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Introduction

THE sphygmomanometer has come into such general use in practical medicine as well as in the laboratory within recent years that it becomes imperative to establish such criteria for the determination of the blood pressure by the various methods employed, that the records of different observers may be comparable. The auscultatory method seems to be particularly reliable, but there has been no conclusive demonstration of the relation of the auscultatory phenomenon in man to the record of an accurate graphic instrument. In this paper we present the results of a comparison of the auscultatory method with the tracings from the Erlanger sphygmomanometer.

The Criteria for Maximum and Minimum Blood Pressure

The criteria used for the determination of maximum blood pressure with the Erlanger sphygmomanometer are: (1) a marked increase in amplitude of the pulsations traced on the cylinder; (2) a change in the direction of the trough line; (3) a change in form of the pulse wave. (Erlanger, 1904 and 1908.)

The minimum blood pressure is determined by the maximum oscillations obtained with the Erlanger sphygmomanometer. Howell and Brush (1901) showed conclusively by animal experimentation that maximum oscillations occur when the artery is subjected to an external pressure equal to the minimum blood pressure, and Erlanger (1904) has shown with an artificial circulation, in which was inserted a piece of artery, that maximum oscillations are obtained with his instrument at minimum pressure. Hence he considers the marked decrease in amplitude of the oscillations as an index for minimum blood pressure.

In the auscultatory method described by Korotkoff in 1905 we now distinguish the five phases first recognized by Ettinger (1907), as follows; 1st, first sounds, clear; 2d, murmurs; 3d, clear sounds; 4th, dull sounds; 5th, cessation of the sounds.

All observers agree that the beginning of the 1st phase is coincident with maximum pressure. But the criterion for minimum pressure is in dispute; such observers as Fischer (1908), Lang and Manswetowa (1908), Van Westenrijk (1908), and Warfield (1912) consider the beginning of the 4th phase as the auscultatory index for minimum pressure; while Ettinger (1907), Gittings (1910), and Goodman and A. A. Howell (1910) consider the 5th phase as the correct index.

A Brief Review of the Literature

Korotkoff (1905), as reported by Schrumpf and Zabel (1909), heard the first sound before the pulse could be palpated at the wrist, the difference being represented by from 10 to 12 mm. of Hg. He measured the minimum pressure after the "endtöne," i.e. at what is now called the 5th phase.

Ettinger (1907) compared the auscultatory with the palpatory and graphic methods. He considered the first sound as an index to maximum pressure, and the cessation of all sounds, i.e. the 5th phase, as an index to minimum pressure. Out of 232 determinations, he found that 207 times the auscultatory maximum was higher than the graphic maximum (Janeway-Massing) or the palpatory maximum (Strassburger). Out of 227 determinations of the minimum pressure he found that 130 times the auscultatory minimum was lower than the palpatory or the graphic, 18 times it agreed with them, 71 times it was higher than either, and 8 times between the two. In general he found the maximum higher and the minimum lower with the auscultatory method.

Lang and Manswetowa (1908), comparing the auscultatory method with the oscillatory method of v. Recklinghausen, found that when the first sound was heard the amplitude of the oscillations showed a marked increase. During the 3rd phase the intensity of the sounds and the amplitude of the oscillations were proportional. At the moment the amplitude began to decrease the sounds became dull, indicating the onset of the 4th phase. This first decrease in the height of the oscillations and the beginning of the 4th phase, these authors believe indicate minimum blood pressure. Experiments with two large dogs led them to the same conclusion.

Van Westernrijk (1908), comparing simultaneously the auscultatory method with Uskoff's graphic method, found no constant relation between the 4th phase and the maximum oscillations obtained with the Uskoff sphygmotonograph. (Erlanger [1908] shows that the Uskoff sphygmotonograph has a physical defect.) He observed, however, a definite relation between the auscultatory phenomenon and the oscillations of Pal's sphygmoscope. The marked increase in amplitude of the oscillations was coincident with the first sound, and the sudden diminution in amplitude occurred at the beginning of what is now called the 4th phase.

Fischer (1908), comparing the auscultatory method with the oscillatory method of v. Recklinghausen, found in 150 cases, normal and abnormal, the maximum determined by both methods agreed 58 times. In 92 cases the oscillatory maximum was higher than the auscultatory maximum. In these same 150 cases he determined the minimum pressure by both methods and found it agreed in 47 cases; in 97 cases the oscillatory minimum was lower than the auscultatory; in 6 cases it was higher. He concluded the 4th phase to be the most accurate index, and found in cases of long 4th phase a low minimum pressure, and in cases of short 4th phase a high minimum.

Gittings (1910), and Goodman and A. A. Howell (1910) consider the 5th phase as an index to minimum blood pressure. The latter even go so far as to say that "it is generally agreed that the disappearance of all sound is coincident with minimal or diastolic pressure." Gittings found in 41 cases out of 48 that the minimum pressure determined at the 5th phase averaged 15.5 mm. of Hg lower than when determined by the visual method.

When our investigation was nearly completed the preliminary report of Warfield (Oct. 1912) appeared, in which he questions the accuracy of the 5th phase as an index to minimum pressure. He used one of the tambours of the Hirschfelder attachment to the Erlanger instrument, fitted with a pipette bulb and a lever, to record the auscultatory phenomenon simultaneously with the blood pressure tracing. He publishes five records (in four of which the pressure recorded is above 150 mm. of Hg) to show the relation of the tracing to the auscultatory phenomenon. The 1st phase coincides with the graphic maximum, but the relation of the 4th phase to the graphic minimum is not clearly shown by his records, yet it is evident that the 5th phase does not correspond to maximum oscillations. He does not state how many cases he has examined. He concludes that the diastolic pressure is not usually at the point of disappearance of all sound, the 5th phase. In a still more recent article (1913) he publishes tracings which demonstrate that the 4th phase coincides with the minimum pressure as recorded by the Erlanger sphygmomanometer.

In another publication (Sept., 1912) Warfield describes his experiments on three dogs, using a method by which he can measure the diastolic pressure by the auscultatory phenomenon, taking as a point of diastolic measurement the sudden dulling of the sound. He says that the sounds heard in the femoral artery of a dog are not like those heard in the brachial artery of man, but correspond in a general way. We may infer, then, that he reads the minimum pressure at the beginning of the 4th phase. By means of a maximum and minimum manometer, and an improvised plethysmograph he shows that this sudden change of sound in the artery of a dog takes place at minimum pressure.

Brief reference may be made to the paper of Taussig and Cook (1913) in which they state that minimum pressure should be read at the 4th phase.

Subjects, Apparatus, and Method

In this investigation sixty-one healthy students were used as subjects. Four of them were women.

An Erlanger apparatus was used, to which was attached the tambour and writing lever of a pneumograph, and two signal-magnet levers, one to mark the auscultatory phases, and the other to record the height of the mercury column. (Fig. 1.) A Bowles sphygmometroscope was used for auscultation.

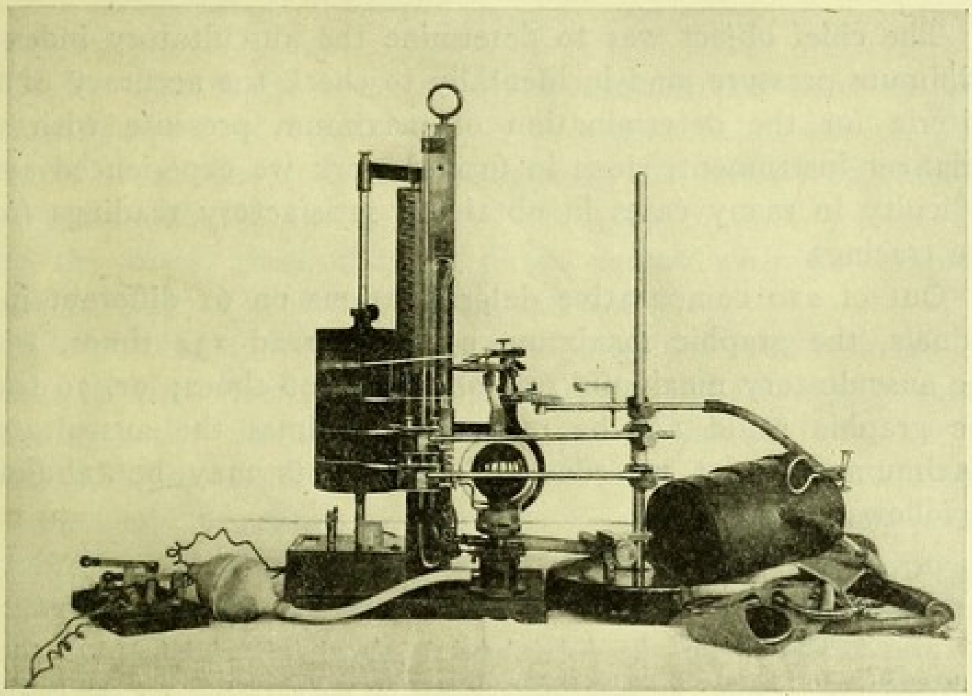


Figure 1. Arrangement of the apparatus.

All the determinations were made on the right arm of the subject, who was seated, so that the cuff of the sphygmomanometer was approximately on the level of the heart. After the levers were put in vertical alignment the pressure was raised to well above maximum and then lowered by the continuous escapement method. The observer recorded the onset of each phase, in some cases waiting one or two pulse beats to make sure of the change, and looked only at the manometer scale in order to record the height of the mercury every 5 mm., and to record the auscultatory phases without being influenced by any changes in the graphic record. In this way a comparative record was made, which showed the relation of the auscultatory phases to the changes in the blood pressure tracing. The levers occupied the same relative positions in all the tracings as shown on the accompanying figures. The first or uppermost recorded the blood pressure, the second respiration, the third the auscultatory phases, the fourth the height of the mercury column.

Results

The chief object was to determine the auscultatory index of minimum pressure, and incidentally to check the accuracy of the criteria for the determination of maximum pressure with the Erlanger instrument, since in former work we experienced some difficulty in many cases in obtaining satisfactory readings from the tracings.

Out of 210 comparative determinations on 61 different individuals, the graphic maximum could be read 134 times, while the auscultatory maximum was obtained 206 times; or, 76 times the graphic could not be read, and 4 times the auscultatory maximum was not recorded. These results may be tabulated as follows:

Number of subjects	61
" " graphic records	210
" " " " in which maximum pressure was obvious	134 or 63.3%
" " " " " " " " could not be read	76
" " cases in which maximum pressure was obvious by auscultation	206 or 98.9%

Of the 134 graphic records mentioned 128 showed the auscultatory maximum equal to or only from 1 to 5 m. of Hg below the graphic maximum; 3 times it was from 1 to 5 mm. above, and 3 times from 5 to 10 mm. below. In these 134 cases, then, the graphic maximum agreed with the 1st phase in 95.5% of the determinations.

Out of the 210 cases the graphic minimum could be read 142 times, while the auscultatory 4th phase was recorded 183 times; or, 68 times the graphic minimum could not be read; 27 times the 4th phase was not recorded because the sounds became dull so gradually that the exact point could not be determined. These results may be tabulated as follows:

Number of subjects	61
" " graphic records	210
" " " " in which minimum pressure was obvious	142 or 67.6%
" " " " " " " " could not be read	68
" " cases in which the 4th phase was obvious	183 or 87.1%

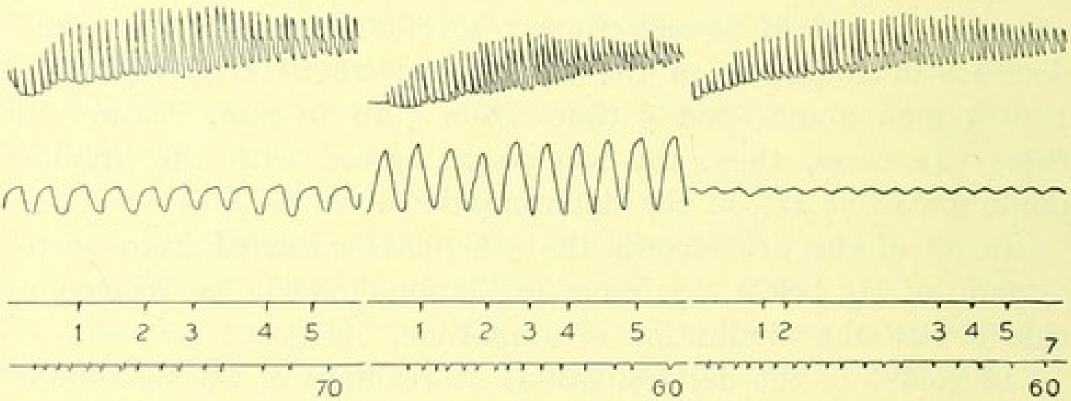
Of the 142 cases mentioned, 108 showed the onset of the 4th phase equal to or only from 1 to 5 mm. below the marked decrease in amplitude of the oscillations; 28 times it was from 1 to 5 mm. above, and 5 times from 5 to 10 mm. below. In these 142 cases, then, the 4th phase agreed with the graphic minimum in 77.4% of the determinations.

In all of the 210 records the 5th phase occurred from 10 to 25 mm. of Hg below maximum oscillations, and in no way coincident with the diminution of amplitude. (Fig. 5.)

In 36.8% of the determinations no readings of the maximum pressure could be obtained with the Erlanger instrument; and in 32.3% no readings of minimum pressure could be obtained. The reason for this percentage of unsatisfactory determinations is not to be found in any peculiarities of the subjects but in factors active when the records were taken, since out of the three or four determinations made on each person two or three satisfactory readings were nearly always obtained.

Among the factors that might affect the record of the sphygmomanometer are movements of the arm, contractions of muscles under the cuff, changes in the vascularity of the arm, and the changes in blood pressure due to respiration. Movements of the arm or the contraction of muscles under the cuff occurring at the time the external pressure is about to equal the maximum blood pressure would undoubtedly alter the usual changes in the sphygmomanometric record by changing the pressure within the cuff. Changes in vascularity affecting the volume of the arm would tend to affect the record in a similar manner, and sudden vasomotor changes or rhythmical waves of blood pressure would likewise have an effect.

Respiration has sometimes a marked effect upon the determinations. Erlanger and Festerling (1912) have shown that arterial blood pressure rises during expiration and falls during inspiration. With the rise in blood pressure there is an increase in the amplitude of the oscillations recorded, — with the fall a decrease occurs. Venous pressure as well falls during inspiration, and this coupled with the fall of arterial pressure would reduce the volume of the arm, causing a lowering of the pressure in the cuff, a condition that would cause an increase in amplitude of the oscillations.



Figures 2 and 3. In these and all the following records the upper curve represents the blood pressure, the next curve the pneumograph tracing, the third line indicates the auscultatory phases, the lowermost line the fall of the Hg column at intervals of 5 mm. These records show clearly the relation between the auscultatory phases and the blood-pressure tracing, and also that maximum pressure occurs on expiration and minimum pressure on inspiration. Figure 2, maximum pressure 123 mm. of Hg, minimum 82 mm. Figure 3, maximum 125 mm., minimum 80 mm.

Figure 4. Similar to records 2 and 3, but illustrating a long 2d phase. Maximum pressure 125 mm., minimum 73 mm.

However, this is more than offset by the greater direct effect of the inspiratory fall of arterial pressure which is manifest on the record as a decrease in amplitude. It is theoretically probable that the expiratory rise of arterial pressure, when it occurs at the time that the pressure in the cuff is about to equal the maximum blood pressure, would tend to accentuate the criteria for determining the latter; under similar conditions the inspiratory fall would tend to obscure them. The graphic minimum should be affected as well, and a decrease in the amplitude of the oscillations should occur with inspiration.

Our records would seem to indicate that the graphic maximum occurs during expiration, i.e. on the upstroke of the pneumograph lever, and the graphic minimum during inspiration, but we are not prepared to say that this is true in all cases. Compare Figs. 2, 3 and 4. The effect of the respiratory changes on the blood pressure is clearly marked in Fig. 7, where the sounds alternate between the 3rd and 4th auscultatory phases synchronously with the respiratory movements, and also in Fig. 6, where the 1st phase disappeared as a result of inspiration

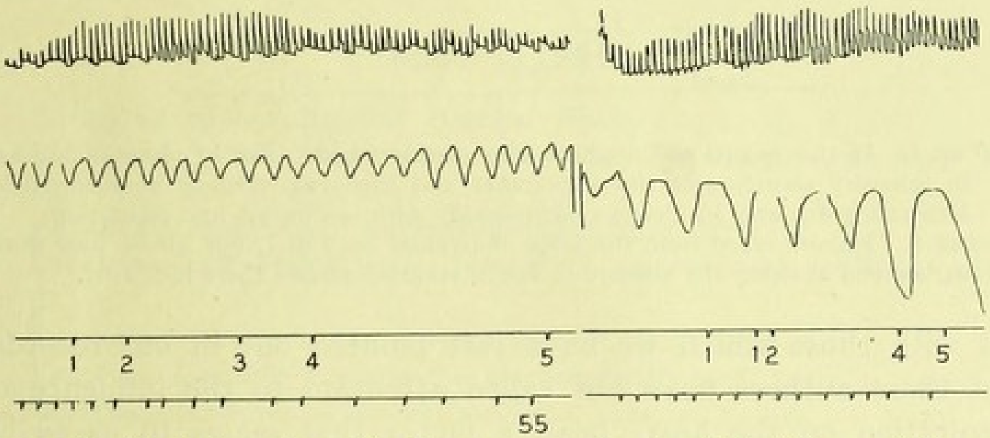


FIGURE 5. Illustrating a long 4th phase corresponding to a fall of 25 mm. of Hg, and showing the error that would result from reading the minimum pressure at the 5th phase instead of at the beginning of the 4th. Maximum pressure 120 mm. of Hg, minimum 82 mm.

FIGURE 6. This record illustrates the disappearance of the first sound on inspiration and its reappearance on expiration.

and then reappeared. The cases in which this phenomenon was observed showed a slightly greater cardiac arhythmia than is present in most normal individuals, and in one case at least the degree of this arhythmia varied on different occasions as in Figs. 7 and 8 which were taken on the same individual at an interval of about four weeks. We are inclined to attribute this slight increase in arhythmia to an increased susceptibility of the heart to respiration.

Goodman and A. A. Howell (1911) note changes occurring in the phases themselves, which they call tonal arhythmia or an alternation of the intensity of the individual sounds, and they regard this arhythmia as evidence of variation of the contractions of the heart. They observe also poor differentiation of the phases, e.g. cases in which murmurs may alternate with tone beats, or dull tones with sharp tones and they believe this to be an evidence of cardiac weakness. These phenomena are identi-

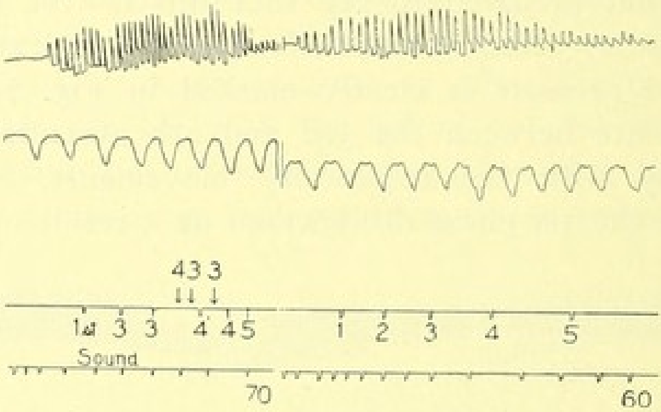


FIGURE 7. In this record no 2d phase was distinguished. The 3d phase diminished in intensity shortly after its appearance and then recovered to be followed by alternating 4th and 3d phases synchronously with inspiration and expiration.

FIGURE 8. Record taken from the same individual as Fig. 7, but about four weeks earlier and showing the absence of the alternating phases there indicated.

cal with those which we have just pointed out in our records, but these authors have not called attention to the influence of respiration on the heart beat, a factor that seems to us to be indicated by our tracings.

Goodman and A. A. Howell (1911) have studied the relative length of the various auscultatory phases, and our records confirm, in general, their results as is evident from the auscultatory tracings in the accompanying figures. The largest oscillations appear with the 3rd phase, and our tracings confirm the conclusions of Lang and Manswetowa (1908) when they say that the height of the oscillations and the intensity of the sounds are proportional.

CONCLUSIONS

1. Maximum pressure as determined with the Erlanger sphygmomanometer on normal individuals is coincident with the onset of the 1st phase of the auscultatory phenomenon.

2. Minimum pressure as determined with Erlanger's instru-

ment on normal individuals is coincident with the onset of the 4th phase.

3. Since the onset of the 4th phase is coincident with the marked decrease in amplitude of the oscillations recorded by the Erlanger sphygmomanometer, it should be considered as the index of minimum blood pressure.

4. Since the 5th phase occurs later than the last maximum oscillations, — in some of our cases (e.g. Fig. 5) as much as 25 mm. of Hg, — it should not be taken as the index of minimum pressure.

5. Maximum pressure occurs commonly, if not always, during expiration, and minimum pressure commonly, if not always, during inspiration.

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