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PRELIMINARY NOTE ON THE ELASTIC HYSTERESIS OF THE HUMAN AORTA

BY A. V. BOCK, P. S. BAUER AND J. H. MEANS

MEDICAL LABORATORY OF THE MASSACHUSETTS GENERAL HOSPITAL AND CRUFT LABORATORY, HARVARD UNIVERSITY

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Introduction.—As a result of a study of blood pressure changes occurring during muscular exercise[1] an attempt has been made to determine the rôle played by the arch of the aorta under conditions producing an increase in

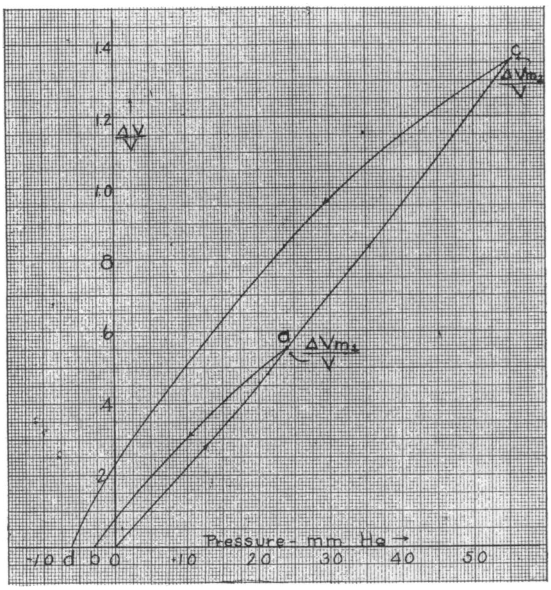

FIGURE 1

Typical curve illustrating elastic hysteresis of human aorta.

systemic blood pressure. Experimental results with reference to changes in blood pressure during exercise in different subjects suggested the possibility that variations in the elastic properties of the arch of the aorta might be chiefly responsible for the reactions observed. Previous work[2] done on this subject has not related functional changes in the aorta to the mechanism of blood flow and blood pressure changes and to the limitations that changes in the arch of the aorta impose upon the body as a whole. The present communication is concerned only with certain aspects of the phenomena of hysteresis in the arch of the aorta.

Apparatus and Procedure.—The arch of the aorta (from aortic valve to first intercostal arteries) under examination is tied on to a water-mercury manometer and, after removal of the air from the system, the internal and external pressure on the aorta is adjusted to equality. The internal pressure is then increased monotonically to a certain maximum value. The pressure is then decreased until the initial volume is attained. At each step, the increment of the internal volume of the aorta is determined from a volumetric scale on one of the branches of the manometer. In this manner curves are obtained of the fractional increment of internal volume against the internal pressure. The process is then repeated, going to a higher maximum pressure.

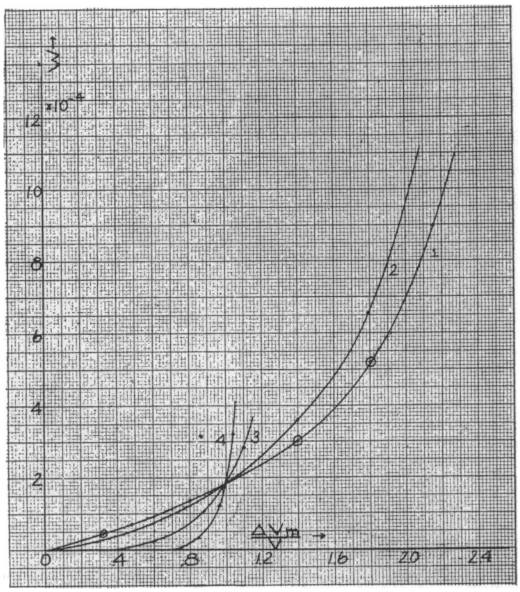

FIGURE 2

Curves of energy lost in heat in gram-calories per cycle per unit internal volume against maximum fractional increase of internal volume. Circles denote values computed from Equation 2. Dots represent experimental values.

Results.—Following the procedure outlined above, typical curves thus obtained are shown in figure 1. Curve *oab* was first obtained and then curve *ocd*. For the latter curve, the true origin is at the point *b*, but in order to preserve symmetry the curve has been translated to the right, placing the origin at the point *o*.

Now it can be shown that the area enclosed by the cyclic curve, *oab*, is proportional to the energy lost in heat by the stretching of the aorta to the maximum fractional increase of internal volume, $\frac{\Delta Vm}{V}$, where V is the unstretched internal volume.

The energy, W, lost in gram-calories per cycle per unit internal volume is given by:

$$W = k \times h \times A^1 \times 3185 \times 10^{-8}, \tag{1}$$

where A^1 is the area enclosed in square inches, h and k are dimensional constants for the ordinates and abscissae.

If we now compute W for each maximum fractional increase of internal volume, $\frac{\Delta Vm}{V}$, we have as an empirical functional relationship, the typical curves illustrated in figure 2. Assuming that the relation between W and $\frac{\Delta Vm}{V}$ is analogous to the Steinmetz Law for magnetic hysteresis and is of the form:

$$W = A\left(\frac{\Delta Vm}{V}\right)^b, \tag{2}$$

we obtain the computed values shown in the graph.

In every case we find that the constant A, which dimensionally is the energy lost in gram-calories per unit internal volume per cycle for a 100 per cent increase of internal volume, is the same. Descriptive data for the curves of figure 2 are given below:

CURVE	AGE	SEX	UNSTRETCHED INTERNAL VOLUME
1	15 months	male	2.0 cc.
2	41 years	male	14.0 cc.
3	78 years	male	15.4 cc.
4	65 years	female	21.2 cc.

The essential difference between aortae from the standpoint of hysteresis loss, lies in the magnitude of the exponent b.

In order to ascertain the effect of hysteresis loss on the work done by the heart, the efficiency of the aorta has been determined. We shall define efficiency as follows: Fractional efficiency is the ratio of the work delivered by the aorta on contraction from a certain maximum fractional increase in volume to the work done on the aorta in expanding it to the same value.

Typical curves of the efficiency against the maximum fractional increase in volume are shown in figure 3.

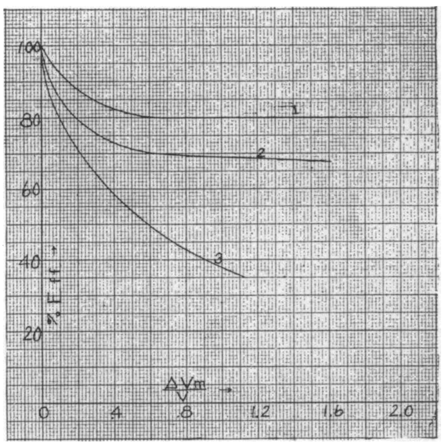

FIGURE 3

Typical cruves of efficiency against maximum fractional increase of internal value.

Let us consider curve 3 in figure 3 and reason qualitatively. We shall assume that the arterial part of the periphery obeys the same law as that for the arch of the aorta. Further we shall assume that the metabolic demand of the system in man at the age of 78 years remains the same as before advanced changes occurred in the arterial walls. Then with a 40 per cent increase of internal volume per systole, or a 20 per cent increase in average diameter, 45 per cent of the energy output of the heart is lost in heat compared with 25 per cent lost at the age of 41 years. The result is that the work of the heart must increase 20 per cent as a result of arteriosclerosis in order to maintain the same blood flow.

The subject will be treated more fully in a later communication.

[1] "Studies in Muscular Activity. III. Dynamical Changes Occurring in Man at Work," A. V. Bock, D. B. Dill, C. VanCaulaert, A. Fölling, and L. M. Hurxthal. (To be published.)

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