Dual-Energy CT Aiming at Visualization of Acute Cerebral Infarction: A Phantom Study

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Purpose

Introduction

In Japan, cerebrovascular disease is the third cause of death and the first cause of bedridden patients. Japan is famous for its high ratio of cerebral hemorrhage in particular. Recently, cerebral infarction has been under serious consideration due to the westernization of the diets and an increase in geriatric diseases. At present, cerebral infarction is still one of the most important diseases to control and prevent.

To establish a method for image-based diagnosis of cerebral apoplexy, the authors developed a phantom that could correctly evaluate disease detection by image-processing and that could visualize disease using X-ray CT imaging, while evaluating the imaging conditions.\(^1\)\(^-\)\(^4\)

Visualization of acute cerebral infarction within three hours after the development of cerebral infarction is essential because it is the time index used to judge whether thrombolytic therapy with use of alteplase (rt-PA) is applicable.\(^5\) (Fig. 1 on page 3)

Traditionally, it has been difficult to visualize acute cerebral infarction from images produced by X-ray CT.\(^6\)

Purpose

# This study attempted to improve the contrast of acute cerebral infarction using dual-energy CT in order to achieve accurate visualization within the critical three-hour period.
**Fig. 1:** An example of acute stage cerebral infarction is shown on this Figure. (A) 3-6 hours later, (B) 24 hours later.

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Methods and Materials

Materials

# Dual-energy CT

In general, the human body, in which multiple substances are mixed, is photographed using X-rays with multi-colored energy. Since the mass attenuation coefficient of the X-ray-effective energy possessed by each substance cannot be correctly calculated, there are cases where different substances in the body possess the same CT value.

Dual-energy CT is one of the methods available to solve this phenomenon. Since the mass attenuation coefficient depends on X-ray energy, images with different CT values can be obtained at different tube voltages.\(^2,7\) (Fig. 2 on page 7)

In this study, dual-energy CT images were obtained using different energy levels in X-ray CT imaging, and composite images were obtained using the dual-energy CT images.

The study investigated the possibility of visualizing acute cerebral infarction using the composite images to achieve improvement in the separation of and the contrast between the section of the brain affected by the cerebral infarction and the remainder of the brain.

# X-ray Phantom

Using a cerebral apoplexy phantom (Japanese Patent Laid-Open No. P2009-90014A), which had been developed by the authors, an imitation disease with 32 HU was set to be visualized.

The phantom, prepared with polyurethane resin and epoxy resin, was composed of three sections: brain, cranium, and imitation disease. The CT value of the brain section was 36 HU and that of the cranium was 500 HU. The imitation disease section was composed of three balls, 2\#10 mm in diameter. The CT values of the three balls were 32, 34, and 40 HU. The balls with 32 and 34 HU reflected acute cerebral infarction and their CT values were lower than that of the brain by 4 and 2 HU, respectively. The ball with 40 HU and a
CT value higher than that of the brain by 4 HU reflected a light cerebral hemorrhage (Fig. 3 on page 7, Fig. 4 on page 8, Fig. 5 on page 9, Fig. 6 on page 10).\(^1\)

**Methods**

### Dual-energy images

Using tube voltages at 80, 100, 120, 140, and Sn140kV, which were assumed to be used clinically in X-ray CT imaging and a mAs value at 400, 600, 800 mAs, images with a slice thickness of 10 mm were obtained. A weight coefficient between 0.1\#0.9 was assigned to each original image.

Subsequently, 3 composite images with tube voltage patterns of 80kV + Sn140kV, 100kV + Sn140kV, and 140kV + 80kV were obtained in such a way that the sum of the weight coefficients became 1.0. (Fig. 7 on page 11)

The CNR value at the 10-mm-diameter imitation disease section in each composite image was obtained using the formula

$$\frac{|ROI_M - ROI_B|}{SD_B}$$

and the ability to visualize acute cerebral infarction was evaluated.

In the formula, \(ROI_M\) represents the CT value of the imitation disease section, \(ROI_B\) represents the CT value of the brain section, and \(SD_B\) represents the standard deviation (SD) value of the brain section.\(^8\) In addition, an image with a CNR value exceeding 1.0 was defined as the ability to visualize acute cerebral infarction.\(^2\)

### Dose measurement

Using a phantom (Fig. 8 on page 12) for dose measurement, which was prepared using the same materials and shape of the cerebral apoplexy phantom developed by the
authors, absorbed dose was calculated from a weighted CT dose index (CTD\textsubscript{W}, CTD\textsubscript{Vol}), and the possibility of dual-energy CT in clinical use was investigated.\textsuperscript{4}
Fig. 2: The externals of Dual-energy CT, by SOMATOM Definition Flash 128DAS in Siemens Corporation.

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<table>
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<tr>
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<td>0.9</td>
<td>1.81</td>
<td>15.49</td>
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</table>

The data are expressed in percent of weight.

**Fig. 3:** Composition of X-ray CT phantom, which was prepared to have a spheres and a annulus.

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Fig. 4: Plan of X-ray CT phantom, which was prepared to have a cranium and a composition and size similar to those of a brain section, cerebral infarction, and cerebral hemorrhage.

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**Fig. 5:** The externals of the X-ray CT phantom to evaluate cerebral apoplexy.

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Fig. 6: An example of X-ray CT image of 10mm slice thickness.

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Fig. 7: Block chart of Composite images for Dual-energy method, obtained at tube voltages of 140kV and 80kV.

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Fig. 8: The externals of the X-ray phantom for measurement of absorbed dose.

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Results

# Dual-energy images

Fig. 9 on page 16 shows the simulation results of Dual-energy images and Fig. 10 on page 16, Fig. 11 on page 17, Fig. 12 on page 18, Fig. 13 on page 19, Fig. 14 on page 20, Fig. 15 on page 21 shows the simulation results of CNR values for each composite image.

Regarding the tube voltage patterns, when the weight coefficient of an original image at the low energy side was 0.4#0.5, and at the high energy side was 0.5#0.6, the composite image possessed the highest CNR value.

In the case of compositing images with high energy, when their weight coefficients were similar to each other, the CNR of the obtained composite image was acceptable. In each tube voltage pattern, the CNR value of the composite image was higher than that of the original image.

The CNR values were the highest when the composite images were obtained under the following conditions: 80 kV: 0.5 + Sn140 kV: 0.5; 100 kV: 0.5 + Sn 140 kV: 0.5; and 140 kV: 0.5 + 80 kV: 0.5. These CNR values were greater than 1.0, which was defined as the ability to visualize acute cerebral infarction by the authors.

Noise (SD value) is considered to be the factor with the greatest influence on the CNR value. When a low tube voltage of 80 kV was applied, although contrast tended to increase, noise also increased. When a high tube voltage of 140 kV was applied, contrast and noise tended to decrease. In this study, by using composite images, noise could be reduced while maintaining contrast at a specified level.

# Dose measurement

Fig. 16 on page 22 shows doses measured at each tube voltage. Based on the results obtained in previous studies, the minimum conditions to obtain images with CNR values exceeding 1.0 were as follows: tube voltage, 120 kV; mAs, 400 mAs; and dose, 21.0 mGy.
Although a composite image with tube voltage patterns of 100kV:Sn140kV, required two images, the sum of the doses was 19.3 mGy. Because of the reduction by approximately 2.0 mGy, dual-energy CT images could be used clinically for visualizing acute cerebral infarction.
**Fig. 9:** Dual-energy CT images were obtained with different tube voltages at (A) 120kV, (B) 80kV:Sn140kV, (C) 100kV:Sn140kV, (D) 140kV:80kV, by the composition images of weight coefficient at the low and high energy sides were 0.5 and 0.5, because of 10mm in image slice thickness and 800mAs.

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Fig. 10: Effect of DE composite images in 80kV and Sn140kV: 600mAs, on the contrast-to-noise ratio (CNR).

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Fig. 11: Effect of DE composite images in 80kV and Sn140kV: 800mAs, on the contrast-to-noise ratio (CNR).

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**Fig. 12**: Effect of DE composite images in 100kV and Sn140kV: 600mAs, on the contrast-to-noise ratio (CNR).

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**Fig. 13:** Effect of DE composite images in 100kV and Sn140kV: 800mAs, on the contrast-to-noise ratio (CNR).

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Fig. 14: Effect of DE composite images in 140kV and 80kV: 600mAs, on the contrast-to-noise ratio (CNR).

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**Fig. 15:** Effect of DE composite images in 140kV and 80kV: 800mAs, on the contrast-to-noise ratio (CNR).

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**Fig. 16:** Measurement results of the absorbed dose of 10mm in image slice thickness, obtained at different tube voltages of 80kV:Sn140kV, 100kV:Sn140kV, 140kV:80kV in Dual-energy, and Single-energy of 120kV, expressed in CTDI Vol.

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Conclusion

In X-ray CT imaging, dual-energy CT images were demonstrated to be effective to visualize acute cerebral infarction; in addition, they allowed for a reduction in X-ray dose.

Dual-energy CT images could be used clinically to judge whether thrombolytic therapy with the use of rt-PA is applicable to acute cerebral infarction.

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