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Maximum a posteriori estimation method for aorta localization and coronary seed identification

Byunghwan Jeon[a], Yoonmi Hong[b], Dongjin Han[b,*], Yeonggul Jang[a], Sunghee Jung[a], Youngtaek Hong[a], Seongmin Ha[b], Hackjoon Shim[d], Hyuk-Jae Chang[c]

[a] Brain Korea 21 Project for Medical Science, Yonsei University, Seoul, Republic of Korea
[b] Yonsei-Cedar Sinai Integrative Cardiovascular Imaging Research Center, Seoul, Republic of Korea
[c] Division of Cardiology, Severance Cardiovascular Hospital, Yonsei University College of Medicine, Seoul, Republic of Korea
[d] Cardiovascular Research Institute, Yonsei University College of Medicine, Republic of Korea

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ABSTRACT

We propose a robust method for the automatic identification of seed points for the segmentation of coronary arteries from coronary computed tomography angiography (CCTA). The detection of the aorta and the two ostia for use as seed points is required for the automatic segmentation of coronary arteries. Our method is based on a Bayesian framework combining anatomical and geometrical features. We demonstrate the robustness and accuracy of our method by comparison with two conventional methods on 130 CT cases.

1. Introduction

Cardiovascular diseases (CVDs) are the leading cause of death in the world [1]. Fully automatic segmentation of the coronary artery is desirable in the analysis of CVDs, and robust detection of the aorta and coronary ostia are prerequisite steps before segmenting the coronary arteries. We propose a robust method to find the ostia, to use as coronary seed points. For the automatic segmentation of the coronary artery from coronary computed tomography angiography (CCTA), the localization of aorta and ostia is essential since it provides the root of the coronary arteries to be reconstructed. Several commercial platforms for the segmentation of the coronary artery [2–4] start from the localization of the aorta.

Aorta localization is an essential prerequisite process for automatic segmentation of the coronary artery. As it is an independent process, its robustness is crucial for the steps that follow. Many methods [5–7] approximate the circular shape of the aorta in axial images using a Hough circle transform (HT) [8]. When the shape of the aorta is circular or elliptical in the axial image, HT is suitable for approximating it. However, when such an assumption fails, the HT-based method does not provide a reliable aorta location. Fig. 1 shows some examples where the ascending aorta does not have a circular shape because of motion artifacts, streak artifacts, or diverse location of slices. Furthermore, the most circular component is not always the ascending or descending aorta because there are similar structures surrounding the aorta as in Fig. 2. A further challenge is that when there exist circular shapes in addition to that of the aorta, it is not easy to choose the correct one from among the various structures. Moreover, HT is highly sensitive to noise and artifacts, which can also cause false positives. We propose a new model that takes into account such variations in aorta shape.

Ostium detection, the process that follows aorta localization, is another independent task. The left and right ostium points are searched for in the aortic region. The methods proposed by Kitslarr et al. [3] and Yang et al. [4] first find the ascending aorta using HT in axial images and then use ray casting to search for the two ostium points within angle constraints. Tek et al. [2] used a global search on a multi-scale medialness map to find the coronary ostium points. Zheng et al. [10] proposed a method to find the coronary ostia using the prior distribution of ostia on the surface of the aorta learned from a training set. Wang and Smedby [11] found the largest components around the aorta to use as the coronary seeds; this is unsatisfactory, however, because there can be other compo-

* Corresponding author at: Yonsei-Cedar Sinai Integrative Cardiovascular Imaging Research Center, Seoul, Republic of Korea
E-mail address: dongjin.d.han@gmail.com (D. Han).

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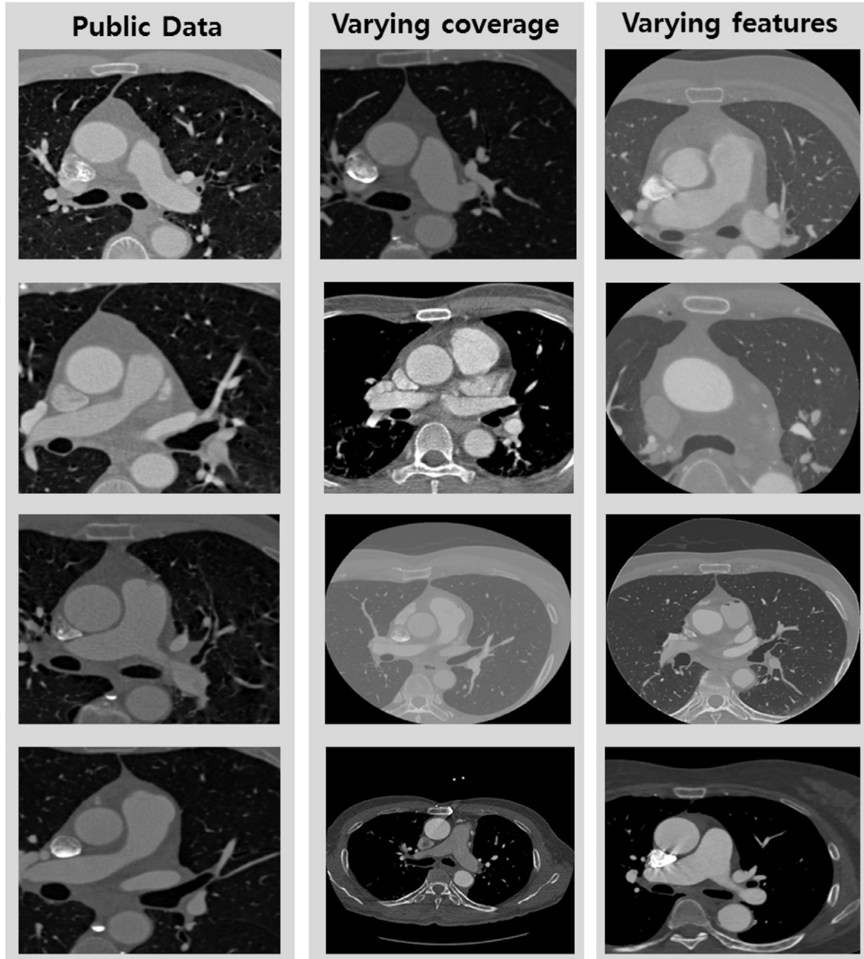

Fig. 1. Variability of CT images. Most cardiac CT images, such as those in the public dataset [9] (left), focus on a heart. However, there are also chest CT images that include not only the heart but also other elements as well; in these, there can be variations in coverage and in the features included in the 2D aorta image.

nents that are larger than coronary arteries. Our proposed method searches for coronary ostia using geometric prior information.

In this paper, we present fully automatic and robust methods for aorta localization (**A. L.**) and coronary seed identification (**C. S. I.**). Each problem is estimated in a pairwise fashion using the anatomical and geometrical relationships of two target objects. In the pairwise estimation for the aorta localization, the ascending and descending aortas are the two target components. For identifying the coronary seed points, the left and right coronary ostium points are the two target components. As mentioned previously, in axial images the ascending and descending aorta does not always appear as circular, so an aortic shape cannot simply be assumed. We use the geometrical priors to address cases with these shape variations in the aorta.

For aorta localization, the method finds both the ascending and descending aorta jointly by designing a Bayesian formulation. The two most circular components in the 2D axial images are selected as the ascending and descending aorta. We exploit three features of the paired circles: their eigenvalues from principal component analysis, the angle between them, and the distance between them. We demonstrate that it is more robust to specify the aorta pair by combining these three features than by using only one of the features individually.

Our rationale for the use of the proposed statistical model for the localization and segmentation of aorta and ostia is that:

(1) In CCTA, the brighter regions enhanced by contrast agent are the aorta, the left ventricle (LV), the left atrium (LA), and the coronary arteries, and so on; the relative locations of such contrasted regions can appear rather irregular and complex.
(2) The ascending aorta can be circular or elliptical or a variation of a 2D ellipse. Furthermore, CT volumes may contain the aortic arch, which makes the detection of the aorta difficult with conventional HT-based methods.
(3) The coronary ostia are the two largest components with high vesselness response near the aortic surface. However, there are other structures that can be mistaken for the coronary ostia.

Hence, we sought a model that would take these variations into account.

This paper is organized as follows. Section 2 presents the method for localization of the aorta using three anatomical and geometrical features; the method for detection of coronary ostium points by a similar approach is also given in this section. We show the experimental results with various clinical datasets in Section 3. Finally, the discussion and conclusion are given in Section 4.

2. Method

The proposed approach estimates the locations of two objects simultaneously using anatomical and geometrical features described in terms of the angle and distance between the objects as well as the features of each object itself. This approach is applied