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● *Original Contribution*

VALIDATION OF A COMPUTER-AIDED DIAGNOSIS SYSTEM FOR THE AUTOMATIC IDENTIFICATION OF CAROTID ATHEROSCLEROSIS

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Abstract—Carotid atherosclerosis represents one of the most important causes of brain stroke. The degree of carotid stenosis is, up to now, considered one of the most important features for determining the risk of brain stroke. Ultrasound (US) is a non-invasive, relatively inexpensive, portable technique, which has an excellent temporal resolution. Computer-aided diagnosis (CAD) has become one of the major research fields in medical and diagnostic imaging. We studied US images of 44 patients, 22 patients with and 22 without carotid artery stenosis, by using US examination and applying a CAD system, an automatic prototype software to detect carotid plaques. We obtained 287 regions: 60 were classified as plaques, with an average signal echogenicity of 244.1 ± 20.0 and 227 were classified as non-plaques, with an average signal echogenicity of 193.8 ± 38.6 compared with the opinion of an expert neurologist (golden test). The receiver operating characteristic (ROC) analysis revealed a highly significant area under the ROC curve difference from 0.5 (null hypothesis) in the discrimination between plaques and non-plaques; the diagnostic accuracy was 89% (95% CI: 0.85–0.92), with an appropriate cut-off value of 236.8, sensitivity was 83% and specificity reached a value of 85%. The experimental results showed that the proposed method is feasible and has a good agreement with the expert neurologist. Without the need of any user-interaction, this method generates a detection out-put that may be useful in second opinion. (E-mail: lillabonanno@gmail.com) © **2014 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **CAD system, Carotid atherosclerosis, Ultrasound image, Watershed segmentation.**

INTRODUCTION

The degree of carotid stenosis is, up to now, considered one of the most important features for determining the risk of brain stroke (Afonso et al. 2012). This feature, together with other patient information such as age, clinical history and risk factors, are the main criteria for determining the risk of stroke and, thus, to decide about eventual surgical intervention (Nicolaides et al. 1995). Ultrasound (US) is a non-invasive relatively inexpensive, portable technique, which has an excellent temporal resolution (Suetens 2002). US imaging is used not only to visualize the anatomy of the stenosis but also to visualize function (Rangaraj 2005). Vascular non-invasive US allows the estimation of morphologic and dynamic parameters of arteries, such as diameter and distension or intima-media thickness (Rossi et al. 2008). The principle of velocity imaging was originally based on the Doppler effect and is therefore often referred to as Doppler imaging (Cloutier et al. 2001). Computer-aided diagnosis (CAD) has become one of the major research directions in the medical imaging field (Doi 2007). CAD should be considered as an objective technique that aims to achieve both goals of lowering cost and effectiveness and is especially well suited for the digital imaging technology, which is being developed to produce digital images (Petrick et al. 1996).

Recently, CAD is beginning to be applied widely in the detection and differential diagnosis of many different types of abnormalities in medical images (Doi et al. 1992; Summers 2003; Giger 2004; Doi 2005).

Many different types of CAD systems are being developed for detection and/or characterization of lesions in medical imaging, including conventional radiography, computed tomography, magnetic resonance imaging and US (Doi et al. 1999, 2005). In literature, there are studies that present a CAD-based technique (atheromatic system) for classification of carotid plaques in B-mode US images

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into symptomatic or asymptomatic classes (Acharya et al. 2012a, 2012b). The general approach for CAD system is to find the exact location of a lesion and also to determine an estimate of the probability of an atherosclerotic disease.

The aim of this study was to develop a CAD system capable of discriminating the plaques and non-plaques and to identify the location and size of each plaque.

We validated a CAD system in a set of US images by using ROC analysis (Zweig and Campbell 1993; Metz 2000). From the obtained results, we could argue that the system is accurate and clinicians could use the computer output as a "second opinion" to support the decision making.

MATERIALS AND METHODS

Study population

We studied 44 patients, 22 with and 22 without carotid artery stenosis. All patients were randomly enrolled.

The Watershed algorithm, implemented using MATLAB 7.6, was tested on US images. For all of the patients, the analysis was performed including the anamnestic risk clinical factors (diabetes, smoking, hypertension, dyslipidemia). The patients (mean age 63.82 ± 16.66 y) presented stenosis at common (CCA), internal (ICA) and external (ECA) carotid artery between 20%–60% with about 35% median and have all risk factors that generate the formation of atherosclerotic plaque. The 22 patients without stenosis (mean age 57.04 ± 21.04 y) presented very low risk factor levels. Detailed socio-demographic characteristics are summarized in Table 1. The patients were recruited from IRCCS Centro Neurolesi "Bonino-Pulejo" of Messina. Local Ethics Committee approval was obtained and all patients gave informed consent.

Instruments and ultrasonography data acquisition

The CCA, ICA and ECA US data were obtained as longitudinal cross-sections using a Philips iU22 ultrasound system (Philips Healthcare, Eindhoven, The Netherlands) with an L9-3 probe and included B-Mode (*i.e.*, gray scale) and color Doppler image sequences. The vascular carotid preset on the machine was used (Vasc Car preset, persistence low, XRES and SONOCT on), and the gain was optimized by the operator (F.S.) who is an experienced vascular sonographer. We used 44 echo color Doppler images that were stored in a database to be read by the algorithm automatically and sequentially.

Table 1. Socio-demographic characteristics of patients

	Patients	Controls
No. Patients	22	22
Age		
Mean	63.8	57
SD	16.7	21
Gender		
M	10	4
F	12	18
Smoker (%)	27.3	4.5
Ex-Smoker (%)	31.8	9.1
Non-Smoker (%)	40.9	86.4
Diabetes (%)	22.7	1.3
Dyslipidemia (%)	72.7	2.5
Hypertension (%)	59.1	40.9

Plaque segmentation algorithm

The dynamic series were retrospectively transferred as anonymized Digital Imaging and Communications in Medicine (DICOM) files to the CAD system. The algorithm implemented a series of processing steps. After reading the B-mode image, a filter was applied (pre-processing phase) to obtain a better segmentation gradient. Watershed technique was used to segment the carotid plaques (processing phase). The B-mode features included average signal echogenicity on plaque region (features extraction phase), including finally, the classification phase of plaques. A similar previous prototype of the CAD system was described in detail by Mayer et al. (2006). The analysis of the images was automatically performed without any user interaction. A workflow diagram is shown in Figure 1.

Pre-Processing

The segmentation of echo color Doppler images is difficult because of variable imaging parameters, overlapping intensities, noise, gradients, motion, blurred edges and normal anatomic variation artifacts. The US artifacts can be classified as to their sources, which are physiologic (*e.g.,* motion, different speeds of sound and acoustic impedance of tissues), equipment (dimension of the ultrasound beam and the converter array) and technical imaging (mode B, spectral Doppler and color Doppler ultrasound) (Amir et al., 2013). Therefore, before applying any approach to carotid artery stenosis, there are generally two pre-processing steps that have to be carried out first, the removal of artifacts from images and the removal of non-plaque features from the image. We considered 44 images, reporting the results obtained on a single image (Fig. 2) of a patient affected by a fibrocalcific atherosclerotic plaque of 25%–30% grade of stenosis localized in the bifurcation of the common carotid artery. As we wanted to maximize performance of the image segmentation methods, it was necessary to remove image inhomogeneities generated by the bias field and suppress the random noise generated by digital acquisition. This caused difficulties in applying techniques for the recovery of the contour of the object. We have applied a filter for removal of artifacts from images. In particular, we applied Sobel filter to detect edges of the image. The

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