

Automatic Algorithm for Segmentation of Atherosclerotic Carotid Plaque

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Background: Carotid atherosclerosis is one of the major causes of stroke. The determination of the intima-media thickness, the identification of carotid atherosclerotic plaque, and the classification of the different stenoses are considered as important parameters for the assessment of atherosclerotic diseases. The aim of this work is to segment the plaques and to allow a better comprehension of carotid atherosclerosis. **Methods:** We considered 44 subjects, 22 with and 22 without the presence of plaques in the carotid axis, and we applied the snake algorithm. **Results:** The resulting interclass correlation coefficients (ICCs) were significant for all 3 parameters (mean echogenicity: $ICC_1 = .78$ [95%CI: .55-0.90]; perimeter: $ICC_2 = .81$ [95%CI: .61-0.92]; area: $ICC_3 = .89$ [95%CI: .75-0.95]). The diagnostic accuracy was 82%, with an appropriate cutoff value of 224.5, sensitivity of 79%, and specificity of 85%. **Conclusions:** In this study, we developed an automatic method to identify the carotid plaque. Our results showed that an automatic system of image segmentation could be used to identify, characterize, and measure atherosclerotic carotid plaques. **Key Words:** Automatic segmentation—carotid atherosclerosis—snake algorithm—ultrasound image.

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Introduction

Atherosclerosis is one of the major causes of cerebrovascular diseases and its diagnosis is considered one of the most important medical examinations for the prevention of cerebral and cardiovascular events.^{1,2} The finding of plaques in ultrasound (US) image is important for the clinician to correctly evaluate the degree of severity of

atherosclerosis disease in an asymptomatic or symptomatic individual at risk of stroke.³

Segmentation of US images by using markers such as shape, area, eccentricity, and thickness is essential for quantitative measurement of plaques.⁴ Plaque-image segmentation methods allow the isolation of the region of diagnostic interest. Noise from the extracted plaques can be removed by using image despeckling methods. Texture features are subsequently computed over the segmented images. Texture features are then used as inputs to provide an overall assessment of the input plaque images.⁵ In particular, in the plaque analysis, the main problem is the necessity to recognize the contour, and the data collection is a crucial phase. Three types of methods that may be used to obtain the contour are (1) manual methods, (2) interactive methods assisted by the computer, and (3) automatic methods. Manual segmentation is laborious and increases interobserver and intraobserver variability.⁴ Several algorithms for the segmentation of carotid arteries have been proposed in US imaging. In the studies of Loizou et al,^{6,7} various snake

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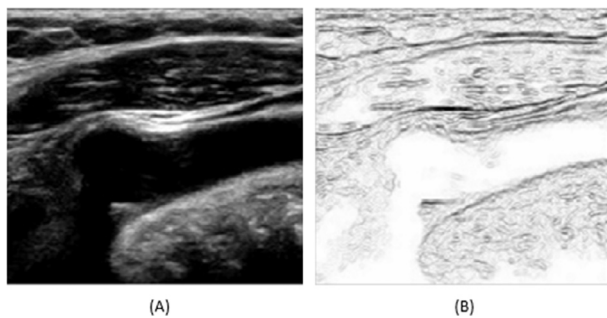


Figure 1. Ultrasound image. (A) Ultrasound (US) image of the stenosis of 25%-30% localized in the bifurcation of common carotid artery; (B) gradient filter.

segmentation methods, with initialization based on the blood flow image, were tested in the context of two-dimensional (2-D) longitudinal images of carotid plaques. The plaque was segmented in 2-D longitudinal images⁸⁻¹⁰ by using a combination of gradient-based segmentation, that is, a snake segmentation method, and a fuzzy K-means algorithm with an initialization based on pixel echogenicity. In Golemati et al,¹¹ Hough transforms were used to perform the segmentation of 2-D longitudinal and cross-sectional images of plaques.

Recently, computer-aided diagnosis systems have been developed to improve the capability of clinicians to interpret medical images and to differentiate between benign and malignant tissues.¹²⁻¹⁶ In this study, we tested an automatic snake algorithm to identify carotid plaques. This algorithm is based on the application of cubic spline functions that allow the best approximation of the snake at contour of plaques. We considered the geometric parameters of the spline to evaluate the automatic acquisition of snake coordinates to compare them with those obtained by manual segmentation.

Materials and Methods

Study Population

We studied 44 subjects, 22 with 1 and 22 without carotid artery stenosis. All subjects were randomly enrolled. For all subjects, the analysis was performed including the anamnestic risk clinical factors (diabetes, smoking, hypertension, dyslipidemia). The patients (mean age 63.8 ± 16.7 years) presented stenosis at the common carotid artery, internal carotid artery, and external carotid artery between 20% and 60%, with about 35% median and have all risk factors that generate the formation of atherosclerotic plaques. The 22 subjects without stenosis (mean age 57.0 ± 21.0 years) presented very low risk factor levels. We dimensioned the image to 200×150 pixels (Fig 1, A). Detailed sociodemographic characteristics are summarized in Table 1. The subjects were recruited from Istituto di Ricovero e Cura a Carattere Scientifico (IRCCS) Centro Neurolesi "Bonino-Pulejo" of Messina. Local ethics com-

Table 1. Measures for the manual and automatic segmentation

Measures	Manual segmentation	Automatic segmentation	ICC
	(Mean $\pm$ SD)	(Mean $\pm$ SD)	
Average signal echogenicity	227.16 $\pm$ 17.14	226.12 $\pm$ 18.92	.78
Perimeter	67.89 $\pm$ 13.76	65.52 $\pm$ 11.42	.81
Area	522.91 $\pm$ 15.49	521.88 $\pm$ 16.85	.89

P-value of the concordance between manual and automatic segmentation using interclass correlation coefficients (ICC).

mittee approval was obtained, and all subjects gave informed consent.

Instruments and Ultrasonography Data Acquisition

US data of the common carotid artery, internal carotid artery, and external carotid artery 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., grayscale) 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 an operator with experience in vascular sonography. We used 22 echocolor Doppler images, which were stored in a database to be read automatically and sequentially by the algorithm.

Manual Method

The manual segmentation consisted of manual contour of the carotid plaque. The manual delineations were performed by using a system implemented in MATLAB (MathWorks, Natick, MA). In our study, after preprocessing phase, the plaque profile on all longitudinal US images was delineated by a neurovascular expert with more than 3 years of clinical experience and blinded to the presence of plaques. The carotid plaque parameters were extracted and saved for comparison with the automatic segmentation method.

Automatic Method

The algorithm consisted of a series of processing steps. After reading the image, gradient filter was applied (preprocessing phase). Gradient vector flow (GVF) snake technique was used to segment the carotid plaques (processing phase). The snake algorithm, implemented using MATLAB 7.6, was tested on US images. The parameters were extracted from plaque region (features extraction phase). The method was fully automatic. The algorithm incorporated normalization, speckle reduction filtering,

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