Preliminary study on the automated skull fracture detection in CT images using black-hat transform

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***Abstract*— Linear skull fracture, following head trauma, may reach major blood vessels, such as the middle meningeal artery or sinus venosus, and may cause epidural hematoma. However, hematoma is likely to be missed in the initial interpretation because it spreads only gradually. In addition, the fracture lines that run along the scan slice plane are often missed during initial interpretation. In this study, we develop a novel method for automated detection of the linear skull fracture using head computed tomography (CT) images and conduct a basic evaluation using digital phantom and head phantom that enclose genuine human bones. In the proposed method, the bone region is first extracted using morphological processing of the head CT images. Then, the cranial vault is determined from the CT scout view image. The skull has low-density cancellous bone between the hard two-layer high-density compact bones. Because the fracture lines of compact bones are more clearly recognized as compared to cancellous bones, the bone surface is then extracted by performing three-dimensional (3D) Laplacian filtering. Finally, linear structures are extracted by applying the black-hat transform to the bone surface image. In the experiments, we evaluated the proposed method using digital phantom and CT images of the head phantom. From the experiments using digital phantom, we were able to detect a crack line with a width of 0.35 mm. In the experiments using head phantom, we were able to clearly detect the crack lines in the phantom. These results indicate that our proposed method will be useful for the automated detection of skull fracture in CT images.**

I. Introduction

In emergency medicine, CT is essential to accurately find the site of injury or disease in a patient [1]. Trauma is one of the major causes of death in the United States [2]. The presence of skull fracture following head trauma may increase the risk of an underlying subdural or epidural hematoma. Therefore, skull fractures are primarily markers of the location and severity of an injury [3]. When a fracture reaches the major blood vessels such as the middle meningeal artery or sinus venosus, it is often associated with epidural hematoma. However, hematoma spreads only gradually because the dura mater is combined with the skull relatively thickly; hence, it is likely to be missed in the initial interpretation [4]. In addition, fracture lines are often missed when they run along the axial plane.

Emergency medicine needs to provide the around-the-clock operation; however, it is difficult to continue to maintain a medical staff with high interpretation ability. Therefore, development of a computer-aided diagnosis system for emergency medicine is strongly desired. In addition, posthumous diagnosis when the cause of death is unclear is likely to be conducted widely in the future [5]. In posthumous diagnosis, existence of skull fracture can be useful for the estimation of the cause of death because it is difficult to recognize head injury from the surface of the body.

Therefore, this study focuses on automated detection techniques of fracture in CT images. Many reports are available on the automated detection of fracture in medical images. A comprehensive review was conducted in the work of Jacob et al. [6]. Liang et al. proposed a morphological method to identify the fractures of tibia bones in X-ray images [7]. Donnelley et al. developed a method for automatically detecting fractures in long bones in X-ray images using gradient analysis [8]. Moreover, Wan et al. proposed a method in order to detect the fracture of skull in 2D head CT images [9]. However, there are only few reports that propose a detection method of skull fractures for 3D CT image data.

Therefore, in this study, we aim to develop an automated detection method of skull fractures using 3D CT images that are collected in emergency clinical care. As a preliminary study, we evaluated the effectiveness of the proposed method using digital phantom and head phantom that enclose genuine human bones.

II. Methods

A. Overview

Figure 1 shows the flowchart of the proposed fracture detection method. Each procedure of the proposed method is described in the sections below.

B. Extraction of the bone region

For extraction of the bone region, we prepared head CT images (Fig. 2(a)) as input image. The input images are then binarized using a predetermined threshold to separate the

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regions of the skull from other regions. Here, the cancellous bone is recognized as background by thresholding because it is a low density bone in the skull. Therefore, a cavity appears inside the skull region. To fill the cavity, closing processing is conducted. Closing processing includes applying a maximum filter to the input images, followed by a minimum filter with the same filter structural element [10]. Figure 2(b) shows an example of a bone region extracted using this procedure. Here, we set a threshold value of 120 [H.U.]; as the structural element of the closing operation, we introduce a sphere having a radius of 5 pixels.

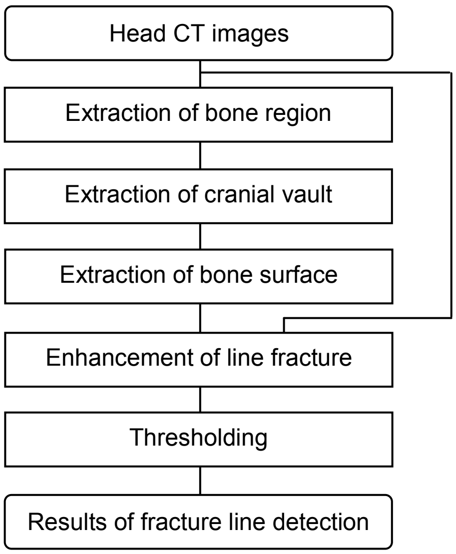
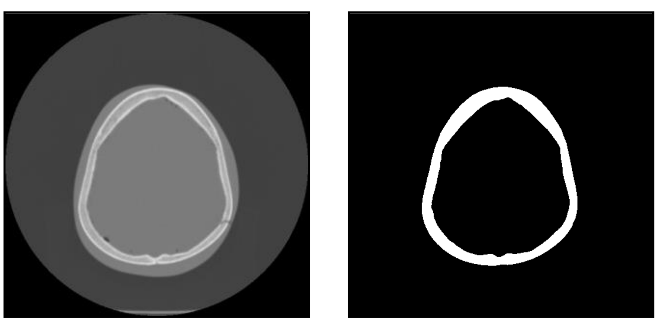


Fig.1 Flowchart of our proposed method for detecting head skull fracture



(a) (b)

Fig.2 Input image(a) and bone extracted image(b)

C. *Extraction of the cranial vault*

The cranial vault is selected using the bone extracted image. By performing a projection along the RL or LR direction using the bone extracted image, a scout view like image in CT examination is obtained as shown Fig. 3.

Using this projection image, supra-orbital margin and occipital bone are set by manual operation as a baseline to decide the base of the skull region. Based on these points, the unnecessary regions such as the outside region of the skull and the bed of CT scanner are eliminated and the cranial vault is extracted.

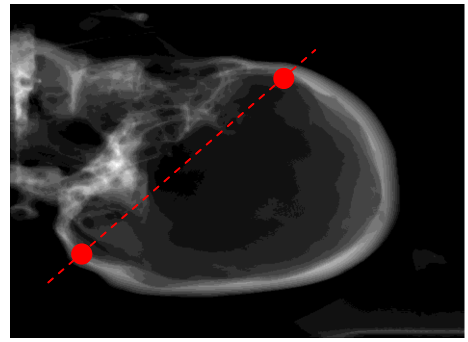
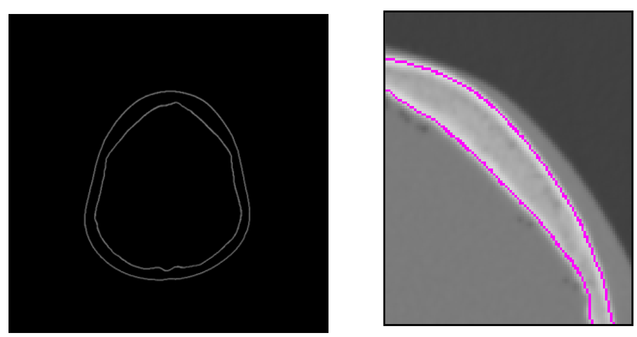


Fig.3 Projection image and selection of cranial vault

D. *Extraction of the bone surface*

The skull is comprised of compact bone and cancellous bone. Here, the fracture line is observed clearly on the bone surface (compact bone) with high density. Therefore, the bone surface is extracted by applying a 3D Laplacian filter. Figure 4(a) shows the 3D Laplacian filtered image. Then, the 3D Laplacian filtered images are binarized using a predetermined threshold value. Finally, by applying the three-dimensional thinning processing, extracted image of bone surface is obtained.

Figure 4(b) shows enlarged superimposed images of the input image and the extracted image of the bone surface; the pink line in the image represents the bone surface. Here, we employ a cube of 5x5x5 pixel as the structural element of the maximum filter and minimum filter.



(a) (b)

Fig.4 3D Laplacian filtered image (a) and enlarged view of bone surface extracted image (b)

E. *Enhancement of the fracture line*

To emphasize the fracture line in the bone surface, black-hat transform which is calculated the morphology operation only in the pixels corresponding to the bone surface is performed on the input image. The black-hat transform is an image processing method; it can emphasize a thin linear pattern using morphological processing [10]. In black-hat transform, first, a maximum filter is applied to the original image to fill the pixels of the line component (dilation). Then, by applying a minimum filter to the dilation images, a closed image is obtained. The linear pattern is extracted by subtracting the original image from the closed image. In this study, these processes were performed in 3D; a sphere with radius of 5 pixels was used as the structural element of the filters.

F. *Thresholding*

In order to detect the fracture line, thresholding processing is applied to the black-hat transformed image.

III. Experiments

A. *Basic evaluation using digital phantom*

First, we created a digital phantom imitating a skull that has crack lines with widths of 0.12 mm, 0.35 mm, 0.58 mm, and 1.05 mm. We applied the proposed method to phantom images and evaluated the results. Here, we assumed that the bone is flat. The thickness of the compact bone (CT value = 1000) was 1.25 mm and that of the cancellous bone was 2.5 mm. In addition, we assumed that there was air around the phantom, so the CT value around the phantom was set to -1000 [H.U.]. Figure 5 shows the schematic view of a digital phantom we used in the experiments. Here, threshold value for crack detection was set to 5 times value of the standard deviation calculated using the background region.

Figure 6 shows the crack detection results of the digital phantom. Using this method, we were able to detect a crack line of width 0.35 mm.

In addition, we evaluated the shape matching ratio between the golden standard and the detection results of the crack lines by using the Jaccard Index (J.I.). J.I. is expressed by the following equation, equation (1). In this equation, A is the region of the crack line in the original image and B is the region of the detected crack line. Figure 7 shows the evaluation result of crack detection using the digital phantom.

$$J.I. = \frac{A \cap B}{A \cup B} \tag{1}$$

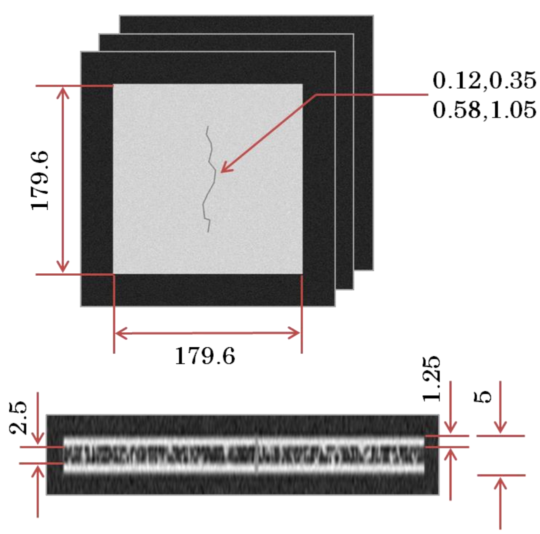


Fig.5 Schematic view of a digital phantom (unit: mm)

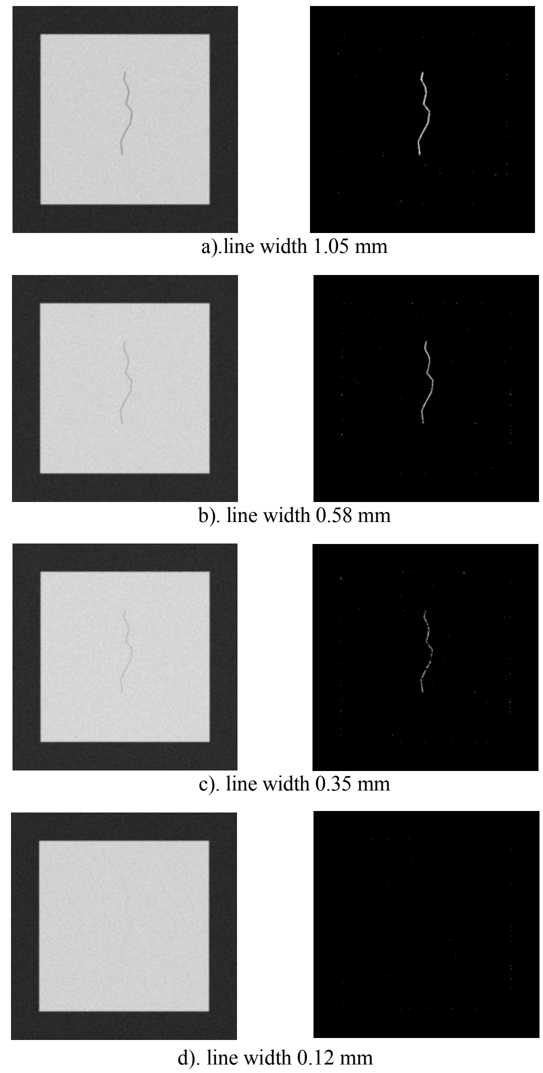


Fig.6 Crack detection results of the digital phantom

(left: original image, right: detection image)

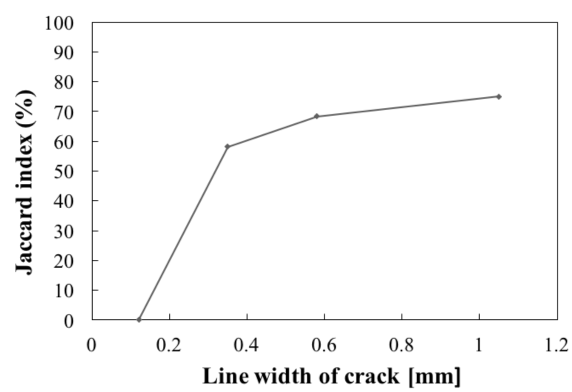


Fig.7 Evaluation results of crack detection of the digital phantom

B. Evaluation of head phantom images

We found that a fracture line is detectable by evaluations using digital phantom. Therefore, we conducted realistic evaluation using CT images of head phantom. For the head phantom, we introduced the head phantom manufactured by Kyoto Kagaku. Figure 8 shows the overview of the head phantom. Genuine human bone is included in this head phantom; it has an artificial crack line between the parietal bone and the occipital bone. The crack gap in the phantom was approximately 1 mm.

Fig.8 The overview of a head phantom

Figure 9(a) shows superimposed images of the extracted bone surface and the detected image. The pink line in this image shows the bone surface and the white dot is the detected region. Figure 9(b) shows the volume rendered image of the detection results with pseudo color.

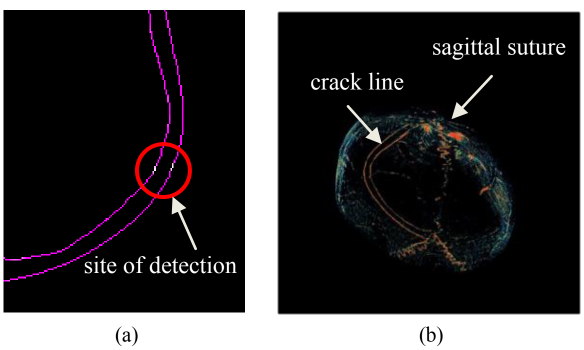


Fig.9 Detection result.(a)enlarged view of axial image,(b)volume rendered image

IV. Discussion

By simulation experiments using digital phantom, we confirmed that a crack line width of 0.35 mm can be detected. In addition, J.I was 80.0% for a line of width 1.05 mm, which is a good result.

Furthermore, we obtained CT images of the head phantom with enclosed human bone and the proposed method was applied to these images. The results of the experiments using the head phantom show that the crack lines in the phantom were clearly detected. However, normal structures such as suture line and vascular grooves were also detected. All linearity structure in images were detected, which is caused by using morphological in this method.

V. Conclusion

In a head injury, the skull fracture is important index of the location and severity of an injury. In addition, the information on whether there is a fracture helps in determining the accurate cause of death during autopsy imaging. However, there is a concern that a fracture running along the scan slice plane is often missed. Therefore, in this study, we developed a novel method for automated detection of the skull fracture using head CT images. We performed a basic evaluation using two kinds of phantoms. The results of the experiments using a digital phantom showed that a crack line of width 0.35 mm could be detected. Evaluation of experiments using head phantom showed that cracks lines in the phantom could be clearly detected. However, there were challenges in that the normal structures such as suture line and vascular grooves were also detected.

In future work, we will develop a false positive reduction method using characteristic features such as the shape of candidate region. We are now collecting clinical images with skull fracture. We may introduce the processing results using some clinical images at the conference.

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