Doppler-Ultrasound and computed tomography correlation for quantification of carotid stenosis

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Carotid disease is a major cause of cerebrovascular events. Risk is proportional to the extent and severity of atherosclerosis. Aim of this study was to assess the correlation between 64-multi-detector-row computed-tomography angiography (MDCTA) and Doppler ultrasound peak-systolic-velocity (DUS-PSV) in the quantification of stenosis. 116 consecutive patients were included; it was calculated the degree of carotid stenosis with the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method using MDCTA and DUS-PSV. MDCTA measurements of stenosis ranged from 35% to 95% (mean 67±16%). DUS-PSV ranged from 102 to 600 cm/s (mean 262±112 cm/s). A moderate correlation ($r^2 = 0.427$) was found between MDCTA-NASCET stenosis and PSV values. At ROC curve analysis, PSV could significantly discriminate between stenoses ≥70% and <70% at MDCTA-NASCET measurement, with area under the curve of 0.807 (p<0.0001). PSV value ≥230 cm/s was identified as optimal cutoff to predict stenosis ≥70% at MDCTA, with a sensitivity of 71%, specificity of 83%, negative predictive value of 67% and positive predictive value of 82%. We found a reasonable concordance between MDCTA and DUS-PSV in quantifying carotid stenosis. PSV value of 230 cm/s is a reliable threshold to predict a >70% stenosis of MDCTA.

Keywords: Carotid; Doppler; MDCTA; Ultrasound

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Introduction

Cerebrovascular accidents are a major medical problem. When considered separately from other cardiovascular conditions, stroke ranks third for females and fourth for male among all causes of death after heart disease and cancer[1]. The most important responsible for the development of cerebrovascular events is carotid artery atherosclerosis.

It has consistently emerged from large studies that the degree of luminal stenosis of the internal carotid artery (ICA), expressed as a percentage reduction in vessel diameter, is a major factor in determining whether a patient is likely to benefit from revascularization treatment [2,3]. However, carotid endarterectomy has been shown to be beneficial in reducing the risk of stroke both in symptomatic patients with severe stenosis [4, 5] and in those with moderate stenoses [6]. These evaluations were performed by using digital subtraction angiography (DSA), which has now been replaced by non-invasive techniques such as magnetic resonance angiography (MRA), computed tomography angiography (CTA) and doppler ultrasonography (DUS).

In daily clinical practice, DUS is the most common functional and imaging examination performed worldwide to aid in the diagnosis of carotid disease. Given the prevalence of carotid disease, the number of DUS examinations performed annually is considerable [7]. This technique
provides many advantages such as a fast, non-invasive, and easily available screening method with high diagnostic accuracy in predicting severe carotid stenosis \[8\]. Moreover, it has been shown that peak systolic velocity (PSV) in the internal carotid artery is the best single velocity parameter for quantifying stenosis \[9, 10\]. Alternatively, CTA may be used in the assessment of carotid artery stenosis \[11, 12\]. CTA also has high diagnostic accuracy for ICA disease with sensitivity and specificity as high as 85% and 93%, respectively, for detection of significant carotid stenoses \[13, 14\]. However, the concordance between these two techniques has not been extensively explored. Therefore, the purpose of our study was to evaluate the correlation between results of 64 multi-detector-row CTA (MDCTA) and DUS-PSV in the quantification of carotid artery stenosis.

Materials and Methods

Patient population

This study included 116 consecutive patients who underwent both DUS and MDCTA at Campus Bio-Medico University of Rome, Rome, Italy, between January 2012 and April 2014. Indications to both exams included suspected or symptomatic carotid artery disease. Patients with aneurysm, pseudoaneurysm, trauma, or carotid tumors were excluded. MDCTA was performed when a previous DUS examination showed a stenosis >50% and/or a plaque alteration (irregular plaque surface, ulcerated plaque), or when DUS could not provide information about stenosis degree and plaque morphology. MDCTA examination was obtained within 1 month following DUS (mean time interval 15 days). In 69 carotid arteries no atherosclerotic lesions were found, whereas 24 carotids were found to have stenoses of 30% or less at MDCTA. Therefore, a total of 139 carotid arteries were considered for this analysis.

MDCTA technique

Supra-aortic vessels MDCTA was carried out using a 64-slices computed tomography (Siemens Sensation Cardiac 64) (Figure 1). Eighty mL of contrast medium were injected into an antecubital vein, by using a power injector at a flow rate of 4-5 mL/s and an 18 gauge intravenous catheter. Bolus tracking technique was used to optimize acquisition delay. CTA technical parameters included: matrix 512×512, field of view (FOV) 11-19 cm; an automatic dose reduction system was used in every patient (Siemens AEC dose reduction); section thickness 1 mm, increment 0.8 mm. All datasets were transferred to a dedicated workstation (Siemens, Leonardo) for post-processing. Multi-planar reconstruction (MPR) and curved planar reconstruction were obtained from each dataset. The degree of stenosis was determined on curved planar reconstruction with a semi-automated software (Siemens, Vessel view). Written consent was obtained from each patient. All measurements were carried out by a single experienced radiologist. Length and extent of carotid artery stenosis were measured and carotid stenosis was calculated by using the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method. With the NASCET criteria the ratio between the residual luminal surface at the stenosis and the surface of the distal normal lumen where there is no stenosis was calculated (Figure 1A). To quantify stenosis degree by using MDCTA, oblique axial images normal to ICA lumen centreline were elaborated with MPR and the value was calculated by comparing the diameter of the stenosed segment (Figure 1B) with the most distal normal one (Figure 1C), where no stenosis was present according to the NASCET criteria.

DUS technique

Ultrasound examinations were performed with a Philips Ie33 ultrasound system with 7-MHz linear-array transducers. Carotid arteries were scanned in supine position with the head slightly elevated and turned to the controlateral side, and tape recordings were made of blood flow velocities in all segments. The Doppler waveform were obtained with an angle of insonation less than or equal to 60. Particular care was taken to position the sample volume within the area of greatest stenosis. The ICA was sampled through the region of stenosis until the distal end of the plaque was visualized, to ensure that the site of highest velocity had been located. The wall filter was 100-150 Hz on average, the pulse repetition frequency was adjusted<1000 Hz (in most patients 500 Hz, depending on the flow characteristics). The color gain was selected just as high
Table 1. Demographic characteristics of the study population

<table>
<thead>
<tr>
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<th>Overall population (n=116)</th>
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</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>38 (33)</td>
</tr>
<tr>
<td>Age, years</td>
<td>74.6±7</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>104 (90)</td>
</tr>
<tr>
<td>Dislipidemia, n (%)</td>
<td>94 (81)</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>47 (41)</td>
</tr>
<tr>
<td>Smokers, n (%)</td>
<td>17 (13)</td>
</tr>
<tr>
<td>Previous smokers, n (%)</td>
<td>47 (41)</td>
</tr>
<tr>
<td>Coronary artery disease, n (%)</td>
<td>57 (49)</td>
</tr>
<tr>
<td>Chronic kidney disease, n (%)</td>
<td>45 (39)</td>
</tr>
<tr>
<td>Creatinine clearance, mL/min</td>
<td>68±22</td>
</tr>
<tr>
<td>Previous AMI, n (%)</td>
<td>33 (28)</td>
</tr>
<tr>
<td>Previous CABG, n (%)</td>
<td>12 (10)</td>
</tr>
<tr>
<td>Previous Stroke, n (%)</td>
<td>23 (20)</td>
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</tbody>
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Figure 2. Spectral and color doppler images obtained 9-days before the MDCTA examination.

as it was necessary to avoid overwriting artefacts (Figure 2).

Statistical analysis

Statistical analysis was carried out using STATA/IC 10 software (STATA Corp., College station). Continuous data are described as mean value ± standard deviation, whereas categorical variables are reported as frequency and percentages. Normal distribution of continuous variable was tested using the Kolmogorov-Smirnov test. Scatter-plot and linear regression analysis correlating MDCTA and DUS measurements was performed. A receiver-operating characteristic (ROC) curve analysis was used to test the ability of PSV to discriminate between arteries with and without stenoses ≥ 70% at MDCTA-NASCET measurement. A p-value less than 0.05 was considered to indicate statistical significance.

Results

A total of 139 carotid arteries were included in the analysis. Clinical characteristics of the study population are reported in Table 1. The MDCTA-NASCET measurements of linear percentage stenosis ranged from 35% to 95% (mean 66.8% ± 16.3%). A total of 57 arteries had stenosis ≥ 70% (41%), whereas 82 had a stenosis < 70% at NASCET measurement. DUS-PSV measurements ranged from 102 cm/s to 600 cm/s (mean 262 ± 112 cm/s). Linear regression analysis (Figure 3) showed a moderate correlation ($r^2 = 0.427$) between MDCTA-NASCET linear percentage stenosis and PSV values. ROC curve analysis showed that PSV could significantly discriminate between stenoses ≥ 70% and < 70% at MDCTA-NASCET measurement, with an area under the curve (AUC) of 0.807 (p<0.0001). A PSV value ≥230 cm/s was the optimal cutoff point to predict a stenosis ≥70% at MDCTA-NASCET measurement with a sensitivity of 71%, a
specificity of 83%, a negative predictive value (NPV) of 67% and a positive predictive value (PPV) of 82%.

Discussion

Multicenter randomized trials have shown that carotid endarterectomy significantly reduces the risk of ipsilateral stroke in patients with severe carotid stenosis [4, 15, 16]. Previous studies utilizing DSA as gold standard to investigate the stenosis degree of carotid arteries have concluded that CTA may underestimate while MRA tends to overestimate the degree of carotid stenosis, and DUS provides an intermediate estimate [16, 17].

Given the risk of complications associated with DSA, the use of non-invasive imaging is increasingly used [18]. The degree of stenosis is a key element in the diagnostic assessment of carotid artery disease, and it is critical in determining the therapeutic choice. However, there is still an ongoing debate over the most accurate image modalities and grading criteria for carotid lesions. DUS is the primary non-invasive imaging method for evaluation of ICA stenosis and is widely used in clinical practice [19]. It involves the use of doppler and color-doppler techniques [20, 22], and is often the only diagnostic method used to determine the degree and extent of carotid artery stenosis, to the point that this imaging modality is increasingly becoming the only examination performed before surgical intervention. Previous investigations have shown that 70% to 99% angiographic stenosis can be excluded by DUS with sensitivity as high as 98% [23]. Advantages of DUS, include relatively low cost, non-invasiveness, mobility, availability of high image resolution, and color flow [24]. Nevertheless, DUS is not applicable as a reliable diagnostic method in patients with short neck, obesity, presence of edema and scar after irradiation treatment, when the bifurcation localization is high, or when changes in the distal part of the artery are not available to DUS review. Ultrasonic diagnosis still largely depends on the skill of the examiner [21, 25, 26].

In our study sonographic PSV measurements showed only a moderate correlation ($r^2 = 0.427$) with MDCTA-NASCET linear percentage stenosis. However, we found that DUS-PSV could identify patients with stenosis ≥70% at MDCTA with an AUC as high as 0.807. Moreover, the results of our study indicate that the optimal PSV threshold for selecting significant carotid artery stenoses was 230 cm/s. This threshold is similar compared with the study of Heijenbrok-Kal et al. [27] where an optimal threshold value of 220 cm/s was found, or compared with the study of Grant et al. [28] where the proposed threshold was 230 cm/s. Yet, our cut-off value is lower compared to that proposed by Moneta et al. (325 cm/s) [29], by Neale et al. (270 cm/s) [30] and Saba et al. (283 cm/s) [31]. Given the heterogeneity of these findings, it seems sensible that clinicians involved in the diagnosis and management of carotid artery disease use with caution hemodynamic criteria. In fact, patients with asymptomatic disease may be over-diagnosed and subjected to unnecessary and costly diagnostics, intervention and its related morbidity. However, the optimal DUS-PSV threshold value of 230 cm/s yielded high specificity (83%) and positive predictive value (82%). This is particularly important when the decision for carotid artery revascularization needs to be made, as high specificity and positive predictive value are essential to avoid disease overestimation resulting in unnecessary procedures for patients with lesser degree of stenosis. In conclusion, the results of our study suggest a
reasonable concordance between MDCTA and DUS-PSV in quantification of the degree of stenosis. The use of a PSV threshold value of 230 cm/s allows obtaining high value of sensitivity, specificity and positive predictive value.

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