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AN AUTOMATED BONE REMOVAL TECHNIQUE FOR EXTRACTION OF CEREBRAL VESSELS FROM HEAD CT ANGIOGRAPHY

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ABSTRACT
We propose a method for automatic removal of bone regions like calvaria and cranial base from head CT angiography (CTA), to extract only cerebral vessels. The method consists of binarization for first extraction of cerebral-vessel regions, Laplacian-like filtering to separate cerebral-vessel regions and bone regions, 2D- and 3D- labeling to eliminate bone regions, and modification of extracted cerebral-vessels regions. These processes are repeated using reconstructed CTA images in the axial- sagittal- and coronal-view planes, to further improve the performance of bone removal. To validate the effectiveness of the proposed method, we apply the method to three clinical cases of head CTA. Our preliminary results show that the proposed method has the potential to automatically detect cerebral vessels from head CTA images with an acceptable accuracy.

KEY WORDS
CT angiography, cerebral vessels, bone removal, Laplacian-like filter, computer-aided diagnosis

1. INTRODUCTION

The mortality rate for cerebrovascular disease is high and increasing in many countries [1]. In Japan, it comes next to the mortality rates for malignant neoplasms and heart disease[2]. Computed tomographic angiography (CTA), magnetic resonance angiography (MRA) and digital subtraction angiography (DSA) are used for diagnosis of cerebrovascular disease. In these modalities, CTA is superior to MRA in spacial resolution and temporal resolution, and is superior to DSA in low-invasiveness [3,4]. Therefore, CTA is used for neurosurgery and so on [3-6]. CTA easily generate volume rendering image (VRI) of cerebral vessels. VRI of cerebral vessels bring improvement of diagnostic quality of cerebrovascular disease. However, bone in the head, like calvaria and cranial base, surely appear together with cerebral-vessels in the VRI. Internal carotid artery goes through cranial base, and they have almost corresponding range of CT values in particular. It is important to remove such bone regions [7,8] in the VRI because medical doctors look at the VRI from multi-viewpoint, it means they rotate the VRI optionally. So, doctor or radiologist manually removes such bone regions in the VRI. But manual removal of bone regions needs operator's experiences and efforts, and it is difficult to reproduce the VRI that removed corresponding bone regions. Therefore, we propose an automated bone removal technique in head CTA in this paper. Our approach consists of a simple binarization technique, a Laplacian-like filter [9], and a statistic feature analysis, and these processes are reapplied to multi-reconstructed images. In this paper, we describe the details of the proposed method and apply the method to three clinic cases.

2. METHODS

Our procedural flowchart is shown in Fig.1, and processed CTA images corresponding to the flowchart are shown in Fig.2. Details corresponding with flowchart will be described in below.

(1) Binarization
Binarization process defines regions of cerebral vessel and bone with high CT values in CTA. Fig.2(a) shows an axial image of CTA around cranial base, and Fig.2(b) is binary image of it in a case threshold of binarization is 61 HU (Hounsfield Units). In Fig.2(a), internal carotid artery is clinging to cranial base. It is difficult to separate such regions by using only simple binarization. Therefore, we used a Laplacian-like filter to separate such regions, describing in (3).

(2) 2D-labeling
This 2D-labeling is used to eliminate small isolated regions in the binary images, and to define the subtraction

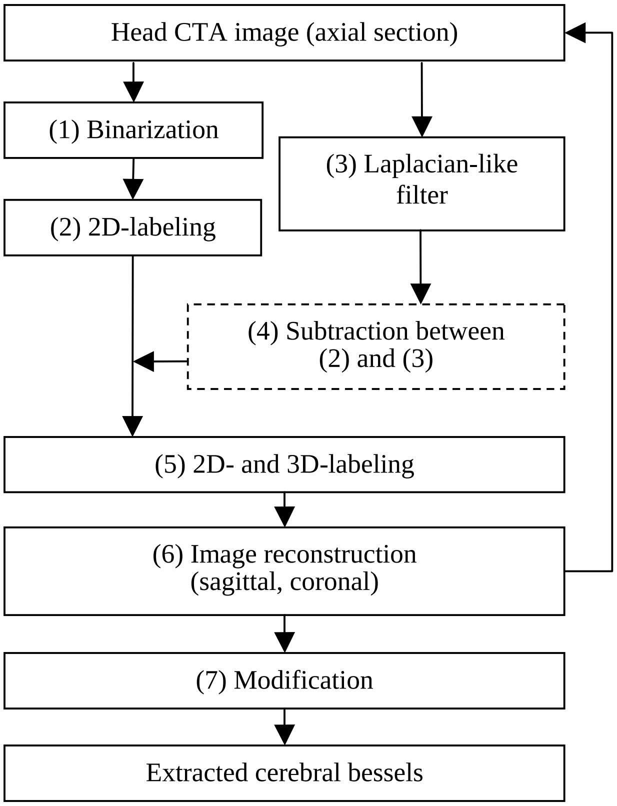


Fig.1 Procedural flowchart of our method

region using in (4). Small isolated regions are corresponding to a part of brain tissue and so on. Isolated regions that area is smaller than 20 pixels are eliminated, and that area is larger than 1000 pixels are defined as the subtraction region.

(3) Laplician-like filter
Fig.3 shows Laplacian-like filter used in this study. This filter is used to separate cranial base and cerebral vessel, mainly internal carotid artery. Fig.2(c) is obtained by applying the Laplacian-like filter to Fig.2(a). Attached cranial base and cerebral vessel in Fig.2(b) was separated in Fig.2(c). The output of this filter is a gradient of pixel values. Pixels having over -50 gradient value are defined as binarized output region, white regions in Fig.2(c).

(4) Local subtraction
Fig.2(d) is local subtracted image between Fig.2(b) after applying 2D-labeling and Fig.2(c). The subtraction is performed in 300x300 matrix from center of image, and in the subtraction region defined in (2). By specifying range for subtraction, deformation of cerebral-vessel regions not attached to bone is restrained. Although this subtraction has three output values {-1, 0, 1} because of subtraction between binary images, -1 is replaced with 0.

(5) 2D- and 3D-labeling
These processes are used to remove bone regions. First, three features are used to eliminate bone regions in 2D-

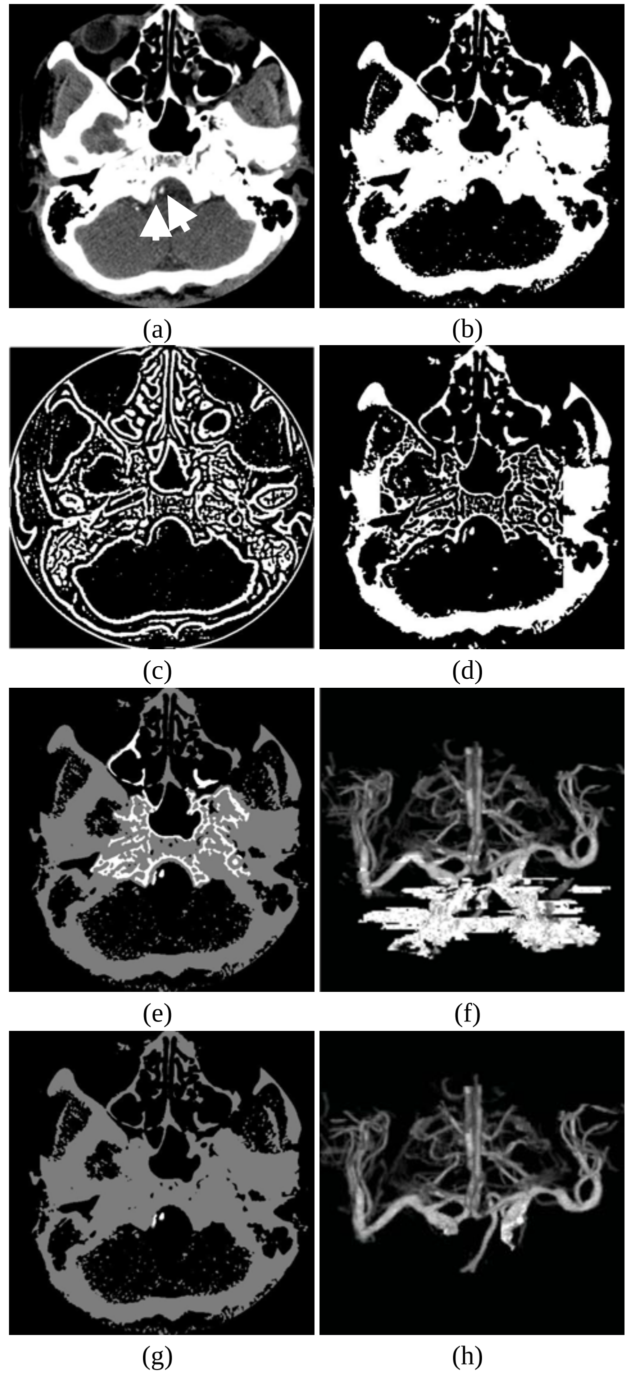
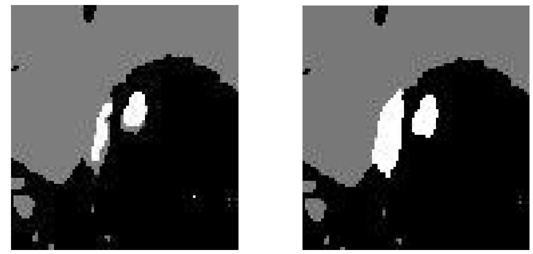


Fig.2 Processed images corresponding to the flowchart. (a) Axial slice image around the cranial base of a CTA case. White arrows indicate cerebral-vessel regions. (b) Binary image of (a). (c) The image obtained after applying laplacian-like filter to (a). (d) Local subtraction image between (b) after applying 2D-labeling and (c). (e) The image after applying the bone-elimination process in the axial plane to (d). (f) Volume rendering of this case after applying the bone-elimination process in the axial plane. (g) The image after applying the bone-elimination process in the coronal and sagittal planes to (e). (h) Volume rendering of this case after applying the bone-elimination process in the axial, coronal and sagittal planes.

0	-1	0	-1	0	-1	0
-1	0	0	1	0	0	-1
0	0	1	1	1	0	0
-1	1	1	0	1	1	-1
0	0	1	1	1	0	0
-1	0	0	1	0	0	-1
0	-1	0	-1	0	-1	0

Fig.3 Laplacian-like filter used in this study.



(a) (b)

Fig.4 Modification sample of extracted cerebral-vessel regions. (a) Cerebral-vessel regions (white regions) before modification. (b) Cerebral-vessel regions (white regions) after modification.

labeling. The features are maximum CT value (MX), mean CT value (MN) and standard deviation (SD) of CT values calculated from each isolated region obtained by 2D-labeling. Some bone regions tend to have higher range of CT values than range of cerebral vessels. These bone regions can be eliminated by MX and MN. Then bone regions difficult to classify by MX and MN tend to have higher variance of CT values than variance of cerebral vessels. These bone regions can be eliminated by SD. Thresholds for elimination were MX>776HU, MN>426HU and SD>140HU. To shorten the processing time, we used only simple statistical features in 2D images. Second, the number of consecutive section images including an isolated region is counted by using 3D-labeling. We assumed that cerebral-vessel region is extracted as a three-dimensional isolated region in consecutive section images. In this study, the isolated region that the counted number of section images exceed 2/3 of the number of total section images is regarded as cerebral-vessel region, and other regions are eliminated as bone regions. Fig.2(e) is the image after applying these bone-elimination processes in the axial plane, and Fig.2(f) is the volume rendering of this case obtained using processes from (1) to (5).

(6) Image reconstruction
In Fig.2(f), a part of cranial base is still remaining. For further elimination of bone regions, processes from (1) to (5) are repeated in the sagittal and coronal planes. First, sagittal plane images are obtained from reconstruction of processed images in the axial plane. Second, coronal plane images are obtained from reconstruction of processed images in the sagittal plane. Fig.2(g) is the image after applying the bone-elimination processes in the coronal and sagittal planes to Fig.2(e), and Fig.2(h) is the volume rendering of this case after applying repeated processes in the axial, coronal and sagittal planes.

(7) Modification
Finally, extracted cerebral-vessel regions are modified. This modification is used to recover cerebral-vessel regions shrunk in subtraction process described in (4), and is performed by simple region expanding. The extracted regions [Fig.4(a)] are expanded as far as binarized region in (2) [Fig.4(b)].

3. RESULTS AND DISCUSSION

The proposed method was applied to three cases of CTA, consisting of 60~195 slice images, with the specifications that tube voltage 120kV, tube current 170mA, table speed 6.25mm/rotation, reconstruction interval 0.625mm, pixel size 0.293mm by LightSpeed Ultra CT (General Electric Company). In each case, cerebral aneurysm was detected by medical doctor.
Our experimental results are shown in Fig.5. Fig.5(a), (b) and (c) is volume rendering obtained from original head CTA, respectively. Fig.5(d), (e) and (f) is volume rendering that removed bone regions from original CTA by using our proposed method, respectively. These results indicate that bone regions like calvaria and cranial base are eliminated very well by using our method.
Processing time is approximately 30 minutes for a case when using PC with Pentium 2.4GHz CPU, 1GByte Memory. About 2/3 of the processing time was caused by 3D-labeling. Therefore we plan to reconsider the 3D-labeling to develop a real-time application, and in the next step, to develop an computer-aided diagnosis (CAD) system for automated detection of cerebral aneurysm from head CTA.

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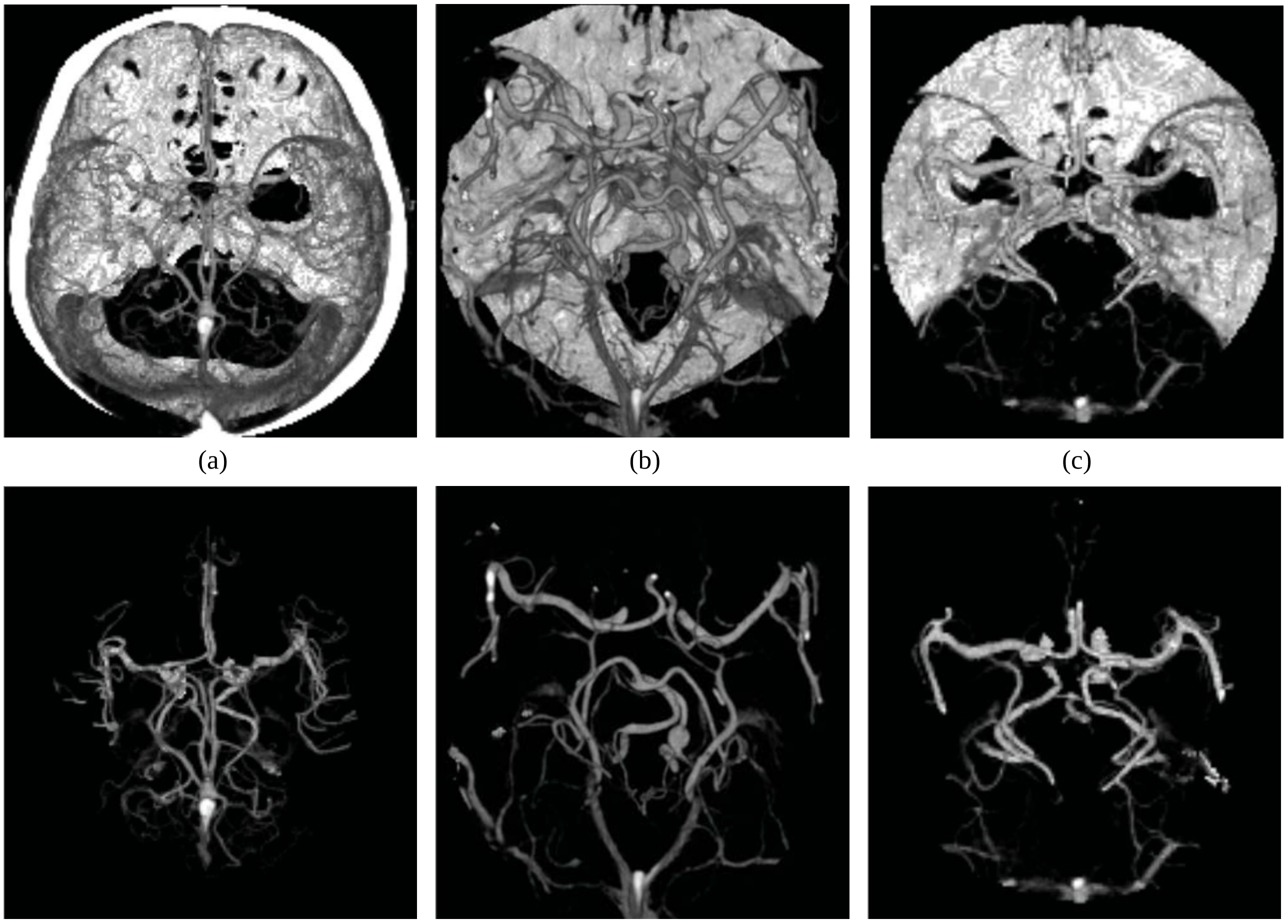

(a) (b) (c)

(d) (e) (f)

Fig.5 Volume renderings of three cases used in this study. (a) Volume rendering of original CTA images of case 1. (b) Volume rendering of original CTA images of case 2. (c) Volume rendering of original CTA images of case 3. (d) Volume rendering of extracted cerebral-vessels from case 1. (e) Volume rendering of extracted cerebral-vessels from case 2. (f) Volume rendering of extracted cerebral-vessels from case 3.

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