EFFECT OF EXTERNALLY APPLIED LOAD ON THE WORK DONE BY THE ISOLATED HEART

By

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Sonnenblick and Downing (5) have reported that, as in the case of the skeletal muscle, the work done by the heart is also determined by its pre-load and after-load. Pre-load here has been taken to be the small pressure developed in the ventricle during diastolic filling which stretches the chamber. Similarly, the after-load has been compared to the arterial pressure against which blood has to be ejected and which comes into play only after the onset of ventricular contraction. In the light of this interesting suggestion we have now carried out experiments to study the effect of external load, applied directly to the ventricle under conditions of pre-loading and after-loading, on the work done by the isolated frog heart. The outcome of these experiments is briefly presented here.

MATERIALS AND METHODS

Isolated frog hearts were perfused with Ringer's solution by Straub's technique. This preparation offered two distinct advantages for the load experiments :

(1) The base of the ventricle, where it joins the truncus arteriosus, remained fixed and well supported by the cannula while the sino-auricular chambers were, at the same time, free to function normally.

(2) Since the same fluid kept on rebounding between the ventricle and the cannula, changes in the diastolic filling pressure were minimal.

After pithing the animal the heart was exposed and the 3 vena-cavae as well as the left truncus were ligated one by one. Straub's cannula was inserted into the right aorta through a small nick and carefully manipulated into the ventricle. The chambers were thoroughly rinsed free of any blood clots. The cannula was then clamped in the vertical position with the heart hanging down and was surrounded by a special glass vessel, holding some water at the base, to prevent drying of the heart-surface. Oxygen was kept slowly bubbling through the cannula which was filled with Ringer's fluid upto a height of 3-5 cm above the heart.

A special heart-clip was attached to the ventricular tip such that it could bear considerable weight without tearing the muscle. This was connected to a lever made out of an unyielding aluminium beam with frictionless pivoting, placed directly below the heart. Hanging vertically down from the lever, in line with the heart, was a weight-pan made of cork. Record taken on a slow-moving kymograph.

During after-loading a rest was provided for the lever at the lower limit of its nor excursions. The actual height of contraction was calculated from the amplitude of the rec taking into account the magnification of the lever.

OBSERVATIONS

In considering the load acting on the ventricle the weight of the lever itself has not be taken into account since the lever was relatively very light and was kept adequately count balanced. Similarly, the work-done by the ventricle has been determined only in terms of t weight lifted, neglecting the small and almost constant fraction expended in pushing the p fusion fluid back into the open cannula during each systole. However, these approximatio have no significant bearing on the observations made.

The effect of load on the amplitude of contraction, under conditions of pre-loading a after-loading, is shown in Fig. 1. The amplitude decreases in both cases from the very beg ning with even an extra load of 1 *gm*. But as is clear from Fig. 1, the shape of the curves f

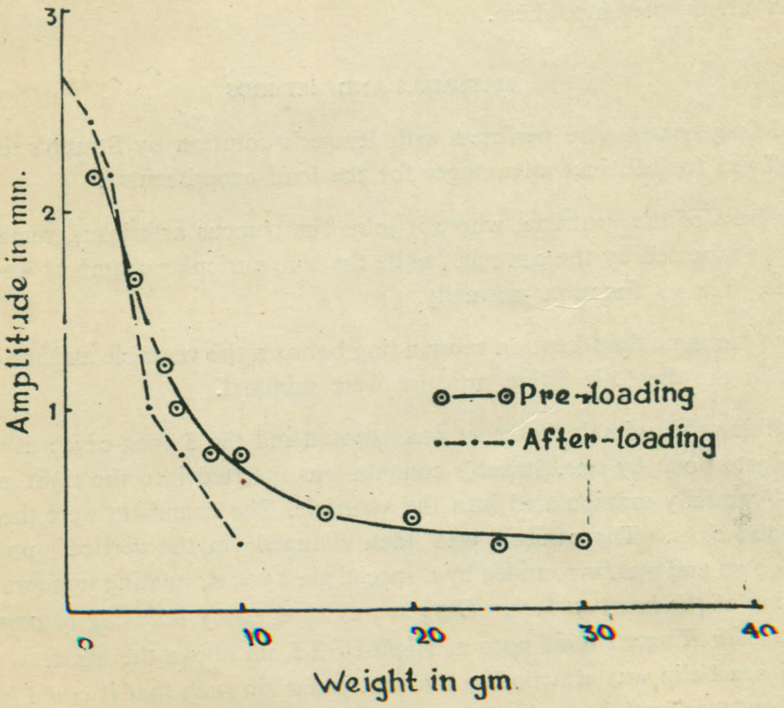

Fig. 1

Showing effect of different amounts of pre-load and after-load on the actual amplitude of contraction of isolated heart.

pre-loading and after-loading are significantly different, being almost linear for after-loading and nearly parabolic for pre-loading. Upto a certain weight, varying between 3 to 6 *gms.* with different frog hearts, the amplitude falls sharply in both cases but beyond it the amplitude is much better sustained under pre-loading. Thus, 10 *gms.* under after-loading and 30 *gms.* under pre-loading are giving nearly the same height of contraction.

The work done by the heart in lifting the weight at different levels of external load is shown in Fig. 2. At first the work done per beat rises with increasing load and uptil about 4-6 *gms.* it is essentially the same under pre-loading and after-loading. Beyond this it begins to decline under after-loading but continues to increase steadily under pre-loading.

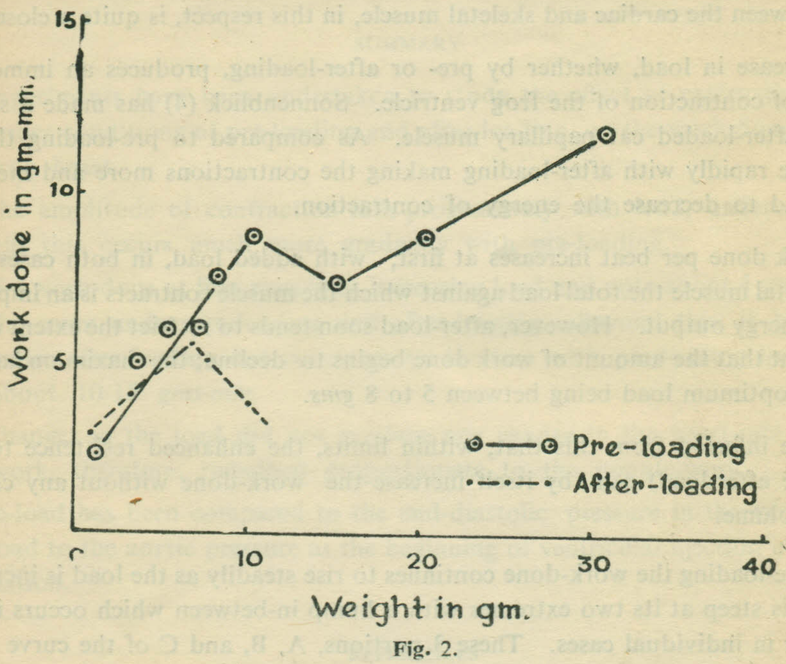

Fig. 2.

Showing the work done by the heart (Weight in gm X Height in mm.) at different levele of pre-loading and after loading.

From Fig. 2, it is obvious that with after-loading the maximum work done is at a weight of 7 *gms.* and below and above it the work output sharply declines. With pre-loading there is no fall in the work done even with a weight of 30 *gms* being, on an average, 10-15 *gms* per beat at this load. The experiments could not be carried out at higher loads because beyond 30 *gms* the weight began to tear the ventricular muscle.

Application of weight and the consequent stretching of the ventricle did not produce any change in the heart-rate. The stroke-work and the minute-work, therefore, remained proportionate throughout.

DISCUSSION

According to Starling's well known law of the heart the force of ventricular contracti under any given inotropic condition of the muscle, is determined by the end-diastolic volu The extent of diastolic distension expresses itself in the small pressure developed in the ventri during the filling phase. This pressure may, therefore, be compared to the pre-loading of skeletal muscle as suggested by Sonnenblick and Downing (5). It determines the resting len of the muscle fibres and, thereby, regulates the force of the ensuing contraction. Simila the arterial pressure against which blood has to be ejected can be equated with the after-lo on a skeletal muscle since it begins to be effective only after the onset of contraction. Th the analogy between the cardiac and skeletal muscle, in this respect, is quite a close one.

Any increase in load, whether by pre- or after-loading, produces an immediate fall the amplitude of contraction of the frog ventricle. Sonnenblick (4) has made a similar obs vation in the after-loaded cat papillary muscle. As compared to pre-loading the amplitu falls much more rapidly with after-loading making the contractions more and more isometri This would tend to decrease the energy of contraction.

The work done per beat increases at first, with added load, in both cases. As in th case of the skeletal muscle the total load against which the muscle contracts is an important dete minant of the energy output. However, after-load soon tends to restrict the extent of shorteni to such an extent that the amount of work done begins to decline; the maximum has been abo 6 *gms-mm*, the optimum load being between 5 to 8 *gms*.

It can be inferred from this that, within limits, the enhanced resistence to ventricul contraction (the after-load) can by itself increase the work-done without any change in th end-diastolic volume.

Under pre-loading the work-done continues to rise steadily as the load is increased. Th curve in Fig. 2 is steep at its two extremes with a hump in-between which occurs in the regio of 10 to 20 *gms* in individual cases. These 3 portions, A, B, and C of the curve could be ex plained as follows :

A—The increasing pre-load stretches the resting fibres and, in accordance with Starling's law, leads to greater force of contraction and greater work output.

B—The total load to be lifted is now such that the shortening of the muscle is restricte considerably, bringing the contractions towards the isometric condition and, thus minimising the advantage of Starling's law.

C—As shown in Fig. 1, the amplitude of contraction under pre-loading tends to remai steady after 15-20 *gm*. Consequently, added load is now again effective in enhanc ing the work done.