Comparison of Elastic Properties of Bilateral Carotid Arteries in Relation to Site of Acute Ischemic Stroke Using Velocity Vector Imaging

Jun-Li Hu[1,2], Xian Li[3], Xi-Ming Wang[1], Zhao-Ping Cheng[1], Dong-Feng Chen[2], Shao-Chun Wang[2], Qing-Xia Kong[4]

[1]Shandong Provincial Key Laboratory of Diagnosis and Treatment of Cardio-Cerebral Vascular Diseases, Shandong Medical Imaging Research Institute, Shandong University, Jinan, Shandong 250021, China

[2]Department of Ultrasound, Affiliated Hospital of Jining Medical University, Jining, Shandong 272029, China

[3]Department of Medical Imaging, No. 2 Clinical Institute, Jining Medical University, Jining, Shandong 272100, China

[4]Department of Neurology, Affiliated Hospital of Jining Medical University, Jining, Shandong 272029, China

Jun-Li Hu and Xian Li contributed equally to this work.

Key words: Acute; Carotid; Ischemic; Stroke; Velocity Vector Imaging

Introduction

Ischemic stroke accounts for 70% of all the cerebrovascular diseases. Severe stenosis and occlusions of extracranial and intracranial artery are all important risk factors causing ischemic stroke. Based on the widespread observation worldwide, intracranial atherosclerosis is the most common vascular lesions in Asians, Hispanics, and Africans.[1] Therefore, accurate and noninvasive methods for early diagnosis of stroke in individuals without significant stenosis of the extracranial carotid artery is of considerable clinical interest.

The elasticity of large artery is known to be associated with cardio-cerebrovascular disease and its risk factors.[2,3] Most noninvasive methods used in the assessment of artery elastic properties include pulse wave velocity (PWV) and conventional ultrasonographic techniques. Ultrasonographic two-dimensional strain imaging with recently introduced speckle tracking technique is regarded as a sensitive and reliable method, which is superior to the conventional measures of vascular stiffness. But limited data on the carotid elastic properties of ischemic stroke were assessed by velocity vector imaging (VVI), a novel technique based on speckle tracking.

Because one side of the internal carotid artery supplies the ipsilateral anterior cerebral circulation area, we hypothesized that the elastic properties of one side carotid artery are about the site of ischemic stroke. As far as we know, this is the first study to investigate the differences in elastic properties between ipsilateral and contralateral common carotid artery (CCA) of acute ischemic stroke (AIS) in unilateral anterior circulation by VVI technique. Our aim was to seek for noninvasive imaging methods to predict ischemic stroke.

Access this article online	
Quick Response Code:	Website: www.cmj.org
	DOI: 10.4103/0366-6999.168075

Methods

Subjects

Forty-four hospitalized patients (28 male, mean age: 63 ± 11 years) with initial onset AIS were enrolled in this study. Inclusion criteria were: (1) Unilateral anterior circulation ischemic stroke which were verified by brain magnetic resonance imaging (MRI) within 72 h of symptom onset. All cases met the Chinese guidelines of diagnosis and treatment for AIS 2010; (2) Echocardiography and carotid ultrasound were performed right after MRI verification. Patients with normal heart function whose stenosis of bilateral extracranial carotid arteries <50%.

Exclusion criteria were: (1) Previous stroke; (2) cerebral hemorrhage; (3) stroke in posterior circulation or bilateral cerebral lesions; (4) the stenosis of extracranial carotid

Address for correspondence: Dr. Xi-Ming Wang, Shandong Medical Imaging Research Institute, Shandong University, Jinan, Shandong 250021, China
E-Mail: wxming369@126.com

Received: 22-05-2015 **Edited by:** Yi Cui
How to cite this article: Hu JL, Li X, Wang XM, Cheng ZP, Chen DF, Wang SC, Kong QX. Comparison of Elastic Properties of Bilateral Carotid Arteries in Relation to Site of Acute Ischemic Stroke Using Velocity Vector Imaging. Chin Med J 2015;128:2960-3.

artery ≥50%; (5) intracranial space-occupying lesions; (6) structural heart disease and coronary heart disease with left ventricular ejection fraction (LVEF) <50%; and (7) arrhythmia.

Age- and gender-matched 40 healthy volunteers (25 males, mean age: 62 ± 8 years) were selected as the control group. The control subjects did not have cardio-cerebrovascular diseases, hypertension, diabetes, hyperlipoidemia, and other systemic diseases upon inquiry of the history, physical examination, electrocardiogram (ECG), echocardiogram, and laboratory tests.

Informed consent was obtained from each study subject. The study protocol was approved by the Institutional Review Committee at our institute.

Echocardiography

All the subjects were kept in left lateral decubitus position and connected to the ECG after 10 min' rest. Siemens Acuson Sequoia 512 ultrasound system (Siemens Medical Solutions Inc., Mountain View, CA, USA) with a frequency range of 2.25–4.25 MHz cardiac transducer was used for scanning. The apical four-chamber and two-chamber biplane modified Simpson's method was used for determination of LVEF and left ventricular stroke volume (SV). Cardiac output (CO) was calculated as SV multiplied by heart rate.

Carotid ultrasound examination

Carotid artery ultrasound was conducted on Siemens Acuson Sequoia 512 ultrasound system. A frequency range of 8–14 MHz linear array transducer was used. All examinations were performed in the supine position with patients in peace. The right and left common carotid arteries were examined in both transverse and longitudinal planes. Intima-media thickness (IMT) was defined as the distance from the lumen-intimal interface to the medial-adventitial border and measured approximately 1 cm proximal to the bulb of the CCA far wall. The final data were averaged after 3 times' measurements. Luminal stenosis was calculated as the percent ratio of internal area to external area at peak diastole. The site and size of plaque were recorded.

Velocity vector imaging acquisition and analysis

Under the VVI mode of the machine, the frame rate was adjusted to higher than 60 frames/s. The transverse distal CCA about 2 cm inferior to the carotid bulb and free of plaque was used for our analysis. Dynamic images of three consecutive cardiac cycles were acquired and stored. Subjects were instructed to hold breath during the acquisition.

With the obtained images, off-line analysis was performed by VVI software (Syngo 3.0, Siemens Medical Solutions Inc., Mountain View, CA, USA). The clearest frame during systole was selected. Vessel wall deformations were analyzed by dividing the vessel into six segments (anterior wall, anterior and posterior medial wall, posterior wall, and anterolateral and posterolateral wall). The reference sign was placed at the center of the arterial lumen. The blood-tissue border was automatically tracked, and the magnitude and direction of arterial velocity could be displayed in vector mode. The segmental values of VVI parameters were measured separately and averaged of each side of the carotid.

Statistical analysis

Continuous variables were summarized as mean ± standard deviation (SD) and categorical variables were reported as number of participants (percentage). A Chi-square test was used for discrete variables analysis. To compare the VVI parameters and IMT intra-group, a Student's paired *t*-test was used. For better study on differences between health controls and stroke patients, independent-samples *t*-test was performed. A $P < 0.05$ was considered as statistically significant. Analysis was performed using SPSS software, version 16.0 (SPSS Inc., IL, USA).

Reproducibility studies

An average of three measurements was taken during the examination. The analysis of VVI was performed by one experienced observer. To evaluate intra-observer and inter-observer variability of the measurements, the VVI parameters of ipsilateral CCA of the stroke patients were analyzed 4 weeks later by the same observer and another observer. Moreover, each was blinded to the other's results.

Intra- and inter-observer variability, coefficients of variance were calculated with the formula:

$$\frac{\mathrm{SD}(x - y)}{\mathrm{average}(x, y)} \times 100\%$$

where, x and y represent values of the first and the second measurement, respectively.

Results

Baseline characteristics

The two groups did not show significant differences in age, gender, LVEF, fractional shortening, and CO ($P > 0.05$), so did total cholesterol and high-density lipoprotein-cholesterol ($P > 0.05$). The groups differed significantly in systolic and diastolic blood pressures ($P < 0.01$). Eighteen ischemic stroke patients had hypertension and 14 patients had diabetes. Twenty-four lesions were in the right anterior circulation area while 20 lesions in the left. The average National Institutes of Health Stroke Scale Score of the ischemic stroke patients on admission was 11.8 ± 3.6.

Comparisons of velocity vector imaging parameters and intima-media thickness between left and right carotid

The VVI parameters and IMT of the left carotid were not statistically different from those of the right carotid in both groups ($P > 0.05$). The VVI parameters of left, right, and average of bilateral carotid were significantly lower in the stroke group than those in the control group ($P < 0.01$), whereas IMT of the stroke group were significantly thicker than those of the control group ($P < 0.01$) [Figure 1].

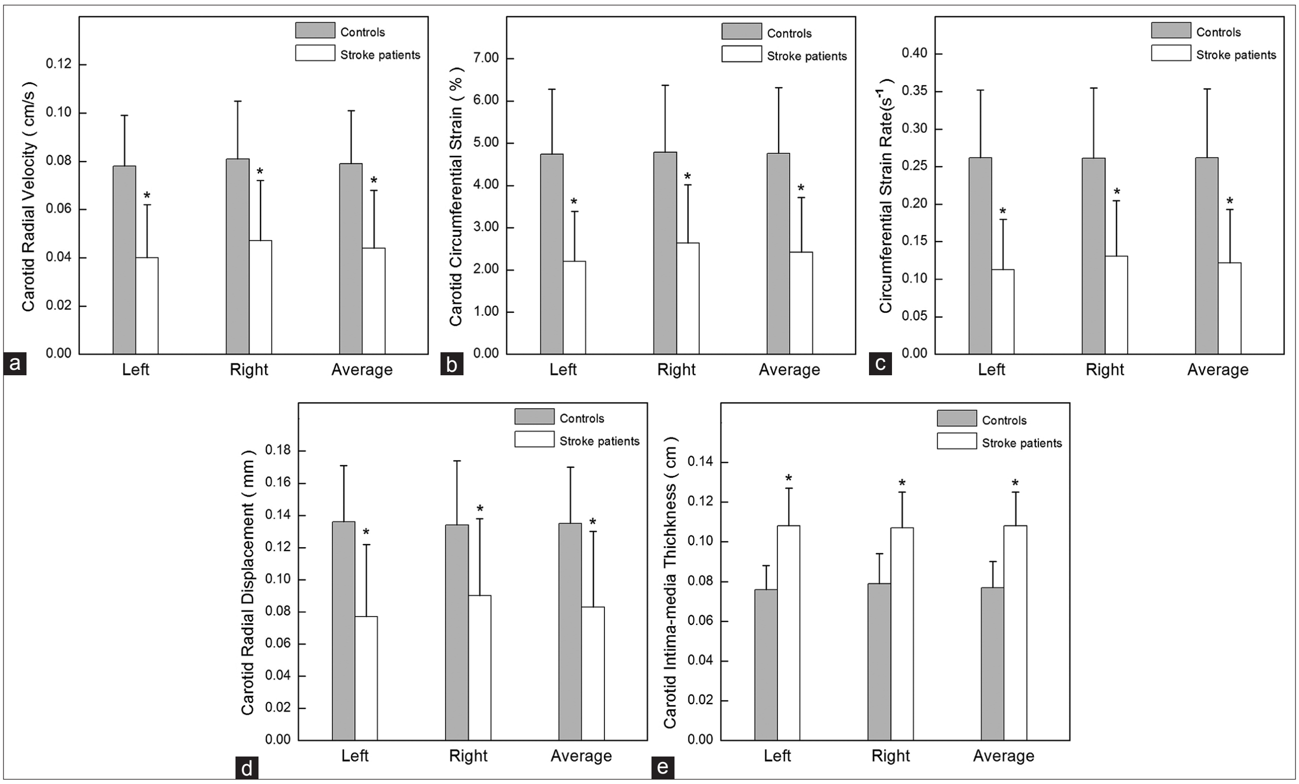

Figure 1: Comparisons of VVI parameters and IMT between left, right carotid, and average of bilateral carotid in controls and patients with stroke. Values listed are means with standard error bars. *$P < 0.01$ compared with controls: (a) Carotid radial velocity, (b) carotid circumferential strain, (c) carotid circumferential strain rate, (d) carotid radial displacement, and (e) carotid intima-media thickness.

Comparisons of velocity vector imaging parameters and intima-media thickness between ipsilateral and contralateral carotid

According to the MRI, the carotid of every stroke patient was divided into ipsilateral and contralateral carotid based on the site of stroke. The ipsilateral carotid of the stroke group showed statistically higher VVI parameters compared with the contralateral carotid ($P < 0.01$). The IMT did not differ significantly between ipsilateral and contralateral carotid ($P > 0.05$) [Table 1].

Reproducibility of measurements

The intra-observer and inter-observer reproducibility of VVI parameters of the ipsilateral CCA were tested (intra-observer, 9.2%, 8.6%, 10.5%, and 4.3%; inter-observer, 9.5%, 9.1%, 11.2%, and 4.9% for RV, CS, CSR, and RD, respectively).

Table 1: Comparisons of VVI parameters and IMT between groups of controls and patients with ischemic stroke, mean ± SD

Parameters	Controls (n = 40)	Patients with ischemic stroke (n = 44)	
		Ipsilateral CCA	Contralateral CCA
RV (cm/s)	0.079 ± 0.022	0.059 ± 0.031*	0.035 ± 0.019*,†
CS (%)	4.761 ± 1.559	3.027 ± 1.290*	1.802 ± 1.008*,†
CSR (s^{-1})	0.262 ± 0.092	0.157 ± 0.086*	0.096 ± 0.056*,†
RD (mm)	0.135 ± 0.035	0.103 ± 0.048*	0.063 ± 0.037*,†
IMT (cm)	0.077 ± 0.013	0.107 ± 0.017*	0.107 ± 0.020*

*P<0.01 compared with controls, †P<0.01 compared with ipsilateral CCA. SD: standard deviation; CCA: Common carotid artery; RV: Radial velocity; CS: Circumferential strain; CSR: Circumferential strain rate; RD: Radial displacement; IMT: Intima-media thickness; VVI: Velocity vector imaging.

Discussion

Carotid elastic properties and incidence of stroke

Aging, hypertension, and diabetes are risk factors for cerebrovascular diseases. It is still a challenge to predict stroke noninvasively in individuals with high risk but without significant stenosis of extracranial carotid artery. Carotid atherosclerosis and cerebrovascular atherosclerosis share the same pathological basis and risk factors. Carotid IMT is the structural change of the local vessel atherosclerosis, whereas the decreased elastic properties and increased stiffness are the functional response to carotid atherosclerosis. Arterial stiffening is a process that involves the progressive disorganization of elastin lamellae, loss of compliance, and earlier than arterial thickening. Favreau *et al*.[4] have found that low mechanical wall strain precedes the development of intimal hyperplastic lesions in a preclinical murine model. Arterial stiffness has been verified to be associated with incident cerebrovascular disease in previous studies. A longitudinal study, in which the average follow-up was 7.9 years, provides the evidence that aortic stiffness can predict the occurrence of fatal stroke beyond the prediction provided by classic risk factors in patients with essential hypertension.[5] In the population of the Atherosclerosis Risk in Communities study, 10,407 individuals with 13.8 years of average follow-up, after full adjustment for risk factors and carotid IMT, ultrasound measures of carotid arterial stiffness are associated with incident ischemic stroke but not incident coronary heart events.[6]

Advantages of velocity vector imaging

Arterial elastic properties can be noninvasively measured by PWV or conventional measurements, such as distensibility, compliance, β stiffness index, or elastic modulus. PWV is considered as the golden standard to assess arterial stiffness. However, PWV has poor sensitivity, and many factors may influence the absolute value of PWV. PWV cannot identify the minor changes of arterial elastic properties.

Ultrasonographic VVI is a novel technique based on speckle tracking algorithm, but its tracking process is more accurate than the speckle tracking technology. It allows automatic frame-by-frame tracking of acoustic markers during the heart cycle that has been successfully applied primarily in cardiac applications. Li *et al.*[7] demonstrated that left ventricular (LV) torsional deformation and strain assessed by echo-VVI were quite consistent with those by tagged MRI with acceptable bias and variability. The VVI technique allows angle-independent measurement of velocity, strain, strain rate, and displacement that can be used as a new echocardiographic measure to evaluate vascular elastic properties.[8]

Comparison with other stroke study using velocity vector imaging technique

Limited data on the carotid elastic properties of ischemic stroke were assessed by VVI presently. Bai and Zhao[2] analyzed the elastic characteristics of the CCA using VVI in patients with AIS. However, this study used only data from the right distal CCA and reflected the characteristics of only that region of the arterial tree.

To our knowledge, we are the first to demonstrate the differences of elastic properties between ipsilateral and contralateral CCA of AIS. Also, we found that the carotid IMT was not statistically different between ipsilateral and contralateral CCA. These observations suggested that elasticity accessed by VVI may be a more sensitive indicator associated with AIS than carotid IMT.

At present, the mechanism of the different elastic properties between ipsilateral and contralateral CCA is still not very clear. Becker *et al*.[9] reported that myocardial deformation is load-dependent measures of LV function. Carotid is a beating chamber, which is similar to the heart. Therefore, we thought that the carotid deformation parameters may depend on loading condition as that of myocardial muscle. We selected AIS patients with normal cardiac function in our study. The LVEF and CO did not differ significantly between stroke patients and normal controls, excluding the influence of preload of the heart. The change of the VVI parameters of the ipsilateral CCA may represent a partially adaptive response to the increase of loading conditions of stroke. These findings validated the hypothesis that the elastic properties of one side carotid artery are in relation with the site of stroke.

This study has several potential limitations. First, VVI technique is dependent on image quality. In order to get good images, the patients need to hold breath and the average frame rate should be adjusted to >60 frames/s. Second, bilateral stroke and stroke in posterior circulation were excluded in this study. At last, we only assessed the carotid elastic properties of AIS in this study. Whether it turns out to be the same findings in convalescence or recurrent ischemic stroke needs to be further evaluated with large sample of patients.

In conclusion, VVI technique with high feasibility and good reproducibility may represent a novel method for noninvasively quantifying carotid elastic properties alteration associated with AIS.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Wong LK. Global burden of intracranial atherosclerosis. Int J Stroke 2006;1:158-9.
2. Bai B, Zhao BZ. Preliminary assessment on elastic characteristics of common carotid artery wall in cerebral arterial thrombosis patients with velocity vector imaging (in Chinese). Chin J Med Imaging Technol 2010;26:1049-52.
3. Kim SA, Park SM, Kim MN, Kim YH, Cho DH, Ahn CM, *et al.* The relationship between mechanical properties of carotid artery and coronary artery disease. Eur Heart J Cardiovasc Imaging 2012;13:568-73.
4. Favreau JT, Liu CW, Yu P, Tao M, Mauro C, Gaudette GR, *et al*. Acute reductions in mechanical wall strain precede the formation of intimal hyperplasia in a murine model of arterial occlusive disease. J Vasc Surg 2013;54:1-8.
5. Laurent S, Katsahian S, Fassot C, Tropeano AI, Gautier I, Laloux B, *et al.* Aortic stiffness is an independent predictor of fatal stroke in essential hypertension. Stroke 2003;34:1203-6.
6. Yang EY, Chambless L, Sharrett AR, Virani SS, Liu X, Tang Z, *et al.* Carotid arterial wall characteristics are associated with incident ischemic stroke but not coronary heart disease in the Atherosclerosis Risk in Communities (ARIC) study. Stroke 2012;43:103-8.
7. Li P, Meng H, Liu SZ, Vannan MA. Quantification of left ventricular mechanics using vector-velocity imaging, a novel feature tracking algorithm, applied to echocardiography and cardiac magnetic resonance imaging. Chin Med J 2012;125:2719-27.
8. Yang WI, Shim CY, Bang WD, Oh CM, Chang HJ, Chung N, *et al.* Asynchronous arterial systolic expansion as a marker of vascular aging: Assessment of the carotid artery with velocity vector imaging. J Hypertens 2011;29:2404-12.
9. Becker M, Kramann R, Dohmen G, Lückhoff A, Autschbach R, Kelm M, *et al.* Impact of left ventricular loading conditions on myocardial deformation parameters: Analysis of early and late changes of myocardial deformation parameters after aortic valve replacement. J Am Soc Echocardiogr 2007;20:681-9.