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Journal of the Neurological Sciences 269 (2008) 74 – 79

Journal of the Neurological Sciences

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Semi-automated computer assessment of the degree of carotid artery stenosis compares favorably to visual evaluation

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Received 6 August 2007; received in revised form 13 December 2007; accepted 19 December 2007
Available online 29 January 2008

Abstract

Objective: To validate a semi-automated computer approach for the assessment of the degree of carotid artery luminal narrowing by comparing it to the visual evaluation by a neuroradiologist.
Study design and main outcome measures: In a retrospective cross-sectional study, consecutive emergency department patients who underwent computed tomography angiography (CTA) of the carotid arteries were identified. CTA studies were reviewed by a neuroradiologist, and also independently processed with a computer algorithm that automatically measures the degree of luminal narrowing at the level of the internal carotid artery bulb. The findings of the neuroradiologist and computer assessment were compared using Chi^2 tests/kappa calculations and linear regression for categorical and continuous measurements of carotid stenosis, respectively.
Results: The study population consisted of 125 patients (74 no stroke/TIA, 18TIA, and 33 stroke). 201 carotid arteries showed no significant stenosis; 33 showed $\geq$70% stenosis, 5 showed 95–99% stenosis, and 11 showed complete occlusion. There was excellent agreement between the neuroradiologist's visual assessment and the automated computer evaluation of the category of carotid stenosis (kappa = 0.918, $p < 0.001$).
Conclusion: The automated computer algorithm for quantifying the degree of carotid stenosis is reliable and shows high concordance with the interpretation of an experienced neuroradiologist.

1. Introduction

Carotid artery atherosclerotic disease occurs frequently in the general population, with a prevalence of 75% in men and 62% in women over 64 years of age [1,2]. The standard parameter used to describe the extent and severity of carotid artery disease is the degree of luminal narrowing. This comes from several randomized clinical trials, including the North American Symptomatic Carotid Endarterectomy Trial (NASCET) [3,4] and the European Carotid Surgery Trial (ECST) [5,6], which demonstrated a reduction in the risk of ischemic stroke in patients with a luminal stenosis of $\geq$70% after carotid endarterectomy, compared with medical treatment alone. The degree of luminal narrowing has been traditionally measured on catheter angiography [7,8]; however it is increasingly being measured using noninvasive techniques such as Doppler ultrasound, CT-angiograms (CTA) or MR-angiograms (MRA) [9,10]. These have been shown to be equivalent to conventional angiograms in characterizing the degree of luminal narrowing [9,11,12].

Measuring the degree of luminal narrowing using CTA or MRA raises some issues in the clinical setting. First, several methods have been reported to characterize the degree of

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doi:10.1016/j.jns.2007.12.023

carotid stenosis, including the NACSET method [3,4], the ECST method [5,6], and the common carotid method [13], which differ as to the reference arterial segment used resulting in different percent measurements for the same absolute residual lumen. [13–16] Also, different visualization methods (maximal intensity projection (MIP), volume rendering, surface-shaded display (SSD)) are available for the display of the same dataset [12,17–21], adding to the variability of the luminal narrowing measurements. Furthermore, inter-observer variability results since, in typical clinical practice, neuroradiologists simply "eyeball" the carotid artery lumen and only obtain quantitative measurements in a limited number of cases. The highest precision in measuring carotid stenosis is known to be attained by using magnified axial images and by getting measurements exactly perpendicular to the longitudinal axis of the vessel [10,21]; this, however, is time-consuming and is rarely performed in the routine clinical practice. Finally, the measurement of the luminal narrowing is influenced by the image quality, and particularly by the quality of the contrast injection. [22]

Recently, software has become available on post-processing workstations that performs semi-automatic segmentation of the carotid artery lumen on CTA studies, and automatic quantitative measurements of diameter and area. This approach could potentially alleviate some of the limitations listed above, but the use of such software has not yet been validated.

The goal of this paper is to validate a semi-automated computer assessment of the degree of carotid artery luminal narrowing by comparing it to the visual evaluation by an experienced neuroradiologist.

2. Methods

2.1. Patients

All consecutive patients admitted to the Emergency Department (ED) between July 2005 and December 2005, who underwent a CTA of their carotid arteries were retrospectively identified. This retrospective, cross-sectional study was approved by our institutional review board. In order to be eligible for the study the patients had to undergo a follow-up brain imaging study (either CT or MRI) after the ED CTA, in order to make a final diagnosis of stroke or absence thereof, and to determine the side of the stroke if one existed. Patients were excluded if: (1) They had an intracranial hemorrhage, or (2) they had a hemispheric stroke prior to the considered admission, as evident from either the clinical history or imaging.

After review of the follow-up brain imaging studies and the medical records, the patients were separated into two groups: patients who had a diagnosis of stroke, and those who did not. Among the non-stroke patients, those with a clinical diagnosis of transient ischemic attack (TIA) at discharge were also considered separately. For the stroke and the TIA groups, the side of the event was recorded, as determined by history and physical examination on admission in the ED (for TIA patients) and by follow-up brain imaging studies (for stroke patients).

2.2. CTA imaging acquisition protocol

The CTA studies were obtained on a 16-slice CT scanner (General Electric Medical Systems, Milwaukee, WI, US). The image acquisition protocol was as follows: spiral mode, 0.6-second gantry rotation, collimation: 16×1.25 mm, pitch: 1.375:1, slice thickness: 1.25 mm, reconstruction interval: 1.00 mm, acquisition parameters: 120 kVp/240 mA. A caudo-cranial scanning direction was selected, covering from the mid-chest to the vertex. Seventy milliliters (mL) of Iohexol (Omnipaque, Amersham Health, Princeton, NJ; 300 mg/mL of iodine) was injected to an antecubital vein with a power injector at a rate of 4 mL per second. Adequate timing of the CTA acquisition was achieved using a test bolus technique.

2.3. Visual assessment of CTA studies by the neuroradiologist

A CAQ-certified neuroradiologist with more than five years' experience after a 2-year fellowship reviewed the CTA studies and assessed them for the maximal degree of stenosis in the right and left internal carotid arteries according to the NASCET method. Specifically, the reviewer was asked (1) to quantify the degree of carotid stenosis and (2) to assign the patients to one of the following four categories: no significant stenosis (<70%), significant stenosis (≥70%), subocclusion (95–99%), or complete occlusion (100%).

The reviewer was blinded to the prior interpretation of the images and to the patients' clinical condition. The review was performed on a post-processing workstation where the reviewer could look at the raw axial CTA images and obtain multiplanar reformats (MPR) and MIPs in multiple planes. The post-processing workstation was equipped with a caliper tool to perform measurements. The reviewer was instructed to proceed exactly as is done in the reading-room for routine cases. Typically, this involves eyeballing the degree of carotid stenosis on 3-mm thick MIP images of the carotid bifurcations obtained in the coronal and sagittal oblique planes, and confirming this result on raw axial CTA images using caliper measurements.

2.4. Semi-automated evaluation of CTA studies by the computer algorithm

CTA studies of the carotid arteries were exported offline to a separate PC computer and processed independently, using dedicated, custom-developed, Matlab (The MathWorks, Inc., Novi, MI)-based software, by a second neuroradiologist, also blinded to the prior interpretation of the images and to the clinical condition of the patients. The role of the second neuroradiologist was to identify and place 'seeds' within the lumen of the common carotid artery and the internal carotid artery, on each side. Based on these seeds,