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The Analytical Investigation of the Normal Heart Sounds.

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I. Introduction.

Analytical investigations of the heart sounds were conducted by many early researchers who attempted to study the acoustic phenomenon produced by the heart action; their aim was to observe precisely the relations between the heart sounds and the cardiac events by this method and to explain the mechanism by which the sounds are produced. But their experiments were not fruitful owing to the difficulty of obtaining perfect records of the heart sounds.

However, the method of recording has been remarkably improved by the application of the principle and the technique of radio telephony, which has made conspicuous progress in recent years.

In the preceding report, the writer has described the method of recording, designed by himself, in which this principle is applied. The records obtained by this method are perfect and sufficiently accurate for practical application; the analytical investigation of them was successful and very interesting relations between the sounds and the apex beat were found.

The aim of the present paper, the first report on the researches into the acoustic phenomena of the heart under various conditions, is to give the results of the analytical investigation of the normal heart sounds.

II. Method.

1. Recording of the heart sounds.

A detailed description of this method was given in the preceding report "Graphical Registration of the Heart Sounds". An electromagnetic transmitter, which was reconstructed from a head-phone receiver, was used as the receiver of the heart sounds. A thick ebonite contactor was glued on to the vibrator of the transmitter, and was made to act as a point contactor of the vibrator when the transmitter was applied directly to the chest of the examinee. The transmitter was applied to a fixed point on the chest by tying it to the chest with elastic rubber tape.

The transmitter was excited only by the acoustic vibrations of the chest, without any interference of mechanical vibrations such as the apex beat. The current excited in the transmitter, corresponding to the heart

sounds, was passed through four stages of amplification, and recorded by an oscillograph. The correctness of the operation of the apparatus and the accuracy of the records obtained, were confirmed by simultaneons listening-in to the actual sounds reproduced through a head-phone receiver which was installed in the output of the amplifier parallel to the oscillograph.

As a rule, the records of the heart sounds here shown and described, were obtained at a point on the fifth costa, about the middle, between the left mammary line and the sternum. In some cases, they were obtained also at other usual auscultatory points of the heart sounds, in the same person, for the purpose of examining how the records varied according to the point of auscultation.

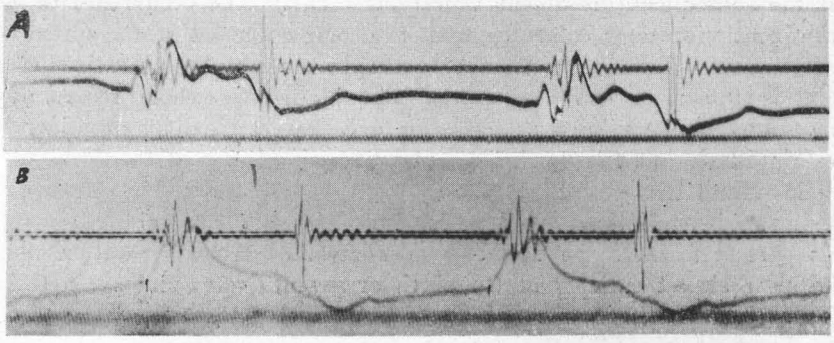
2. Recording of the apex beat.

The apex beat was recorded by *Frank*'s capsule. A tambour for the apex beat was connected to a *Frank*'s capsule with a rubber tube 100 cms. long. The delay of this record on the polygram was found by measurement to be about 0.003 sec. The tambour was applied in the same manner as the transmitter.

III, Results.

Two examples of the records of the normal heart sounds are shown in figure 1.

Fig. 1.



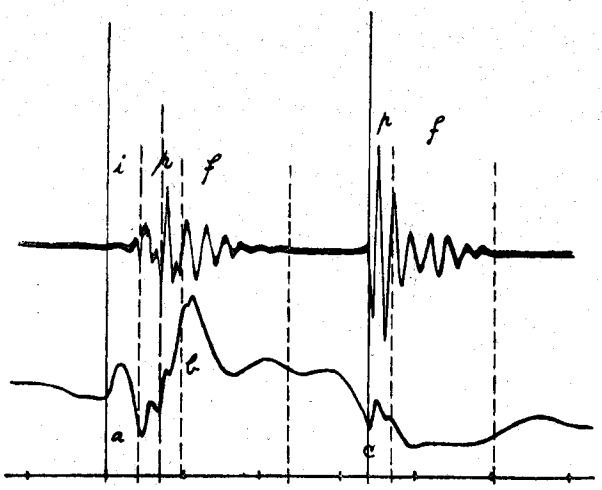
The features of the record of each cardiac cycle are quite constant, though some slight variations may be observed. This is the case in all records of the normal heart sounds.

For convenience in explaining the details, a copy of the record (A) is given in figure 2.

1. First sound.

The straight part of the line in the record, which shows that there

Fig. 2.



is not yet any acoustic vibration in the heart is disturbed by a very slight movement at the same time as the the wave *a* of the apex beat commences, and thereafter, a group of vibrations appears.

The vibrations become rather suddenly marked about 0,04 sec. after the initial vibration. The vibrations thereafter are quite irregular owing to the superposition of rapid oscillations of relatively small amplitudes. The frequency of the fundamental vibrations is found by measurement to be about 60 per sec. and these vibrations continue for about 0.0 3 sec. till the subsequent prominent vibrations occur. The occurrence of these prominent vibrations coincides with the commencement of the aortic wave *b* of the apex beat. The change in the features of the vibrations at this point is the most conspicuous and abrupt in the whole record of the first sound. The vibrations hereafter are characterised by prominence in the amplitudes at the beginning and the simplicity of the form of the whole vibrations except the initial two waves, on which a number of small rapid oscillations are superposed. The fundamental frequency of this part is found to be about 48 per second. These vibrations finally disappear almost entirely at the sixth or seventh wave and again the line of the record returns to rest till the outbreak of the second sound.

In short, the vibrations of the first sound appear some what at the same time as the commencement of the apex beat and they can be divided into three parts, namely the initial, the principal and the final part. The principal part is sub-divided into the first and the second section. The occurrence of the latter corresponds exactly to the commencement of the aortic wave.

This manner of investgation was applied to all the records of the normal first sound, and the following data were obtained. The initial part appeared almost at the same time as the commencement of the apex beat, but in a few cases the initial vibration preceded the apex beat by

0.02 to 0.03 sec. and in other cases this part was scarcely distinguished. Its duration was found by measurement to be 0.00 to 0.05 sec. The occurence of the first section of the principal part was always rather clear and preceded the commencement of the aortic wave *b* by 0.01 to 0.03 sec. But the whole duration of the principal part could not be measured exactly in some cases, because the change from this part to the final part was some times insignificant. But it can be accepted as 0.02 to 0.09 sec. The final part was found to be about 0.09 to 0.18 sec. The frequency of the fundamental vibrations was as follows:- the initial part 25 to 40; the first section of the principal part, 50 to 100; the second section of the principal part and the final part were the same, namely 25 to 60.

2. Second sound.

The record of the second sound, as is shown in the figure, is quite differnt in appearance from that of the first sound. Its form is very simple as compared with that of the first sound. It will be found by close investigation that it has no significant vibration corresponding to the initial part and the first section of the principal part of the first sound. But it shows a prominent oscillation after a very slight sign of movement of the straight line. This prominent vibration is followed by a number of less prominent vibrations of the same fundamental frepuency showing quite a similar appearance to the final part of the first sound. So, the record of the second sound can be divided also into the principal part and the final part. The total duration of the second sound is about 0.145 sec.

In all the other cases observed, the duration of the principal part was about 0.015 to 0.03 sec., and that of the final part was 0.08 to 0.16 sec. The commencement of the second sound coincided with the incisura of the apex beat.

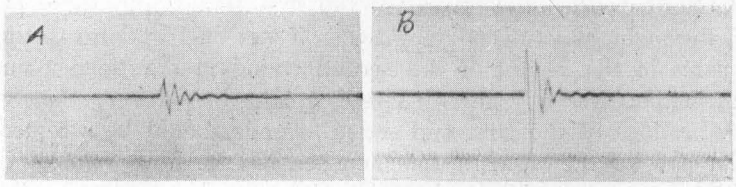
IV. Consideration.

Battaerd divided the record of the first sound into three parts, the initial, the main, and the end vibrations. Later on Hess also distinguished three parts in the record of the second sound in the same manner, but the distinction was not clear. Hess explained however, that only the main vibrations of the first and second sounds should be accepted as the essential part of the acoustic phenomenon of the heart which could be perceived by auscultation, and that the initial and the end vibrations were not audible on account of the lack of intensity, though they had the character of acoustic vibrations. But this explanation can not be accepted as correct, because the harmonics accompanying the fundamental vibrations of those parts were not considered by him. In the writer's experiments vibrations of such low frequency as 32 hertz were still audible when they were represented in the record with the small amplitude of 1 mm.

Hess concluded also from his experiment that the main vibrations occurred at the last moment of the period of rising tension in the ventricle, just before the opening of the semilunar valves. Other researchers also examined the durations of those parts and their time relations to the events in the cardiac cycle. But their results were rather conflicting. For instance Ohm, and later on Benatt, attributed the occurrence of the initial vibrations to the contraction of the auricle. Scütz has reported recently that the most conspicuous vibrations of the first sound in the apex and the aortic orifice do not occur at corresponding times but appear in the apex in the period of rising tension in the ventricle before the ventriuclar discharge and in the aortic orifice the in period of ventricular discharge. He explained that the first sound was composed of two component acoustic vibrations occurring in the period of rising tension in the ventricle before the ventricular discharge and in that of ventricular discharge respectively. In the early experiment carried out by Einthoven and Geluk, it was found that the first sound in the aortic orifice commenced 0.06 sec. after the first sound in the apex.

The results obtained by the writer are as mentioned in the preceding article, namely, that it was very easy, and also convenient, to divide the record of the first sound into two parts at the point where the aortic wave of the apical beat commenced. This point of division was always distinct in the records of the normal first sound without exception, because, at this point the fundamental frequency of the vibrations occurring thereafter were always different from those of the precending ones. The distinction of the initial and the principal parts was however, rather clear. But the interval between this point and the commencement of the ventricular discharge varied considerably. This fact, the writer believes, is worth noticing, and it will be discussed further in another description. But the change from the principal part to the final part was not so clear and sometimes quite imperceptible owing to the superposition of relatively marked rapid oscillations or to the very simple form of the principal part.

Fig. 3.



The writer was especially interested in the fact that the features of the second sound resembled those of the vibrations of the first sound in the ventricular discharge, the second section of the principal part and the final part. The curve of the second sound is composed of two components at least, the one, being slow vibratins remaining rather long and the other being raped vibrations disappearing rapidly. These vibrations

occur at the same time, so that the principal part of the second sound is complicated but the final part is simple. To find an explanation of this fact, an experiment with a model was carried out. In the first place, the proper vibration of the model, consisting of a tambour, a rubber tube and a *Frank*'s capsule was recorded as shown in figure 3. A. Then the membrane of the tambour was struck gently, and the vibrations of the model were also recorded as shown in figure 3. B. This record is quite similar in appearance to those of the second sound. This analogy can be applied to the vibrations of the first sound in the ventricular discharge also.

The fundamental frequency of the vibrations in the ventricular discharge of the first sonnd is almost the same as that of the second sound though it is slightly more rapid than that of the second sound.

The records of the heart sounds did not vary conspicuously accordiug to the point of auscultation, except in the principal part of the first sound. The first section of the principal part was relatively prominent in the record obtained on the apex and the reverse fact was observed in the record on the aortic orifice i. e. the second section was more prominent.

This fact may also serve as a basis for dividing the record of the first sound in the manner mentioned above.

V. Conclusion

The record of the first sound may be divided into three parts according to its form, the initial, the principal, and the final part. The initial part probably occurs at the same time as the commencement of the apex beat, but this part can not be distinguished in some cases. The commencement of the principal part is always clear. But it has no definite time relation either to the commencement of the apex beat, or to the commencement of the ventricular discharge. However, the vibrations in the principal part always change at a point coincident with the commencement of the aortic wave of the apex beat, so that, the principal part can be subdivided at this point into the first and the sesond sections. The second section has the same fundamental frequency as the final part and it can be distinguished from the latter merely by the superposition of rapid oscillations.

No fundamental difference between the records of the first sound obtained on the apex and the aortic orifice can be found, but in the records obtained on the apex the first section of the principal part is rather prominent and in those obtained on the aortic orifice, the second section.

Therefore, it will be also very convenient for the purpose of investigation to divide the record of the first sound into two parts belonging to the period of rising tension in the ventricle before the ventricular ejection and to the period of the ventricular ejection respectively.

The second sound appears abruptly as the same time as the incisura

of the apex beat and can be divided in two parts, the initial, and the final. The features of the second sound are quite similar to those of the first sound in the ejection phase.

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