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Studies on Peripheral Circulation by "Ultrasonic Blood-Rheograph"

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The authors have studied on the condition of the peripheral circulation with a new diagnostic method using "Ultrasonic Blood-Rheograph". By applying this method to peripheral blood vessels on the surface of the skin, it has been possible to study clinically the state of the blood flow in various conditions and to diagnose pathological conditions. The wave pattern of the detected sounds varied according to the type of the blood vessels and also to the increase of the peripheral blood vessel resistance, such as was caused physiologically by application of cold stimuli on the skin and pathologically by arteriosclerosis.

THE METHOD of recording and studying the condition especially the instantaneous change of the blood flow in the peripheral blood vessels has been studied from various viewpoints because of its importance in circulatory physiology and in clinical practice. The recent progress in electronics has brought the method of a fairly correct recording, but no non-operative method has yet been found to be put to clinical use.

In view of these facts, the authors have taken up the "Ultrasonic Blood-Rheograph"¹⁾ as a new method for recording the condition of the blood flow with instantaneous changes. The principle of this method is based on the fact that, when ultrasonic waves are transmitted in a moving fluid, reflected waves are produced at the boundary surface where occur differences in the velocity of the flow or in the acoustic impedance. By applying this method to peripheral blood vessels on the surface of the skin without giving any artificial injury, it has been possible to study clinically the state of the blood flow in various conditions and to diagnose pathological conditions such as arteriosclerosis, arteriostenosis etc. although quantitative measurement has not yet been developed.

PRINCIPLE

When a sound wave impinges at a certain angle upon the boundary surface between a static homogeneous medium and a moving same one, there occur reflected and refracted waves at the boundary surface²⁾. Also when ultrasonic waves impinge upon a fluid which is in a state of turbulent or agitated flow, (there occur difference of velocity of flow everywhere in the fluid, so that) it is to be postulated that the sound waves are scattered everywhere in the fluid and the frequency of these scattered waves must be subjected to change due to Doppler's effect³⁾.

In other cases, when sound waves impinge upon a fluid in which are involved particles with acoustic impedance (the product of the particle density and its sound velocity) different from that of the fluid, the sound waves are scattered by these particles. If the fluid is in motion, the frequency of these scattered waves must be subjected to change due to Doppler's effect.

In both cases, by composing these reflected waves together with the direct waves and demodulating them, it is possible to obtain a kind of noise consisting of various

frequencies. When the ultrasonic wave is applied to a blood flow, two phenomena mentioned above are considered to be as mechanism of generation of the noise detected.

In experiments in a glass tube using water flow (up to 1m/s velocity) which contains starch particles, the indications of the out put meter are proportional to the square root of flow velocity, and the frequency of maximum intensity in the detected noise is proportional to the flow velocities. A frequency distribution of the noise detected when a small stone (some tenth millimeter in diameter) passes through water in a glass tube, is nearly equal to that of the noise detected when the flow speed of water containing starch particles is equal to the speed of pass of the small stone. From these experiments, it is to be postulated that the detected noise may be due to the reflection of sound wave by small particles involved in the fluid. Another experiments have shown that the detected noise in this case is not due to the low frequency elastic waves produced by the moving fluid. Thus it may be concluded that the detected noise by using this ultrasonic method is an entirely different one from that obtained by the microphone method hitherto used.

APPARATUS AND METHODS

As shown in Fig. 1, the apparatus consists of a high frequency oscillator, a high frequency receiver, a transducer, a low frequency amplifier, an earphone and a recorder. The high frequency oscillator is a self-oscillator using a power tube of about 1-2 watts, and the receiver composed of a

Fig. 1. Diagram of the apparatus.

one-stage high frequency amplifier circuit, a diode detector circuit and a low-frequency amplifier circuit. The transducer is made of barium titanate with a thickness of 0.6 mm and a diameter of 5 mm. The frequency of the ultrasonic waves was set at 5 MC. Efforts were made to eliminate the beats due to Doppler's effect caused by the pulsation of the blood vessels, by lowering the amplification of the frequency range (lower than around 100c/s) in the low frequency amplifier circuit. Recording was made by using the mingograph (a direct writing apparatus which can register sounds linear to about 500c/s and frequencies up to 900 c/s) while listening to the detected sound with the earphone. A cathode ray tube oscilloscope and a frequency analyser were also used as a further help in observation and in recording.

In measurement, the possible presence of cardiac diseases was previously diagnosed not only by auscultation, but also by Ultrasonic Doppler-Cardiograph⁴⁾ and electrocardiograph. In case the blood vessel is superficial or exposed, since the pattern of the detected sound tends to be modified when pressure is applied, care was taken to make slight contact of the transducer with the skin through a contact medium (liquid paraffin).

The power of the ultrasonic waves was set at 0.05 w/cm², the speed of the recording paper was set at 5 cm/s for the human body, and at 10 cm/s for animals, and the electrocardiogram-II was simultaneously recorded as an indicator.

RESULTS

1. Sound Obtained from Arteries and Veins.

The sound patterns obtained in the graphical record were grossly classified into a continuous and discontinuous pattern. The former showed a continuous band-like pattern with an approximately definite amplitude through the cardiac cycle, and the latter showed a discontinuous pattern with one or more marked decrease or disappearance through the cardiac cycle.

The sounds obtained from arteries showed various patterns from the continuous to discontinuous according to various changes in the circulatory factors or to the parts of arteries investigated. The veins, however, generally showed the continuous pattern except in the major veins such as v. femoralis of which pattern showed respiratory variations, v. jugularis which showed pulsation, and v. cephalica which displayed slight pulsation in the forearm rather than the upper arm when the room temperature rised.

When analysed by the frequency spectrometer, the sounds obtained from the arteries were strongest around 800c/s and were distributed around

120–1,000 c/s. In general, the frequencies in the diastolic period were fairly lower as compared to those in the systolic period. A. carotis interna showed peculiarly high frequencies reaching more than 3,000 c/s in certain cases. On the other hand, the sounds obtained from the veins, though showing variations according to the loci, were strong around 200–300 c/s in the veins of the extremities and were distributed around 125–800 c/s. V. jugularis interna, just as in case of the artery, showed peculiar high frequencies reaching 1,000–3,000 c/s. (Fig. 2)

Fig. 2. Frequency-spectrum of the detected sounds from the blood flow.

2. The Detected Sound Pattern of the Arterial Blood Flow in the Normal Condition.

1) In the healthy adolescent human.

In the lying position, a. carotis communis generally showed a continuous pattern, though revealing a slight tendency to discontinuity at the part where it bifurcated into a. carotis interna and externa and at the upper edge of the clavicle. A. carotis interna, a. vertebralis and a. chorioidea (of the eye) showed a most conspicuous continuous pattern. A. carotis externa and its branches, a. facialis and a. temporalis superficialis, showed a slight trough in their wave patterns, therefore a tendency to discontinuity (Fig. 3).

All arteries in the upper and lower extremities such as a. subclavica, a. axillaris, a. brachialis, a. radialis, a. femoralis, a. poplitea and a. dorsalis pedis showed the discontinuous pattern when the room temperature was as low as around 20°C, while they showed on the whole a tendency to continuity and accentuation of the detected sound when the room temperature was as high as 30°C. Of these the peripheral arteries, such as a. brachialis, a. radialis and a. dorsalis pedis showed a tendency to be more conspicuously continuous patterns. When the room temperature was around 20°C, the detected sound patterns of brachial artery were approximately the same as those obtained when the hand was made to grasp or a cold stimulus was given to part of the body (Fig. 4). The detected sounds at the finger tip from arterioles and capillaries showed a continuous pattern.

2) Animal experiments.

In order to find out whether the ultrasonic waves reached rightly the blood vessel aimed at and whether the soft tissue superficially lying on

Fig. 3. The patterns of the detected sounds from arteries at neck region.

Fig. 4. The pattern changes by the grasp test and cold stimulation of the detected sounds from the brachial artery at 30°C room temperature. (27-year-old male).

the blood vessel did not influence the detected sound, experiments were made to compare the sounds obtained from the surface of the skin with those obtained directly from the exposed arteries of the external, internal, common carotid and femoral arteries. The results showed that both sounds obtained from the surface of the skin and from the exposed arteries were essentially the same but were different in the intensity.

As to the external and internal carotid arteries, which had the same rhythmic characteristics in the tone and quality of the sounds as the human body, it was easy to distinguish the sounds obtained from these two arteries, and therefore it was possible to differentiate the two. Another experiment, which was conducted by opening a part of the skull of a dog, showed that the sound directly from a. cerebri anterior exhibited a typical continuous pattern.

3. Changes in the Arterial Blood Flow Pattern Due to the Peripheral Flow Resistance.

1) In the healthy adolescent body.

In the brachial artery, the continuous pattern was obtained when the room temperature was around 30°C, while it changed into the discontinuous pattern by firm grasping the hand or by applying a cold stimulus to a part of the body.

This pattern change in the detected sound was due to the increase in the resistance of the peripheral flow by the mechanical pressure of grasping or by the vasoconstriction brought from a cold stimulus. This phenomenon was most distinctly observed when a manchetle was applied and a pressure was given higher than the systolic blood pressure at the peripheral part (Fig. 4, 5A).

As to the changes in the blood flow pattern by cold stimuli, all the arteries of the extremities showed the response, but the internal carotid artery had never responded (to the stimuli applied). The external carotid artery generally responded, although with individual differences, and the facial artery showed a response approximately the same as those of the arteries of the extremities. The common carotid artery showed a slight response considered as due to the influence of the external carotid artery.

2) Animal experiments.

In order to confirm the observed relationship between the changes in the peripheral resistance and those in the detected sound pattern, the changes in the detected sound by administration of vasomotor drugs to the dog were observed. Intravenous administration of vasodilator (1cc. Priscol), while bringing about marked bradycardia, rendered the detected sound pattern of the femoral artery much

Fig. 5. Changes in the blood flow pattern of brachial artery. Peripheral flow resistance is increased by applying pressure higher than the maximum blood pressure and then is decreased. (at 30°C room temperature).
Figure 5A is the patterns in the healthy adolescent and figure 5B is those in the aged individual with arteriosclerosis. The upper figures are without compression and the lower are with extreme compression.

more continuous as compared with that before the injection. When vasoconstrictor (0.7 cc. Epinephrine) was intravenously administered, the detected sound pattern showed a trough concurring with the baseline between systole and diastole.

4. Changes in the Blood Flow Pattern with Age.

The detected sound of the common carotid artery in the lying position in general showed a continuous pattern. But, with age, this pattern came to show a more marked trough and tended to shift to the discontinuous. In that case the discontinuous pattern showed a characteristic lengthening of the trough, which turned into the baseline, and the sudden appearance or the disappearance of the detected sound, in which the abruptness of the appearance at the starting point of the wave was early observed. Extreme cases of this condition were seen in aged individuals possibly with arteriosclerosis, so that the changes with age may be interpreted as transitional stages to this condition. (Fig. 6).

As stated above, the detected sound in the brachial artery generally showed a continuous pattern around 30°C room temperature, but, just as in case of the common carotid artery, it came to

show the discontinuous pattern with increase in age even at 30°C. An extreme case was observed in the patient with arteriosclerosis whose pattern showed the same characteristics as that of the com-

Fig. 6. Changes with age in the detected sound patterns from common carotid arteries.

Fig. 7. Changes with age in the detected sound patterns from brachial arteries. (at room temperature 30°C)

mon carotid artery. (Fig. 7). This characteristic condition was quite similar to that stated in results 3,1) which obtained when a pressure was applied with a manchette immediately below the cubital fossa of an adolescent body. On the other hand, if a pressure was similarly applied in a patient with sclerosis, this peculiar wave pattern was separated into two. (Fig. 5B).

5. The Time Elapsed from Q in the Simultaneous Electrocardiogram to the Starting Point of the Detected Sound and its Relation to Age and Blood Pressure.

The time elapsed from Q in the electrocardiogram to the starting point of the wave pattern of the detected sound of the brachial artery was named α , the time from the starting point of the first detected sound obtained by gradual decreasing the pressure after applying the pressure higher than the maximum blood pressure as in case of blood pressure measurement at the brachial artery to Q was named β . Using subjects without cardiac dysfunction, the correlation was studied of α , β and $\beta-\alpha$ with age and the systolic and diastolic blood

Fig. 8. The detected sound patterns from brachial artery (showing α and β). The upper shows the pattern when no pressure is applied. The lower shows the pattern occurring for the first time when pressure is lowered after the application of the pressure.

TABLE I THE DURATION TIME ELAPSED FROM Q IN THE SIMULTANEOUS ELECTROCARDIOGRAM-II TO THE STARTING POINTS OF THE DETECTED SOUNDS (α , β), WHERE β REPRESENTS THE DURATION TIME ELAPSED FROM Q TO THE STARTING POINT OF THE FIRST DETECTED SOUND OBTAINED BY GRADUAL DECREASING OF THE PRESSURE AFTER APPLYING THE HIGH PRESSURE. ($\frac{1}{100}$ SEC)

$n=136$	α	β	$\beta-\alpha$
distribution.	9. 10.~19.	25. 20.~45.	24. 6.~30.
mean.	14.	30.	- 17.
standard deviation.	1.89	5.49	5.49

pressures measured by the auscultatory method. (Fig. 8)

Statistical study showed with more than 99% certainty a certain correlation between the values of α , β and $\beta-\alpha$ and age and blood pressure. But it showed that there was a danger in inferring the degree of this correlation, that is, the proportion of common factors. Keepig this in mind and comparing the degrees of correlation, it was of interest to note that the correlation of age with $\beta-\alpha$ was highest, while in blood pressure, α showed a higher correlation with the minimum blood pressure, β with the maximum blood pressure and also $\beta-\alpha$ with the maximum blood pressure. (Tab. I, II)

TABLE II THE CORRELATION OF α , β AND $\beta-\alpha$ WITH AGE AND BLOOD PLESSURE
($P < 0.01$, ρ ; 0.01 COEFFICIENT INTERVALS)

$n=136$	α	β	$\beta-\alpha$
age	$r = -0.325$ $-0.509 < \rho < -0.113$	$r = 0.488$ $0.300 < \rho < 0.640$	$r = 0.588$ $0.422 < \rho < 0.716$
minimum blood pressure	$r = -0.337$ $-0.516 < \rho < -0.122$	$r = 0.284$ $0.068 < \rho < 0.475$	$r = 0.419$ $0.218 < \rho < 0.586$
maximum blood pressure	$r = -0.320$ $-0.503 < \rho < -0.105$	$r = 0.404$ $0.201 < \rho < 0.573$	$r = 0.506$ $0.322 < \rho < 0.653$

6. Cases.

1) 53 year-old male; 59 year-old male.

(Fig. 6 A, B)

Of the cases diagnosed as cerebral arteriosclerosis from the detected sound pattern in the common carotid artery, two patients here reported were died about five months later by myocardial infarction and nephritis. On autopsy marked atheromatous degeneration was revealed in both cases in the basilar and vertebral arteries, circulus arteriosus Willisii and a. cerebri media, the atheromatous abscess was visible through the adventitia. Thus the diagnosis of cerebral arteriosclerosis was confirmed.

2) 38 year-old male. (Fig. 9)

- bifurcation of internal and external carotid artery.
- midpoint of a and f.
- 1cm departed from b to f.
- 1cm departed from c to f.
- 1cm departed from d to f.
- the part of common carotid artery the upper limit of clavícula.

Fig. 9. The detected sound patterns from common carotid arteries of the patient diagnosed as the right carotid artery angiostenosis.

This patient visited our clinic complaining of heaviness in the head and stiffness in the left shoulder. Cerebral angiographical findings led to the diagnosis of the right carotid artery angiostenosis. Applying the present method to this case, a marked difference in the detected sounds of the right and left common carotid arteries and a difference according to the locus investigated of the right side (the diseased side) was found. Weakening and a tendency to discontinuity of the detected sounds according to the locus on the diseased side might rightly be attributed to the changes in the condition of the blood flow due to stenosis of the inner wall of the blood vessels. Therefore topographical diagnosis might be possible by this method.

DISCUSSION

The circulatory dynamics of the blood flow caused by cardiac ejection may be considered as follows: the progressive impact of the pressure waves keeps on changing the potential energy of pressure into kinetic energy of flow through the buffer action and pressure gradient of the viscosity of the blood etc. in the elastic compression chamber of the arteries so as to maintain a constant capillary flow⁸⁾.

As to the relationship between the pressure and flow during this process in the arterial system, there are two different considerations. The first is that with each beat of the heart a "standing wave" which arises from reflections advances with showing back and forth between the periphery and the root of the aorta, that is, the case without the continuous transfer of the potential energy of pressure into the kinetic energy of flow. The second is that the pulse caused by the heart is gradually transformed toward the periphery and eventually is extinguished by the summated effect of each successive vessel segment without reflections or back flow components, that is, the case with an adequate transformation of the potential energy of pressure into the kinetic energy of flow⁵⁻⁸⁾.

How are these blood flow patterns represented in the Ultrasonic Blood-Rheogram? The results will be compared with those of other methods and their significance will be discussed in the following.

Comparing the pressure pulse curve ob-

tained by using a pickup of Rochelle salt with the detected sound, in the brachial artery, a detected sound occurs coinciding with the beginning of the ascending slope of the pulse curve, forms a rise centering around the main peak, diminishes gradually, becomes stronger again around the dicrotic wave, and then disappears rapidly. In the carotid artery, the first half is almost same as in the brachial artery, but after the descending part of the dicrotic wave, the detected sound generally continues till the next heart systole.

A few results are next referred which obtained by the use of the square-wave electromagnetic flowmeter which is considered to be able to record the blood flow wave in the natural condition with the least artificial deformation of the blood vessel with special respect in the blood flow patterns, especially in the zero level⁵⁾⁹⁾¹⁰⁾. As shown in Fig. 10 C, first the initial caudal (systolic) main movement of blood caused by the cardiac ejection is found, second the reverse flow to the cardiac direction crossing on the zero level at a time early in diastole, and third the damped sine wave like oscillations recognized as resonant waves. Occasionally is seen the flow wave which rises above the zero level and is considered as the stationary flow. (Fig. 10D). Other cases are known in which a triangular appearance of the blood flow wave descends by a gradual slope at the diastole, forming patterns as presented in Fig. 10 A or B with the degree of the rise above the zero level. Thus variations in the condition of the blood flow are to be observed ranging from the case in which blood advances with a plug motion to that in which blood advances mainly by the pressure head.

The blood flow pattern measurement by the ultrasonic method is achieved by recording the blood flow pattern in terms of the amplitude of low frequency waves, and more exactly by observing not only the amplitude of low frequency waves but also the involved frequencies. There is another possibility that the characteristics of the recording apparatus tend to lessen the amplitude of the high frequency waves in the parts where the blood

stream flows with high speed, but, for convenience sake, the condition of the detected sound has always been observed in terms of wave patterns representing chronological changes of the amplitude as presented on the recording paper. Therefore it should be kept in mind that the parts where the blood flow streams with high speed (the parts above the dotted line in Fig. 10) are represented in-

Fig. 10. The upper figures show some types of the blood flow waves obtained by using square-wave electromagnetic flowmeter (by M. P. Spencer and H. Okino et al). The lower figures show the schematic figures of the detected sound patterns corresponding with upper figure of the flow wave.

creased frequencies although they disappear in recording and observation in terms of the amplitude of the detected sounds. The recorded pattern of the detected sounds by the ultrasonic method is regarded as the same pattern as that obtained when the blood flow wave pattern is turned up around the zero level as the axis of symmetry without including of the high speed parts of the blood flow above the dotted line.

Although it is not possible to know the direction of the blood flow from the detected sounds obtained by the ultrasonic method and therefore to use it as grounds for claiming the presence of back flow components, and although quantitative measurement cannot be conducted as yet at the present stage, it is quite possible to find out the condition of the movement of the blood, especially the shift from the state with marked oscillations with the resonant waves to that in which the stream is mainly reinforced by pressure head. This will enable us to know the condition of the blood flow resistance or its changes.

As stated in the result 3,1), when the pressure higher than the maximum blood pressure is applied to the lower part of the blood flow, the recorded pattern is caused by only the back and forth movements, the oscillation of the blood, since the effective blood flow volume is naturally zero. The obtained pattern in this case is believed to be the peculiar wave pattern obtained when the peripheral resistance markedly increases as seen in arteriosclerosis of results 4, although it is not possible to find out in the record the locus where the direction of the flow is reversed. The fact that in arteriosclerosis the dissociation occurs in the detected sound pattern more clearly by applying pressure in the distal part means as follows from the viewpoint of the elasticity and plasticity of the blood vessels. If the blood vessel is of elasticity, the blood flow wave pattern forms an angle approaching the perpendicular at the cross of the zero level where the wave pattern shift to the back flow phase, whereas in arteriosclerosis, this angle tends to be sharp owing to the residual strain due to the plasticity of the blood vessel.

The detected sound pattern from the arteries of the extremities also changes with the room temperature. This phenomenon is due to the fact that these arteries dilate or contract according to temperature change. The fact that the continuous pattern from the brachial artery shifts to the discontinuous one by the grasp test is to be considered as due to the increase in peripheral resistance brought by pressure from outside of the blood vessel. The similar phenomenon has been noted to be produced by cold stimuli through the intermedium of vasomotor nerves. In these phenomena, the degree of approaching the trough in the wave pattern of the detected sound to the baseline is considered to be roughly proportional to the degree of increase in peripheral resistance. In order to further clarify this relationship between peripheral resistance and changes in the detected sound pattern, the experiment of giving vasodilators and vasoconstrictors to the dog, has been made and the results obviously showing the above mentioned relationship has been obtained al-

though including the influence due to the drug effect on cardiac function.

From these results and considerations, the degree of discontinuity of the wave pattern obtained by the Ultrasonic Blood-Rheograph is obviously related to increase in blood flow resistance. This is the reason why the discontinuous pattern in the carotid artery which commonly shows the typical continuous wave pattern in the lying position, reveals to conclude the presence of an increase in the resistance of cerebral blood flow and is possible to be a diagnosing standpoint of the degree of cerebral arteriosclerosis, if other factors resulting in the discontinuity of the wave pattern are omitted.

As to the starting point of the wave pattern obtained by the ultrasonic method, if neglecting the phenomena like hysteresis, α is regarded as being similar in significance to the starting point of the rise of the pressure pulse curve and β to the main peak in the pressure pulse curve. The values of α and β has shown significant correlations with age and blood pressure, inferring the possible presence of hardness of the arterial vessels or arteriosclerosis as common factors in the cases. If α and β is considered to be mainly related to the elasticity of the blood vessels and the total peripheral resistance, the present data can be more rationally understood that the total peripheral resistance is more related to the maximum blood pressure and the elasticity to the minimum blood pressure.

Since $\beta-\alpha$, which is taken up in order to eliminate the possible influences of the condition of the cardiac function etc., shows a higher correlation with age and blood pressure, this value is an important indicator in diagnosing arteriosclerosis as indicating at least a decrease in the elasticity of the arteries and an increase in the total peripheral resistance.

SUMMARY

"Ultrasonic Blood-Rheograph" was clinically used and the following results were obtained.

1. The wave pattern of the detected sounds divided into two types, i. e. the continuous

and the discontinuous; the former was generally found in the arteries flowing within the skull and the latter in the extremity arteries.

The veins usually showed the continuous pattern except a part of them which displayed pulsation or respiratory variations.

The involved frequencies of the detected sounds were distributed around 800c/s for the arteries and 200-300c/s for the veins, but both internal carotid arteries and jugular veins involved specifically high frequencies as reaching even 3,000c/s.

2. The peripheral parts of the limb arteries shifted to the continuous pattern when the room temperature was around 30°C. When, under this condition the hand was firmly grasped or a cold stimulus was given to a part of the body, the pattern immediately changed to the discontinuous. This phenomenon was most distinctly observed when the blood flow was blocked by applying a manchette to the distal part of the locus investigated.

The response to the cold stimulus was observed in the extremity arteries and also in the external carotid artery and its branches, while no response was ever observed of the internal carotid artery to the cold stimulus examined.

When vasoconstrictor and vasodilator are administered to dogs, the detected sounds of the femoral artery shifted conspicuously to the discontinuous and continuous patterns respectively.

3. The sound pattern of the common carotid artery, which generally showed the continuous pattern, tended to accentuate its trough with aging, thus shifting to the discontinuous pattern. The sound pattern of the brachial artery showed, as of common carotid artery, discontinuous with age.

4. When the time elapsed from the starting point of the detected sound of the brachial artery to Q of the electrocardiogram is named α , and the time from the starting point of the first detected sound by gradual decreasing of the pressure after applying the high pressure to Q is named β , α showed a minus-correlation with age and blood pressure and β and $\beta-\alpha$ a plus-correlation.

REFERENCES

- 1) Satomura, S., and Kaneko, Z. Report of Third International Conference on Medical Electronics, London, 1960.
- 2) Keller, J. B., *J. Acoust. Soc. Amer.* **27**: 1044, 1955.
- 3) Barlow, E. J., *I. R. E.* **37**: 340, 1949.
- 4) Satomura, S., *J. Acoust. Soc. Amer.* **29**: 1181, 1957.
- 5) Spencer, M. P., Johnston, F. R. and Denison, Jr. A. B., *Circ. Res.* **4**: 476, 1956.
- 6) Wright, G. W. and Phelps, K., *J. Clin. Invest.* **19**: 273, 1940.
- 7) Shipley, R. E., Gregg, D. E. and Schroeder, E. F., *Am. J. Physiol.* **138**: 718, 1943.
- 8) Wiggers, C. J., *Circulatory Dynamics*, Grune & Stratton, 1952.
- 9) Okino, H., Fujisaku, K. and Sakaguchi, D., *Respiration & Circulation* (Japanese), **7**: 11, 1021, 1959.
- 10) Spencer, M. P., Johnston, F. R. and Denison, Jr. A. B., *Circ. Res.* **6**: 491, 1958.