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● *Original Contribution*

WAVEFORM PATTERNS AND PEAK REVERSED VELOCITY IN VERTEBRAL ARTERIES PREDICT SEVERE SUBCLAVIAN ARTERY STENOSIS AND OCCLUSION

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Abstract—This study investigated the value of analyzing spectral Doppler waveform patterns and measuring the peak reversed velocity (PRV) of the vertebral artery (VA) in predicting proximal severe subclavian artery (SA) stenosis and occlusion. Fifty-one patients with proximal SA stenosis were studied retrospectively. Based on the depth of the mid-systolic notch, the Doppler waveforms of the ipsilateral VA were divided into five subtypes (type I, n = 8; type II, n = 8; type III, n = 6; type IV, n = 13; and type V, n = 16). PRV was also measured. PRV receiver operating characteristic curves were constructed to obtain the best cutoff value for predicting severe SA stenosis or complete SA occlusion. The results indicated that both VA Doppler waveform and PRV were associated with the degree of SA stenosis ($p < 0.05$). PRV and the Doppler waveform in the VA had similar accuracy in predicting SA occlusion (84.3%, 43/51). PRV was more accurate than VA waveforms in predicting severe SA stenosis (98%, 50/51 vs. 94.1%, 48/51). However, no significant differences between the two methods in predicting severe SA stenosis were observed ($p = 0.84$). Thus, with severe obstruction of the SA, typical Doppler waveform patterns of the VA could be observed. PRV is a helpful criterion in predicting severe stenosis and occlusion of the SA. (E-mail: csping123@163.com or doctorhyp1@163.com) © 2015 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Occlusion, Ultrasound, Vertebral artery, Subclavian artery, Angiography.**

INTRODUCTION

Although most patients with atherosclerotic stenosis of the subclavian artery (SA) are asymptomatic, a number of them have symptoms, such as pre-syncope or syncope, neurologic deficits and impaired circulation of the extremities (Osiro et al. 2012). For symptomatic cases, particularly those with severe SA stenosis or SA occlusion, percutaneous transluminal angioplasty (PTA), with or without stenting, or surgery is indicated (Aziz et al. 2011; Silingardi et al. 2014).

The success rate for PTA approaches 100% for symptomatic patients with SA stenosis (Kablak-Ziembicka et al. 2007; Sixt et al. 2009). Thus, PTA is the recommended first-line treatment for stenotic SA lesions (Sixt et al. 2009). However, when patients with complete SA occlusion are treated with PTA, success rates range from 48% to 87% (Kablak-Ziembicka et al. 2007; Schillinger et al. 2001; Sixt et al. 2009). In contrast, surgical approaches such as carotid subclavian transposition have high success rates with excellent long-term patency of the vessel (Aburahma et al. 2007; Ballotta et al. 2002). These statistics suggest that diagnosis of severe stenosis or SA occlusion has clinical implications in symptomatic patients with SA stenosis. Severe stenosis is usually treated using PTA, whereas total occlusive disease may be treated surgically. Therefore, diagnosis of severe SA stenosis or complete SA occlusion using a non-invasive imaging method before invasive treatment would aid in the development of ideal treatment strategies.

Because of its cost-effectiveness, Doppler sonography in the inter-transverse segment of the vertebral artery (VA) has been the most frequently used method to obtain vascular imaging of the posterior circulation. The spectral Doppler waveform of the VA has also proven useful for predicting the degree of ipsilateral SA stenosis and determining if blood flow is antegrade or retrograde (Buckenham and Wright 2004; Kaneko et al. 1998;

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Kliewer et al. 2000; Sakima et al. 2011). In previous studies, VA peak reversed velocity (PRV) has been used to determine the cause of reversed flow (Chen et al. 2013, 2014). However, the correlation between VA PRV and degree of SA stenosis has not been examined. To the best of our knowledge, the quantification of reversed flow in the ipsilateral VA to predict proximal high-grade SA stenosis or occlusion has not been reported.

Accordingly, this study investigated the correlation between severe SA stenosis and complete SA occlusion with the VA waveform by Doppler, as well as the quantification of reversed flow in the ipsilateral VA. Also, these two Doppler sonographic methods were compared with respect to diagnostic accuracy. Digital subtraction angiography was used as the reference standard for the assessment of degree of SA stenosis.

METHODS

Patients

This study was approved by the institutional review board at the hospital. The requirement for informed patient consent for this retrospective review was waived. From January 2004 to October 2013, digital subtraction angiography of the conventional aortic arch and/or selective SA was performed in 1,307 patients, whom we retrospectively analyzed. Fifty-one patients (35 men and 16 women, mean age: 67.6 ± 8.7 y, range: 47–82 y) were included in our study. The inclusion criteria were as follows: (i) Atherosclerosis was the cause of proximal one-sided SA stenosis or occlusion. (ii) The patients did not have severe common carotid artery or internal carotid artery stenosis, which would cause overestimation of the velocity because of a collateral flow effect. (iii) The patients did not have severe heart disease with a low ejection fraction, resulting in reduced blood flow through the VA. (iv) The interval between digital subtraction angiography and Doppler examinations was no longer than 2 wk.

Doppler sonography

Doppler sonographic assessments were performed by experienced vascular radiologists on patients in the supine position using standard sonographic equipment (HDI 5000 and IU 22, Philips Healthcare, Bothell, WA, USA; Acuson Sequoia 512, Siemens Medical Solutions, Mountain View, CA, USA) with a 4.0- to 8.0-MHz linear probe. Sampling for the VA waveform was performed in the mid-portion of the VA extracranial segment. The measured angle of insonation was ≤60° (Kliewer et al. 2000).

On the basis of the depth of the mid-systolic notch, Doppler waveforms of the ipsilateral VA were divided into five subtypes: normal (type I, n = 8), mid-systolic notch (type II, n = 8), retrograde flow smaller than or equal to antegrade flow (type III, n = 6), retrograde flow larger than antegrade flow (type IV, n = 13) and retrograde flow without antegrade flow (type V, n = 16) (Fig. 1a–e). Reversed flow measurements of the VA included peak reversed velocity (PRV), peak antegrade velocity and diameter. Antegrade flow measurements of the VA included peak systolic velocity (PSV), end-diastolic velocity and diameter. The resistance index was also calculated from the VA antegrade flow measurements. PRV represents the value from baseline to the reversed systolic peak and was measured as previously described (Chen et al. 2014). As illustrated in Figure 2a–c, the measurements were acquired on waveforms that could be reproduced for at least three consecutive heartbeats.

Angiography

Angiography of the conventional aortic arch or selective SA was performed using intra-arterial digital subtraction techniques. A 5-F catheter was inserted into the femoral artery according to the Seldinger method. The degree of SA stenosis was calculated by comparing the lumen diameter measured at the point of maximum stenosis with the diameter of a disease-free segment of the SA distal to the stenosis. According to the angiographic results, the degree of SA stenosis was classified as <70% (n = 19), ≥70% but not completely occluded (n = 20) and completely occluded (n = 12).

Statistical analysis

Statistical analysis was performed using the SPSS 11.0 software package (IBM, Armonk, NY, USA). Statistical significance between compared groups was estimated using the χ^2-test and Fisher's exact test for discrete variables and one-way analysis of variance with a Student–Newman–Keuls post-test. Student's *t*-test was used for continuous variables. Correlations between degree of SA stenosis and VA waveform pattern were assessed with Pearson's correlation analysis. $p < 0.05$ was considered to indicate statistical significance. PRV receiver operating characteristic curves were constructed to obtain the best cutoff value for diagnosing complete SA occlusion or severe SA stenosis. This cutoff value was correlated with the highest accuracy resulting from the maximal Youden index calculation.

RESULTS

Clinical characteristics of the patients

Among the 51 cases, SA stenosis was present in the left proximal SA in 45 cases and in the right proximal SA in the remaining 6 cases. All patients exhibited symptoms of posterior circulation ischemia (dizziness in 25 cases,