Contribution

Quantitative Detection of Cerebral Arteriosclerosis by the Ultrasonic Doppler Technique: Criteria for the Diagnosis of Cerebral Arteriosclerosis

Manabu MIYAZAKI

Department of Internal Medicine Miyazaki Naika Clinic

The correlation between continuity of cerebral blood flow velocity (CBFV) pattern (internal carotid artery) and cerebral vascular resistance, indicating cerebral arteriosclerosis (CA), was investigated by the ultrasonic Doppler technique. A significant correlation between continuity of the CBFV pattern and the severity of CA was recognized: the greater the decrease in continuity of the CBFV pattern, the greater the severity of CA. In a previous study, the continuous index (CI) of the CBFV pattern was devised as an objective parameter of the continuity of the CBFV pattern for evaluating cerebral hemodynamics in CA. Pulsatility index (PI) and resistance index (RI) are similar in nature to the CI. These parameters are useful as objective indexes of cerebral vascular resistance, indicating CA, particularly of the arteriole. Among these parameters, PI seems to be more useful clinically than CI and RI. Criteria for the quantitative detection of CA, particularly of the arteriole, are proposed by calculation of the PI.

Key words: continuous index (CI), pulsatility index (PI), resistance index (RI)

Introduction

Quantitative detection of cerebral arteriosclerosis (CA) will play an important role in the treatment of cerebral vascular diseases. However, no suitable technique has yet been developed in this field because of methodological difficulties.

Examination of the cerebral blood flow velocity (CBFV) pattern by the ultrasonic Doppler technique is the easiest method for the quantitative detection of CA. This method is based on a significant correlation between continuity of the CBFV pattern and the severity of CA²⁻⁷⁾.

In a previous study in 1967, the continuous index (CI) of the CBFV pattern was devised as an objective parameter of continuity of the CBFV pattern (cerebral vascular resistance), and CA was examined using this parameter²⁻⁷⁾. In further studies, Gosling et al.¹⁾ and Taylor et al.¹³⁾ described the pulsatility index (PI) and resistance index (RI), which are similar in nature to the CI.

In this study, the quantitative detection of CA was examined using the ultrasonic Doppler technique, with a view to developing criteria for the quantitative detection of CA, particularly of the arteriole.

Correlation between continuous index, pulsatility index and resistance index

Correlation between CI and PI

CI, PI and RI were calculated by the methods shown in Fig. 1 (A, B, C).

In the equations presented in Fig. 1, when X and Y are set down as constant, $X/Y = A$ and $Y-X = B$, CI and PI are calculated as $CI = A \times Z$ and $PI = B/\text{mean}$, respectively. Generally speaking, $\text{mean} \propto Z$, so $PI = B/\text{mean} \propto B/Z = A \times B/CI$. Therefore, $PI \propto 1/CI$. In conclusion, it is suggested that an inverse correlation exists between CI and PI.

Indeed, a significant inverse correlation was recognized between CI and PI in clinical practice using 30 young healthy volunteers as well as elderly patients with cerebral vascular diseases ($r = -0.803$, $p < 0.01$, $Y = 2.427 - 0.035X$) (Fig. 2)⁹⁾.

Correlation between CI and RI

In the equations presented in Fig. 1, when X and Y are set down as constant, $X/Y = A$ and $Y-X = B$, CI and RI are calculated as $CI = A \times Z$ and $RI = 1-A = 1-CI/Z$, respectively. Under conditions where no significant changes are recognized in pulse rate, Z can be regarded as constant, and $RI \propto -CI$. This indicates that a negative correlation exists between CI and RI.

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Manabu MIYAZAKI : Miyazaki Naika Clinic, 1-15 Shimamachi 2-chome, Chuo-ku, Osaka Japan

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Fig. 1 Calculation of continuous index (CI), pulsatility index (PI) and resistance index (RI).

Fig. 2 Correlation of continuous index (CI) and pulsatility index (PI) of cerebral blood flow pattern (internal carotid artery) in young healthy subjects and elderly patients with cerebral vascular diseases.

The above results support that idea that CI, PI and RI are similar in nature and that these parameters may be useful as objective parameters of cerebral vascular resistance suggesting CA.

Problems with CI, PI and RI

When these parameters are applied clinically, the calibration of heart rate is most important. Z, the interval of one cardiac cycle in CI, and mean, the mean blood flow velocity of one cardiac cycle in PI, are important factors in the calibration of heart rate.

On the other hand, no calibration of heart rate in RI is a demerit of RI. RI seems to give rise to non-negligible errors in severe arrhythmia such as tachycardia and bradycardia.

As for CI, the following considerations are essential: (i) CI cannot be calibrated at zero point of X (blood flow in diastole is arrested); and (ii) PI and RI change in parallel with cerebral vascular resistance. On the other hand, CI changes inversely with change in cerebral vascular resistance.

In conclusion, PI is considered more suitable than CI and RI as an objective parameter of cerebral vascular resistance

Fig. 3 Classification of cerebral blood flow velocity pattern (internal carotid artery).

(A) Continuous type, (B) intermediate type, (C) discontinuous type.

suggesting CA.

Correlation of CBFV pattern (internal carotid artery) and cerebral vascular resistance

Clinical investigation

The CBFV patterns (internal carotid artery) measured by the Doppler ultrasonic technique were classified according to continuity of the CBFV pattern into the following three types: (i) continuous type; (ii) intermediate type; and (iii) discontinuous type (Fig. 3).

Correlation between continuity of the CBFV pattern and the severity of CA was investigated by comparing intracerebral arteriosclerosis with extracerebral arteriosclerosis anatomically, and with retinal arteriosclerosis, clinically. The results showed a significant correlation between continuity of the CBFV pattern and the severity of CA: the greater the decrease in continuity of the CBFV pattern, the greater the severity of CA^{2,7,9-12}.

Table 1 and Fig. 3 show criteria for the quantitative detection of CA by the ultrasonic Doppler method (continuity method).

Table 1. Criteria for the quantitative detection of cerebral arteriosclerosis by the ultrasonic Doppler technique

Type of cerebral blood flow velocity pattern	Severity of cerebral arteriosclerosis	Note
Continuous type	Extracerebral atherosclerosis and intracerebral arteriosclerosis are absent or minimal	Pseudo-continuous type
Intermediate type	Extracerebral atherosclerosis and intracerebral arteriosclerosis may belong to the continuous and discontinuous types	Pseudo-intermediate type
Discontinuous type	Extracerebral atherosclerosis and intracerebral arteriosclerosis are severe. Among them, intracerebral arteriosclerosis is more severe than extracerebral atherosclerosis	Pseudo-discontinuous type

Table 2. Criteria for the quantitative detection of cerebral arteriosclerosis by pulsatility index (PI) measurement (internal carotid artery)

Age	PI	Cerebral arteriosclerosis
< 60 years	< 1.3	Normal artery
	1.3-1.7	Mild arteriosclerosis
	1.7-2.0	Moderate arteriosclerosis
	> 2.0	Severe arteriosclerosis
> 60 years	< 1.4	Normal artery
	1.4-1.8	Mild arteriosclerosis
	1.8-2.1	Moderate arteriosclerosis
	> 2.1	Severe arteriosclerosis

Continuous index (CI) of the CBFV pattern was devised as an objective parameter of continuity (i.e., cerebral vascular resistance and CA).

Basic investigation

Alterations of blood flow velocity patterns were investigated in the following circulatory stress tests: (i) hand-grasping; (ii) brachial-binding; and (iii) cold and warm-stimulating tests. It was revealed that the more peripheral vascular resistance was increased, the more discontinuity of the brachial blood flow velocity pattern increased.

Fig. 4 shows the alterations of CI and PI in the brachial artery examined by the antebrachial binding test ("manchette" method). A significant decrease of CI and increase of PI in the brachial artery were observed in response to an increase in antebrachial binding using a cuff. Alterations of CI and PI in the blood flow velocity pattern in the brachial artery were also observed in the other examinations (hand-grasping, cold and warm-stimulating test).

It is postulated from the above clinical and basic investigations that continuity of the CBFV pattern and the three parameters, CI, PI and RI, seem to be useful as objective parameters of cerebral vascular resistance (i.e., CA, particular of the arteriole).

Fig. 4 Change of continuous index (CI) and pulsatility index (PI) in the antebrachial-binding test (brachial artery).

Fig. 5 E-Point (exponential point) is detected instead of Y-point, in case the initial spike is observed in the cerebral blood flow velocity pattern.

Criteria for quantitative detection of CA by measurement of PI

The correlation between PI of the CBFV pattern measured by the ultrasonic Doppler technique and risk factors of cerebral vascular diseases (e.g., aging, hypertension, diabetes mellitus and hypercholesterolemia) was investigated and a significant correlation was recognized between PI and the risk factors.

Table 2 shows criteria for the quantitative detection of CA, particularly of the arteriole, by the PI measurement technique. When applying these criteria, the differences in PI between the vessels (internal carotid artery, external carotid artery, common carotid artery, internal jugular vein, etc.), architecture and variation of the vessels should be considered.

In general, PI in the internal carotid artery is smaller than that in the external and common carotid arteries. On the other hand, PI in the internal jugular vein seems to be smaller than PI in the internal carotid artery.

An initial large spike may occasionally be observed at the onset of the blood flow velocity pattern (Fig. 5). In this case, it may be appropriate to detect the E-point (exponential point) instead of the usual Y-point. As for the mechanisms responsible for this spike, several factors such as cardiac function and elasticity of the carotid artery may be involved.

Conclusion

The three parameters, CI, PI and RI, of the CBFV pattern measured by the ultrasonic Doppler technique are similar in nature. These parameters are useful as objective parameters of cerebral vascular resistance suggesting CA, particular of the arteriole.

PI seems to be more suitable than CI and RI from the standpoint of clinical usefulness. Criteria for the quantitative detection of CA, particularly of the arteriole, by measurement of the PI are proposed.

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