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Internal carotid artery stenosis measurements from 3D reconstructed multi-directional views using phantom data set on MRA image sequence

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Abstract

Purpose: To evaluate the inter-observer variability of stenosis measurements by using multi-directional 3D reconstructed projection view of internal carotid artery (ICA) that simulate the pre-determined stenosis degree on magnetic resonance angiography (MRA) image sequence of phantom data set and to compare the difference in measured percentages of maximum ICA stenosis between projection and axial images.

Materials and methods: By using adaptive region growing and circumscribed quadrangle on the clinical data set, the cylinder shape of a mathematical phantom was modeled and implemented. The maximum ICA stenosis was categorized as mild (30%), moderate (50%), and severe (70%) stenosis those simulated on the tomographic image sequence of ICA only and synthesized phantom. The 36 maximum intensity projection (MIP) images were radially projected at 10° increments that were rotated about the long axis of the body by using the simulated stenosis degree on the tomographic image sequence of phantom data sets. The six different projection image data sets were used to measure the minimum residual lumen and reference diameter by three blinded observers. The percentage of maximum ICA stenosis was calculated as the following. The ICA stenosis grading was [1 − (minimum residual lumen/averaged reference diameter)] × 100%.

Results: The percentage of maximum ICA stenosis degree measured on projection image was underestimated on ICA only phantom and overestimated on synthesized phantom compared to the simulated ICA stenosis degree on the axial image. In addition, the synthesized phantom provided the less projection image for stenosis measurement than ICA only phantom. These results attributed to the nature of MIP algorithm and the overlapping effects of surrounded anatomic structures such as other ICA, pair of external carotid artery (ECA), pair of VA, and background tissues. Furthermore, the inter-observer variability was also introduced by manual measurement.

Conclusion: The automated scheme is recommended to measure the ICA stenosis by using axial image. This technique is not only accurate as possible but also robust, simple to handle, and less time consuming compared with manual measurements. A computerized ICA stenosis measuring method, which applied the image processing technique on the axial image, is necessary to overcome the drawbacks introduced by using the projection image and manual measurement.

Keywords: Carotid artery; Maximum intensity projection; Geometric modeling; Mathematical phantom; Inter-observer variability

1. Introduction

The carotid arteries in the neck conduct blood to the brain are a common site of atherosclerosis, which may severely narrow or block off an artery, reducing blood flow to the brain and even causing a stroke [1].

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The North American Symptomatic Carotid Endarterectomy Trial (NASCET) provided a method to measure the carotid stenosis using the distal internal carotid artery (ICA) diameter as the reference diameter, and recommended that carotid endarterectomy be performed in symptomatic patients with stenosis of 70% or greater [2]. The European Carotid Surgery Trial (ECST) also provided a method to measure the carotid stenosis using the approximate diameter of the carotid bulb as the reference diameter, and recommended that carotid endarterectomy should be performed in symptomatic patients with stenosis of 80% or greater [3]. Another method was developed to measure the carotid stenosis based on the measurement of the common carotid (CC) lumen diameter as the reference diameter [4].

Currently, carotid stenosis is evaluated on conventional digital subtraction angiography (DSA), rotational angiography, maximum intensity projection (MIP) image which is 3D reconstructed carotid artery by using axial image sequence of computed tomography angiography (CTA) or magnetic resonance angiography (MRA).

Conventional angiography is considered the standard method for evaluating carotid stenosis. Most severe stenosis is used to assess the percentage of ICA stenosis using projection image from conventional DSA and rotational angiography. However, this technique is associated with a risk of thromboembolic event because of the use of an arterial catheter [5]. Thus, non-invasive techniques, such as CT angiography or MR angiography, are required for imaging vessels and it is strongly recommended to avoid conventional angiography whenever possible. However, angiogram-like 3D reconstructed MIP projection image is still used to measure the carotid stenosis, even though CTA or MRA is non-invasive technique and provides additional projection images compared with conventional angiography.

In addition, the narrowest residual lumen is not always revealed in case of using the projection image of carotid artery. Hence, the maximum degree of ICA stenosis is not always evaluated. Furthermore, there are major and clinically important disparities between measurements of stenosis acquired using different methods of measurement on the same angiogram. The equation was developed so that carotid stenosis measurements made by one method could be converted to those from another method [6]. Also, there are different measuring results dependent on laboratories and produce the variability of intra-observer, inter-observer.

In this study, therefore, we provide multi-directional views of internal carotid artery stenosis that are 3D reconstructed projection image by using pre-determined stenosis degree on MRA image sequence of phantom data set. The objective of this study is to evaluate the inter-observer variability of stenosis measurements and to compare the difference in measured percentages of maximum ICA stenosis between projection and axial image.

2. Materials and methods

Physical phantom [7] provides an accurate depiction of the image acquisition process but typically do not present a realistic representation of anatomy. On the contrary, whereas digital (voxel-based) phantoms [8,9] are mainly derived from segmented tomographic images of the human anatomy obtained by either CT or MRI, mathematical (analytical) phantom [10] consist of regularly shaped continuous objects defined by combinations of mathematical geometries such as spheres, ellipsoids, cylinders, and cones. Although anatomically less realistic than phantoms derived from CT or MRI images of patients, the mathematical phantom has the advantage that it can be easily modified to simulate a wide variety of patient anatomies. Furthermore, the combined approach that synthesizes the digital phantom with geometric model of specific human organ provides realistic simulation of tomographic image sequence; and the modifications such as identifying particular structures, adding pathologies, and highlighting activation are easily performed.

2.1. Carotid artery phantom modeling

Considering various medical image modalities, multi-dimensional human organs modeling is essential to simulate and validate the medical image-related applications. Although human organs are real 3D objects, however, two-dimensional geometric modeling is necessary to simulate the tomographic image sequence. Anatomically, the carotid artery is classified into common carotid artery (CCA), internal carotid artery, and external carotid artery (ECA). The CCA is branched off ICA and ECA at the position of thyroid cartilage and then connected to Circle of Willis through anterior and posterior communicating artery. Regarding to the artery diameter in the neck, ICA has similar radius of CCA but is relatively bigger than ECA. The topology of carotid and vertebral artery is isometric that almost symmetrically resides in left and right side of the neck; even though variations exist among the subjects. For the purpose of anatomically realistic carotid artery modeling, the analysis of clinical data set is required to determine the geometric parameters such as size of each blood vessels, spatial location, branch position, bifurcation direction, and intensity distribution that represents the intensity value of blood vessels.

2.2. Geometric parameters determination on clinical data set for phantom design

The 3D time-of-flight (TOF) neck MRA image sequence from GE Signa Horizon Echospeed scanner (TR = 25 ms, TE = 6.9 ms, FA = 25°, and FOV = 220 mm) was used to determine the central axis and bifurcation of blood vessels for phantom design. The clinical data set consists of 136 axial images and the dimension of image is 512 × 512 pixels, pixel spacing is 0.43 mm and slice thickness is 1.4 mm. The carotid artery (CA) and vertebral artery (VA) were segmented for central axis determination and bifurcation detection based upon the combined thresholding and region growing approach. The central axis of carotid and vertebral artery was determined as the following sequence: (1) image analysis, (2) initial segmentation for seed selection, (3) region growing, (4) bifurcation detection, and (5) center coordinates determination.

The image was analyzed to automatically segment the carotid/vertebral artery and to determine the geometric parameters for accurate carotid artery modeling. These consisted of two image examination tasks, which were (a) the gray level distribution between objects and background, and (b) the anatomic structure of carotid and vertebral artery. Whereas Fig. 1(a) shows the pairs of CCA and VA before branch, Fig. 1(b) shows the ICA and ECA just after bifurcation from CCA. Seen from Fig. 1, CA and VA were brighter than surrounding tissues and background. This is the nature of MRA scanning protocol that focus on the blood flow area and suppresses the signal intensity of surrounding tissues. In terms of the anatomic structure of carotid and vertebral artery, a priori knowledge was used to select the seed