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Lumen segmentation in magnetic resonance images of the carotid artery

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A R T I C L E I N F O

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A B S T R A C T

Investigation of the carotid artery plays an important role in the diagnosis of cerebrovascular events. Segmentation of the lumen and vessel wall in Magnetic Resonance (MR) images is the first step towards evaluating any possible cardiovascular diseases like atherosclerosis. However, the automatic segmentation of the lumen is still a challenge due to the low quality of the images and the presence of other elements such as stenosis and malformations that compromise the accuracy of the results. In this article, a method to identify the location of the lumen without user interaction is presented. The proposed method uses the modified mean roundness to calculate the circularity index of the regions identified by the K-means algorithm and return the one with the maximum value, i.e. the potential lumen region. Then, an active contour is employed to refine the boundary of this region. The method achieved an average Dice coefficient of 0.78 ± 0.14 and 0.61 ± 0.21 in 181 3D-T1-weighted and 181 proton density-weighted MR images, respectively. The results show that this method is promising for the correct identification and location of the lumen even in images corrupted by noise.

1. Introduction

The segmentation of medical images is an important diagnostic tool to detect and/or to follow-up various diseases. An examination of the arterial system allows the identification of pathologies associated to cardiovascular diseases [1,2]. One of the main cardiovascular diseases is atherosclerosis, which is when fatty components, calcium, cholesterol and fibrous tissues form plaques on the artery walls. Consequently, atherosclerosis reduces or blocks the blood flow through the artery, which can cause amaurosis fugax and strokes [3–5]. Several imaging modalities are able to identify atherosclerosis in a non-invasive way, allowing treatment planning before the onset or recurrence of symptoms.

Magnetic Resonance Imaging (MRI) of the carotid artery has been widely used in studies to identify the atherosclerotic plaques and their main components in order to analyze the progression of the disease [6]. However, the correct identification of the lumen and vessel boundaries is an important step before segmenting the atherosclerotic plaque components, since atherosclerosis is located between those boundaries. The automatic/semi-automatic segmentation of the lumen and vessel wall has been proposed in several studies and in most cases it is considered as the first step to identify and evaluate atherosclerosis [7–12]. However, this task is not always performed automatically and therefore, in several studies, the boundaries of the lumen and vessel wall in the images have to be delineated manually [9,13]. Typically, the lumen boundary is located inside the vessel wall. Hence, the lumen boundary can be extended until it reaches the vessel wall boundary [8].

Three-dimensional ultrasound (3D-US) is also an interesting imaging modality to envisage the anatomy of the carotid artery [14–16]. However, the segmentation of lumen and wall boundaries in 3D-US images is a challenge because of the poor contrast and weak boundaries caused by shadows that are due to calcifications; however, several studies have been proposed to overcome such difficulties [17,18].

The segmentation of the lumen and wall of the carotid artery is a strong focus of research due to the lack of automation. Although the refinement of the lumen boundary can be easily achieved by deformable models [19–21], finding the region corresponding to the lumen is the most important step towards a fully automatic segmentation.

The semiautomatic segmentation of the lumen and wall of the carotid artery was tackled by Adame et al. [22,23]. In those studies, ellipse fitting was used to detect the vessel wall boundary, while fuzzy clustering was applied to identify the lumen and carotid plaques. Although the segmentation results had high correlation with the manual segmentations, the method requires user interaction to determine the centre point of the lumen.

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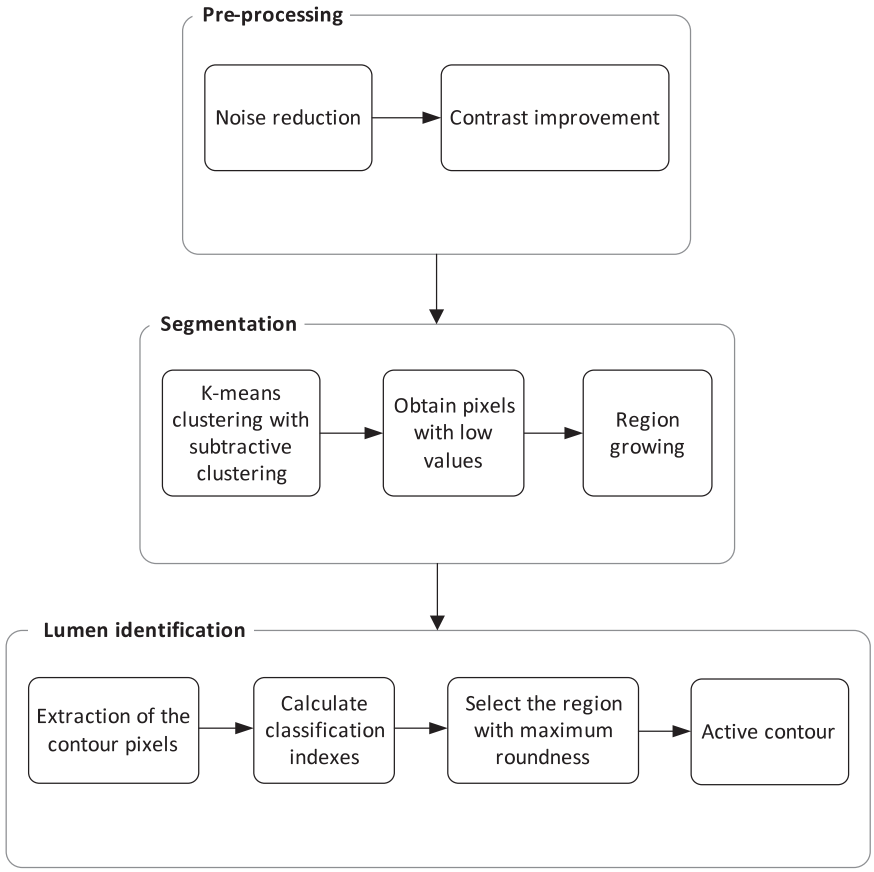

Fig. 1. Diagram of the proposed segmentation method.

Another study carried out by Saba et al. [8] proposed the segmentation of the lumen and wall of the carotid artery based on the level set algorithm. The radial expansion from a specific point is used to define the initial contour of the lumen. The final contour of the lumen, which is expanded by two pixels, is then used to initialize the contour of the carotid wall.

An attempt to automatically segment the lumen in transverse ultrasound images of the carotid artery was undertaken by Yang et al. [24]. The proposed method used the Canny algorithm to find the edges in the input image and the morphological closing operation was used to find and fill the region corresponding to the lumen.

Gao et al. [25] proposed a method to identify the media-adventitia and lumen regions on intravascular ultrasound (IVUS) images by applying an adaptive region growing algorithm and the combination of the K-means and 2D Otsu algorithms to identify the lumen inside the media-adventitia region. The algorithms were applied individually and the minimization of the curvature was used to obtain the region with the least curvature variation, which is the best representation of the lumen.

Santos et al. [26,27] addressed the segmentation of the lumen and bifurcation of the common carotid artery in B-mode ultrasound images. After a limiarization process, the binary image containing the region corresponding to the lumen was used to generate the masks that were applied in the segmentation of the lumen and bifurcation boundaries. The Chan-Vese segmentation algorithm correctly detected the inferior and superior lumen walls. Although the segmentation was fully automatic, the method is only for longitudinal B-mode ultrasound images.

This study proposes a fully automatic method to identify the location of the lumen in MR images of the carotid artery. This method relies on the analysis of the regions in the input image to identify the ones corresponding to the potential lumen. We hypothesized that, since the lumen is a low intensity region with an approximately circular shape on axial MR images, the use of the mean roundness index would allow the identification of the region with the maximum circularity that may represent the potential lumen. In addition, an active contour method is applied to refine the region boundaries. In order to evaluate the method, a comparison between the computer and manual segmentations was made to attain a quantitative analysis.

The article is organized as follows: the steps of the proposed method are described in Section 2. The results of the segmentation, as well as the comparison with the manual segmentation, are presented in Section 3. Section 4 points out the advantages and limitations of the proposed method. Finally, the conclusions are drawn in Section 5.

2. Materials and methods

2.1. Image acquisition

The MR images of the carotid artery selected for this study were used in research by Engelen et al. [9] and kindly provided by the authors on request. The proposed method was performed on images that are the regions of interest surrounding the carotid arteries. A registration procedure was previously performed to match the original MR images with the corresponding histology images, which only contained the region of the artery under study [9]. Once the matching was completed, the MR images were cropped to obtain only the part that matched the histology images [9]. The original dataset was composed of five MRI scans acquired from thirteen patients: T1-weighted (T1W), Proton Density Weighted (PDW), Time-of-Flight (TOF) and two 3D-T1W scans. The first three MRI scans were acquired without administration of intravenous (IV) contrast media, whereas the 3D-T1W scan was acquired with and without contrast media. The post-contrast 3D-T1W scan was performed 4.6 ± 3.4 min after the admin-