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# ON THE NEWER METHOD FOR DIRECT MEASUREMENT OF HEART MOVEMENT IN ANIMALS

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Wire strain gauges were attached to the flexible part of one leg of the compass form apparatus. This apparatus was used to register the heart muscle movement electrically. It is light in weight, is suspended and attached to the heart surface by suturing or with an instant adhesive. The part on which the strain gauge was attached, was so thin that the leg of the apparatus followed the heart muscle movements with high responsibility giving the load to the heart as little as possible. Thus this apparatus can be used in the investigation of the auricular or ventricular movements of not only large animals but also small animals, even the frog. The significance of using such an apparatus besides the arch form strain gauge was discussed.

A number of methods have been devised to record the movement or contractile force of the animal hearts *in situ*. Connecting a thread with an apex or a part of the auricle, the movement can be observed on the ventricle or auricle. This is an easy and convenient method, but the respiration and other factors are apt to disturb the accurate registration of the heart movement only. To avoid such a defect, Cushny[1] developed the myocardiograph which was first made by Roy and Adami[2]. The subsequent modifications were made on this instrument by other investigators. Many efforts were made to record the contractile force of the human and animal ventricles by Walton and Brodie[3], Dipalma and Reiss[4], and Walton, Cotten, Brill and Gazes[5]. Furthermore, other types of instruments to record the contractile force were devised by Boniface, Brodie and Walton[6], and Cotten and Maling[7].

The contractile force is one of the useful indices of cardiac function. However, we sometimes need a real cardiac movement or change of the muscle segment, because the myocardiac contractile force and segment length do not always change in the same direction. In fact, in larger effective or toxic doses of digitalis glycoside, while the heart muscle shows the stronger contractile force, the amplitude of ventricular movement and cardiac output may be

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smaller than before the drug was administered. As others[7)8)] and we[9)] observed, in considerably large doses of adrenaline, while the contractile force is stronger than before, peripheral resistance is very high and temporarily the left ventricle is dilated and cannot contract or stroke out the blood sufficiently. In these cases, we cannot say that the heart function is better than the control. Thus, if we observed not only the contractile force but also the muscle movement of the ventricle, the heart performance would be revealed more precisely. Accordingly, it would be useful to reconsider what kind of procedures have been developed for this purpose.

As stated before, the method in which the atrium or ventricle is connected with a recording lever by thread is simple and convenient, but the records are disturbed by many extracardiac movements. Cushny's myocardiograph excluded such a defect in some degree. However, the instrument has still such a defect that the heart muscle investigated is streched by the dead weight pull of levers which is estimated to be about 10 grams (3). Moreover, myocardiograph would not be applied to the auricle of small animals, the wall of which is too thin to be attached by this apparatus. In addition, the frequency character of the lever system including the myocardiograph would be very low and it could not follow the rapid movement accurately.

Rushmer[10)] developed the mercury gauge for measurement of the cardiac segment length which was first devised by Whitny[11)] for plethysmography. Linden and Mitchell[12)] used the special myocardiac segment length recorder which includes two microtorque potentiometer for their investigation. These are, of course, for the large animals but thought to be much improved over the older one.

The movements of heart muscle segment are a reflection of the whole heart movements. Hence, it is natural that we are interested in the procedure to register the whole heart movement: Henderson's cardiometer[13)], roentgenographic investigation and others. Those methods have many merits but it is not possible to obtain volume curves from one ventricle of heart *in situ*. Nuki's cardiotambour[14)] is also the instrument to register the ventricular movements of large animals. Anyway they have the significance in the point that the stroke volume can be presumed about which more will be mentioned in our other paper[9)].

As described above, the resistance wire strain gauge was introduced to cardiology by Boniface, Brodie and Walton[6)], and many valuable investigations have been made using their strain gauge arch. We intended to use the resistance strain gauge to record the changes in the distance between two points on the hearts surface without load to the muscle investigated.

## APPARATUS

As shown in Figs. 1 and 2, two 1 mm thick plastic plates, to each of which

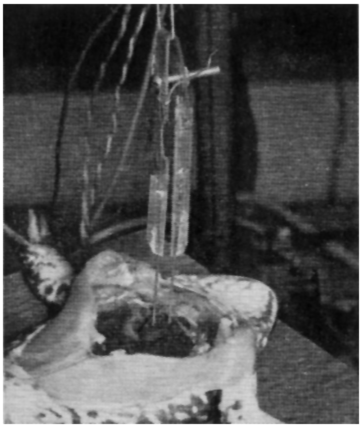

FIG. 1

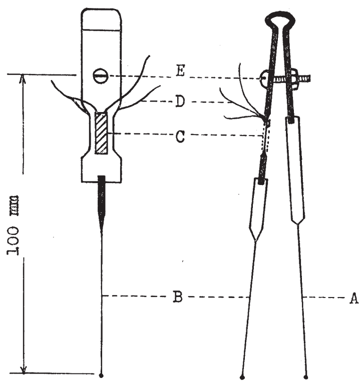


FIG. 2

FIG. 1. Strain gauge compass attached to the surface of the bullfrog's ventricle.
FIG. 2. Diagram of the strain gauge compass.
A: Rigid leg, B: Flexible leg, C: Wire strain gauges, D: Lead wires, E: Set screw.

a needle was attached were fixed together at the top, like a compass. A certain plastic part of one leg was planed to be so thin that it bent when the distance between the legs was changed. Thus, one is a flexible leg and the other is a rigid leg. On both sides of planed place of the flexible leg, S-type wire strain gauges ($4 \times 3$ mm, $120\,\Omega$) were attached with nitrocellulose adhesive cement. Recently phosphor bronze (0.05 mm thick) has been introduced instead of plastic as a plate between two gauges. The distance between the legs or points which are to be attached to the heart can be adjusted by the set screw equipped between two legs at the upper part of the compass monitoring the recorder. This permitted a more sensitive arrangement for the compass than when attachment was made previously under the vigorous movement of the heart. The two gauges were put together with other resistances forming Wheatstone bridge (Fig. 3). A three volt cell was used as a source to this

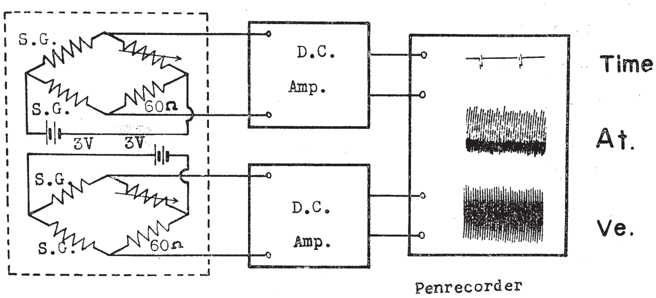


FIG. 3. Diagram of recording apparatus.

bridge. The output was carried to the D. C. amplifier, ADH-2 and direct inking oscillograph, WI-260 M (Nihon Koden Co.).

The relationship between the deflection of the legs' distance and the output change was linear, as shown in Fig. 4. The force to make the different distances was also measured. Within 10 mm deflection they were almost parallel, only 0.5 gram being necessary in case of the 5 mm deflection. Generally the deflection was found to be within 5 mm in case of the rabbit ventricle of our experiment. Therefore, it is postulated that the natural movement of heart would not be disturbed by attaching of this instrument. Usually we used instruments of 10 cm legs length and 3 grams whole weight.

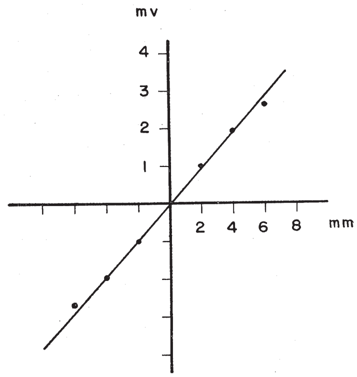


FIG. 4. Rerationships between changes of legs distance and electric output from the circuit containing strain gauges of a compass.

EXPERIMENTS

*1) In Rabbits*

Rabbits were anesthetized with urethane and their chests opened by midline incision. Artificial respiration was provided. After pericardium was incised widely and secured to the chest wall, two instruments were attached to the left atrium and left ventricle. Attachments were made mostly with an instant adhesive, $\alpha$-cyano acrylate. In other cases, suturing, instead of using of adhesive in the ventricle, was done by passing the threads through the holes at the legs' tip. The distance between the legs was usually 10–15 mm and adjusted by the set screw as stated before. An attempt was made to align the axis of the compass with the transverse axis in the case of the auricle and with the longitudinal axis in the case of the ventricle. Considerable care was taken to avoid the inclusion of any visible coronary vessels at the attaching points. The whole body of the compass was suspended by a thread to avoid influence of the instrument weight to the heart. Thus the change of distance between the legs was influenced as little as possible except by the change of the segment length investigated. Drugs were injected into the ear vein.

Effects of epinephrine, isoproterenol and acetylcholine on the heart movements registered by the compass are shown in Figs. 5, 6, 7 and 8, with blood pressure and electrocardiogram.

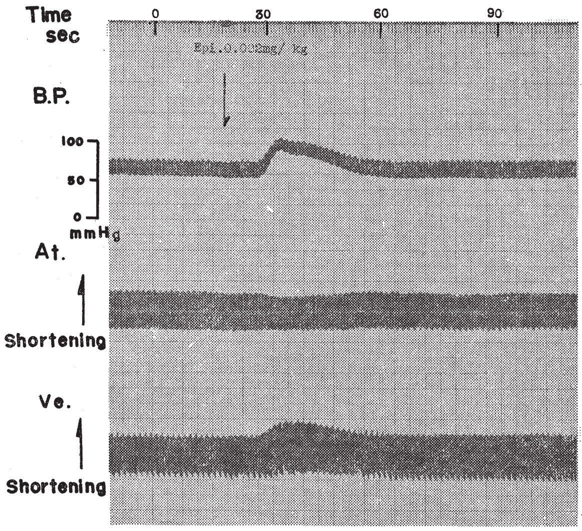


FIG. 5. The effects of epinephrine in the rabbit.
B.P.: blood pressure, At.: left atrial movement, Ve.: left ventricular movement.

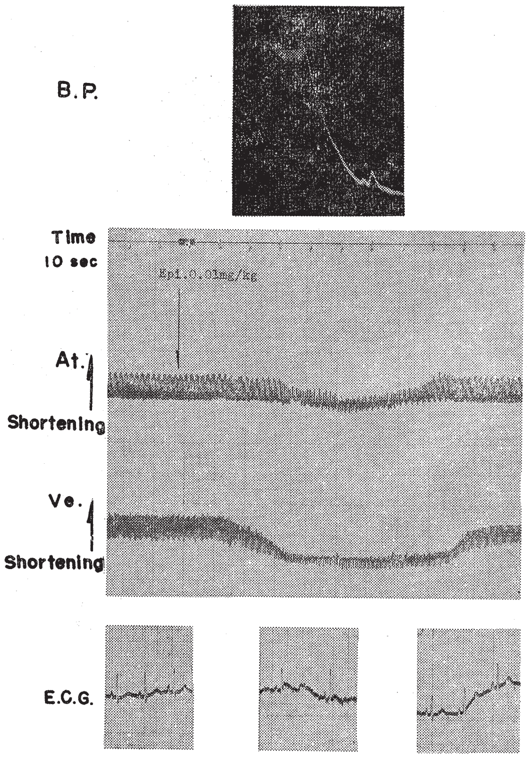


FIG. 6. The effects of epinephrine in the rabbit.
B.P.: blood pressure, At.: left atrial movement, Ve.: left ventricular movement.

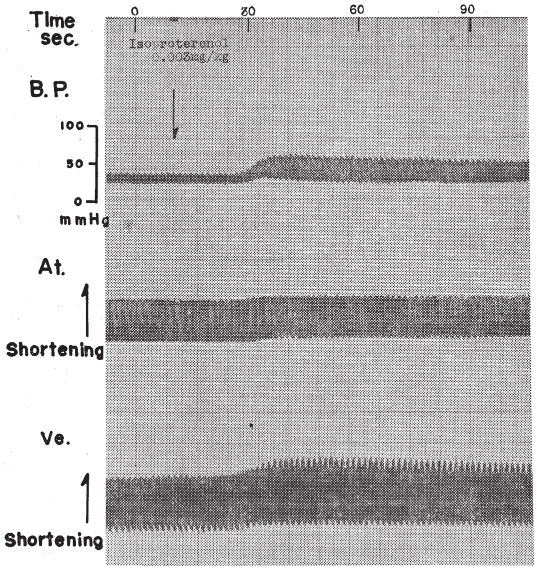


FIG. 7. The effects of isoproterenol after administration of hexobarbital sodium 5 mg/kg in the rabbit.
B.P.: blood pressure, At.: right atrial movement, Ve.: right ventricular movement.

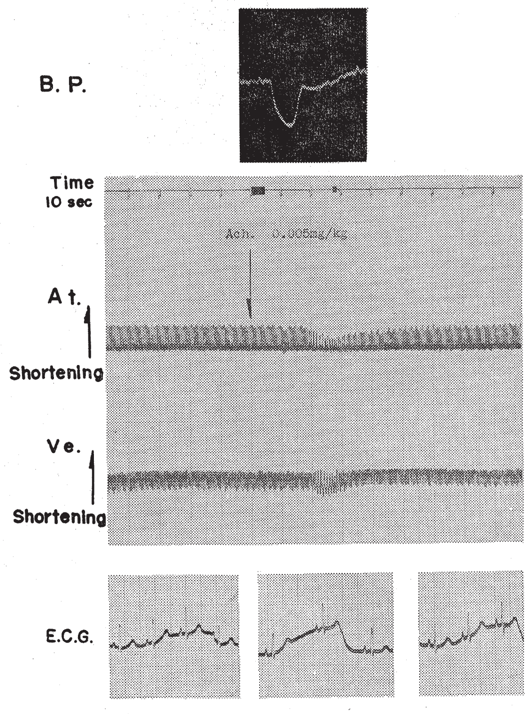


FIG. 8. The effects of acetyl-choline in the rabbit.
B.P.: blood pressure, At.: left atrial movement, Ve.: left ventricular movement.

*2) In Frogs*

Frogs (*Rana nigromaculata*) and bullfrogs were used. The brain and spinal cord were destroyed, chest opened and pericardium excised.

The same compass as that used in rabbits was attached to the ventricle of the frog, as described in the experiment in rabbits, except that the distance between the legs was set to be about 5 mm. The instant adhesive was used for attaching.

In the case of the bullfrog, the atrial movements were also attempted to register but it was found that even this apparatus was too heavy for this very thin, delicate organ of the frog.

The ventricle movements were able to be registered for a long time without disturbance of the heart function. Injection of drugs was made into the abdominal vein.

Effects of the infusion of Ringer's solution on the bullfrog's heart are shown in Fig. 9. In Fig. 10, the effect of epinephrine on the frog's heart is shown.

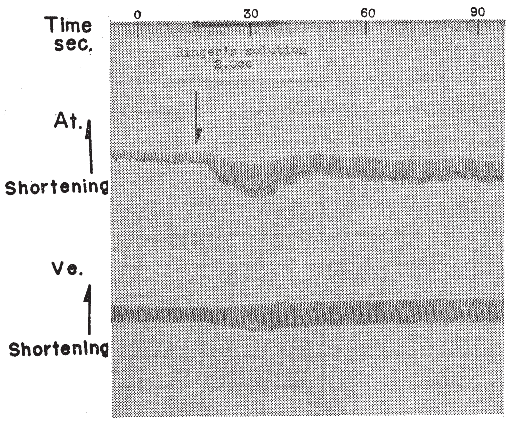


FIG. 9. The effect of the infusion of Ringer's solution into the abdominal vein in the bullfrog.

At.: atrial movement, Ve.: ventricular movement.

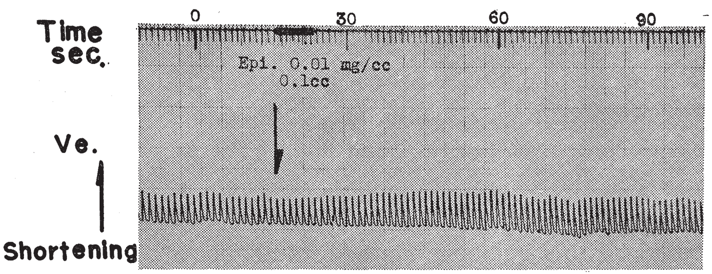


FIG. 10. The effect of epinephrine on the ventricular movements in the frog.

## DISCUSSION

As stated before, besides the measurement of the contractile force or tension, the direct registration of the natural excursion of the heart is often required to observe the heart function. Several methods have already been devised for this purpose. We believe we have now developed it further. First, attaching of the apparatus and its moving gave little load to the muscle investigated. Namely, the apparatus itself is light (about 3 grams) and suspended lightly, and therefore, it does not disturb the natural heart movements. Second, registration is not disturbed by the deflection and rotation of the whole heart directly or respiration and others indirectly, because the compass or rigid leg itself can move with such movements. These characteristics make this compass possible to be applied not only to the ventricle of larger animals, but also to the ventricle and auricle of a rabbit's heart, and to the smaller heart, for example, even a frog's heart. Of course, surgical operations are very simple to attach this compass. Myocardial segment length recorder by Linden and Mitchell[12] is considered to be one of the useful methods in the point that it does not hinder the natural movement of muscle segment, but the measurment must be made during the stoppage of the artificial respiration because the apparatus itself is fixed. Mercury gauge modified by Rushmer[10] from Whitney's plethysmograph[11] is also an excellent method to measure the length change of ventricular muscle in dogs and cats but it is, of course, difficult to be applied to the auricle of the smaller animals. Third, frequency character of this apparatus is considered to be fairly high because its moving parts are very light in weight, and only little force is required to deflect the legs' distance. Cushny's or other levers are unsatisfactory in this point.

We should like now to consider what the figure registered by this apparatus signifies. As understood easily, amplitude in these records shows the excursion of the muscle segment, upwards shortening or contraction, and downwards lengthening or dilation; and upper tip is the maximum contractory state, and lower tip is the maximum dilatatory state in that cardiac cycle. Thus upper and lower lines made by many amplitudes move themselves also upwards and downwards; the former shows decrease and the latter increase of the chamber (auricular and ventricular) volume in end-systolic and -diastolic state. Here we could not calculate accurately the change of volume (cardiac output) only from the amplitude between two lines, because it depends also on the level of its maximum diastolic state. However, if the maximum systolic or diastolic state was constant and one of the two lines continued to be the same in height, the change of amplitude could show the cardiac output change qualitatively. Henderson already devised his cardiometer[13], and the figure registered by this valuable method could show the volume change of the ventricular chamber. Unfortunately, it does not show the change of one chamber, but of both, and it would be difficult to be applied to the smaller animals.

In some experiments we recorded changes in the heart movement with our apparatus and the blood pressure, simultaneously recording changes in cardiac output by means of electromagnetic flowmeter and ventricular muscle tension by means of an arch form strain gauge. Comparison will be made among the results given by these various methods in relation to the drug action in subsequent reports.

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