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Automatic Segmentation of Vertebral Arteries in Head and Neck CT Angiography Images

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We propose an automatic vessel segmentation method of vertebral arteries in CT angiography using combined circular and cylindrical model fitting. First, to generate multi-segmented volumes, whole volume is automatically divided into four segments by anatomical properties of bone structures along z-axis of head and neck. To define an optimal volume circumscribing vertebral arteries, anterior-posterior bounding and side boundaries are defined as initial extracted vessel region. Second, the initial vessel candidates are tracked using circular model fitting. Since boundaries of the vertebral arteries are ambiguous in case the arteries pass through the transverse foramen in the cervical vertebra, the circle model is extended along z-axis to cylinder model for considering additional vessel information of neighboring slices. Finally, the boundaries of the vertebral arteries are detected using graph-cut optimization. From the experiments, the proposed method provides accurate results without bone artifacts and eroded vessels in the cervical vertebra.

Key Words Computed tomography angiography · Vertebral artery · Vessel segmentation · Vessel tracking.

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Introduction

Computed tomography (CT) angiography is a useful imaging technique for the evaluation of the intra- and extra-cranial vasculature. With the introduction of multi-detector row CT scanners, head and neck CT angiography images make it easy to detect cerebral aneurysms, arterial stenosis, and other vascular anomalies. To get an arterial anatomy in three-dimensional views, CT angiography images are often displayed using conventional volume rendering and maximum intensity projection (1-3). However, there is the limitation to get a clear arterial anatomy where arteries are contiguous with the bone.

Two main approaches are generally used for vessel segmentation in CT angiography. First approach is to subtract enhanced images which taken after injecting a contrast material from non-enhanced images. Gratama et al. proposed a multi-scale matched mask bone elimination using combined high resolution and low resolution image of the non-enhanced scan (4). Kwon et al. proposed a 3D registration to align a CT to CTA using normalized mutual information and subtraction-and-refinement to effectively remove unwanted residuals (5). Hong et al. proposed 3D rigid registration technique based on locally weighted 3D distance map of feature point and bone masking (6). Kim et al. extracted vessels using multi-segmented volume subtraction of lower extremities based on the 3D rigid registration (7, 8). These methods have been shown to be good quality results. However, bone masking requires the acquisition of an additional CT scan, thereby increasing the radiation dose to the patient. Second approach is directly vessel extracting method from CT angiography by using vessel tracking procedure. Shim et al. proposed a vessel segmentation method via the ellipse travelling and tracking in three-dimensional space (9). Manniesing et al. proposed a 3D vessel axis tracking based on evolving surfaces using skeleton and shape constraint topology (10). Gulsun at al. proposed a centerline tracking based on multi-scale medialness filters and lumen boundary segmentation with graph-cut optimization (11). These methods typically require user interaction in the form of one or more seed points placed in the vessel to be extracted.

In this paper, we propose a fully automated vessel segmentation method of vertebral arteries in head and neck CT angiography. For generating multi-segmented volumes in head and neck CT angiography images, whole volume is automatically divided into four segments by anatomical properties of skull structures. For extracting vertebral arteries, initial vessels are tracked by combined circular and cylindrical model fitting and the initial vessel boundaries are refined by graph-cut optimization.

Methods

Multi-Segmented Volume Partitioning

Since spatial relationships of bone and vessel structures in head and neck CT angiography are different according to their position, it is necessary to apply customized algorithm to each subvolume. Thus, whole volume of head and neck is automatically divided into four segments and the segmentation of vertebral arteries in neck part is performed.

To decide an upper- and lower-head partition, cortical bone with high density is selected by using thresholding with 400 HU and the number of skull structure is counted by using connected component labeling. Starting position of upper-head partition (A) is decided by the location of glabella, whereas that of lower-head partition (B) is decided by the location of mandible. Starting position of neck partition (C) is decided by the location which the collar bone at both sides in axial plane is detected.

To narrow a segmentation region and minimize the wrongly segmentation of vertebral arteries, Anterior-posterior bounding and lateral bounding is defined. Initial bones (blue mask) in Fig. 1B are segmented by region growing with 400 HU and morphological dilation. Initial vessels (red mask) in Fig. 1B are segmented by region growing with 200 HU. Then, MIP images of the initial vessel region is generated in the coronal and sagittal planes and vertical lines including vessels in neck part is detected.

Vessel segmentation

The vertebral and common carotid arteries in neck part have a tubular shape and their appearance is shown as circular region in the axial slices. Thus, the vertebral and common carotid arteries are segmented by vessel tracking based on circular model fitting (8) in the axial slices. However, since boundaries of the vertebral arteries are ambiguous in case the arteries pass through the transverse foramen in the cervical vertebra, it is necessary to cylinder model fitting for considering additional vessel information of neighboring slices.

To search the starting position of vertebral arteries in neck partition, common carotid arteries and vertebral arteries are segmented by three-dimensional region growing with 250 HU threshold value. Then the starting position of common carotid arteries are detected by searching the circle shape based on circular model fitting with largest radius because the common carotid arteries are well separated from neighbor bones. However, the starting positions of vertebral arteries are detected by searching the cylinder shape based on cylindrical model fitting with second largest radius because the vertebral arteries are contiguous to bones with similar density.

For the segmentation of vertebral arteries, vessel tracking is performed in two steps. First, a potential center point is generated based on the center point of staring vessel region. Second, a new vessel border is detected using the center point and maxi-

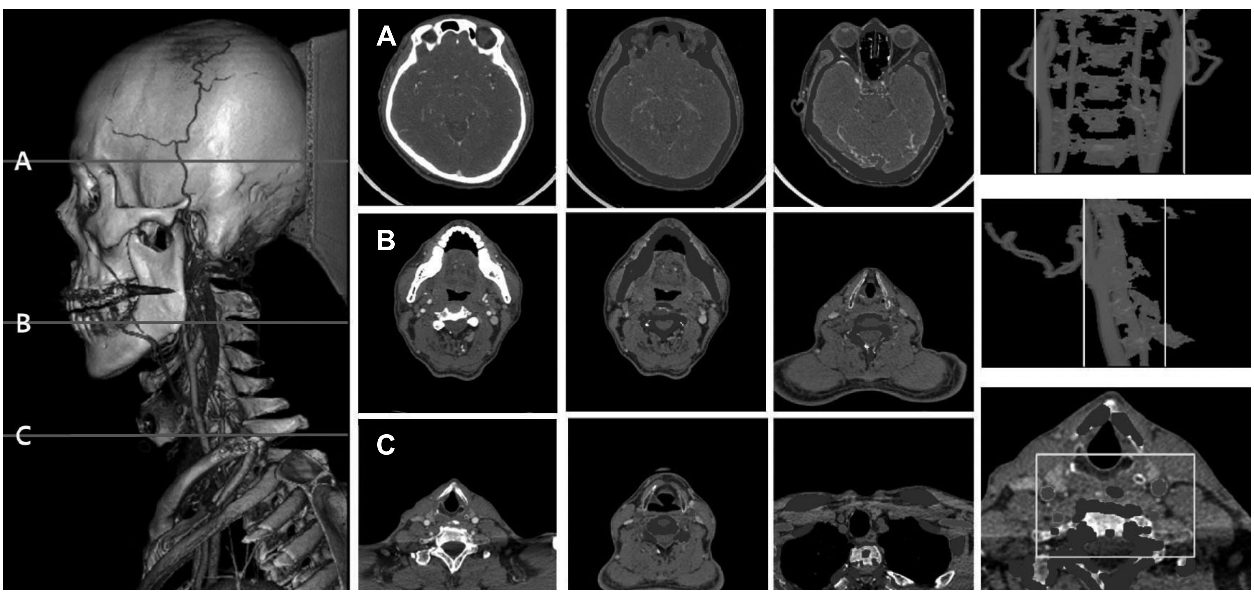

Fig. 1. Multi-segmented volume partitioning and AP(Anterior-Posterior)-lateral boundings. (A) Multi-segmented volume partitioning according to the skull structure, (B) Segmentation of initial bone(blue mask) and vessel(red mask) region, (C) Coronal and sagittal MIP images of the initial vessel region and AP and lateral boundings (yellow line).

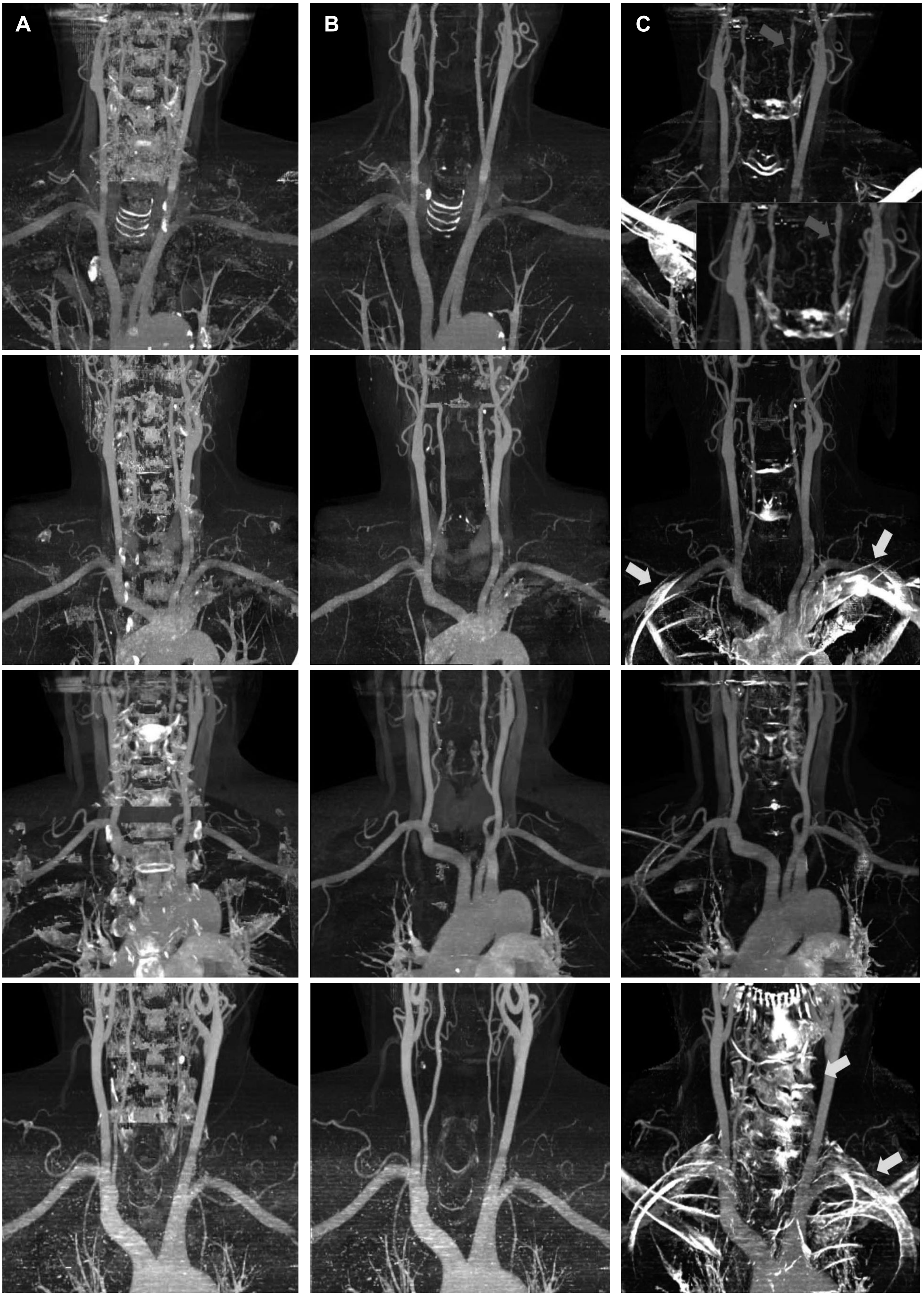

Fig. 2. The results of automated segmentation of vertebral arteries in head and neck CT angiography. (A) Density-based segmentation (B) the proposed method and (C) registered subtraction are displayed as Maximum Intensity Projection.

mum radius acquired from circular model fitting on the potential center point. When boundaries of the vertebral arteries are ambiguous in case the arteries pass through the transverse foramen in the cervical vertebra, a maximum radius value is very small. Then, the circle model is extended along z-axis to cylinder model for considering additional vessel information of neighbor slices. The two steps are repeated until vertebral arteries are reached at the top of neck partition. The border of vessel segmented using combined circular and cylindrical model fitting is likely to be modeled by circular form. Therefore, it is necessary to boundary refinement of the extracted vessels using graph-cut optimization (12).

Results

Our method has been applied to five data sets of head and neck CTA images acquired by the Brilliance 64 CT scanner (Philips), the Discovery CT scanner (GE) and SOMATOM Definition (SIEMENS). Each image had a matrix size of 512× 512 pixels with in-plane resolutions ranging from 0.39 mm to 0.47 mm. The slice thickness ranged from 1.0 mm to 1.25 mm and the number of images per scan ranged from 291 to 400. The performance of our method is evaluated with the aspect of visual inspection.

Fig. 2 shows the results of segmentation of vertebral arteries using proposed method and two comparative methods using MIP display. In density-based segmentation (Fig. 2A), bone artifacts remain due to similar density of enhanced vessel and bone. In registered subtraction (Fig. 2C), bone artifacts remain (yellow arrow) as well as enhanced vessels (red arrow) are eroded due to mis-registration of CT and CT angiography. The proposed method (Fig. 2B) provides accurate results without bone artifacts and eroded vessels in the cervical vertebra.

Conclusion

We have developed an automatic segmentation method of vertebral arteries in head and neck CT angiography using combined circular and cylindrical model fitting. Our multi-segmented volume partitioning improved the accuracy of the vessel extraction by applying customized algorithm to each segment. Our combined circular and cylindrical model fitting detected a circular shape like a vessel border in axial slice. Moreover, our method was efficient in case the vertebral arteries pass through the transverse foramen in the cervical vertebra. As a result of visual assessment, the proposed method provides accurate results without bone artifacts and eroded vessels in the cervical vertebra. Our method can be used in the diagnosis of cerebral aneurysms, arterial stenosis, and other vascular anomalies.

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