

Computed Tomography Using a Low Tube Voltage Technique for Acute Ischemic Stroke

Kenji Nakamura^{1*}, Katsuhiko Maeda¹, Masao Tanooka², Shuhei Aoyama¹, Reiichi Ishikura³, Noriko Kotoura¹

¹Department of Radiological Technology, Hyogo College of Medicine College Hospital, Nishinomiya, Japan

²Department of Radiotherapy, Takarazuka City Hospital, Takarazuka, Japan

³Department of Radiology, Hyogo College of Medicine, Nishinomiya, Japan

Email: *hotatom8@yahoo.co.jp

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Abstract

Computed tomography (CT) is commonly used to assess for cerebral hemorrhage and acute ischemic stroke. We investigated the accuracy of CT using a low tube voltage technique in acute ischemic stroke. We compared the standard deviation (SD), contrast between gray and white matter, and contrast-to-noise ratio (CNR) between three groups (120 kV 500 mAs, 100 kV 850 mAs, and 100 kV 750 mAs using hybrid iterative reconstruction) in 50 patients without lesions, and visual evaluation using the normalized rank approach was also performed. The mean value of SD was 4.02, 4.22, and 4.04, respectively, and the contrast between gray and white matter was 7.08, 8.66, and 8.68 HU, respectively; in addition, the CNR was 1.77, 2.06, and 2.15, respectively. The difference between the 100 kV and 120 kV groups was significant ($p < 0.01$). Visual evaluation showed a significant difference between the 100 and 120 kV groups ($p < 0.05$).

Keywords

Low Tube Voltage Technique, Computed Tomography, Acute Ischemic Stroke

1. Introduction

Computed tomography (CT) is useful in determining the treatment plan for patients with acute stroke. According to the guidelines of the American Heart Association/American Stroke Association (AHA/ASA), the information necessary to make decisions on emergency measures should be obtained using non-contrast enhanced CT in most cases [1]. CT is useful for excluding cerebral hemorrhage

and a diagnosis of acute ischemic stroke by identifying early ischemic changes (EIC).

The CT findings indicative of EIC include obscuration of the lentiform nucleus, loss of the insular ribbon, loss of gray-white matter differentiation, and effacement of the cortical sulci. To facilitate identification of these findings, the image should preferably have a high contrast between white matter and gray matter and low noise.

As a tool for increasing the agreement rate between readers, it has been recommended that the Alberta Stroke Program Early CT Score (ASPECT) be used to evaluate for EICs in the middle cerebral artery region [2] [3]. The lower the ASPECT score, the higher the risk of cerebral hemorrhage after treatment with thrombolytic agents [4] [5].

An evaluation method that combines diffusion-weighted imaging (DWI) using magnetic resonance imaging (MRI) and ASPECTS has been reported [6]. MRI alone may result in underestimation of EIC. If the EIC signal on CT is not elevated on DWI, this has been termed reversed discrepancy (RD) [7]. One study identified RD in 24% of 164 cases of hyperacute cerebral infarctions within 3 hours of onset and reported that many cases had atrial fibrillation [8].

Evaluation of the vascular occlusion site, collaterals, and penumbra using CT angiography (CTA) and CT perfusion (CTP) is now possible. The usefulness of these modalities in endovascular therapy has been widely reported [9]-[21]. However, while previous studies have reported the utility of low tube voltage imaging for acute ischemic stroke in contrast-enhanced CT [22] [23] [24], to our knowledge no study has evaluated the use of unenhanced CT using low tube voltage.

Therefore, we investigated the accuracy of unenhanced CT using the low tube voltage technique for acute ischemic stroke.

2. Materials and Methods

2.1. Patients and Imaging Protocol

This retrospective study was approved by the institutional ethics committee of Hyogo College of Medicine (approval number: 2501) and conducted in accordance with the ethical standards of the Declaration of Helsinki. All images used in the study had been acquired as part of routine clinical care during past medical treatment. The purpose of the study and information regarding its implementation were published on the home page of the web site of our institution, and patients were provided the opportunity to opt out.

All patients were scanned using a 128-slice MDCT scanner (Somatom Definition AS+: Edge, Siemens Healthcare, Forchheim Germany). Quantitative evaluation of three groups of 50 patients each was performed at either 120 kV 500 mAs, 100 kV 850 mAs, or 100 kV 750 mAs using sinogram-affirmed iterative reconstruction (SAFIRE). The patient characteristics and scan parameters are shown in **Table 1**. All included patients were confirmed to not have any lesions,

including hemorrhage or acute infarction, by neuroradiologists, and their images were studied to quantitatively evaluate the diagnostic performance of the clinical image quality itself. These scan parameters were determined in fundamental physics experiments using a Catphan[®] 515 (The Phantom Laboratory, Salem NY, USA) low-contrast detection module based on 120 kV and visual evaluations by neuroradiologists.

To estimate the CT radiation dose, the CT volume dose index (CTDI_{vol}) and dose length product (DLP) were recorded. The effective dose (ED) for the brain was derived from the product of DLP and a previously reported conversion coefficient for the brain ($k = 0.0021 \text{ mSv}\cdot\text{mGy}^{-1}\cdot\text{cm}^{-1}$) [25].

2.2. Image Analysis

To evaluate image quality under the different protocols, 5 mm thick images from each reconstruction technique were downloaded from the PACS viewer (Synapse: Fuji Film Medical, Tokyo, Japan) to a workstation (Zio Station2: Ziosoft Inc., Tokyo, Japan). CT values and standard deviation (SD) were measured by setting the region of interest (ROI) as shown in **Figure 1**. The ROI was set at the putamen and posterior limb of the internal capsule on the axial sections through the basal ganglia to measure CT values of gray and white matter. An ROI with a

Table 1. Patient characteristics and scan parameters.

| | 120 kV | 100 kV | 100 kV i |
|---------------------------------|------------------------------------|------------------------------------|---------------------------------------|
| Characteristics | | | |
| Number of Patients | 50 | 50 | 50 |
| Age | 54.5 ± 18.1 | 52.6 ± 17.7 | 59.1 ± 14.6 |
| Gender (male) | 25 | 26 | 23 |
| Period | From January 2011 To April 2013 | From May 2013 To September 2016 | From October 2016 To November 2018 |
| Scan parameters | | | |
| Equipment model | AS+ | AS+ | Edge |
| Tube voltage (kV) | 120 | 100 | 100 |
| Reference mAs | 500 | 850 | 750 |
| Scan method | Non-helical | Non-helical | Volume |
| Beam collimation (mm) | 12 × 1.2 | 12 × 1.2 | 128 × 0.6 |
| kernel | H37s medium smooth | H37s medium smooth | J45s medium smooth |
| Hybrid iterative reconstruction | no | no | SAFIRE (strength level 3) |
| FOV (mm) | 250 | 250 | 250 |
| Scan time (sec) | 2 | 2 | 2 |
| CTDI _{vol} (mGy) | 83.51 | 86.87 | 64.82 |

FOV: Field of view; CTDI vol: Volume CT dose index.

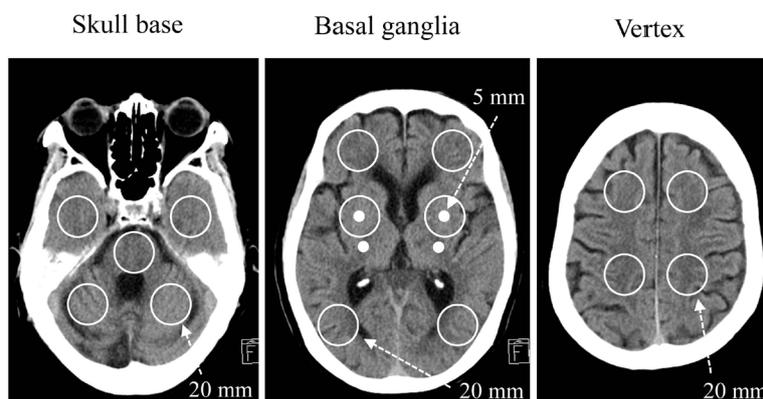


Figure 1. The ROIs were set at the position shown and the SD was measured. ROIs were set at the putamen and posterior limb of the internal capsule to measure the CT value. The diameters of the ROIs are 20 mm and 5 mm, respectively.

diameter of 20 mm was used to measure SD, and an ROI with a diameter of 5 mm was used to measure CT values of gray and white matter.

Image noise was defined as the mean SD of fifteen ROIs. The contrast-to-noise ratio (CNR) was calculated as follows [26]:

$$\text{CNR} = (\text{CT value}_{\text{gray matter}} - \text{CT value}_{\text{white matter}}) / (\text{image noise}) \quad (1)$$

2.3. Statistical Analysis

Data are expressed as means \pm standard errors of means. Multigroup comparisons were carried out using one-way analysis of variance followed by Tukey-Kramer multiple comparisons test, and $p < 0.01$ was considered statistically significant.

For visual evaluation, five radiological technologists with between 5 and 35 years of experience (mean: 14 years) evaluated the image quality of the brain CT, including image contrast, image noise, and image sharpness. The results obtained were transformed into normalized scores and analyzed using the least significant difference (LSD) method (significance level 5%) using a normalized rank approach [27]. The five radiological technologists were blinded to the acquisition parameters but were allowed to adjust the window level and width using 2 megapixel color liquid-crystal display monitors (Eizo Nanao Corporation, Ishikawa, Japan).

3. Result

A summary of the quantitative evaluation is shown in **Table 2**. For each imaging protocol, the SD of the skull base, basal ganglia, vertex, and their means are shown in **Figure 2**. The SD was significantly higher only in the 100 kV group in all cross sections. The mean CT value of the gray and white matter and the increased CT value of the 100 kV group over that of the 120 kV group and contrast are shown in **Figure 3** and **Figure 4**. The rate of increase in CT value was larger for gray matter than for white matter when lowering the tube voltage. A significant

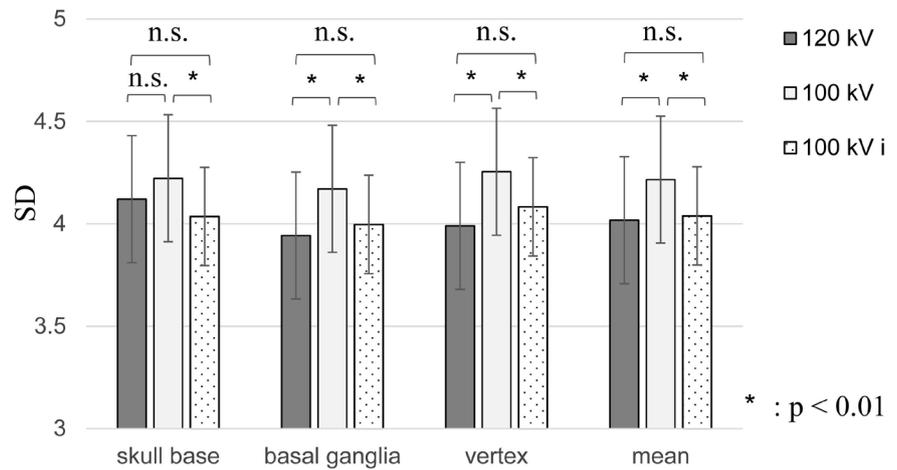


Figure 2. Comparison of the mean SD of the skull base, basal ganglia, and vertex between each imaging protocol. The SD was significantly higher only in the 100 kV group.

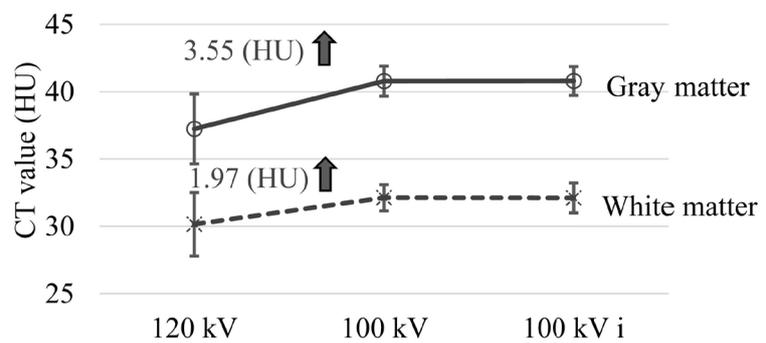


Figure 3. The mean CT value of gray and white matter for each imaging protocol. Note that the CT value of the 100 kV group was significantly higher than that of the 120 kV group. The rate of increase in CT value when lowering the tube voltage was larger for gray matter than for white matter.

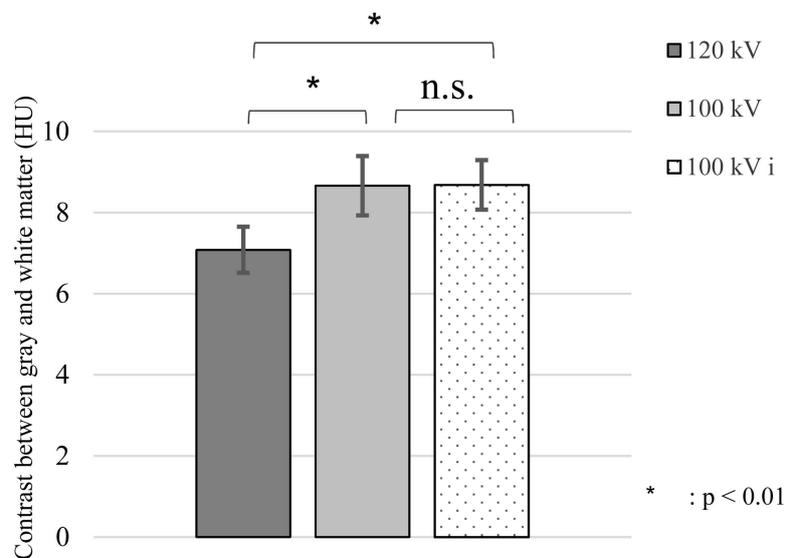


Figure 4. Contrast between gray and white matter. A significant difference was observed between the 100 kV and 120 kV groups.

difference was observed between the 100 kV and 120 kV groups ($p < 0.01$). The CNR calculated from the contrast between gray and white matter and the mean SD is shown in **Figure 5**. A significant difference was observed between the 100 kV and 120 kV groups ($p < 0.01$). The combined use of SAFIRE and a low tube voltage allowed reduction of the exposure dose. The result of visual evaluation using the normalized ranking method is shown in **Figure 6**. The LSD was 0.533. In the case that the distance between the two groups was > 0.533 , there was a significant difference. Therefore, a significant difference was observed between the 100 kV group and 120 kV group ($p < 0.05$).

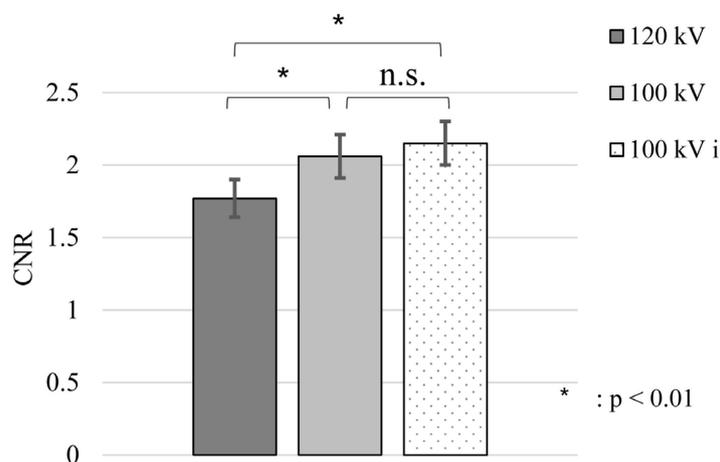


Figure 5. CNR calculated from the contrast between gray and white matter and average of SD. A significant difference was observed between the 100 kV and 120 kV groups.

Table 2. Summary of quantitative evaluation.

| | 120 kV | 100 kV | 100 kV i |
|---|--------------|--------------|--------------|
| SD (HU) | | | |
| Skull base | 4.12 ± 0.36 | 4.22 ± 0.31 | 4.04 ± 0.33 |
| Basal ganglia | 3.99 ± 0.34 | 4.17 ± 0.31 | 4.00 ± 0.24 |
| Vertex | 3.99 ± 0.35 | 4.25 ± 0.37 | 4.08 ± 0.36 |
| Average | 4.02 ± 0.27 | 4.22 ± 0.23 | 4.04 ± 0.24 |
| CT value (HU) | | | |
| Gray matter | 37.24 ± 2.59 | 40.79 ± 1.07 | 40.80 ± 1.12 |
| White matter | 30.16 ± 2.36 | 32.13 ± 1.11 | 32.11 ± 0.97 |
| Contrast of them | 7.08 ± 0.56 | 8.66 ± 0.73 | 8.68 ± 0.61 |
| CNR | 1.77 ± 0.13 | 2.06 ± 0.15 | 2.15 ± 0.15 |
| Output dose (estimated patient exposure dose) | | | |
| CTDIvol (mGy) | 84.23 ± 3.87 | 85.90 ± 1.46 | 58.78 ± 4.33 |
| DLP (mGy-mm) | 1412 ± 109.1 | 1481 ± 143.1 | 1027 ± 92.7 |
| Effective dose (mSv) | 2.97 ± 0.23 | 3.09 ± 0.30 | 2.16 ± 0.19 |

CNR: Contrast to noise ratio; CTDI vol: Volume CT dose index; DLP: Dose length product.

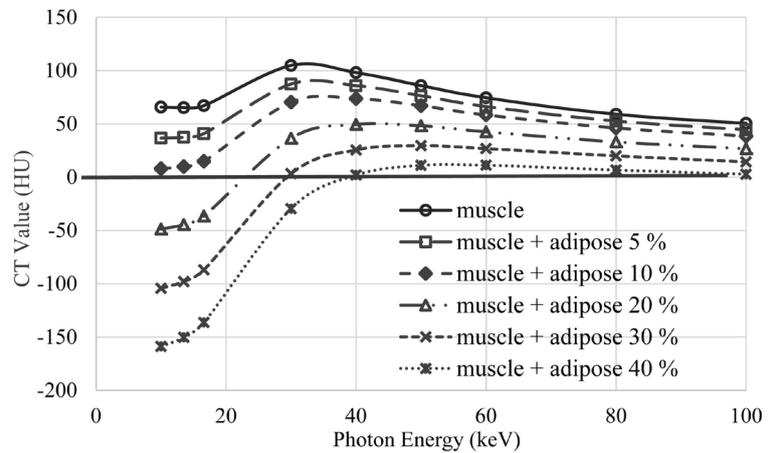


Figure 7. Approximate curve of the CT values of muscle and muscles with varying adipose content at each energy level from a simulation using known linear attenuation coefficient data. As the tube voltage decreased, the larger the adipose content, the larger the CT value difference for the muscle was shown.

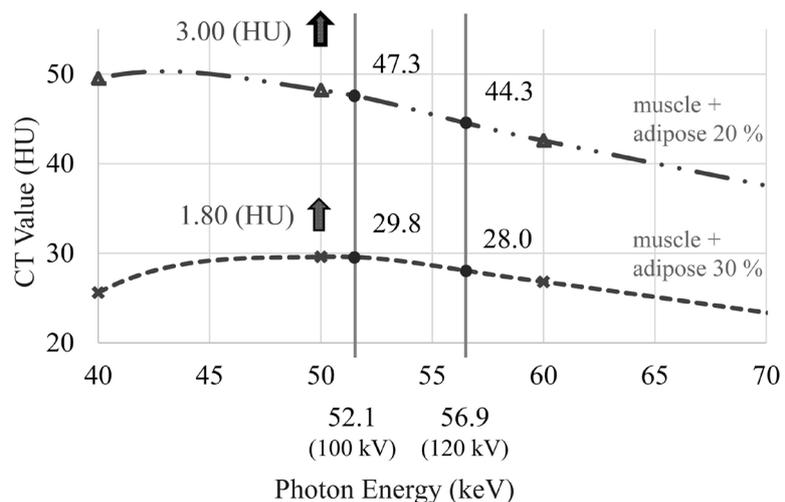


Figure 8. This Figure showing **Figure 7** limited to the region of interest. The result was obtained by simulating the approximate curve of the CT values of (muscle + 20% adipose) and (muscle + 30% adipose) for each energy. CT values at effective energies of 120 kV and 100 kV are also shown. Assuming gray matter is equivalent to muscle + 20% adipose and white matter is equivalent to muscle + 30% adipose, the changes in CT values due to low tube voltage correlated well with results obtained from image analysis.

Assuming gray matter as (muscle + 20% adipose) and white matter as (muscle + 30% adipose), the changes in CT values due to low tube voltage correlated well with the results obtained from image analysis.

The ideas obtained from the simulation can be explained by the following two points. First, as the adipose content increases, the effective atomic number decreases. Second, as the tube voltage decreases and the atomic number increases, the cross section of photoelectric absorption exponentially increases [33]. Therefore, we considered that white matter, covered with myelin, contains significant adipose, so that the change in CT value due to the change in tube vol-

tage was smaller than that for gray matter.

This study has several limitations. All imaging data were obtained with a single CT device. Even at the same tube voltage, differences among equipment manufacturers mean that the energy spectrum differs; therefore, devices with lower effective energy may show results discrepant with our results due to the greater influence of beam hardening.

Moreover, since hybrid iterative reconstruction (HIR) is a nonlinear image processing method, a previous study recommended that image noise should be evaluated using the noise-power spectrum (NPS) instead of SD [34]; however, calculating CNR using NPS did not change the finding of a significant difference in this study. Furthermore, a setting of 100 kV using SAFIRE could reduce image noise while maintaining improved contrast between gray and white matter, and its estimated patient exposure dose was lower than that of other methods. However, the HIR algorithm could not improve low-contrast detectability over that achieved with filtered back projection at the same radiation doses [34]; therefore, we considered that a sufficient dose (*i.e.* SD of the brain parenchyma is 4 or less at a slice thickness of 5 mm, with reference to GALACTIC by the Japanese Society of Radiological Technology) was necessary to evaluate EIC to the same extent.

5. Conclusion

CT with an adequate exposure dose using a low tube voltage technique can effectively utilize the difference in adipose content between gray and white matter to improve image quality required in cases of acute ischemic stroke with or without SAFIRE.

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Research Involving Human Participants and/or Animals

All procedures in studies involving human participants were performed in accordance with the ethical standards of Hyogo College of Medicine, and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed Consent

The purpose of the research and information on its implementation were published on the home page of the web site of our institution, and patients were provided the opportunity to opt out.

Presentation at Conferences

This work was presented in part at the 33rd Japan Conference of Radiological

Technologists, in Hakodate, Japan, on 22-24 September, 2017.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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