Bidirectional Flow in the Vertebral Artery Is Not Always Indicative of the Subclavian Steal Phenomenon

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**Objective**—To evaluate the causes of bidirectional flow in the vertebral artery detected by Doppler sonography and its differential diagnosis.

**Methods**—Twenty-nine patients with bidirectional flow in the vertebral artery were retrospectively studied. The vertebral artery parameters, including peak antegrade velocity (PAV), peak reversed velocity (PRV), maximum peak velocity (MPV), peak systolic velocity, resistive index (RI), and diameter, were measured. The MPV was defined as the MPV of bidirectional flow regardless of the velocity of antegrade or retrograde flow. To better predict the cause of bidirectional flow, receiver operating characteristic curves were constructed for these parameters, and the best cutoff values were obtained. The cause of bidirectional flow was determined by angiography.

**Results**—The causes of bidirectional flow were classified as the subclavian steal phenomenon (n = 21) and factors unrelated to the steal phenomenon (n = 8, including a hypoplastic vertebral artery [n = 4] and proximal vertebral artery stenosis and occlusion [n = 4]). Significant differences were observed between the steal phenomenon and non–steal phenomenon groups (P < .05) for MPV, PRV, PAV, target vertebral artery diameter, and contralateral RI. To determine the cause of bidirectional flow, areas under the receiver operating characteristic curves for the different parameters were obtained: 0.929 for MPV, 0.881 for PRV, 0.753 for target vertebral artery diameter, and 0.845 for contralateral RI. The cutoff value for MPV was 26.1 cm/s, and the accuracy was 93% (27 of 29).

**Conclusions**—Bidirectional flow in the vertebral artery is not always indicative of the subclavian steal phenomenon. Measurement of hemodynamic parameters in the vertebral artery, such as MPV, can facilitate determination of the cause of bidirectional flow.

**Key Words**—angiography; bidirectional flow; occlusion; sonography; subclavian steal; vertebral artery

It is estimated that up to 20% of ischemic events involve vertebrobasilar (posterior) circulation, and many of these cases occur in patients with previously unrecognized or misdiagnosed vertebrobasilar disease. Accurate diagnosis of vertebrobasilar disease is currently dependent on vascular imaging. Although digital subtraction angiography is a reference standard for evaluating vertebrobasilar circulation, the less-invasive methods of computed tomographic (CT) angiography, contrast-enhanced magnetic resonance (MR) angiography, and Doppler sonography have emerged as useful alternatives for evaluating the extent of vertebrobasilar disease. Both CT angiography and contrast-enhanced MR angiography have high sensitivity and specificity for diagnosing posterior circulation disease, yet Doppler sonography of the vertebral artery in the intertransverse segment is the most widely used of the three for detection of diseases related to any aspect of vertebrobasilar circulation due its cost-effectiveness.

To date, most diseases related to vertebrobasilar circulation, such as occlusion, stenosis, and congenital variations of the vertebral artery, have been diagnosed with Doppler sonography in previous studies.\(^5\)\(^-\)\(^7\) The spectral Doppler waveform of the vertebral artery has also proven useful for predicting the degree of ipsilateral subclavian artery stenosis and determining whether blood flow is antegrade or retrograde.\(^1\)\(^,\)\(^8\) Doppler sonographic detection of reversed flow (including bidirectional flow) in the vertebral artery is considered an indicator of the subclavian steal phenomenon, which is defined as the reversal of blood flow in the vertebral artery ipsilateral to proximal high-grade stenosis or occlusion of the subclavian or innominate artery before the origin of the vertebral artery.\(^4\)\(^,\)\(^9\) Therefore, bidirectional flow in the vertebral artery is a clinically detectable feature of the subclavian steal phenomenon. However, a hypoplastic vertebral artery and high-grade stenosis of vertebral artery origin may also result in bidirectional flow.\(^10\)\(^,\)\(^11\)

To gain a better understanding of the features for differential diagnosis of bidirectional flow in the vertebral artery, this study evaluated the causes of bidirectional flow in the vertebral artery using Doppler sonography. The results from other angiographic techniques, including digital subtraction angiography, CT angiography, and MR angiography, served as reference standards for the observations made with Doppler sonography.

**Materials and Methods**

**Patients**

Fifty-four patients with a Doppler sonographic diagnosis of bidirectional flow in the vertebral artery in our hospital between January 2005 and April 2012 were retrospectively studied. Of these, 29 patients (22 men and 7 women; mean age ± SD, 71.3 ± 7.1 years) were also examined by angiography, with 21 undergoing digital subtraction angiography, 4 undergoing CT angiography, and 4 undergoing contrast-enhanced MR angiography, were included in the data analysis. The interval between angiography and Doppler sonography did not exceed 2 weeks for the 29 patients. The patients’ clinical records and diagnoses made via angiography were used as reference standards for investigating the causes of bidirectional flow in the vertebral artery. Informed consent was obtained from the patients for participation in the study. In cases in which the patient was unresponsive or incapable of making a decision, informed consent was obtained from the patient’s family. The study was approved by the hospital’s Institutional Review Board.

**Doppler Sonography**

Doppler sonography was performed with standard sonographic equipment (HDI 5000; Philips Healthcare, Bothell, WA; Acuson Sequoia 512; Siemens Medical Solutions, Mountain View, CA; and SSD-α10; Aloka Co, Ltd, Tokyo, Japan) equipped with 4.0–8.0-MHz linear probes. Doppler sonography was performed with patients in the supine position. Sampling for the vertebral artery waveform was performed in the midportion of the vertebral artery extracranial segment, and the measured angle of insonation was 60° or less.\(^12\)

The bidirectional flow waveform was defined as a vertebral artery waveform with initial antegrade flow and subsequent retrograde flow observed during each cardiac cycle.\(^12\)\(^,\)\(^13\) Measurements taken in the target vertebral artery included peak antegrade velocity (PAV), peak reversed velocity (PRV), maximum peak velocity (MPV), and diameter. Measurements taken in the contralateral vertebral artery included peak systolic velocity (PSV), end-diastolic velocity, and diameter. The resistive index (RI) was also calculated for the contralateral vertebral artery. A hypoplastic vertebral artery was indicated when the artery’s diameter was 2 mm or less.\(^14\) The MPV in bidirectional flow is defined as the MPV recorded in either antegrade or retrograde flow. The PRV represented the value from baseline to the reversed systolic peak and was calculated by the instrument’s accompanying software. The hemodynamic measurements were required to be reproduced for at least 3 consecutive heartbeats to be considered valid. All measurements were performed 3 times, and the highest measurement value was selected for use in analysis.

**Statistical Analysis**

SPSS version 11.0 statistical software (SPSS Inc, Chicago, IL) was used for all statistical analyses. Statistical significance of intergroup differences was determined by the Fisher exact test (for discrete variables) or Student t test (for continuous variables). The results were considered significant at \(P < .05\). For determining the causes of bidirectional flow in the vertebral artery, receiver operating characteristic curves were constructed for each parameter. On the receiver operating characteristic curve, the best cutoff value for each parameter correlated with the highest diagnostic accuracy resulting from the maximal Youden index.\(^15\)

**Results**

The causes of bidirectional flow in our study cohort were the subclavian steal phenomenon (\(n = 21\), including subclavian artery atherosclerotic stenosis (\(n = 20\) and sub-
clavian artery dissection \( [n = 1] \) and factors unrelated to the steal phenomenon \( (n = 8) \), including a hypoplastic vertebral artery \( [n = 4] \), proximal vertebral artery occlusion \( [n = 3] \), and proximal vertebral artery stenosis \( [n = 1] \)\. All patients had symptoms of posterior circulation ischemia, such as dizziness, loss of consciousness, and upper limb fatigue. Cerebral infarction was the most frequently observed condition, and it was present in 18 patients. Hypertension was observed in 13 patients and transient ischemic attacks in 4. Among the 29 patients, 15 had at least 2 conditions, including infarction, hypertension, atherosclerosis, and diabetes mellitus.

The 29 patients were classified into a steal phenomenon group \( (n = 21) \) and a non–steal phenomenon group \( (n = 8) \) based on angiography. Table 1 lists the parameters monitored for each group. Significant differences in the MPV, PRV, PAV, target vertebral artery diameter, and contralateral RI were observed between the steal phenomenon and non–steal phenomenon groups. However, there were no significant differences in the site of bidirectional flow in the vertebral artery, contralateral vertebral artery diameter, hypoplastic vertebral artery, or PSV between the groups.

The cutoff points were 26.1 cm/s (sensitivity, 95.2%\%; specificity, 87.5%) for MPV, 18.3 cm/s (sensitivity, 81.0%\%; specificity, 87.5%) for PRV, 20.5 cm/s (sensitivity, 81.0%\%; specificity, 87.5%) for PAV, 2.2 mm (sensitivity, 85.7%\%; specificity, 62.5%) for target vertebral artery diameter, and 0.64 (sensitivity, 85.7%\%; specificity, 62.5%) for contralateral RI. The areas under the receiver operating characteristic curves were 0.929 for MPV, 0.881 for PRV, 0.824 for PAV, 0.753 for target vertebral artery diameter, and 0.845 for contralateral RI. These results suggest that MPV is the single best parameter for suggesting the cause of bidirectional flow (Figures 1–3).

Two cases would have been misdiagnosed by Doppler sonography using the MPV cutoff of 26.1 cm/s. The MPV for 1 patient was 13 cm/s, however, the reason for bidirectional flow in the vertebral artery was the subclavian...
steal phenomenon. The other patient’s MPV was 35 cm/s, but the cause of bidirectional flow in the vertebral artery was proximal vertebral artery occlusion. Therefore, the overall accuracy of MPV for diagnosing the causes of bidirectional flow in the vertebral artery was 93% (27 of 29) for the entire study cohort.

Discussion

Our study showed that bidirectional flow in the vertebral artery is not always indicative of the subclavian steal phenomenon. Although bidirectional flow in the vertebral artery was detected in patients with the steal phenomenon, it was also found in patients without the steal phenomenon and in whom the disease was attributed to other causes, such as a hypoplastic vertebral artery, proximal vertebral artery occlusion, and vertebral artery stenosis. These findings are consistent with previous studies.3,10,11

Figure 2. Occlusion of the proximal left vertebral artery in a 64-year-old man with bidirectional flow in the left vertebral artery. A, Doppler waveform. The MPV was 16.4 cm/s (<26.1-cm/s cutoff). B, Aortic arch branch angiogram showing occlusion of the proximal left vertebral artery (arrow).

Figure 3. Hypoplastic right vertebral artery in a 74-year-old man with bidirectional flow in the right vertebral artery. A, Doppler waveform. The MPV was 18 cm/s (<26.1-cm/s cutoff). B, Vertebral arterial angiogram showing a hypoplastic right vertebral artery (arrows).
Päivänsalo et al.\textsuperscript{10} reported that reversed flow, including completely reversed flow and bidirectional flow, in the vertebral artery occurred in 91.7\% of patients (44 of 48) with the subclavian steal phenomenon and 8.3\% of patients (2 of 24) with bidirectional flow in the vertebral artery, as detected by Doppler sonography without reversed flow on digital subtraction angiography. Von Reutern and Pourcelot\textsuperscript{11} also presented data that suggested that bidirectional flow in the vertebral artery might be associated with vertebral artery stenosis without the subclavian steal phenomenon. Our study cohort included 1 patient with vertebral artery stenosis and bidirectional flow in the vertebral artery.

A previous study indicated that bidirectional flow might occur in a hypoplastic vertebral artery.\textsuperscript{3} Our study cohort included 4 cases of hypoplastic vertebral arteries with bidirectional flow in the non–steal phenomenon group and 3 cases in the steal phenomenon group. However, the rate of hypoplastic vertebral arteries did not differ between the groups. A hypoplastic vertebral artery is characterized by a small vertebral artery diameter and high RI.\textsuperscript{16,17} Therefore, we speculate that bidirectional flow in a hypoplastic vertebral artery may occur for 2 reasons: a vertebral artery diameter that is too small and a concomitant disease involving posterior circulation that results in elevation of distal vertebral artery blood flow resistance. Thus, the reason may not always be “subclavian steal.” In our study cohort, all 4 patients with hypoplastic vertebral arteries had symptoms of posterior circulation, and of those 4 patients, 2 had ipsilateral cerebellar infarctions, which may support our hypothesis.

To date, very few cases of bidirectional flow in the vertebral artery due to proximal vertebral artery occlusion have been reported. Our study cohort included 3 patients with bidirectional flow in the vertebral artery due to proximal vertebral artery occlusion. Previous studies have suggested that bidirectional flow in the vertebral artery is due to vertebral artery stenosis.\textsuperscript{10,11} In this study, we found that bidirectional flow was due to either vertebral artery stenosis or vertebral artery occlusion. The vertebral artery communicates with multiple extracranial and intracranial arteries that provide collateral circulation.\textsuperscript{4,10} Therefore, if the vertebral artery origin has high-grade stenosis or occlusion, a vertebral steal may pass the vertebral occlusion through the collateral vessels to other arteries, such as the spinal arteries, thereby causing bidirectional flow in the vertebral artery.

This study also showed that MPV can be helpful in suggesting the etiology of bidirectional flow. In particular, the patients without the steal phenomenon in our study cohort had lower MPV values than those with the steal phenomenon; the MPV cutoff value for distinguishing the subclavian steal phenomenon from other causes was 26.1 cm/s, and the accuracy of this cutoff was 93\%. To our knowledge, this observation has not been reported previously and should be confirmed by future studies with larger sample populations.

Collectively, the findings from this study may also have important clinical implications, as most patients with the subclavian steal phenomenon are asymptomatic and have benign outcomes, and the treated patients can be followed.\textsuperscript{13,18} In contrast, when the causes of bidirectional flow are unrelated to the steal phenomenon, other factors such as occlusion of vertebral artery origin may be the source of embolism in acute posterior circulation ischemic stroke.\textsuperscript{1} In such cases, further treatment is required. Overall, our findings may be particularly useful when intensive care or emergency patients are at high risk and the use of bedside Doppler sonography may easily diagnose the causes of bidirectional flow and guide clinical decision making.

It is important to note that 2 of the patients in our study cohort were misdiagnosed by Doppler sonography. One patient in the steal phenomenon group had a lower MPV, and the other in the non–steal phenomenon group had a higher MPV; both of these patients were incorrectly diagnosed on the basis of our diagnostic criteria for the causes of bidirectional flow in the vertebral artery. We speculate that having the patients perform some form of activity, such as exercising the arm for 5 minutes before testing, might have helped achieve the correct diagnosis. In that case, if the cause of bidirectional flow is not the subclavian steal phenomenon, complete reversed flow in the vertebral artery cannot be induced by a decrease in peripheral arterial pressure.\textsuperscript{11}

Our study had several limitations that must be considered when interpreting our data. First, the study was retrospective in design and may have been affected by a selection bias. Second, digital subtraction angiography, CT angiography, and contrast-enhanced MR angiography are all relatively insensitive to minimal flow states and may not accurately differentiate between an occluded and a hypoplastic vertebral artery. Third, we used CT angiography and MR angiography instead of digital subtraction angiography as the reference standards in 8 cases. Compared with digital subtraction angiography, CT angiography and MR angiography both are relatively imperfect reference standards for determining the causes of bidirectional flow in the vertebral artery. Several studies have reported that both CT angiography and MR angiography
are well correlated with digital subtraction angiography for diagnosis of subclavian artery or vertebral artery stenosis and occlusion. However, at our institution, digital subtraction angiography is not always performed for confirming the causes of bidirectional flow in the vertebral artery because of the invasive nature of the procedure. Therefore, only 72% of the patients (21 of 29) with bidirectional flow underwent digital subtraction angiography in our study population. In addition, the study cohort was relatively small and from a single institution. Future studies with larger numbers of patients from multiple institutions are needed to more accurately assess the efficacy of hemodynamic parameters, such as MPV, for diagnosing the cause of bidirectional flow. Last, as the 29 patients included in the data analysis were all symptomatic, extrapolation of the results to asymptomatic patients should be attempted with care.

Nonetheless, our study indicates that bidirectional flow in the vertebral artery is not always indicative of the subclavian steal phenomenon. Moreover, Doppler sonographic measurement of hemodynamic parameters, such as MPV, may facilitate diagnosis of the causes of bidirectional flow in the vertebral artery. These findings can be used to evaluate proximal vertebral artery occlusive lesions in patients with acute stroke when the spectral Doppler waveform in the vertebral artery indicates bidirectional flow.

References