left ventricular portion prior to weighing the left ventricle. However, as discussed by others, an accurate division of the septum into right and left ventricular portions is very difficult, if not impossible, and was not attempted in this study. The method used for dissecting and determining left ventricular weight in this study is similar to that used by others.

The method described here for determining left ventricular mass can only be applied when a segment of left ventricular wall is clearly visible and is representative of the over-all thickness of the left ventricle. Pericardial effusion or thickening would be expected to give the appearance of an abnormally thickened left ventricular wall and invalidate the method. An erroneously thick-appearing left ventricular wall was also demonstrated to be the case in the angiocardiograms from the subject with marked right ventricular hypertrophy in this study. In addition, this method cannot be applied to patients in whom the left heart border is obscured by a pleural effusion, a pulmonary lesion, or by the lateral rib cage, as is not uncommon in recumbent patients with greatly enlarged hearts. Finally, in patients with a ventricular aneurysm involving the free wall of the left ventricle and in patients with asymmetric left ventricular hypertrophy, as has been described in some subjects with subaortic hypertrophic aortic stenosis, the free-wall thickness would very likely not be representative of the thickness of the remainder of the left ventricle. In such patients, this method would not be expected to give a reliable estimation of left ventricular mass.

Summary

A method for determining left ventricular mass by the use of biplane angiocardiography is described. This method was tested on 23 postmortem human hearts with left ventricular weights of 121 to 453 Gm. The left ventricular chambers of these hearts were distended with known volumes of contrast material and biplane x-rays were recorded over an 80- to 300-ml. range of volumes. Values for left ventricular mass were calculated from the biplane x-ray films and were demonstrated to agree closely with directly measured left ventricular weights. The standard error of estimate was 23 Gm. In six patients, left ventricular weights were calculated from angiograms performed during life and compared with postmortem left ventricular weights. There was close agreement between the calculated and measured values for ventricular weight in all but one subject. This subject had marked right ventricular hypertrophy which resulted in an erroneously large calculated value of left ventricular mass.

References

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The Observational Method in Clinical Medicine

In order that observation should have its proper value certain principles must be thoroughly familiar. The true nature of the method must be understood, its special liabilities to fallacy must be known, and its weakness of trusting to intuition when actual proof is possible, overcome. There can be little doubt that it is this last-named characteristic of ordinary clinical practice that inclines the critics of the observational method in medicine to view it with so little charity or hope. In clinical work proof is usually difficult to obtain, often tedious and unencouraging to attempt, and not rarely altogether impossible; at the same time any effort towards it is constantly overshadowed by the urgency to act. It is natural, therefore, for the expert clinician to rely on his intuition and judgement even when actual and final proof is possible, though this preference does constitute a reproach to the method from any scientific point of view. If clinical observation is to renew its prestige and to continue its indispensable function of stimulating the experimental attack on medical problems, it can do so by showing resolution in looking for proof wherever proof is possible, and a scientific standard in its scrutiny of evidence.—The Collected Papers of Wilfred Trotter, F.R.S. London, Oxford University Press, 1946, p. 124.
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