10489 P

Measurement of the Stroke Output of the Human Heart by Roentgenkymography.

ANCEL KEYS AND H. L. FRIEDELL.

From the Laboratory of Physiological Hygiene and the Department of Radiology, University of Minnesota, Minneapolis, Minn.

Measurement of the area of the frontal silhouette of the human heart as registered on an X-ray plate permits calculation of the total heart volume with an average error of less than ±5% (studies on "fresh" cadavers, Keys and Friedell[1]). By means of the multiple slit roentgenkymograph (*cf.* Johnson,[2] Roesler[3]), it is possible to trace the outlines of the living human heart in both (ventricular) systole and diastole of a single cardiac cycle (Keys and Friedell[4]). From measurement of these areas the volume of the heart in systole and in diastole can be calculated. The error in volume estimation from the frontal area is mainly a reflection of abnormality in the relation between frontal and anterior-posterior shape of the heart. Since these abnormalities must be reflected both in systole and in diastole, the error in the estimation of the difference of volumes should be relatively small.

The difference between the volume of the heart in systole and in diastole should be directly related to the stroke output if the valves allow no back flow. The precise numerical relation, however, could not be predicted *a priori* because the auricular and ventricular cardiac cycles are not absolutely simultaneous in phase. In addition, the difference between the areas of the systolic and diastolic kymogram outlines must be underestimated because the kymogram only registers excursions in one of the 2 planes of the surface of projection.

We have developed a procedure in which roentgenkymograms are made immediately before and after acetylene rebreathing experiments. By this means we obtain estimates of diastolic and systolic volumes of the heart from the kymograms and of the cardiac stroke output by the method of Grollman.[5] Since the 2

1 Keys, A., and Friedell, H. L., PROC. SOC. EXP. BIOL. AND MED., 1939, **40**, 267.

2 Johnson, S. E., *Am. J. Roentgenol. Rad. Ther.*, 1937, **37**, 167.

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

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

5 Grollman, A., *Cardiac Output in Man in Health and Disease*, Charles C. Thomas, Baltimore, 1932.

kymograms always check very closely, the 2 types of measurement can be considered to be physiologically simultaneous.

With this procedure we have found that:

$$\text{cardiac stroke} = 0.64\ (\text{Area}^{1.45}_{\text{diastole}} - \text{Area}^{1.45}_{\text{systole}}).$$

In 22 experiments the correlation between calculated and measured stroke was +0.984, the mean discrepancy was ±5% and the greatest differences were +10 and —11% referred to the acetylene method as standard. When duplicate determinations were made on the same subjects the averages agreed even more closely, the maximum error being only about ±7%. Typical results are shown in Table I.

These results were obtained on normal subjects; similar results were obtained on patients with normal heart valves but with myxedema, hypertension, glomerulonephritis, etc. The subjects studied had systolic heart volumes ranging from 450 to 750 cc—that is, approximately the entire normal range for adults. The stroke volumes ranged from 24 to 92 cc.

Our equation for the relation of frontal projection area to volume is: $V = 0.63\ (A)^{1.45}$ (Keys and Friedell[1]). The equation found here for stroke volume indicates that the net stroke output is almost exactly equal to the maximum volume difference between systole and diastole. The discrepancy is so slight that we can legitimately modify our area-volume coefficient from 0.63 to 0.64 to simplify the calculations. But the total stroke output (pulmonary plus systemic circulation) must be exactly twice this value. Something close to this relation would be predicted for the reasons given in the second paragraph of this paper.

Comparison with the results of other workers and trials by ourselves indicate that results with the acetylene method when re-

TABLE I.

Typical Results from Simultaneous Roentgenkymography of the Heart and Acetylene Rebreathing with 2 Normal Subjects in Rest (but Not Basal). Numbers in brackets refer to the order of the kymogram plates. Areas in cm², volumes in cc.

Subject	Corrected Frontal Area		Volume = 0.64(A)$^{1.45}$		O_2 Uptake cc/min.	A.V. O_2 diff. cc/L.	Cardiac Index L/min./m.²	Stroke Volume	
	Diast.	Syst.	Diast.	Syst.				Kymo.	Acet.
W.O.									
(1)	136.3	125.9	797.0	709.7	264	44.2	3.20	87.3	85.3
(2)	136.2	126.0	796.0	710.7				85.3	
A.Li.									
(1)	106.3	97.9	556.1	492.8	252	51.0	2.65	63.3	63.6
(2)	106.2	98.1	555.4	494.5				60.9	

peated under constant conditions at the shortest possible intervals frequently vary by ±5% or more. The excellent agreement between the kymographic and the acetylene-rebreathing methods is remarkable in view of this. It would appear that the kymographic method provides an estimate of stroke output at least as accurate as the acetylene method within the limits of heart size and output studied by us.

It should be pointed out that the kymographic method requires practically no coöperation on the part of the subject; it is only necessary that the breath be held for about 3 seconds during the exposure. However, there is generally some apprehension or excitement involved in placing the subject in position and minimal cardiac output under basal conditions is not attained until several experiments have been made. This is similar to but less marked than in the acetylene rebreathing procedure.

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Quantitative Measurement of Valvular Efficiency of the Human Heart.

ANCEL KEYS AND H. L. FRIEDELL.

From the Laboratory of Physiological Hygiene and the Department of Radiology, University of Minnesota, Minneapolis, Minn.

In the preceding paper it was shown that the stroke output of the heart may be measured accurately by calculation from the diastolic and systolic areas traced on a roentgenkymogram. Actually, this is a measure of the amount of blood expelled from the heart; in the subject with normal valves it equals the net amount of blood *circulated* by the stroke. In the patient with aortic or mitral regurgitation, however, we should expect that such equality would not hold and the amount of blood circulated would be less than the amount expelled from the heart by the amount of regurgitation.

The net amount of blood circulated may be measured by the acetylene-rebreathing method. We have found it possible to make what are essentially simultaneous roentgenkymograms and acetylene cardiac output determinations. Comparison of the two results with this procedure should give an absolute quantitative measure of the extent of the back leakage (or the efficiency) of the mitral and aortic valves.