Evaluation of Cross-Circulation Through Circle of Willis Using An Ultrasonic Doppler Technique

Part II. Comparison Between Blood Flow Velocity by Ultrasonic Doppler Flowmetry and Cerebrovascular Resistance

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SUMMARY The correlation between the increase in velocity of blood flow in both the internal carotid and vertebral arteries during a carotid compression and the cerebrovascular resistance (CVR) was investigated in 11 patients with chronic ischemic cerebrovascular disease and 4 without organic brain lesions. The velocity of blood flow was measured by an ultrasonic Doppler flowmeter. CVR was calculated from cerebral blood flow and arterial blood pressure. There was no correlation between the increased velocity of blood flow in the internal carotid and vertebral arteries and CVR. The increased velocity of blood flow in patients with low CVR was, however, significantly higher than that of patients with high CVR.

The investigation of cross-circulation by ultrasonic Doppler flowmetry is a useful non-invasive method for the detection of changes in cerebral vascular resistance.

Materials and Methods

Eleven patients with chronic ischemic cerebrovascular disease (CBVD) in the brain supplied by the carotid system without an aplastic anterior cerebral artery on angiogram, and 4 without organic brain lesions (normal brain) were examined. The ages of patients varied from 15 to 70 years with an average age of 48.9 years. Among the 11 patients with cerebrovascular disease there were 10 with completed stroke and one with transient ischemic attacks.

This study was performed to evaluate the relationship between the cross-circulation through the circle of Willis and cerebrovascular resistance (CVR). Cross-circulation via the circle of Willis was evaluated by an ultrasonic Doppler flowmeter measuring changes of velocity of blood flow in the internal carotids and vertebas during carotid compression.
Doppler Flowmetry

**Apparatus and Examination Technique**

The velocity of blood flow in both the internal carotid and the vertebral arteries was measured by a directional Doppler flowmeter (Hitachi EUD-3B, 5 MHz, Hitachi Medical Corporation, Tokyo).

All examinations were performed with the patient in the supine position. The technique for both internal carotid and vertebral artery flow determination was previously reported in detail. The blood flow velocity (mean velocity) curve obtained from the directional Doppler flowmeter was integrated every 3 seconds. This value was employed so as to simplify the calculation of the increase of velocity of blood flow during a carotid compression. The velocity of blood flow, the integrated blood flow velocity, the electrocardiogram and the ear plethysmogram were all recorded simultaneously on a polygraph (Hitachi ECP-1, Hitachi Medical Corporation, Tokyo).

**Examination Procedure**

The changes in velocity of both the internal carotid and the vertebral arterial blood flows were measured before and during digital compression of the common carotid artery. The change was expressed as the percent of increase above the blood flow velocity in the steady state. The flow change in the internal carotid artery was measured during a compression of the contralateral common carotid artery when it was believed that blood flow in the non-compressed internal carotid artery is redistributed to the contralateral cerebral hemisphere through the anterior communicating artery.

Changes of velocity of flow in the vertebral artery were measured during a compression of the ipsilateral common carotid artery when it was believed that blood flow in the vertebral artery was redistributed to the cerebral hemisphere via the ipsilateral carotid system through the posterior communicating artery. Complete compression of the carotid artery was confirmed by a plateau wave of an ipsilateral ear plethysmogram. Patients who showed significant changes in blood pressure and in heart rate during the carotid compression were excluded.

For patients without cerebrovascular disease, cerebral blood flow was measured only unilaterally. Bilateral hemispheric cerebral blood flow was assumed to be equal, and bilateral hemispheric cerebral vascular resistance was believed to be equal. Accordingly, the percent increase of velocity of blood flow in patients without cerebrovascular disease was related to bilateral internal carotid and vertebral arteries. It is known that in ischemic cerebrovascular disease, blood flow on the healthy side may recover to nearly normal levels.

In this study, the increase in velocity of flow in the internal carotid artery on the healthy side during a carotid compression on the ischemic side was used to determine the percent of increased blood flow in patients with cerebrovascular disease (fig. 1). This percent increase is believed to correspond to the degree of the cross-circulation via the anterior communicating artery from the healthy to the ischemic side. The blood flow increase in the vertebral artery on the ischemic side during a carotid compression on the ischemic side was used to determine the percent increase of blood flow in patients with ischemic cerebrovascular disease (fig. 2). This increase is believed to

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**TABLE Angiographic Findings of Patients with Cerebrovascular Disease**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Anterior Cerebral Artery</th>
<th>Wall irregularity or stenosis of ICA</th>
<th>Wall irregularity of ACA &amp; MCA</th>
<th>Wall irregularity of ICA &amp; MCA</th>
<th>Wall irregularity of peripheral branch of ACA &amp; MCA</th>
<th>No evidence of vascular disease</th>
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<td>Bilateral CAG &amp; VAG (n = 2)</td>
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ICA = Internal Carotid Artery; MCA = Middle Cerebral Artery; ACA = Anterior Cerebral Artery; VA = Vertebral Artery.
FIGURE 1. The blood flow velocity increase of the internal carotid artery of the non-ischemic side during a digital compression of the common carotid artery of the ischemic side. The dotted area represents the ischemic hemisphere. The black shaded artery represents the vessel on which measurement of the flow velocity is performed. The dotted artery is the collateral channel. The big dotted arrow shows the velocity increase during a carotid compression. The small dotted arrow shows the flow direction through the circle of Willis.

correspond to the degree of cross-circulation through the posterior communicating artery from the vertebral artery on the ischemic side to the internal carotid artery on the ischemic side.

Results

1. Flow Velocity Increase in Internal Carotid Artery

The relationship between the CVR and the percent increase of velocity of blood flow was investigated in 7 internal carotid arteries in 4 patients without CBVD and in 10 internal carotid arteries on the ischemic side in 10 patients with CBVD and normal anterior communicating artery. There was no correlation between the percent increase of the velocity of flow in internal carotid arteries and CVR in 17 arteries among 14 patients (fig. 3). The percent increase in 5 arteries among those 5 patients with the high CVR (above 2.2 mm Hg/ml/100g/min) was 18.8 ± 11.6 (SD). In 12 arteries among those 9 patients with low CVR (i.e. lower than 2.2 mm Hg/ml/100g/min) it was 36.3 ± 17.3 (SD)%. This is a significant difference between the 2 groups (p < 0.02, fig. 4).

2. Flow Velocity Increase in Vertebral Artery

The relationship between the CVR and the percent increase of vertebral blood flow velocity was investigated in bilateral vertebral arteries in the 3 patients with normal brain and in 11 vertebral arteries on the ischemic side in 11 patients with CBVD. There was no correlation between the CVR and the percent increase of velocity of flow in the vertebral artery (fig. 5). The percent increase of the 11 vertebral arteries among the 8 patients with low CVR and the 6 arteries among 6 with the high CVR were respectively 34.5 ± 17.0 (SD) and 13.8 ± 11.3 (SD) %. This difference between the 2 groups was significant (p < 0.05, fig. 6).

Discussion

Our previous study suggested that no increase in velocity of flow in the internal carotid artery during a contralateral compression occurred in patients with no anatomical connection between the internal carotid arteries via the anterior communicating artery. The data also suggested that a peripheral vascular factor distal to the circle of Willis might also play a significant role in regulating cross-circulation through the
FIGURE 3. Relationship between percent increase of the internal carotid blood flow velocity and cerebral vascular resistance in 17 internal carotid arteries of 14 patients. There was no correlation.

FIGURE 5. Relationship between percent increase of the vertebral blood flow velocity and cerebral vascular resistance in 17 arteries of the 14 patients. There was no correlation.

In this study there was no correlation between the percent increase in velocity of flow in the internal carotid and the cerebral vascular resistance in 14 patients with a normal anterior communicating artery (fig. 3). The percent increase of velocity of flow in the internal carotid artery in patients with low CVR, however, was significantly higher than that in those with high CVR (fig. 4). It is believed that the flow velocity increase of the internal carotid artery is in part dependent on CVR.

The percent increase in velocity of flow in the vertebral artery in patients with low CVR was significantly higher than that for patients with high CVR (fig. 6).
The investigation of the cross-circulation by ultrasonic Doppler flowmetry is an excellent non-invasive method for the detection of changes in cerebral vascular resistance.

References

Evaluation of cross-circulation through circle of Willis using an ultrasonic Doppler technique. Part II. Comparison between blood flow velocity by ultrasonic Doppler flowmetry and cerebrovascular resistance.
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