cerebrate cats and in cats under ether and dial anesthesia by faradic stimulation with an inductorium or repetitive stimulation with a thyratron stimulator does not elicit a contraction of the panniculus carnosus muscle, but simultaneous or independent stimulation of the gall bladder or the splanchnic nerve (right) does evoke a contraction of the panniculus carnosus muscle.

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Measurement of the Heart Size with the Roentgenkymograph.

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The estimation of heart size in the living subject by the usual X-ray methods is generally inadequate in one or more respects: (1) the phase of the heart cycle is neglected—the total stroke output of the heart varies from 6% to 40% of the systolic heart volume, (2) it is assumed that simple linear measurements (*e.g.*, transverse diameter) accurately reflect true heart size (volume), (3) proper correction is not made for body size, (4) correction for distortion in the teleroentgenogram is disregarded, (5) accuracy is not proved by controls and duplicate measurement, (6) pendulum motion of the heart is included.

The roentgenkymograph, in which the film is moved during exposure behind a lead grid (Roesler;[1] Stumpf, Weber and Weltz;[2] Keys and Friedell[3]) registers the systolic and diastolic excursions of the heart contour, eliminates the effect of pendulum motion, and gives better visualization of the upper and lower borders.

We consider heart volume to be the ultimate reference measurement. Except with cadavers we have used frontal roentgenkymographs made at 66 to 72 inches with 2.5 second exposure, and have obtained the correction factors for distortion from lateral plates. All measurements were made on tracings of the X-ray plates and independently checked. Areas were measured with the planimeter.

1 Roesler, H., *Clinical Roentgenology of the Cardiovascular System*, Charles C. Thomas, Baltimore, Md., 1937.

2 Stumpf, P., Weber, H. H., and Weltz, G. A., *Röntgenkymographische Bewegungslehre innere Organe*, George Thieme, Leipzig, 1936.

3 Keys, A., and Friedell, H. L., *Science*, 1938, **88**, 456.

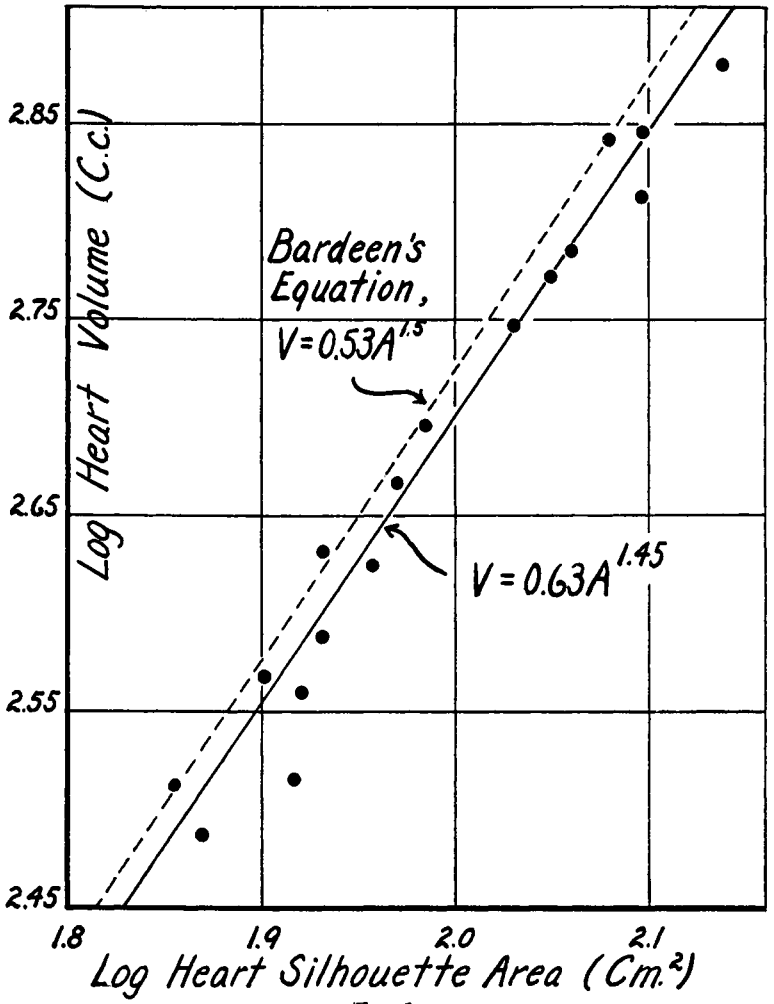

FIG. 1.

Relation between the corrected frontal silhouette area and the true total heart volume in 17 cadavers. Bardeen[4] assumed an exponent of 1.5; he included parts of the great vessels in the volume

Measurement of the frontal systolic silhouette area is very precise. Kymographs were repeated on 8 subjects at intervals of 2 to 10 minutes. The average deviation from the means for the 8 subjects was ±0.55% and the maximum deviation was only 1.6%. Three other subjects were studied from 4 to 6 times each over a period of 3 months. The average deviations from the means of the systolic areas for these subjects were ±0.7%, ±1.9%, and ±1.1%.

The accurate estimation of heart volume from a measurement of silhouette area would be possible if the heart may be considered to

be any combination of ellipsoids, spheroids or other regular geometric forms. The relation would be of the form:

$$\text{volume} = \text{constant} \times (\text{area})^{\text{exponent}}.$$

In a series of 17 cadavers we have made frontal teleroentgenograms and immediately thereafter we opened the chest, tied off the vessels and removed the heart for direct measurement. The relation in these hearts between the frontal silhouette area and the volume is shown

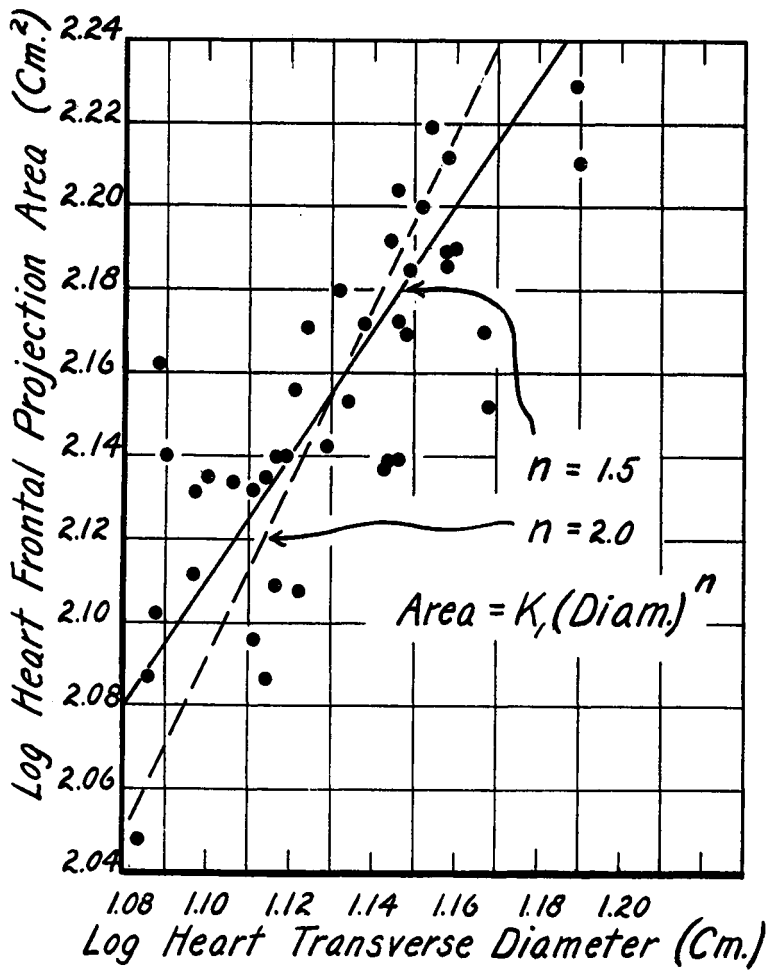

FIG. 2.

Relation between transverse diameter and the corrected frontal projection area in 41 normal cases. Measurements made from roentgenkymograph tracings, thereby eliminating questions of phase in the cardiac cycle, pendulum motion, distortion from divergent rays, etc.

in Fig. 1 together with the line of best fit and the line for Bardeen's[4] equation, which assumed perfect spheroidal form.

With our equation, $Vol = 0.63\ (area)^{1.45}$, the average error in the estimation of heart volume from the frontal silhouette area was only ±4.4%; except for a single case where the error was —15.9%, the error was never greater than ±7%. For comparison we have made transverse diameter measurements on 41 kymograph plates from normal subjects. The relation between frontal t.d. to silhouette area is shown in Fig. 2. For this material the best prediction formula is: $area = 2.9(t.d.)^{1.5}$, or $\log area = 1.5\ (\log t.d.) + 0.46$. The mean error in prediction of the area from the transverse diameter was ±4.9%, and the extremes were +14.2% and —15.0% of the true silhouette area. In pathological hearts the error is generally much larger.

The error in the estimation of heart size resulting from neglect of pendulum motion is variable but ±5% of the volume might be a fair average estimate for resting normal subjects. The mean errors from all sources may be summarized: (1) pendulum motion, +5%; (2) phase of the cardiac cycle, +20%; (3) irregularity in the shape of the frontal projection area (relation between area and transverse diameter), ±5%; (4) irregularity in the anterior-posterior shape of the heart (relation between frontal area and volume), ±4.5%; (5) neglect of distortion in teleroentgenograms, +12% (with a 6-foot plate). The largest errors from these sources may be estimated roughly: (1) +20%, (2) +40%, (3) ±15%, (4) ±15%, (5) +20%. Where frontal projection area is measured in teleroentgenograms inclusion of parts of the great vessels in the area may introduce a further error of the order of 5 to 10%.

When the roentgenkymograph is used as we do only error number 4 enters appreciably. We believe that this method makes possible accurate study of both functional and anatomical changes in given individuals. Precise comparison of different individuals is possible with this method provided adequate correction is made for body size. We believe this is accomplished by the expression of cardiac size in terms of units of total body surface as estimated from the usual height-weight formulæ (Keys and Friedell[3]). We have already established the relative constancy of the total systolic heart size per square meter of body surface in over 200 young men as measured by our method. Further work is in progress to extend these standards to females and to cover the entire age range.

[4] Bardeen, J. A., *Am. J. Anat.*, 1918, **23**, 423.