Measurement of Cerebral Blood Flow by Ultrasonic Doppler Technique

— THEORY —

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I have already pointed out that, in order to anticipate the cerebral vascular accident, the following are of most clinical importance.¹⁾ The one is the quantitative and qualitative analysis of cerebral arteriosclerosis and hypertension, the other is the investigation of circulatory regulation. Among them, the detection of cerebral arteriosclerosis is more valuable and difficult. Although this problem have been investigated by using many operative and non-operative method, the ideal technique for clinical use has not yet been developed.

On the other hand, SATOMURA and KANEKO has initiated the unique technique of measuring cerebral circulation, i. e., ultrasonic Doppler technique.²⁻⁴⁾ In this study, several problems regarding to theoretical concept of the method are investigated.

PRINCIPLE

WHEN ultrasonic waves impinge upon the blood stream, the reflected waves are subjected to frequency change due to Doppler's effect from moving blood particles and turbulent (agitated) flow, particularly the former⁵⁾. A kind of noise was obtained by composing the reflected waves together with the direct waves and demodulating them. Frequencies of this noise are proportional to the blood flow velocity.*

* When ultrasonic waves impinge upon the moving subject, the frequencies of reflected waves(f') are converted as follows.

$$f' = \frac{c + u \cos \alpha}{c - u \cos \alpha} f$$

f : frequency of direct wave
 c : sound velocity

u : velocity of moving subject

α : angle between the direction of ultrasonic wave and the direction of moving subject

The frequencies of Doppler beat are obtained by composing the reflected waves together with the direct waves and demodulating them. The frequencies of Doppler beat (f_d) are demonstrated as follows.

$$f_d = f - f' = \frac{2u \cos \alpha}{c - u \cos \alpha} f \doteq \frac{2u \cos \alpha}{c} f = \frac{2u}{\lambda} \cos \alpha$$

λ : wave length

From above formula, it is postulated that the moving subject was converted to audible sound, since the frequencies of Doppler beat were proportional to the velocity of subject. Dop-

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pler's effect are minimum at $\alpha=90^\circ$ and maximum at $\alpha=0^\circ$. (Fig. 1) shows the relationship between flow velocity and output voltage of the detected sound in water-flow experiment.

APPARATUS AND METHOD

Fig. 2 shows the block diagram of the apparatus and Fig. 3 shows the electrical circuit. 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 selfoscillator using a power tube of about 1-2 watts, and the receiver composed of a one-stage high frequency amplifier circuit, a diode detector circuit and a low-frequency amplifier circuit. The transducer is made of barium

vanate (PZT) with a thickness of 0.6 mm and a diameter of 0.5 mm. The frequency of the ultrasonic waves was set at 6 Mc/s. Effort 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 100 c/s) in the low frequency amplifier circuit. Fig. 4 shows the frequency characteristics of the apparatus. The output voltage are proportional to the frequencies from around 100 c/s to 6,000 c/s. From this characteristics the beats, due to Doppler's effect caused by the pulsation of the blood vessels (lower than around 100 c/s at artery) were eliminated. Recording was made by using the Visigraph (a direct-recording oscillograph which can register the frequencies linear up to around 1700 c/s, while listening to the detected sound with the earphone.

Fig. 1 Relationship between flow-velocity and output voltage of the detected sound in water-flow experiment

Fig. 2 Block diagram of the apparatus

Fig. 3 Electrical circuit of the apparatus

Fig. 4 Frequency characteristics of the apparatus

In measurement, ultrasonic vibrator was placed on the surface of the skin above the vessel, and ultrasonic waves impinge upon the blood stream. Since the pattern of the detected sound tends to be modified when pressure is applied to the vessels, 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 set at 0.05 w/cm^2 , the speed of the recording paper was set at 2 cm/s and electrocardiograph-II was simultaneously recorded as an indicator.

RESULTS

I) Hemodynamics in the upper extremities :

A) Hand-grasping test (Fig. 5).

In this test, the blood flow of brachial artery is decreased and the blood flow pattern is prone to be more discontinuous proportional to in-

tensity of hand-grasping. This is due to the increase of peripheral vascular resistance in brachial artery.

B) Brachial-binding test (Fig. 6).

In this test, the blood flow of brachial artery is decreased and the blood flow pattern is prone to be more discontinuous proportional to intensity of brachial-binding using by manchette.

C) Cold and warm-stimulating test (Fig. 7).

When the hand is soaked in the cold water, the increase of peripheral vascular resistance of upper extremity was observed, the blood flow of brachial artery decreased and the blood flow pattern is prone to be more discontinuous. On the other hand, when the hand is soaked in warm water, the decrease of peripheral vascular resistance of upper extremity

Fig. 5 Hand-grasping test

(1): control   (3): moderate grasp
 (2): mild grasp   (4): severe grasp

Fig. 6 Brachial-binding test

(1): control   (3): moderate binding
 (2): mild binding   (4): severe binding

Fig. 7 Cold and warm-stimulating test

- (1) control
- (2) cold-test
- (3) warm-test

Fig. 8. Blood flow patterns in internal carotid artery in normal young men and normotensive old men with slight cerebral arteriosclerosis

hypertensive old man
61 Yrs B.P. 220/90 mmHg
Scheie's grade : III

hypertensive young man
31 Yrs B.P. 230/130 mmHg

hypertensive young man
(after hypotension in the same)
B.P. 160/110 mmHg

Fig. 9 Blood flow patterns in internal carotid artery in hypertensive young men and old men with severe cerebral arteriosclerosis

TABLE I CORRELATION OF BLOOD FLOW PATTERNS AND RETINAL ARTERIOSCLEROSIS (SCHEIE'S GRADE) IN THE OLD MEN

<i>blood flow pattern</i> <i>Scheie's grade</i>	<i>continuous</i>	<i>intermediate</i>	<i>discontinuous</i>	<i>total</i>
0	4 (2)	3 (3)	0 (2)	7 (7)
I	5 (1)	3 (3)	3 (3)	11 (7)
II	0 (1)	1 (2)	3 (3)	4 (6)
<i>total</i>	9 (4)	7 (8)	6 (8)	22(20)

Figures in round bracket : no. of cases with normotension
Figures out round bracket : no. of cases with hypertension

was seen, the blood flow of brachial artery increased and the blood flow pattern is prone to be more continuous. From above results, it is postulated that the decrease of blood flow patterns were caused by the increase of vascular resistance of the vessels.

II) Hemodynamics in the brain, with special reference to internal carotid artery :

A) The cerebral blood flow patterns in the young and old men (Fig. 8, 9).

The blood flow patterns in normal young men and normotensive old men with slight cerebral arteriosclerosis are prone to be continuous in general. On the other hand, hypertensive young men (mainly, during attack of hypertensive

encephalopathy) and hypertensive old men with severe cerebral arteriosclerosis are prone to be conspicuously discontinuous. In hypertensive young men, the cerebral blood flow patterns have mostly returned to continuous patterns by administration of antihypertensive drug.

B) Correlation of the cerebral blood flow patterns in internal carotid arteries and the retinal arteriosclerosis in the old men (Tab. I).

The discontinuous patterns in internal carotid arteries have been frequent in severe retinal arteriosclerosis in both normotensive and hypertensive old men. In another words, the significant correlation between the blood flow patterns in internal carotid arteries and

Fig. 10 Blood flow patterns in internal, external and common carotid arteries
79 Yrs B.P. 180/90 mmHg

- (1): internal carotid artery
- (2): external carotid artery
- (3): common carotid artery

Fig. 11 Doppler beat caused by the pulsation of the blood vessel

common carotid artery
73 Yrs B.P. 200/50 mmHg

cerebral arteriosclerosis are suggested.

C) The blood flow patterns in internal, external and common carotid arteries (Fig. 10). The blood flow patterns in internal carotid arteries are most continuous. On the other hand, the blood flow patterns in external carotid arteries are most discontinuous. In common carotid arteries, the blood flow patterns have a tendency of intermediate type of the above two arteries.

D) The great spikes which may be caused by the pulsation of the blood vessels are occasionally observed at the onset of blood flow

patterns. The frequency of this spikes are lower than around 100 c/s as a whole (Fig. 11).

DISCUSSION

The measurement of blood flow by ultrasonic Doppler technique is very unique compared with other techniques, although the method has still been controversial from the various points of view. Based on the principle of this method and the results in this study, the useful characteristics of this method are as follows.

A) The dynamic change of the blood flow at the vessel resulting from the various stresses to circulatory system can be observed instantaneously and non-operatively.

B) The cerebral circulation and cerebral arteriosclerosis are objectively and simply evaluated based on the Doppler beat patterns.

With respect to the former, it should be considered that the detected sound consists of combined effects of blood flow velocity, density of blood particles, distribution of sound-pressure, correlation of ultrasonic wave and blood stream, etc. When the components other than blood

flow velocity are constant, the output-voltage of detected sound reflects the blood flow pattern of the vessel. With respect to the latter, on the other hand, the following two items are to be considered.

A) The blood flow pattern using by this method do not only reflect the cerebral arteriosclerosis, but also the cerebral vascular resistance. In another words, the discrimination of functional component (cerebrovascular contraction) and organic component (cerebral arteriosclerosis), which consist of the cerebral vascular resistance, are essential.

B) The simultaneous investigation of hemodynamics in internal carotid artery and vertebral artery, which consist of the cerebral circulatory system, are essential, because the cerebral circulation consist of mainly both the internal carotid artery and vertebral artery.

The conspicuous differences of blood flow patterns in internal, external and common carotid artery may well be resulted from the following components.

A) The cerebral vascular resistance in internal carotid artery is lowest, because the territory of the artery have much pliable tissue and Virchow-Robin's space protecting against the pressure as a cushion.

B) On the other hand, the cerebral vascular resistance in external carotid artery is highest, because the territory of the artery have much stiff skin, fascia and muscle compressing the vessel directly.

The great spikes occurring at the onset of blood flow patterns may be mainly caused by both the pulsation of blood vessels and the increase of reflection of ultrasonic waves from the ves-

sels. In support of above concept, the following factors may be considered.

A) The frequency of the spike is lower than around 100 c/s.

B) The spike is more clearly manifested by the activation of the pulsation of vessel, e.g, increase of blood pressure.

C) The spike is more conspicuous in asthenic men than in obese men.

D) The spike is more conspicuous in soft attachment of transducer with skin than in hard attachment.

E) The spike is more conspicuous in shallow vessel than in deep vessel.

The clinical significance of the spike is not clear.

CONCLUSION

The principle and clinical application of ultrasonic Doppler technique are presented and the useful characteristics of the method are investigated.

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