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Original research article

Impact of reduction of flux overlap region on kilovoltage cone-beam computed tomography image quality and patients' exposure dose

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ARTICLE INFO

Article history:
Received 29 December 2015
Accepted 13 April 2016
Available online 16 May 2016

Keywords:
Cone beam CT
Flux overlap region
IGRT

ABSTRACT

Aim: In high-precision radiation therapy, kilovoltage cone-beam computed tomography plays an important role in verifying the position of patient and localization of the target. However, the exposure dose is a problem with kilovoltage cone-beam computed tomography. Flux overlap region increases the patient dose around the center when the scan is performed in a full-scan mode. We assessed the influence of flux overlap region in a full-scan mode to understand the relationship between dose and image quality and investigated methods to achieve a dose reduction.

Method: A Catphan phantom was scanned using various flux overlap region patterns in the pelvis on a full-scan mode. We used an intensity-modulated radiation therapy phantom for measuring the central dose. DoseLab was used to perform image analysis and to evaluate the linearity of the computed tomography values, uniformity, high-contrast resolution, and contrast-to-noise ratio.

Results: The Hounsfield unit value varied by ±40 Hounsfield unit of the acceptance value for the X1 field size of 3.5 cm. However, there were no differences in high-contrast resolution and contrast-to-noise ratio among different scan patterns. The absorbed dose decreased by 7% at maximum for the case within the tolerance value.

Conclusion: Dose reduction is possible by reducing the overlap region after calibration and by performing computed tomography in the appropriate overlap region.

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http://dx.doi.org/10.1016/j.rpor.2016.04.005

1. Introduction

With advancements in radiation therapy (RT), intensity-modulated radiation therapy (IMRT) has facilitated the delivery of large irradiation doses in a treatment volume with a high degree of conformity. Although highly conformal treatment offers the advantage of sparing the delivery of high-dose radiation to the surrounding normal tissue, this advantage may only be achieved if patients are accurately positioned during each treatment session. Recently, image-guided radiotherapy (IGRT) systems have been developed to accurately set the patients' position.[1,2] Among IGRT systems, the use of kilovoltage cone-beam computed tomography (kV-CBCT) has become widespread.[3–6]

There are two types of kV-CBCT scanning methods used with the On-Board Imager system (OBI; Varian Medical Systems, Palo Alto, CA). One is a half-scan method that creates an image by rotating 200°, and the other is a full-scan method that creates an image by rotating 360°. The advantage of the full-scan method is the ability to expand the field of view. However, the exposed dose in the center region of the full-scan method is higher than that of the half-scan method due to a flux overlap region (FOR) around the center. Dose can be reduced during CBCT scan through two different methods: one is by reducing the tube current; the other is by reducing the projections used in volumetric imaging reconstruction.[7] The first method would result in a reduced signal-noise ratio due to less incident photons (reduced mAs) interacting with detectors, which ultimately degrade the image quality. Those degrading effects have been studied by several investigators, and solutions to alleviate them have been proposed.[8–10] Alternatively, the second strategy to reduce the patient's dose underlies the reduction of sampling frequency during image acquisition. However, there are no report that the higher dose in the center region, which was the disadvantage of the full scan method, is reduced.

In this study, we investigated the influence of the FOR using the full-scan method on kV-CBCT image quality and patients' exposure dose.

2. Methods and materials

2.1. CBCT system and scan parameters

All measurements in this study were performed using an OBI system mounted on a Varian Clinac iX linear accelerator (Varian Medical Systems). The kV-CBCT scanning parameters were as follows: tube voltage of 125 kV, tube current of 80 mA, slice thickness of 2.5 mm, tube rotation angle of 364°, and use of a half-fan filter. The default field size at the time of the scan was $X1 = 6.8$ cm, $X2 = 23.5$ cm, and Y1 and Y2 = 8.0 cm. FOR reduction of the kV-CBCT scans was performed by varying the field size ($X1 = 6.8$ cm, 6.5 cm, 6.0 cm, 5.5 cm, 5.0 cm, 4.5 cm, 4.0 cm, 3.5 cm, 3.0 cm, 2.5 cm, 2.0 cm, 1.5 cm, 1.0 cm, 0.5 cm, and 0 cm). We performed a visual evaluation of the image and the image quality according to the FOR reduction, as described below.

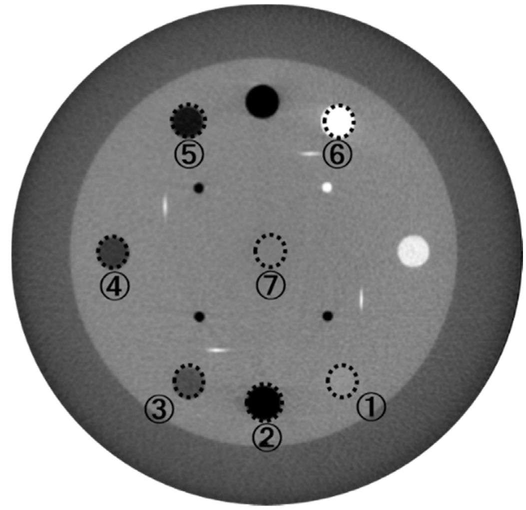

Fig. 1 – CBCT image of HU reproducibility (Catphan CTP 404).

2.2. Evaluation of artifacts by FOR reduction

A Catphan phantom (The Phantom Laboratory, Salem, NY), which comprises several modules with geometrical structures, was set at the top of the couch and kV-CBCT scans of the Catphan phantom according to FOR reduction were performed. Then, we visually evaluated the presence of artifacts in the image according to FOR reduction against the CBCT image at the default condition.

2.3. Evaluation of image quality according to FOR reduction

The image data of the Catphan phantom was analyzed using the image analysis software DoseLab (Mobius Medical Systems, LP). The image quality was evaluated by the reproducibility of Hounsfield unit (HU) values, high-contrast resolution, low-contrast resolution, and uniformity.

2.3.1. Reproducibility of HU values

The reproducibility of HU values was measured using the scanned data of the Catphan module CTP404 (Fig. 1). In this module, there are six regions of interest (ROI) with different compositions, namely acrylic, air, polystyrene, low-density polyethylene, polymethylpentene, and Teflon®. The measured HU values of those six ROI were compared with the reference HU values of the CTP404. The deviation between the reference HU values and the measured HU values were calculated. In this study, tolerance of the deviation was defined as values within 40 HU.

2.3.2. High-contrast resolution

High-contrast resolution was evaluated with the modulation transfer function (MTF), which obtains information about the spatial resolution of the imaging system. In this study, the MTF was calculated using HU values of multiple ROI that were set for 21 different line bar patterns (Fig. 2) in the Catphan module