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About the Production of the Normal Heart Sounds.

By

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The obstacle which prevented the development of researches and experiments of the acoustic phenomena of the heart was the lack of a perfect method of their graphical representation which is indispensable for the analytical investigation and for the study of the time relations between the sound phenomena and the events in the cardiac cycle.

However, the method of graphical representation was remarkably improved by the application of the technique of radio telephony which has made a rapid progress in recent years. And concequently, the writer has obtained accurate records of the heart sounds, with an electromagnetic transmitter, an audiofrequency amplifier of four stages and an oscillograph. Thus the normal heart sounds could be observed in the minute. And the changes in the sound phenomena according to the varieties of the physiological and the pathological conditions of the heart caused by various influences, were investigated. It was found that the acoustic phenomena of the heart in pathological conditions such as mitral insufficiency, aortic stenosis and so on, showed characteristic features and that even in the normal heart, the features of the sounds vary rather considerably according to the condition of the heart beat. The results obtained in each of those investigations were described in detail in the previous reports.

In this paper, the writer aims to describe the causation of the normal heart sounds.

1) The first sound.

Rouanet explained simply that the first sound was produced by the vibrations of the atrioventricular valves, in consequence of the sudden straining of them at the beginning of the ventricular contraction. In opposition to this idea, some other researchers such as Ludwig and Dogiel considered the first sound to be caused by the cotration of the muscle fibres, as it is observed when the skeletal-muscles contract. Their argument was based upon the following fact that the sound phenomenon could be observed when the exstirpated and empty heart contracted and even in experiments when the valves were cut off or prevented from their normal display in various manners. Hess however, not inclining to either of these contentions, explained the first sound as the "Wandspannungston". He explained that the first sound was caused by vibrations of the whole heart provoked abruptly at the end of the period of rising tension in the ventricle just before the opening of the semilunar valves. On the other

hand, some authors considered that the opening of the semilunar valves and the rapid outflow of blood from the ventricle into the arteries caused sound vibrations. Einthoven and Geluk observed that the first sound in the aortic orifice was delayed by 0.06 sec. as compared with the first sound in the apex, and considered that the commencement of the first sound in the aortic orifice was closely related to the commencement of the ventricular ejection. Bamberger had also the same opinion. And other researchers such as Sahli, Gerhaltz and others mentioned that the auscultatory tone quality of the first sound was altered at the commencement of ejceton or that the features of the graphic record of the first sound changed at this point. Schütz divided the record of the first sound into two components— "Anspannungs und Austreibungs-Komponent" —and pointed out that the former was more prominent in the apex while in the aortic orifice the latter was more prominent.

But some of these contentions were based upon experiments which were carried out in an unsuitable manner. For instance, the acoustic phenomena perceived in an extirpated heart can not be accepted immediately as identical to the normal heart sound under normal conditions. Because, as already mentioned in the previous report, the acoustic phenomena varied rather conspicuously with slight changes in the condition of the heart beat even in the normal heart. So, the acoustic phenomena observed in those experiments may be accepted as special cases but they can not be applied to all other cases. The most important and indispensable matter in the investigation into the normal heart sounds is to examine these phenomena under strictly normal condition. Otherwise, nothing can be observed regarding the character of the normal heart sounds or the time relation between the sounds and the events of the cardiac cycle. Investigation of the varieties of the acoustic phenomena according to the various conditions of the heart can also serve as an important key to know the actual cause of the normal heart sounds.

The record of the normal heart sounds.

The normal first sounds occupy more than the first half of systole. The first sound can de divided into three parts according to its appearance— the initial, the principal and the final part. The principal part is subdivided into the first and the second section at the point corresponding to the commencement of the ventricular ejection. The commencement of the initial part shows no difinite relationship to the commencement either of the apex beat or of the ejection phase, but it appears slightly later than the apex beat. The vibrations of this part are slow and irregular and increase in amplitude gradually till the first section of the principal part appears. This transition from the initial to the principal part is always distinct. It is marked by abrupt increase in the amplitude and the frequency of the vibrations. This point preceded the commencement of ejection by about 0.01—0.03 sec. The frequency of the vibrations of this first section is about 60—100 per sec. These vibrations never show a crescendo form. The vibrations in the second section also show a decre-

secondo form and a number of small rapid vibrations are superposed on them. The following final part is the most simple and regular part of the first sound. The fundamental frequency of the vibrations of the final part is the same as that of the preceding second section, namely, 30—60. The transition from the second section of the principal part to the final part is therefore not very distinct in some cases.

In short, the first sound always shows significant changes in the vibrations at two points, the first change at the occurrence of the first section and the second change at the second section corresponding to the commencement of the ventricular ejection. The duration of the first section varies between 0.01 and 0.03 sec.

The second sound resembles the first sound after the second section of the principal part, and it is also divided into two parts, the principal and the final part. The fundamental vibrations are almost the same as those of the corresponding part of the first sound. The transition from the principal part to the final part is also indistinct in some cases. The commencement of the second sound coincides with the incisura of the apex beat.

These successive changes in the feature of the normal first sound can not be explained by a simple mechanism. That the atrioventricular valves play no important rôle in the production of the first sound is confirmed by the fact that the record of the systolic murmur in mitral insufficiency shows no modification of the fundamental vibrations of the normal first sound, but small rapid vibration due to the murmur appearing in the whole record. Regurgitation or incomplete closure of the atrioventricular valves can not affect the fundamental form of the normal first sound. The contraction of the muscle also can not be accepted as the actual cause of these vibrations of the first sound, because if the first sound is produced actually by the contraction on the muscle, the sound must be most intense in the relatively later period of systole when the ventricle contracts to its maximum. But the first sound is found in the early time of systole, when the initial deflections of the electrocardiogram are found, while there appear no significant vibrations corresponding to any other deflection of the electrocardiogram. But the writer does not ignore the fact that a certain weak sound phenomenon may be produced by the contraction of the muscle as Ludwig and Dogiel have observed. But as already mentioned, such a phenomenon observed under special conditions has nothing to do with the explanation of the normal first sound; it means only that a very weak component of the heart sound, which is produced by the muscular contraction, can be perceived under such special conditions when the other important components of the heart sounds are entirely extinguished. In fact such a weak component of the sound has no connection with the fundamental vibrations of the normal heart sounds.

Therefore, it requires another explanation.

According to Hess, the vibrations of the first sound are caused by the mechanical events of the heart in the early period of systole. He

divided the record of the first sound into three parts— "Vorsegment, Tonsegment" and "Nachsegment", and explained it as follows; — "Als ursächliches Moment kann weder das Zuschlagen der Klappen noch eine direkte Tonerzeugung durch den Muskel in Frage kommen. Als wesentlich erkennen wir dagegen eine kurze Phase der Systole, die der isometrischen vorangeht, in der sich der Herzmuskel fast widerstandlos kontrahieren kann. Sie kommt dadurch zustande, dass aus der diastolischen Form des Herzens heraus eine Formveränderung möglich ist, welche bei konstantem Inhalt zu kleiner Oberfläche der Herzhölen überführt. Diese mit einer Verkürzung der Muskulatur einhergehende Einstellungsbewegung findet ihren Abschluss, wenn die kleinste Oberfläche erreicht ist, welche die gefasste Ventrikelfüllung bei der gegebenen Struktur der Herzwandungen einnehmen kann. In diesem Moment straffen sich alle die die Ventrikelhöhlen begrezenden Teile plötzlich über dem inkompressiblen Inhalt an, wodurch die Bedingung für die Erzeugung der im ersten Herzton gehörten Schwingungen gegeben sind. Das Zusammenlegen der Segelklappen erfolgt früher und tonlos, weil in dieser Phase die zur Tonerzeugung nötige Kraft noch fehlt, ebenso die Spannung, welche einem schwingenden Substrat die Fähigkeit zu frequenten Schwingungen verleiht. The first section of the principal part may cerrespond to the "Tonsegment" of Hess, because it is distinguished from the preceding part by an abrupt change in the vibrations. But it is to be noticed that the first section always precedes the ventricular ejection by 0.01—0.03 sec. Hess considered that the semilunar valves opened at the same time as the occurrence of the Tonsegment. In the writer's record, however, there occured again prominent vibrations of the second section at the commencement of ejection.

The first section of the first sound indicates the limit of the ventricular contraction without a change in volume but with a rise in the inner pressure of the ventricle. At the beginning of the ventricular contration, the heart form is changed rather abruptly from the greater surface to the smaller manifesting the tension of the heart wall with regard to its content. This motion of the heart causes the vibrations of the initial part, so that the vibrations of the initial part can occur at various time early in the systole according to the vigorousness of the ventricular contraction. When it reaches the limit, the motion of the heart is hindered, with a shock, and there occur the prominent vibrations of the first section. But at that time the inner pressure is not yet sufficient to open the semilunar valves; some time is required, during which the inner pressure exceeds that in the arteries. This time is represented as the duration of the first section. The second section begins at the opening of the semilunar valves. It is caused by the outburst of blood into the arteries and the rapid onflow of blood in the arteries. Such a blood flow into the arteries can obviously provoke vibrations at the beginnings of the arteries. These vibrations occur with a number of overtones by which the second section is distinguished, but after the diminishing of these overtones, there remain the fundamental vibrations lasting rather longer. These vibrations are the final part, so the transition from the former to the latter is not sel-

dom indistinct. Therefore, these vibrations in the ejection phase are controlled largely by the ventricular output, as was observed after exercise. In that case, the vibrations in the ventricular ejection phase increased in amplitude considerably, showing a crescendo form, when the heart beat became vigorous. Such a modification of the normal heart sounds confirms the view that a component of the first sound is caused by the vibrations of the beginnings of the arteries provoked by the blood flow in them. In the previous paper, the writer pointed out that the vibrations of the first sound in the ejection phase show quite a similar appearance as those of the second sound. This fact serves also as a basis for the contention made above, because the second sound is obviously due to the vibrations at the beginnings of the arteries, occurring at the beginning of the diastole.

2) The second sound.

It is generally believed that the second sound is caused by the vibrations of the semilunar valves and the beginnings of the arteries occurring at the end of the systole. The blood in the arteries tends to move backwards to the ventricle in accordance with the difference in pressure between the ventricle and the arteries, when the ventricle relaxes. But such a movement of the blood is stopped by the semilunar valves the next moment, and consequently the valves and the arterial wall surrounding the blood are strained abruptly and are set vibrating, so that the fundamental vibrations of the second sound are almost the same as those of the first sound in the ejection phase, as mentioned repeatedly. The overtones appearing at the beginning, by which the principal part is distinguished are controlled largely by the properties of the valves and the arterial wall, and the blood presure. With regard to the rôle played by the closing mechanism of the valves in the production of the second sound, it is considered that the valves close spontaneously at the end of systole when the outflow of blood ceases. In fact, the vibrations of the second sound appear always abruptly with a prominent amplitude, so that the closing mechanism has probably no important part to play in the production of the second sound. But the features of the normal second sound are lost almost entirely in aortic insufficiency. So, the perfectness of the valves is very important in the production of the second sound.

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