Assessing internal carotid artery stenosis with a semiautomated computed tomography angiography tool and duplex ultrasound

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Objective: **Duplex ultrasound (DUS) and computed tomography angiography (CTA) are both used as first-line noninvasive methods to investigate patients for internal carotid artery (ICA) disease. Although manual assessment of CTA is well established, semiautomated vessel analysis programs have yet to prove their clinical benefit. We compared one such vessel analysis program (TeraRecon, Foster City, Calif) with DUS.**

Methods: **A total of 85 arteries in 50 patients (35 men, 15 women; mean age, 73 ± 10 years) were eligible for comparison with the North American Symptomatic Carotid Endarterectomy Trial method. Duplex scanning comprised stenosis estimation based on (1) the intrastenotic and distal ICA diameter measurements on color-coded imaging (CCI), (2) the application of German Society for Ultrasound in Medicine (DEGUM) criteria (intrastenotic peak systolic velocity [PSV] ≥200 cm/s indicates 50% stenosis; intrastenotic PSV ≥300 cm/s together with a PSV of ≥50 cm/s in the distal ICA indicates 70% stenosis), and (3) the application of the University of Washington stenosis criteria (≥50% stenosis is indicated by PSV >125 cm/s and end-diastolic velocity <140 cm/s; ≥80% stenosis is indicated by PSV >125 cm/s and end-diastolic velocity ≥140 cm/s). The minimum and maximum diameters at the stenosis site and at the distal reference ICA were automatically measured with the CTA vessel analysis tool. In addition, automated tracking generated corresponding cross-sectional areas at these two sites. Angiographic stenosis was then calculated using the minimum diameter (CTAmin), the average of the minimum and maximum diameters (CTAavg), and the areas (CTAarea) at both sites.**

Results: **Compared with duplex CCI, the three CTA modalities exhibited only a moderate agreement in terms of regression analysis (R^2 = 0.41-0.54) and Bland-Altman analysis (the standard deviation of the stenosis differences was >20%). In terms of sensitivity, specificity, positive predictive value, negative predictive value, and accuracy, DEGUM stenosis graduation was best balanced by duplex CCI (50% stenosis: 100%, 93%, 85%, 100%, 95%; 70% stenosis: 71%, 100%, 100%, 97%, 98%) followed by CTAarea (50% stenosis: 80%, 73%, 54%, 90%, 75%; 70% stenosis: 66%, 94%, 55%, 96%, 96%). University of Washington stenosis was best balanced by duplex CCI followed by CTAarea.**

Conclusions: **CTA analysis with a semiautomated vessel analysis tool provides variable results. Large discrepancies between methods in the degree of reported stenosis must be taken into consideration when CTA and DUS are used for clinical purposes. The semiautomated software tools need further improvements. (J Vasc Surg 2015;61:1449-56.)**

With the emergence of noninvasive magnetic resonance angiography and computed tomography angiography (CTA) and the adjustment of duplex ultrasound (DUS) criteria to the (intra-arterial) angiographically derived stenosis measurement methods in the North American Symptomatic Carotid Endarterectomy Trial (NASCET),[1] the need for intra-arterial digital subtraction angiography (DSA) has decreased strikingly. In clinical practice nowadays, patients with cerebral or ocular ischemia undergo DUS, CTA, or magnetic resonance angiography as the initial method to assess their cerebrovascular system. If an internal carotid artery (ICA) stenosis is present and two of the three noninvasive methods agree on its severity, invasive angiography is not necessary for management of the patient. When the noninvasive methods show discrepancies, invasive angiography might be indicated because the professional is still accepted as the "gold standard" for cerebrovascular assessment.[2]

Compared with DSA, DUS and CTA can also provide highly accurate stenosis assessment results for the NASCET method.[3-9] Compared with duplex scanning, CTA has the advantage of collecting and storing a three-dimensional data set, which allows many postprocessing possibilities, including detailed vessel analysis. Although DUS would theoretically allow the acquisition of a three-dimensional data set as well, this has not been developed for stenosis grading; hence, DUS is usually performed in two dimensions for the analysis of vessel morphology and most often uses frequency shift measurements (a three-dimensional parameter) for stenosis graduation. Postprocessing of a three-dimensional CTA data set is believed to enable complete visualization of the vessel anatomy and to allow precise determination of the maximum stenosis. Consequently, some CT scanner manufacturers provide semiautomated

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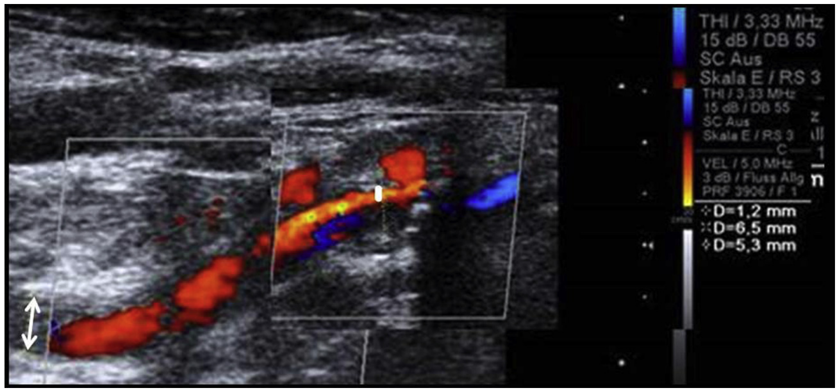

Fig 1. Diameter assessment by color-coded imaging (CCI) at the tightest stenosis point (*white bar* |) and at the reference vessel segment (*white arrow* ↕).

(manual vessel and stenosis selection and fine adjustment; thereafter, automatic stenosis calculation) stenosis assessment tools.[6] We were interested in seeing how well such a tool would fit the clinical need. For this, we compared a semiautomated assessment tool with DUS techniques that have been evaluated against DSA with high reliability.[8,9]

METHODS

The study was approved by the Institutional Review Board as consistent with the Declaration of Helsinki. Each patient gave informed consent for participation in such studies at the time of examination. We performed a retrospective analysis of consecutive patients who presented with cerebral ischemic symptoms (transient ischemic attack or stroke) and whose institutional routine diagnostic workup included both a standardized CTA protocol and duplex scanning of the extracranial and intracranial arteries, including stenosis assessment by direct diameter determinations on color-coded imaging (duplex CCI) (see later). Both examinations had to have been performed within 3 days of each other. Between June 2011 and June 2012, we identified 50 such patients (35 men, 15 women; mean age, 73 ± 10 years). Neither the CTA protocol nor the routines for DUS examinations were changed during this time. Comparisons were made using the NASCET method alone.

DUS

All examinations were performed by the same two experienced ultrasonographers (M.M., M.Ö.). All ultrasound examinations were performed with a high-end ultrasound machine (Acuson Antares 5.0; Siemens, Erlangen, Germany). The extracranial arteries were examined with the use of a 4-9 MHz linear scanner with a Doppler transmitted frequency of 5 MHz and with freely adjustable color frame and angle corrections (definite angle of insonation $\leq$60 degrees). The supraorbital artery and the intracranial arteries were examined with the use of a 1-4 MHz sector scanner with a transmitted frequency of 2 MHz for velocity measurements, and again, color frame and angle corrections were freely adjustable (angle of insonation $\leq$60 degrees); these arteries were assessed to examine for presence or absence of collateral blood flow (such as cross-fillings through the anterior or posterior communicating artery or a retrograde flow in the supraorbital artery).

The recorded parameters were as follows: peak systolic velocity (PSV) and end-diastolic velocity in the stenosis and in the distal ICA, and direct diameter measurements on duplex CCI during the systolic vessel dilation. A representative image showing measurement of the tightest stenosis diameter and the distal reference diameter is provided in Fig 1. The ICA reference diameter for use with NASCET was measured when the vessel walls were well visualized and parallel.

On the basis of these parameters, we calculated stenosis severity according to the following.

Duplex CCI. M.M. has validated the duplex CCI and the frequency shift approach in a comparison with intra-arterial DSA in a total of 116 carotid arteries.[8] To detect a $\geq$50% NASCET stenosis with duplex CCI, overall accuracy was 93%; to detect a $\geq$70% stenosis, accuracy was 84%. Best peak systolic frequency to detect $\geq$50% stenoses was 7 kHz; to detect $\geq$70% stenoses, it was 10 kHz. In the now used duplex machine, these frequencies correspond to a PSV of 190 cm/s to detect $\geq$50% stenosis and to 290 cm/s to detect $\geq$70% stenosis. M.Ö. is trained to these validated data for at least 5 years at the beginning of the recording period. Because our laboratory PSV values are close to the German Society for Ultrasound in Medicine (DEGUM) cutoff PSV and we additionally classified the stenosis according to the University of Washington (UoW) criteria, we chose to report the DEGUM criteria only and to relinquish reporting of the results of our laboratory PSV values to provide clearer readability.

DEGUM main criteria.[9] In short, 50% NASCET stenosis is indicated by a PSV of >200 cm/s; 70% stenosis, by a PSV of >300 cm/s in combination with a >50 cm/s PSV in the distal ICA; and 80% stenosis, by a PSV >350 cm/s in combination with a PSV <50 cm/s in the distal ICA or the presence of a collateral pathway. The DEGUM PSV criteria were derived from scanning plots