DEVELOPMENT OF CEREBRAL ANEURYSM COMPUTER-AIDED DETECTION SYSTEMS WITH 3D MRA DATA

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Brain disease is one of the three major diseases in Japan, and the most serious case is subarachnoid hemorrhage where eighty-five percent is caused by the rupture of cerebral aneurysms. It is estimated that about 5 percent of adults are unaware of having unruptured cerebal aneurysms, which makes early detection of cerebal aneurysms a significant issue. Although three-dimensional magnetic resonance angiography (3D-MRA) is generally used in screening for cerebral aneurysms, the detection of cerebral aneurysms requires considerable skill and experience due to the complexity of cerebrovascular networks. This study is intended to verify the effectiveness of our computer-aided diagnosis (CAD) system in clinical use, which we have developed in collaborative research with Chiba Rousai Hospital for detecting cerebral aneurysms applying 3D-MRA data. In order to detect cerebral aneurysms, we firstly developed an image filtering method for extracting cerebrovascular areas and then examined the vessel diameter from the corresponding cerebrovascular area, and finally reviewed the characteristic values for cerebral aneurysms detection.

INTRODUCTION

In the field of medical imaging, massive amounts of image data are generated as the performance of modalities becomes increasingly advanced. Thus, radiology imaging exams have become indispensable as a means of diagnosis. Recently, multi-slice CT systems, which are being introduced in large-scale hospitals at an accelerating rate, have made possible high-speed image acquisition at sub-millimeter intervals. Images of the entire human chest can now be acquired in several tens of seconds and more than 1,000 sliced images are produced in a single imaging exam. However, it is an excessive burden for a doctor, to examine such a large volume of images, one at a time, without the aid of a computer. Commonly, hospitals have begun to apply computer-aided 3D imaging, due to the increase in computer processing speed and capable amount of loaded memory. However, it is not easy to freely observe reproduced 3D images of complex shaped organs and blood vessels presented on a 2D display screen.

In recent years, studies of CAD are being actively conducted such as a CAD system that detects breast cancers from mammograms or pulmonary nodules from chest CT or X-ray images with the aim of alerting doctors at the time of diagnosis. Some have already been commercialized and a number of medical institutions have begun using the system on an experimental basis.

In this paper, we report on the joint research conducted between our company and Chiba Rousai Hospital on cerebral aneurysms detection as part of CAD.

Detecting cerebral aneurysms serves to prevent subarachnoid hemorrhage which is one of the most critical subjects for workers' healthcare. As the usual means of screening, maximum intensity

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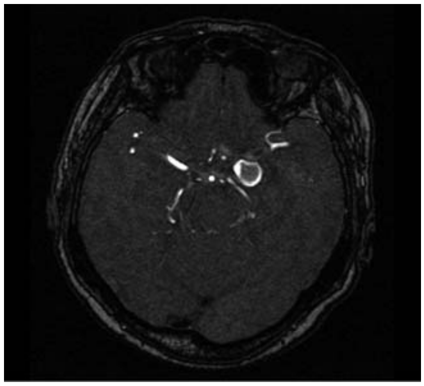


Figure 1 Example of MRA Data

projection (MIP) images based on 3D MR angiography (hereafter 3D-MRA) are widely used. An MIP image is a set of pixel values on a perpendicular axis to the projection plane. MIP imaging is commonly used as a method for viewing blood vessels. In MIP imaging, however, the produced images not only lack depth information, but also include images of veins and fats which are not in concern. If cerebral aneurysms are difficult to observe, it is necessary to reconstruct MIP images from various directions.

In this research, to support cerebral aneurysms detection utilizing 3D-MRA data, we firstly extracted cerebrovascular areas by locally determining threshold values and expanding the observation area considering blood vessel continuity[1]. Secondly, classifying cerebral aneurysms by focusing on its shape and size, we determined the methodology and characteristic values to detect cerebral aneurysms[2]. This paper reports the results of these considerations and study.

EXTRACTION OF CEREBROVASCULAR AREAS

(1) Method

Figure 1 shows a single sliced image taken from 3D-MRA data. MRA is a commonly used method to obtain cerebrovascular information which detects bloodstreams, rather than using any enhancing agent. Areas where bloodstreams exist are imaged in white. Aneurysms are a place where parts of blood vessels have swelled into clots, and an image of large aneurysms tend to be blurred due to disturbance in bloodstreams. The data dealt which is created by stacking sliced images vertically on top of each other at constant intervals. The algorithm for extracting cerebrovascular areas is shown in the flowchart on the left of Figure 2. Firstly, an initial vascular area is specified, and on the basis of this area, the searching vascular area of the adjacent image slice is set. As shown in the upper-right corner of Figure 2, the searching vascular area is set by expanding the initial vascular area of the former slice so that the searching vascular search area is twice the size of the initial vascular area. Next, a concentration histogram is created for pixels within the searching vascular area. On the presumption that vascular and non-vascular areas form a normal distribution pattern, as shown by the dashed lines in the lower-right corner of Figure 2, then apply binary

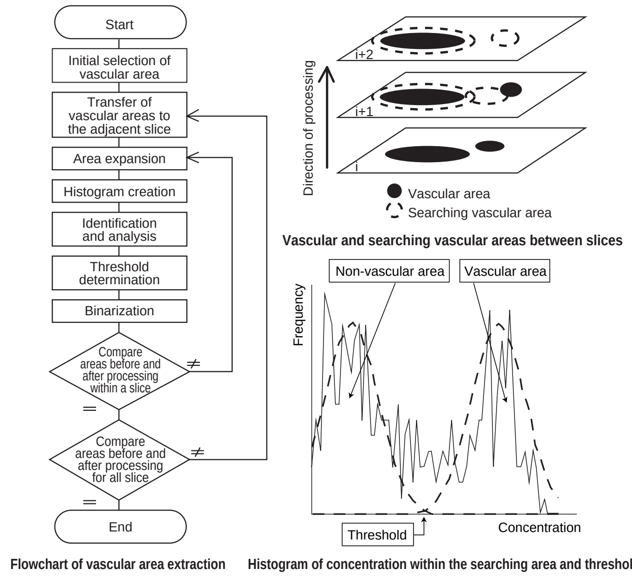


Figure 2 Vascular Area Extraction Processing Algorithm

processing to the searching vascular area using the boundary value of these two distributions as the threshold. Hereafter, vascular areas are extracted in succession from the remaining adjacent slices. By applying this extraction processing to all of the slices, it is possible to extract vascular areas in a three-dimensional manner.

(2) Results

We performed vascular area extraction targeted at 20 cases, which contains cerebral aneurysms instances. The 3D-MRA data is composed of 512 × 512 pixels × 108 slices. In all of the cases, we confirmed that arteries whose continuity is apparent can be extracted very well. We also confirmed that vascular extraction was not always possible at locations where blood

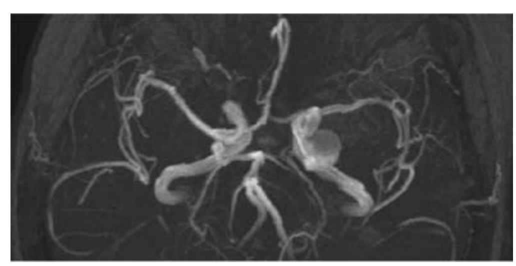


Figure 3 MIP Image Based on Cephalic 3D-MRA Data

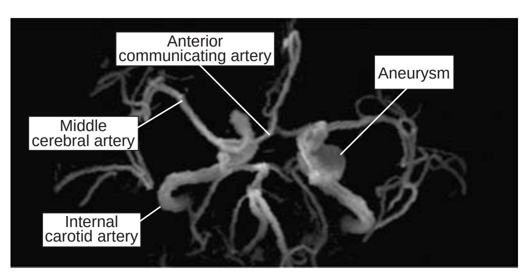
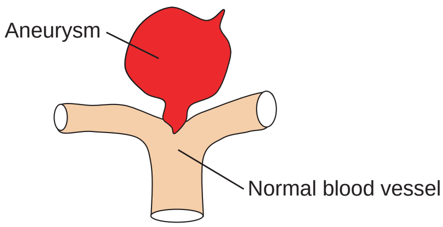
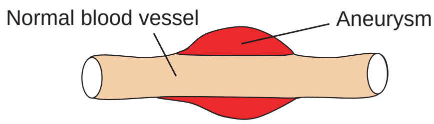


Figure 4 MIP Image after Vascular Area Extraction Processing



(a) Saccular cerebral aneurysm



(b) Fusiform cerebral aneurysm

Figure 5 Shapes of Cerebral Aneurysms

flows were disrupted due to medical treatment or illness. Another finding was many noise components were contained in such areas like narrow blood vessels near ends of arteries or areas in low contrast with the brain parenchyma as in the base of brain. For such areas, we added a process for identifying and eliminating noise components from information on the shapes of the extracted areas, as well as from the concentration information.

MIP images are commonly used to observe the blood vessel network. Figure 3 shows an example of an MIP image containing aneurysms which was created from 3D-MRA data. Figure 4 shows another MIP image which was created from the same 3D-MRA data though subjected to vascular area extraction processing. In the original MIP image, it is difficult to observe the blood vessel network due to the effects of the brain parenchyma and fats. In contrast, from the MIP image subjected to vascular area extraction, it is understood that non-vascular areas were removed and the entire structure of arteries including cerebral aneurysms are now clearly visible.

Thus, by removing non-vascular areas using this cerebrovascular area extraction processing method, it is possible to clearly observe the complex blood vessel network.

Although this processing is regarded as preparation for the subsequent cerebral aneurysms detection, we confirmed that it is adequately effective in understanding the blood vessel network in a three-dimensional manner.

DETECTION OF CEREBRAL ANEURYSMS

Aneurysms are parts of cerebral arteries that are swelled into clots and shapes or sizes vary widely. In this research, the minimum size of clots to detect was set to 2 mm. Aneurysms are classified roughly in terms of shape into saccular and fusiform aneurysms (Figure 5). In this paper, we classified aneurysms into three types, taking into account both their shapes and sizes:

(I) Large saccular cerebral aneurysm (Figure 6)
(II) Small saccular cerebral aneurysm (Figure 7)
(III) Fusiform cerebral aneurysm (Figure 8)

There are reports from other researchers[3][4] on the issue of cerebral aneurysms detection, but no research is being conducted, however, in which detection methods are explored that consider aneurysm classification by shape and size.

In this paper, out of the above three types of aneurysms, we conducted studies on methods for detecting type-I large saccular cerebral aneurysms and type-III fusiform cerebral aneurysms, and investigated their characteristic values.

(1) Method

In principle, a blood vessel tapers toward its end. However, since a cerebral aneurysm is shaped like a spherical swelling, it is expected that its diameter will have uneven slopes when the cerebrovascular area is measured. Accordingly, when detecting cerebral aneurysms, we first determined the vessel diameter profile (spherical diameter profile) to extraction processed areas by conducting a matching with spherical filters, which spherical diameter range varies from 2 to 15 mm. Figure 9 shows a spherical diameter profile overlaid on the original image. Respective spherical diameters that achieved a match are colored differently. The cerebrovascular area is almost uniformly colored, indicating that the diameter is virtually the same across the area. It is also understood that a spherical diameter profile is formed concentrically in the

Figure 6 MIP Image of a Large Saccular Cerebral Aneurysm

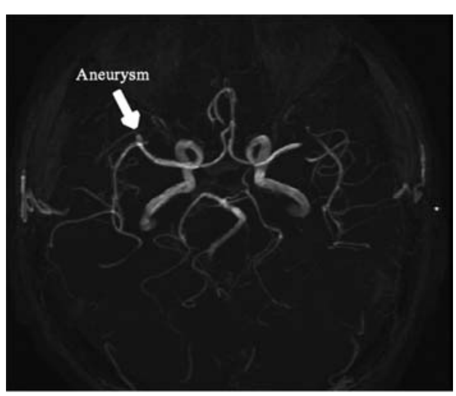


Figure 7 MIP Image of a Small Saccular Cerebral Aneurysm

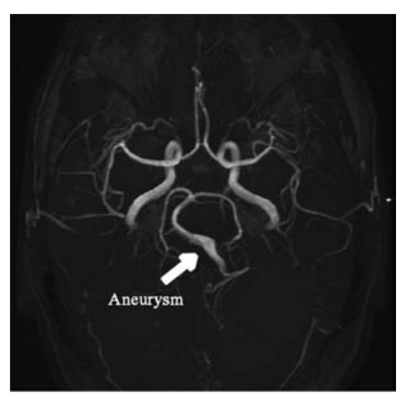


Figure 8 MIP Image of a Fusiform Cerebral Aneurysm

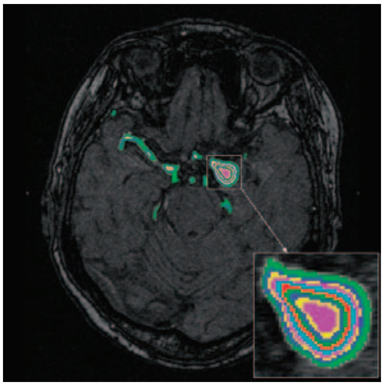


Figure 9 Example of a Sliced Image after the Diameter Profiling of a Large Saccular Cerebral Aneurysm

aneurysmal area.

(2) Study of Characteristic Values

When detecting aneurysms from the isolated spherical diameter profile, we attached labels to the diameter-by-diameter regions of the profile and examined the following three characteristic values:

(i) Label volume Vl
(ii) Convexity level T
(iii) Concentration level C

Label volume Vl represents an actual volume obtained by converting a volume determined from the number of pixels, the interval between pixels and the interval between slices into an actual volume, which make up the label. Convexity level T is the ratio of label volume Vl to the convex hull of volume Vch. In other words, T is a value for rating how small the number of concavities presents in the label's shape. Concentration level C is a value for rating to what degree the gradient vectors of spherical diameters concentrate within the label. C is obtained by determining the inner product of gradient vector at a given position of a pixel and each of the gradient vectors at the positions of all other pixels and dividing the maximum of these inner products by the number of pixels that compose the label so that the concentration level is normalized.

(3) Results

In this paper, we conducted studies to 14 vascular extraction applied instances, which contain cerebral aneurysms. The 14 cases were broken down by the type of cerebral aneurysm, into 6 cases of large saccular cerebral aneurysms, 6 cases of small saccular cerebral aneurysms, and 2 fusiform cerebral aneurysms. For data on these cases, we determined spherical diameter profiles, calculated characteristic values and examined their effectiveness in cerebral aneurysms detection.

In the case of large saccular cerebral aneurysms, aneurysms were found in the label of the largest spherical diameter profile in all of these 6 cases. Some cases however, showed that bends in internal carotid arteries existed in the label of the largest spherical diameter profile. We confirmed that images of these bends can be separated using the convex level. We therefore believe that it is possible to detect these cerebral aneurysms by combining the spherical diameter and convexity level.

In the case of fusiform cerebral aneurysms, we confirmed that the labels of spherical diameter profiles exist corresponding to aneurysmal regions. Although we were not able to analyze trends in the characteristic values of this type of aneurysm due to paucity of cases, our study showed that it is possible to detect these aneurysms out of the spherical diameter profile.

In the case of small saccular cerebral aneurysms, the size of clots is so identical with the diameter of neighboring blood vessels that they show up concatenated with these blood vessels in the profile of small spherical diameters. Consequently, we must look for other detection methods.

The effectiveness of the concentration level for aneurysm detection was not confirmed in any type of cerebral aneurysm.

CONCLUSION

In this paper, we extracted vascular areas from 3D-MRA data, studied detection methods and characteristic values for each type of cerebral aneurysm, and showed the feasibility of detecting cerebral aneurysms. In future, we will develop these methods and combine them with image viewers, in order to develop aneurysm detection systems.

This research is built on the combination of the expertise and opinions of brain surgeons who actually confront cerebral aneurysms, radiology technicians who routinely acquire examination image data, along with image processing technologies.

CAD systems are intended to assist doctors in their diagnostic work; they are not designed to conduct diagnoses in place of doctors. Research on CAD is being done extensively from an engineering point of view. In order for CAD systems to be utilized as support tools in clinical scenes, it is essential to study the combination of screening methods based on doctors' diagnostic technology with image acquisition techniques implemented in examination work flows. Through this research, we would like to contribute to providing diagnostic support in line with the requirements of clinical scenes. ◆

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