# Decreased Flow Velocity with Transcranial Color-Coded Duplex Sonography Correlates with Delayed Cerebral Ischemia due to Peripheral Vasospasm of the Middle Cerebral Artery

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*Background and Objective:* Despite intensive therapy, vasospasm remains a major cause of delayed cerebral ischemia (DCI) in worsening patient outcome after aneurysmal subarachnoid hemorrhage (aSAH). Transcranial Doppler (TCD) and transcranial color-coded duplex sonography (TCCS) are noninvasive modalities that can be used to assess vasospasm. However, high flow velocity does not always reflect DCI. The purpose of this study was to investigate the utility of TCD/TCCS in decreasing permanent neurological deficits. *Methods:* We retrospectively enrolled patients with aSAH who were treated within 72 hours after onset. TCCS was performed every day from days 4 to 14. Peak systolic velocity (PSV), mean velocity (MV), and pulsatility index were recorded and compared between DCI and non-DCI patients. In patients with DCI, endovascular therapy was administered to improve vasospasm, which led to a documented change in velocity. *Results:* Of the 73 patients, 7 (9.6%) exhibited DCI. In 5 of the 7 patients, DCI was caused by vasospasm of M2 or the more peripheral middle cerebral artery (MCA), and the PSV and MV of the DCI group were lower than those of the non-DCI group after day 7. Intra-arterial vasodilator therapy (IAVT) was performed for all patients with DCI immediately to increase the flow volume by the next day. *Conclusions:* Increasing flow velocity cannot always reveal vasospasm excluding M1. In patients with vasospasm of M2 or more distal arteries, decreasing flow velocity might be suggestive of DCI. IAVT led to increases in the flow velocity through expansion of the peripheral MCA. **Key Words:** TCD—TCCS—vasospasm—vasodilator.


## Introduction

Although delayed vasospasm of the major cerebral arteries has been regarded as the main cause of delayed cerebral ischemia (DCI) after aneurysmal subarachnoid hemorrhage (aSAH), chronic vasospasm of distal arteries, microthrombosis, impaired autoregulation, and spreading depolarization remain under intense investigation as complementary factors in the pathogenesis of DCI.[1-4] Transcranial Doppler (TCD) and transcranial color-coded duplex sonography (TCCS) are noninvasive methods for bedside monitoring of vasospasm,[5-8] and TCD has recently been recommended for monitoring the development of vasospasm, according to the 2012 American Stroke

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Association/American Heart Association guidelines.[9] Although some patients remain asymptomatic, a peak systolic velocity (PSV) higher than 200 cm/s is well known to suggest a tendency toward angiographic vasospasm.[5,10-12] While TCD/TCCS findings have been correlated with angiographic vasospasm of the horizontal portion (M1) of the middle cerebral artery (MCA),[10] the possibility of a relationship between a PSV higher than 200 cm/s and DCI remains controversial.

Endovascular therapy is often used to treat vasospasm, and is recommended in the 2012 American Stroke Association/American Heart Association guidelines.[9] Intra-arterial vasodilator therapy (IAVT) is considered to be safe and effective in improving patient outcomes.[13-16] Although IAVT certainly improves vasospasm, to our knowledge, there has been no report of TCD/TCCS findings before and after IAVT.

The aim of the present study was to elucidate whether TCD/TCCS is useful for DCI and what the main findings of TCD/TCCS should be to reduce permanent neurological deficits.

## Methods

### *Patients and Management*

From November 2010 to February 2014, we examined 73 patients with aSAH. The patients underwent clipping or coil embolization within 72 hours after onset, and were treated in the intensive care unit (ICU) up to day 14. All patients were treated appropriately to achieve normovolemia, hypertension, and hemodilution. Intravenous fasudil (60-90 mg/day) was administered from days 4 to 14. Acute hydrocephalus was managed with external ventricular drainage, cisternal drainage, and/or lumbar drainage to discharge the cerebrospinal fluid from 200 to 300 mL/day. TCCS was performed daily from days 4 to 14 by a neurosonographer. DCI was defined by the presence of new neurological deficits and/or brain infarction on computed tomography (CT) or magnetic resonance imaging (MRI) when the cause was considered to be attributable to vasospasm.

The clinical definition of deterioration due to DCI is "The occurrence of focal neurological impairment (i.e., hemiparesis, aphasia, apraxia, hemianopia, or neglect), or a decrease of at least 2 points on the Glasgow Coma Scale (either on the total score or on one of the individual components [eye, motor on either side, verbal]). This should last for at least 1 hour, is not apparent immediately after the aneurysm occlusion, and cannot be attributed to other causes by means of clinical assessment, CT or MRI scanning of the brain, and appropriate laboratory studies."[17]

When patients suffered from DCI, emergency digital subtraction angiography (DSA) was performed. If needed, endovascular therapy was administered, which involved intra-arterial fasudil (10-30 mg) from M1–M2 or percutaneous transluminal angioplasty. Patients were excluded if they did not undergo surgery within 72 hours and/or TCCS could not be performed because of the lack of cranial windows.

### *Clinical Data*

The following clinical data were collected: (1) age and gender, (2) aSAH grading according to Hunt and Kosnik classification, (3) location of the aneurysm, (4) Fisher CT grade, (5) clipping or coil embolization, (6) TCCS findings, (7) presence of DCI, (8) delayed ischemic lesion on CT or MRI, and (9) outcome according to the Glasgow outcome scale.

### *Transcranial Color-Coded Duplex Sonography (TCCS)*

TCCS was performed using a ProSound Alpha 7 (Hitachi Aloka Medical Ltd, Tokyo, Japan) with a 1- to 5-MHz 90° phased-array probe for B-mode imaging and color Doppler imaging. M1 flow signals were recorded showing the Doppler velocity with a 4-mm-wide sample volume. In patients who underwent clipping with the pterional approach, the probe was fixed at an extended line of M1 to show the ipsilateral M1 flow without angle compensation through the craniotomy opening. Contralateral M1 flow was shown from the contralateral side of the temporal window. In patients who underwent coil embolization or clipping with another craniotomy, bilateral M1 flow was shown from each temporal window with angle compensation. The highest PSV was documented by manually moving the sample volume over the M1 observing color Doppler. PSV, mean velocity (MV), endodiastolic velocity, and pulsatility index (PI) were calculated by automatic analysis with the ProSound Alpha 7. In patients with DCI, the data of the affected side were used. In patients without DCI, the data from the side that had the highest PSV from days 4 to 14 were used.

### *Statistical Analysis*

The Mann–Whitney *U*-test was used to compare variables between patients with and without DCI. *P* values less than .05 were considered significant in all analyses. All study protocols followed the principles outlined in the Declaration of Helsinki. The present study was approved by the Ethics Committee of Yamaguchi University.

## Results

### *Patient Characteristics*

We analyzed 73 patients with aSAH. Fifty-four were females, and the mean age (±standard deviation) was 57.9 ± 12.4 years old. Clipping was performed in 64 patients (88%). The baseline characteristics of the patients without DCI (non-DCI group, n = 66, 90.4%) or with DCI (DCI group, n = 7, 9.6%) are shown in Table 1. In a series