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A SPECIAL METHOD FOR RECORDING THE ACTIONS OF THE HEART: THE CAIRIVIBOGRAPH AND THE VIBOGRAM *

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SOME ten years ago (1944) I conceived the idea of clamping two pie pans together with a thin, moderately flexible membrane between the pans. Into the edges, on opposite sides of one of the pans, large (1¼ inch) tubulatures were soldered so that a patient could breathe back and forth through pan A while the flexible membrane separated pan A from pan B. Thus air vibrations (both large and small) in pan A could be transmitted by the flexible membrane to pan B. Also, small tubulatures for ¼ inch rubber tubing were soldered into each pan. Through the tubulature in pan A oxygen, carbon dioxide, cyclopropane, nitrous oxide, trichloroethylene, ethyl chloride or any other volatile or gaseous substance could be introduced into pan A, so that the patient or investigator or animal might inhale any desired amount of the substance while at the same time observations could be made regarding any changes which might occur in the air vibrations within the two pans.‡ An ordinary face mask was attached to one of the large tubulatures in pan A, and thus the patient could breathe directly back and forth through the mask and pan A. If the patient voluntarily stopped breathing for five or ten seconds, preferably just at the end of expiration during which time he remained motionless with the vocal cords and glottis entirely relaxed and with the distal tubulature in pan A momentarily closed off, it could readily be seen that air vibrations were produced within the lungs, the respiratory passages and the pans by the beating of the heart and the circulation of the blood within the heart, lungs and chest cavity.

I at first tried to record these vibrations by means of a very sensitive tambour connected to pan B which wrote on a smoked drum. This method will produce records of about 3 to 6 millimeters in amplitude, but it was obvious that the method was not sufficiently sensitive to be of use clinically. It did, however, reveal clearly the problem which was to be solved, that is, the devising of a method which would be sufficiently sensitive and flexible for immediate and efficient use in the clinic.

In the intervening years since 1944 I have made up and tried out a

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‡ Earlier workers in this general field have had such diverse objectives in view, and have arrived at such variable conclusions, that references to the literature have been omitted from this article.

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large number of devices for picking up and recording these vibrations. These devices utilize a number of electrical elements which are now well known and which produce tracings either of the displacement, or of the velocity, type. From a clinical standpoint these two types of records are equally serviceable but, practically, devices producing velocity type tracings are easier to manage and are less likely to get out of order. I have made up a number of these involving various adjustments, safety devices, and so on. To all these various forms of pick-up devices I have given the name "cairivibograph" (fig. 1) or simply "vibograph". This word is derived in highly unorthodox fashion from three other words: cardiac, air, and vibrations. The new word is not intended to produce exaltation among etymologists but simply to make things easier for the medical student who may wish to remember the process or even to discuss it with others. According to this nomenclature the record produced would be a "cairivibogram," or simply a "vibogram". The air waves themselves would be "cairivib" waves. They are constantly being produced throughout life.

The pick-up device or vibograph is used with any type of equipment which will make a graphic record of variations in a very small electric current. In practice this will very generally be an electrocardiograph or an oscilloscope. Permanent records may be made quickly and easily with an electrocardiograph in connection with an electrocardiogram. The vibograph is connected through lead I with the regular patient cable to the electrocardiograph (fig. 2). To the face mask is (adjustably) fitted a special breathing valve carrying a tubulature from which a rubber tube passes to the vibograph. If the lid of this valve is left open, the patient can breathe back and forth into the open air; but if the valve is closed by pressing down the lid and the patient holds his breath for five or ten seconds, then the cairivib waves will be transmitted through the rubber tubing to the vibograph in which a vibrating electric current which corresponds to the beating of the heart will be generated and can at once be recorded through lead I in the electrocardiograph. The record (vibogram) will differ from all other types of records made from the heart. If a very special fitting be connected to the face piece, then the patient may breathe normally back and forth into the air while the cairivib waves are led off from a side tube to the recording mechanisms. In this case the large respiratory air waves may be filtered out electrically from the recorded heart tracing. In actual practice, however, I have generally found it more satisfactory for the patient voluntarily to cease breathing for a brief interval while the record is made.

A *special technique* should be followed in making the records: The patient should be at rest for some time and should lie supine and breathe as nearly normally as he can. The mouth should be kept closed, with the tip of the tongue resting gently against the posterior surface of the lower incisor teeth. The patient may preferably hold

FIG. 1. The cairivibograph. The face-piece and rubber tube can be placed in the metal carrying case when not in use. Note the hinged lid on the fitting at the top of the face-piece. This lid is closed by pressing down for the brief interval during which the record is taken. Binding posts at the left hand end of the carrying case provide connections to lead I of the electrocardiograph.

the mask himself on his face, air-tight, and practice for a little while breathing through the mask with the valve open. He will soon become accustomed to this maneuver and he can then try a few times to cease breathing while he closes the breathing valve by pressing it down with one finger. As soon as he needs to breathe he opens the valve and at once breathes back and forth into the open air. With a little practice and some instruction the technique is quickly learned.

The records are made with the patient breathing through the nose

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while his mouth is kept shut. The reason for this is that the dead space in his lungs and respiratory passages should not be altered but should remain perfectly constant for the brief interval during which the record is made. If the patient tries to take a record with his mouth open he will almost certainly close off or move his soft palate, or make swallowing movements, or move his pharynx, larynx, diaphragm or even his chest walls. While with practice and for special investigations one may overcome these difficulties, still in clinical work it is much easier to close the mouth and make the records through the nose. It is best to make the record just after the end of a normal expiration because at this time the vocal cords and glottis are relaxed and the airway is entirely open from the nostrils down into the lungs. The patient is just ready to inhale, but he delays the actual inhalation for five or ten seconds while the record is made.

The character of the cairivib waves depends on many factors: the heart and its congenital or acquired status or pathology; the lungs, (normal or abnormal); the movements of the blood within the heart, lungs and chest cavity; and the status and condition of all blood vessels of the organs within the chest, and of the venae cavae and the aorta

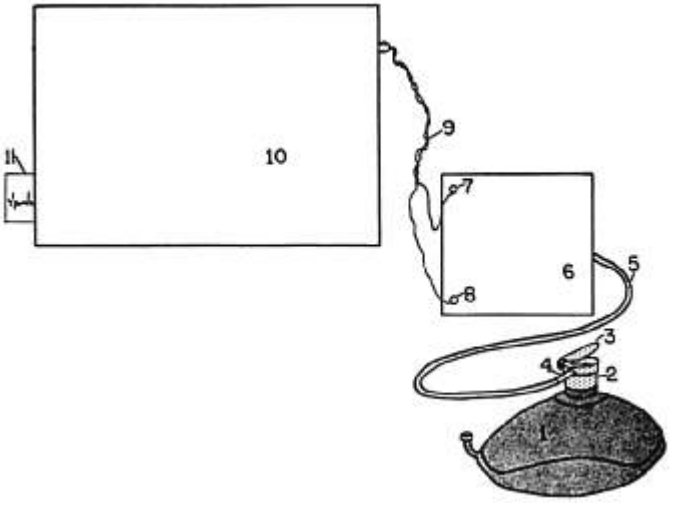

FIG. 2. Diagrammatic arrangement of the equipment: (1) face mask; (2) metal fitting, which carries the tubulature (4) and the lid (3) which is held open by a spring; (5) rubber tube connecting the mask to the cairivibograph (6); (7) and (8) are binding posts from which wires (9) lead to the electrocardiograph (10). These wires (9) represent lead I in the patient cable. (11) Emerging record.

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and their branches. With such a conglomeration of factors one might question whether or not anything useful could be learned from a study based on all these diversified phenomena. In answer to this, one may recall that most other information which one can obtain about the heart and circulation is also dependent on many variable factors, and all observations should be considered in relation to each other and to the patient as a whole. While it is impossible now to determine how much or how little useful information may be obtained by this method, still it may be noted that new observations are yet being made from time to time with the electrocardiograph which was introduced by Einthoven in 1902.

In the laboratory especially, new drugs may be studied by this method. An animal may be kept quiet if need be by curare or one of its congeners. And with a few special fittings the action of the heart may be studied with the lungs inflated or deflated. This method affords one of the most direct approaches to the heart and its activities. Perhaps only by opening the chest and attaching a recording instrument directly to the heart, or by holding the beating heart in the hand, could one obtain any more direct information. But such procedures are not well adapted for clinical use. This process may be considered as somewhat analogous to catching a fish with a hook and line. The force and direction and any eccentricities of the movements of the fish can readily be appreciated by the fisherman.

Clinically, this process can be of diagnostic use in a variety of conditions: such as in the ordinary cardiac arrhythmias, patent ductus arteriosus, septal defects between the auricles or between the ventricles, coarctation of the aorta, cor pulmonale, heart action during cardiac catheterization, valvular incompetancies, certain drug reactions, anginal attacks, hypertension or hypotension, time of beating of right and left ventricles (with or without synchronicity), coronary involvement, aneurysm, pericardial effusion, hyperthyroidism, constrictive pericarditis, and mitral valvectomy.

It seems highly probable that certain involvements of the lungs must be reflected in records made by this process. Among these may be mentioned absence of one or more lobes, extensive involvement by tumor or some infectious process, bronchiectasis, asthma, firobsis, and various other conditions. The method also may be used to make follow up records in such conditions as coronary involvement or other chronic disturbances or to watch the results of treatment.

By special electrical connections from the patient to the electrocardiograph the exact instant of cardiac systole can be indicated in the vibogram by superimposing a very small R-wave in the record.

The altitude of these tracings may be made to vary with the preference of the operator and the sensitivity of the recording instruments. I have found that an altitude of about 1½ inches is satisfactory for the highest waves, but they can be made much larger.

I have felt that some simple easily remembered system for naming these waves might be helpful, and I accordingly suggest that they be numbered (fig. 3). The waves bear a certain resemblance to ballistocardiographic waves. Each wave, of course, is made up of movements in two directions, upward and downward. At the instant of change in direction of movement the record will register an acute angle. It is these angles that may be numbered. At the beginning of each complex in the vibogram there is a short downward movement followed by a long upstroke. This sharp downward angle corresponds closely to the I wave in the ballistocardiogram. I suggest that this first sharp downward angle be numbered 1. The following long upward stroke will form a second angle as it starts to descend at the top of the record. This second angle (probably the J of the ballistocardiogram) will be number 2. Each following sharp angle is numbered in turn. By this

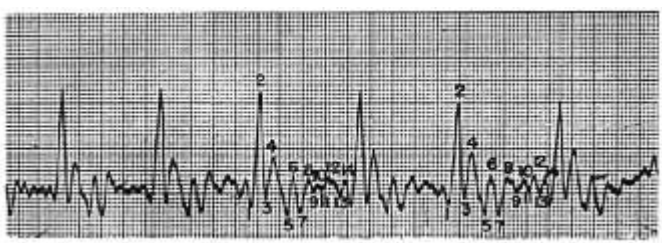

FIG. 3. A cairivibogram, showing the method of numbering the waves. In this tracing there are 14 waves to each cardiac cycle. I believe this represents the normal (resting) number. Under normal (resting) conditions I believe that the tracings for all cardiac cycles should be practically exactly alike, but I have generally not been able to get perfect repetitions for two reasons: first the unsatisfactory conditions under which I have had to work, and second, difficulties with the electrocardiograph (AC interference and wandering of the writing arm). The record in Figure 3, with the subject at rest, was followed shortly after by fig. 4, after exercise.

system all odd numbers will appear at the bottom of the tracing, the even numbers at the top. It is probable that the number 1 angle represents mainly the contraction of the auricles whereas the number 2 angle (or the upstroke from number 1 is the result of ventricular contraction. This first upstroke is usually the largest in the series, but there may be exceptions to this rule.

I have been interested in the number of waves which should appear in each cardiac cycle. While I have not had an opportunity to make extensive observations in this matter, still it has seemed probable to me that a perfect record made from a normal individual at rest will show 14 angles, that is, 7 above and 7 below. But I have seen tracings from time to time which show, in decreasing order, 12, 10 or even 8 waves. It is the smaller waves at the right of the record that either

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disappear or become blended with others. I suspect that these small waves are very important and that they may represent the finer adjustments of the whole circulatory mechanism to meet sudden emergencies, exercise, emotional states, overventilation, and so forth. They may be very important in certain pathological conditions. For this reason I have felt that the numbering of these waves would probably

FIG. 4. After exercise (climbing up and down 27 stair steps). Made from the same subject as in figure 3 but a few minutes later. Note there are 10 waves to each cardiac cycle here, but many of these are obscured by wandering of the writing arm.

furnish the easiest method of referring to them. A word of caution is necessary here. With different vibographs, or different adjustments, I have seen variations in the number and shape of waves recorded in the tracings (figs. 4, 5). Obviously this calls for complete standardization of all equipment. The special clinical significance which may attach to such physiological phenomena as the small waves

FIG. 5. A vibogram showing 12 waves to each cardiac cycle. Note that number 4 wave is slightly higher than number 2. Could this mean non-isochronicity in contraction of the ventricles?

(10, 12, 14) of the vibogram has recently been emphasized by Starr (1) in his excellent essay on the ballistocardiogram.

With proper adjustments of the vibograph, records may be made with the patient in *any* position. Elderly patients, if sufficiently intelligent, to cooperate, give excellent records. The patient is not injured or pained in any way.

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It should be noted that the electrocardiogram shows 5 waves, *p*, *q*, *r*, *s*, and *t*, whereas the vibogram may show as many as 14. Apparently these extra waves represent circulatory phenomena occurring within the chest but which cannot be picked up by the electrocardiograph.

Records made by this method should probably be correlated with the ballistocardiogram rather than with the electrocardiogram, for the diaphragm undoubtedly acts like a rubber membrane to transmit vibrations from the abdominal aorta and other viscera up into the chest.

SUMMARY

This paper describes a special method for recording the activities of the heart and indicates their physiological and clinical significance. The application of the method to the study of such drugs as the anesthetics, or substances which act on the circulation or respiration, is discussed. The method may be used in both human and animal investigations.

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