

Are systolic velocity duplex metrics negatively affected by flow aliasing in areas of critical internal carotid artery stenosis

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ABSTRACT

Purpose: Duplex scanning is a useful noninvasive screening tool for the detection of carotid bifurcation disease. Internal carotid artery (ICA) peak systolic velocity (PSV) and ICA/common carotid artery (CCA) PSV ratios are proven metrics determining 70%–99% ICA stenosis. A potential disadvantage of using dramatically increasing systolic velocity measurements in areas of critical arterial stenosis is flow aliasing. Diastolic velocity should be less influenced by this flow artifact. We evaluate ICA and CCA end diastolic velocity (EDV) metrics in predicting severe ICA stenosis and document the prevalence of an aliasing artifact in a population of patients with critical ICA stenosis.

Methods: Consecutive patients undergoing carotid duplex assessments and contrast angiography were compared ($n = 140$). ICA and CCA PSV and EDV were recorded as was evidence of the flow aliasing of ICA waveforms. ICA/CCA PSV and EDV ratios were calculated. Duplex parameters were compared with angiographic ICA measurements. Receiver-operator characteristic curve (ROC) analysis was used to determine optimal criteria to identify ICA stenosis of 70% to 99%.

Results: Of 256 carotid bifurcation duplex studies, critical angiographic stenosis was present in 105 arteries. Only four completed arterial duplex scans demonstrated flow aliasing. In three of these patients, systolic metrics were non-diagnostic versus ICA/CCA EDV ratios. An ICA/CCA EDV ratio of 2.3 provided the best combination of sensitivity 73.8% and specificity 75.18%.

Conclusion: ICA/CCA diastolic ratios reliably determine 70% or greater ICA stenosis. Flow aliasing infrequently complicates ICA PSV.

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1. Introduction

Duplex scanning is a useful screening method for the noninvasive evaluation of carotid artery stenoses [1]. The North American Carotid Endarterectomy Trial (NASCET), the European Carotid Study Trial (ECST), and the Asymptomatic Carotid Atherosclerosis Study (ACAS) have all documented that carotid artery endarterectomy significantly reduces the risk of stroke in patients with severe ICA stenosis [2–4]. In most non-invasive vascular laboratories, ICA stenoses are categorized based upon one of the following: ICA PSV measurements, ICA/CCA PSV ratios, or ICA PSV triggers coupled with ICA EDV thresholds, to best discern 70% to 99% ICA stenoses. These diagnostic metrics are all dependent on ICA PSV data [5–7]. It is known that the flow phenomenon of aliasing can complicate ICA PSV measurement in areas of critical stenoses.

In duplex ultrasound two modes of ultrasound are combined, B mode and Doppler. Using a transducer a grayscale image of the artery of interest is obtained. With this image as a guide, a sample of flowing blood within the vessel segment is assessed. Pulsed Doppler involves both the transmission of short bursts of ultrasound signal and the reception of reflected signal from flowing red blood cells. Doppler frequency shift, the

difference between transmitted and received signal, is proportional to blood flow velocity. Increases in both systolic and diastolic flow velocity indicate worsening carotid artery stenosis. Aliasing is an imaging artifact affecting both pulse wave and color Doppler high-flow recordings in areas of severe vessel stenoses. Pulses signals are transmitted at a given sampling frequency (pulse repetition frequency, PRF). The maximum Doppler frequency that can be measured is half the PRF. Aliasing occurs when the peak velocity of the blood flow is faster than the peak velocity (frequency shift) set on the Doppler spectral scale. As a result, the spectral image is distorted, with high velocities becoming converted to reverse flow at the point of aliasing. Because of aliasing, flow direction appears reversed distorting velocity measurements [8]. The aliasing phenomenon has never been quantified in pulse Doppler assessments of carotid stenoses. We wondered how frequently is the aliasing phenomenon recognized when imaging a population of patients with significantly stenosed ICAs? Does aliasing affect the duplex measurement of carotid stenoses and are related measurement errors overcome using diastolic velocity data?

The purpose of this paper was to document flow aliasing frequency and affect on our population.

Furthermore, we plan to evaluate the reliability of ICA/CCA EDV ratios as predictors of 70%-99% ICA stenoses.

2. Materials and methods

2.1. Patients

We retrospectively compared extracranial carotid duplex scans with carotid angiograms of 141 patients evaluated at our institution from April 2011 to April 2014. In all patients, carotid artery duplex scanning was performed within three months of angiography and prior to any intervention. This study was approved by our hospital's IRB committee.

Patients were identified through our hospital's computer-based registry. There were 71 men and 69 women. The average patient age was 70. Seventy-one per-cent of patients suffered cerebrovascular symptoms. The remaining 29% presented with severe asymptomatic ICA stenosis.

2.2. Duplex scanning

All patients underwent duplex scanning with an imager using a 3.0–7.0 MHz probe. Visualization of the common carotid, internal carotid, external carotid and of the vertebral arteries was attempted in both sagittal and transverse plans. Measurements were performed with the ultrasound beam intersecting the flow stream as close to an angle of 60 degrees as possible [9]. Our technologists, at their discretion, took measures to minimize aliasing by either shifting the frequency baseline in a given direction or by activating a higher duplex PRF mode [10].

2.3. Angiograms

Arteriography was performed by use of a modified Seldinger technique through a femoral approach. Biplane arch, cervical, and intracranial views were obtained in all patients using digital subtraction techniques. CCA stenosis was measured from the angiographic view showing the greatest luminal reduction and with the assumed normal vessel as comparison. The degree of ICA stenosis was calculated according to the method recommended by NASCET. The percentage of diameter reduction was determined by comparing the luminal diameter at the site of maximal stenosis with the diameter of the normal appearing internal carotid artery immediately distal to the area of disease [2].

2.4. Data analysis

The data for the duplex scans and contrast angiograms were gathered independently. Receiver-operator characteristic (ROC) curves were plotted to compare

arteriographic data with ICA PSV, ICA/CCA PSV ratio, ICA EDV, ICA/CCA EDV, CCA PSV and CCA EDV to determine optimum velocity criteria for ICA stenosis 70%-99%. Duplex parameter cut-offs were selected to maximize accuracy. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated based on 2 × 2 tables. Also, the presence of aliasing on final duplex images was visually documented.

3. Results

Of the 256 carotid bifurcations available for analysis, angiographic 70%-99% ICA stenoses were present in 105. There were 17 ICA occlusions, and one innominate artery occlusions. A Doppler waveform showing an aliasing pattern was seen in 4 (3.9%) carotid bifurcations having critical angiographic ICA stenoses. Recorded diagnostic duplex metrics for the 4 patients are given (Table 1).

ROC curves illustrating the ability of ICA PSV, ICA/CCA PSV, ICA EDV, ICA/CCA EDV, CCA PSV and CCA EDV to distinguish 70%-99% ICA stenosis are shown (Figure 1). A pair-wise comparison of ROC curves documents significant differences between CCA PSV and CCA EDV versus all other metrics.

Table 1. Diagnostic velocity metrics of patients whose duplex images show aliasing.

Patient	ICA PSV	ICA EDV	ICA/CCA PSV	ICA/CCA EDV
1.	254	78	6.05	4.88
2.	318	96	3.3	78
3.	236	64	3.69	17
4.	388	178	3.3	4.9

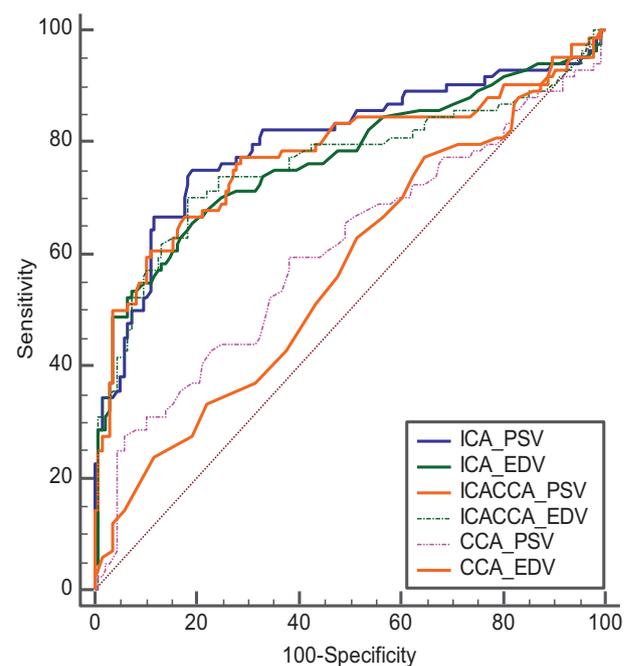


Figure 1. Receiver operator curves of assessed metrics in differentiating 70% or greater angiographic ICA stenosis.

Table 2. Comparison of area under each receiver operator curve (AUC).

Metric	AUC	Standard Error
ICA PSV	0.798	0.0340
ICA EDV	0.767	0.0360
ICA/CCA PSV RATIO	0.774	0.0362
ICA/CCA EDV RATIO	0.760	0.0377
CCA PSV	0.603	0.0411
CCA EDV	0.579	0.0402

Furthermore, AUC (area under curve) measurements for CCA PSV and CCA EDV are poor (Table 2). When using ICA PSV alone as a predictor, 155 cm/sec appeared to provide the best balance between accuracy 73.7%, sensitivity 75.28%, specificity 71.98%, negative predictive value (NPV) 84.87%, and positive predictive value (PPV) 61.32%. With ICA EDV as a predictor of critical stenoses, a value of 41 cm/sec provided optimal balance with over all accuracy 72.77%, sensitivity 68.54%, specificity 70.14%, NPV 81.81%, and PPV 62.13%. An ICA/CCA PSV ratio of 2.0 provided overall accuracy of 75%, sensitivity 70.93%, specificity 73.57%, NPV 84%, and PPV 63%. When ICA/CCA EDV alone is used as predictor of critical ICA stenosis a value of 2.3 provided 76% accuracy, 73.81% sensitivity, 75.18% specificity, 82% NPV, and 67% PPV.

4. Discussion

Completed symptomatic carotid endarterectomy trials have demonstrated conclusive benefits of surgery plus antiplatelet drugs versus drug therapy alone for patients with 70–99% ICA stenoses. Moreover, the ACAS showed that carotid endarterectomy reduces stroke risk in asymptomatic patients with $\geq 60\%$ angiographic ICA stenosis. Historic modified University of Washington duplex ICA categorizations did not concur with stenosis thresholds proven relevant in these trials. Clinicians have relied on published institutional experiences for interpreting ICA stenosis. Several studies stand out. Moneta et al found that ICA stenoses in the 70–99% range were identified with an 88% accuracy using an ICA/CCA PSV ratio of > 4.0 . Subsequently, Faught et al reported that an ICA PSV of 130 cm/sec combined with an ICA EDV exceeding 100 cm/sec provided an overall accuracy of 95% for identifying 70–99% stenoses [11,12]. Peak ICA EDV has also been proven a predictor of 70–99% ICA stenoses [13,14].

Daigle et al, evaluating various doppler velocity parameters for their relative abilities to differentiate between historically relevant 60–79% and $>80\%$ ICA stenosis, demonstrated that in instances of critical ICA stenosis, both ICA EDV or ICA/CCA EDV ratio were more efficacious in deducing disease than systolic based parameters. It was theorized that the

enhanced diagnostic capabilities of diastolic parameters might be because diastolic velocity waveforms are infrequently aliased [15].

In this study, ROC analysis failed to demonstrate any benefit of established ICA PSV or ICA/CCA PSV ratio versus ICA EDV or ICA/CCA EDV. Flow aliasing was documented infrequently. The anomaly is easily recognized and good vascular technologists minimize the amount of aliasing by intervening in one of the following ways: increasing the velocity scale (increasing the Nyquist limit), shifting the baseline to increase the Nyquist limit in a particular direction or, activating a higher PRF mode. In the 3 of 4 patients with evidence of aliasing, systolic velocities proved nondiagnostic. EDV based metrics, however, identified 70–99% ICA stenosis.

Because of our study result, ICA/CCA EDV criterion has been incorporated in our hospital's vascular laboratory. We are uncertain whether using an ICA/CCA EDV ratio of 2.3 is universally applicable. It has been shown that velocities recorded by different duplex systems vary significantly. Although the utilization of this velocity ratio might compensate in part for machine variabilities, we feel it essential for other vascular laboratories to validate these and other duplex metrics that they wish to use against a standard method of angiographic assessment of carotid stenoses [16].

5. Conclusion

Analysis of our data revealed that an ICA/CCA EDV ratio of 2.3 provides a good combination of sensitivity (73.81%), specificity (75.18%), positive predictive value (67%), negative predictive value 82%, and overall accuracy (76%) for the detection of a 70–99% angiographic stenosis. Flow aliasing proved an infrequent occurrence. If flow aliasing is present, duplex metrics based upon current PSV measurements may be inaccurate.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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