Measurement of Cerebral Blood Flow by Ultrasonic Doppler Technique

Cerebral Venous Return in Various Diseases

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The measurement of blood flow by ultrasonic Doppler technique is very unique compared with other technique, although the method has still been controversial from the various points of view. The characteristics of this method are as follows. (1) The cerebral circulation and cerebral arteriosclerosis are objectively and simply evaluated based on the Doppler beat patterns. (2) The dynamic change of the blood flow at the objective vessel resulting from the various stresses to circulatory system can be observed instantaneously without any surgical procedure. In this study, the application of this method to the measurement of cerebral venous return (blood flow in internal jugular vein) in several diseases was presented.

Cerebral venous return (blood flow pattern in internal jugular vein) mainly depends on its front based on cardiopulmonary function. In another words, cerebral venous return for the thorax mainly depends on the respiratory pump action resulting from the decrease of intrapleural pressure at inspiratory phase and pressure-suction pump action resulting from the decrease of intra-atrial pressure at ventricular contraction.¹⁻²)

Therefore, the measurement of the cerebral venous return are useful for understanding of the pathophysiology both of cardiopulmonary function and cerebral circulation. However, the measurement of venous return has been controversial from the anatomical and physiological point of view.

In this study, cerebral venous return were determined by ultrasonic Doppler technique¹⁻⁶ in various diseases as a part of the application of this technique.

Materials and Methods

Materials: normal young mon, hypertensive old men (healthily-looking), very old men (healthily-looking and normotensive); patients with congestive heart failure (mitral stenosis), chronic pulmonary emphysema and severe anemia (no cardio-pulmonary diseases).

Methods: Fig. 1 shows the block diagram of the apparatus. Ultrasonic vibrator (PZT) was placed on the surface of the skin above internal jugular vein. Ultrasonic waves (6 Mc/s) impinge upon the internal jugular blood stream. The reflected waves are subjected to frequency change due to Doppler's effect from moving blood particles. A kind of noise was obtained by composing the reflected waves together with the direct waves and modulating them. Frequencies of this noise are proportional to the blood flow velocity.¹ Fig. 2 shows the frequency characteristics of the apparatus. The output voltages are proportional to the frequencies from around 100 c/s to 6000 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. Fig. 3 shows the relationship between flow velocity and output voltage measured by this apparatus in water flow

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![Fig. 1. Block diagram of the apparatus](image-url)
In the experiment, the output voltage are proportional to the water velocities.

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  
\( \alpha \): 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 modulating them. The frequencies of Doppler beat \( (fd) \) are demonstrated as follows.

\[
fd = f - f' = \frac{2U \cos \alpha}{C - U \cos \alpha} f = \frac{2U \cos \alpha}{C} f = \frac{2U \cos \alpha}{\lambda}
\]

\( \lambda \): 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. Doppler effect are maximum at \( \alpha = 90^\circ \) and minimum at \( \alpha = 0^\circ \).

![Graph showing frequency characteristics of the apparatus](image1)

**Fig. 2.** Frequency characteristics of the apparatus

![Graph showing water-flow experiment](image2)

**Fig. 3.** Water-flow experiment

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RESULTS

Fig. 4 shows the cerebral venous return in normal young man in a steady state throughout cardiac cycle. In these figures, the upper pattern shows the blood flow of internal carotid artery and the lower pattern shows the blood flow of internal jugular vein.
Fig. 5 shows the cerebral venous return in a patient with chronic pulmonary emphysema obtained at only inspiratory phase. This disappears at expiratory phase.

The cerebral venous return in patients with severe anemia (no cardiopulmonary diseases) consist of two types; a steady flow and an unsteady flow. Fig. 9 shows a steady flow. Fig. 10 shows an unsteady flow.

**DISCUSSION**

Venous return mainly depends upon the combined effect of Vis a tergo and Vis a fronte,
especially upon the latter. Vis a fronte consists of many factors, i.e., the respiratory pump resulting from respiratory movement, the pressure-suction pump resulting from ventricular contraction, hydrostatic effect of gravity, the massaging effect of muscular contraction, neurohormonal regulation and the effect of blood chemical agent. Among these factors, Vis a fronte resulting from respiratory pump and ventricular contraction are most important. That is, these two factors play a predominant role in developing effective venous pressure, which is assumed to be basic force in Vis a fronte.1-3)

According to this concept, the precapillary and postcapillary blood flow are regulated by the different mechanism. Therefore, the circulatory insufficiency of blood flow may be resulted from the essentially different disorders. However, the insufficiency of either side plays the trigger's role resulting in the circulatory insufficiency of the other side, since these two blood flow systems construct the series-coupled circuits anatomically and physiologically. In another words, the measurement of cerebral venous return are useful for understanding the pathophysiology of insufficiency in cardiopulmonary function and cerebral circulation.

Brecher1) pointed out that the pliable central vein forms a collapse chamber which is the functional counterpart of the aortic compression chamber (windkessel). The aortic compression chamber assures the transformation of the discontinuous cardiac ejection into steady flow for the tissues. On the venous side, a collapse chamber assures the transformation of steady flow from the tissues into discontinuous pulsatile flow at the atrial entrance which is need for the discontinuous filling. The blood flow patterns in internal jugular vein in normal young men and hypertensive old men support the Brecher's concept as to the peripheral venous hemodynamics.

Normal rapid forward movement of central venous blood during ventricular systole is reversed in the presence of a large atrioventricular valve insufficiency. Maximal forward flow occurs under these circumstances during ventricular diastole.1) The blood flow patterns in internal jugular vein in the very old men and the patients with mitral stenosis are in agreement with above concept.

There are various and controversial opinions as to the effect of respiration on venous return because of the absence of direct evidence. The best represented views are the classical theory of Donders, according to which venous return increases with inspiration, and the new collapse theory of Holt and Duomarco, according to which venous return does not increase with inspiration.13) The blood flow patterns in internal jugular vein in patients with chronic pulmonary emphysema, in which the blood flow patterns were obtained at only inspiratory phase and disappeared at expiratory phase, support the inspiratory-return theory. The extreme negative intrapleural pressure at inspiratory phase and positive pressure at expiratory phase in chronic pulmonary emphysema also support this theory.7)

The discontinuity and irregularity of blood flow patterns in internal jugular vein, synchronized with neither cardiac nor respiratory cycle, in patients with severe anemia, might be due to the unbalance of returning blood volume and venous diameter. Since internal jugular vein is least elastic in whole venous system,9) it may well be due to venous collapse resulted from extreme decrease of returning blood volume.

SUMMARY

In this study, the cerebral venous return (blood flow pattern in internal jugular vein) were examined by ultrasonic Doppler technique in normal young men, hypertensive old men (healthily-looking), very old men (healthily-looking and normotensive); patients with congestive heart failure (mitral stenosis), chronic pulmonary emphysema and severe anemia (no cardiopulmonary diseases). Results were as follows.

1) The cerebral venous return in normal young men and hypertensive old men were continuous throughout cardiac cycle. From these results, it was suggested that cerebral venous return in both groups were in steady state.

2) The cerebral venous return in very old men were discontinuous in synchrony with the cardiac cycle. The results indicate the disor-
ders of cerebral venous return resulting mainly from heart failure (the insufficiency of pressure-suction pump).

3) The cerebral venous return in patients with congestive heart failure were conspicuously discontinuous in synchrony with the cardiac cycle. The results indicate the disorders of cerebral venous return resulting mainly from the insufficiency of pressure-suction pump.

4) The cerebral venous return in patients with chronic pulmonary emphysema were observed at only inspiratory phase and disappeared at expiratory phase. The results indicate the disorders of cerebral venous return resulting mainly from the respiratory insufficiency in these patients (the insufficiency of respiratory pump).

5) The cerebral venous return in patients with severe anemia consist of two types; steady flow and unsteady flow.

6) From above results, it was suggested that the ultrasonic Doppler technique were useful for detection in disorders of cerebral venous return.

REFERENCES

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