Journal of the Korean Physical Society, Vol. 67, No. 1, July 2015, pp. 82∼88

Operating Characteristics of Tube-current-modulation Techniques when Scanning Simple-shaped Phantoms

Kosuke Matsubara* and Kichiro Koshida
Department of Quantum Medical Technology, Kanazawa University, Kanazawa 920-0942, Japan

Pei-Jan Paul Lin†
Department of Radiology, Beth Israel Deaconess Medical Center, Boston 02215, USA

Atsushi Fukuda
Department of Radiology, Shiga Medical Center for Children, Moriyama 524-0022, Japan and Division of Health Sciences, Kanazawa University Graduate School of Medical Science, Kanazawa 920-0942, Japan

(Received 8 December 2014)

Our objective was to investigate the operating characteristics of tube current modulation (TCM) in computed tomography (CT) when scanning two types of simple-shaped phantoms. A tissue-equivalent elliptical phantom and a homogeneous cylindrical step phantom comprising 16-, 24-, and 32-cm-diameter polymethyl methacrylate (PMMA) phantoms were scanned by using an automatic exposure control system with longitudinal (z-) and angular-longitudinal (xyz-) TCM and with a fixed tube current. The axial dose distribution throughout the elliptical phantom and the longitudinal dose distribution at the center of the cylindrical step phantom were measured by using a solid-state detector. Image noise was quantitatively measured at eight regions in the elliptical phantom and at 90 central regions in contiguous images over the full z extent of the cylindrical step phantom. The mean absorbed doses and the standard deviations in the elliptical phantom with z- and xyz-TCM were 12.3 ± 3.7 and 11.3 ± 3.5 mGy, respectively. When TCM was activated, some differences were observed in the absorbed doses of the left and the right measurement points. The average image noises in Hounsfield units (HU) and the standard deviations were 15.2 ± 2.4 and 15.9 ± 2.4 HU when using z- and xyz-TCM, respectively. With respect to the cylindrical step phantom under z-TCM, there were sudden decreases followed by increases in image noise at the interfaces with the 24- and 16-cm-diameter phantoms. The image noise of the 24-cm-diameter phantom was, relatively speaking, higher than those of the 16- and 32-cm-diameter phantoms. The simple-shaped phantoms used in this study can be employed to investigate the operating characteristics of automatic exposure control systems when specialized phantoms designed for that purpose are not available.

PACS numbers: 87.57.-s, 87.58.Sp, 87.57.Ce
Keywords: Computed tomography, Tube current modulation, Dose, Phantom, Image noise
DOI: 10.3938/jkps.67.82

I. INTRODUCTION

There are concerns about individual and population doses of ionizing radiation due to computed tomography (CT) examinations. Recently, radiation exposure related to CT examinations has been identified as the largest source of medical radiation exposure [1,2]. Several available techniques have been shown to reduce the radiation dose during CT imaging. Manufacturers have developed automatic exposure control (AEC) systems that enable tube current modulation (TCM); such systems are widely available and contributes to radiation dose optimization in CT examinations.

Three types of TCM are in use: angular (in the x-y plane [xy-]), longitudinal (z-axis [z-]), and angular-longitudinal (x-y plane and z-axis [xyz-]) TCM. AEC constitutes a method that aims to improve the consistency of image quality and to optimize the absorbed dose by modulating the tube current according to a patient's attenuation [3–5]. Although different CT manufacturers provide the operating concepts and the performance characteristics of TCM, they are not necessarily fully understood by the end users. Muramatsu *et al.* [6] evalu-

*E-mail: matsuk@mhs.mp.kanazawa-u.ac.jp; Fax: +81-76-234-4366
†Current Address: Department of Radiology, Virginia Commonwealth University Medical Center, Virginia 23298, USA

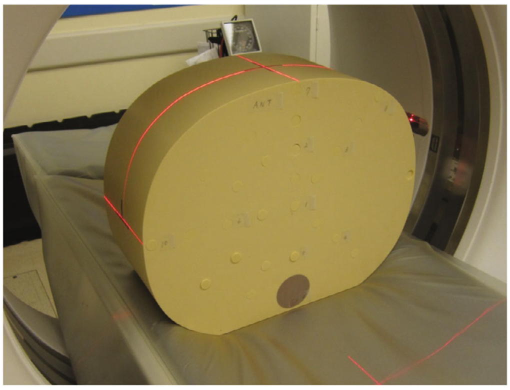

Fig. 1. (Color online) Photograph of a tissue-equivalent elliptical phantom. The phantom was designed to simulate a large adult's abdomen.

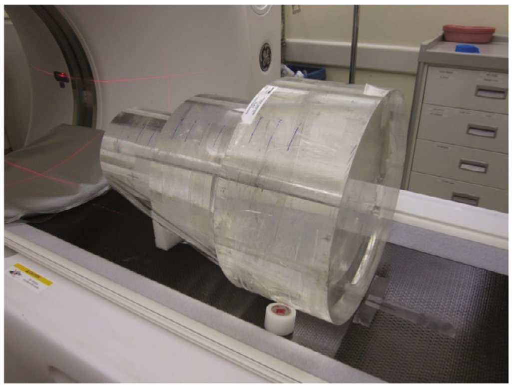

Fig. 2. (Color online) Photograph of a homogeneous cylindrical step phantom. The phantom was comprised of three different-sized cylindrical phantoms. The axial centers of these cylindrical phantoms were aligned, and they were fastened with adhesive tape.

ated the performance of AEC systems by using a cone, an ellipse, a variable-shaped ellipse, and a stepped phantom while several other studies evaluated the performance of AEC systems by using anthropomorphic phantoms [7–10]. However, specialized phantoms designed for that purpose or anthropomorphic phantoms are not usually available in most medical facilities. To ease this difficulty, Tsalafoutas *et al.* [11] presented a simple phantom for investigating and understanding the operational characteristics of AEC systems. In their investigation, a nested CT dose index (CTDI) phantom commonly employed for CTDI dosimetry was employed to evaluate the tube current modulation of CT scanners. Sookpeng *et al.* [12] used a custom-built phantom with three elliptical sections of differing dimensions, referred to as a "wedding cake" phantom, and evaluated the tube current modulation, image noise, and image quality, but no estimate of the impact on the absorbed doses was provided. We believe simple-shape phantoms can also be useful for evaluations of the absorbed dose and the image noise under TCM operation.

II. MATERIALS AND METHODS

1. CT Scanner and TCM

A 64-row multi-detector-row CT scanner (Discovery CT750 HD, GE Healthcare, Milwaukee, WI, USA) was selected for this study. This CT scanner was equipped with a modern AEC system that facilitated TCM in both the angular (Smart mA) and the longitudinal (Auto mA) directions. When the Smart mA mode is activated, the Auto mA mode is also activated. Therefore, there are two different modes of AEC on this CT scanner, namely, the z-TCM and the xyz-TCM modes.

The AEC system is based on the concept of the noise index (NI). The NI is entered by users to determine the desired noise level, which is referenced to the standard deviation (SD) of the pixel values in the central region of interest (ROI) in a 30-cm-diameter water phantom [13, 14]. For a given NI, the Auto mA mode automatically modulates the tube current along the z-direction to maintain a constant noise level in contiguous images. The Smart mA mode modulates the tube current several times within a given rotation.

A NI of 23.71 was selected based on the values recommended by the CT manufacturer in part to provide a sufficiently wide dynamic range for the modulation of the tube current. In so doing, the tube current was prevented from reaching its upper limit while potential overheating of the X-ray tube was avoided.

2. Phantoms

For evaluations of the absorbed dose and the image noise distributions in the axial direction when the z- and the xyz-TCM were activated, a tissue-equivalent elliptical phantom (model 007TE-08 [Fig. 1], CIRS, Norfolk, VA, USA) was used. The size of the phantom was 31.0 cm in AP diameter, 38.0 cm in lateral diameter, and 15.0 cm in thickness. The body of the phantom was made from epoxy resin that was almost soft-tissue-equivalent in the diagnostic X-ray energy range. This phantom had a vertebral-bone-equivalent cylinder equipped in it. The phantom had 27 holes with an inside diameter of 1.30 cm to insert the CT pencil ionization chamber. To plug the holes not in use, the phantom also had 26 soft-tissue-equivalent rod and one vertebral-bone-equivalent rod to fit into the vertebral-bone-equivalent cylinder.

For evaluations of the absorbed dose and the image noise distributions in the longitudinal direction when the z-TCM was activated, a homogeneous cylindrical step phantom comprising 16-, 24-, and 32-cm-diameter cylindrical polymethyl methacrylate (PMMA) phantoms was used (Fig. 2). Although the 32- and 16-cm-diameter