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Original paper

Effect of diagnostic cone-beam computed tomography protocols on image quality, patient dose, and lesion detection

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ABSTRACT

Objective: To evaluate the effect of cone-beam computed tomography (CBCT) image acquisition protocols on image quality, lesion detection, delineation, and patient dose.
Methods: 100-patients and a CTDI phantom combined with an electron density phantom were examined using four different CBCT-image acquisition protocols during image-guided transarterial chemoembolization (TACE). Protocol-1 (time: 6 s, tube rotation: 360°), protocol-2 (5 s, 300°), protocol-3 (4 s, 240°) and protocol-4 (3 s, 180°) were used. The protocols were first investigated using a phantom. The protocols that were found to be clinically appropriate in terms of image quality and radiation dose were then assessed on patients. A higher radiation dose and/or a poor image quality were inappropriate for the patient imaging. Patient dose (patient-entrance dose and dose-area product), image quality (Hounsfield Unit, noise, signal-to-noise ratio and contrast-to-noise ratio), and lesion delineation (tumor-liver contrast) were assessed and compared using appropriate statistical tests. Lesion detectability, sensitivity, and predictive values were estimated for CBCT-image data using pre-treatment patient magnetic resonance imaging.
Results: The estimated patient dose showed no statistical significance ($p > 0.05$) between protocols-2 and -3; the assessed image quality between these protocols manifested insignificant difference ($p > 0.05$). Two other phantom protocols were not considered for patient imaging due to significantly higher dose (protocols-1) and poor image quality (protocol-4). Lesion delineation and detection were insignificant ($p > 0.05$) between protocols-2 and -3. Lesion sensitivities generated were 81–89% (protocol-2) and 81–85% (protocol-3) for different lesion types.
Conclusion: Data acquisition using protocols-2 and -3 provided good image quality, lesion detection and delineation with acceptable patient dose during CBCT-imaging mainly due to similar frame numbers acquired.

Key points

- Effect of CBCT image acquisition protocols on patient doses and associate image quality are scarce in literature.
- Recent CBCT device capable to produce multiple imaging protocols with different rotation angles and frame numbers.
- Data acquisition protocol-2 and -3 produced good image quality, lesion detection and delineation with acceptable patient dose.

Introduction

Diagnostic cone-beam computed tomography (CBCT) imaging produces patient cross-sectional image data, which can display patient internal anatomy, vascular and lesion information with contrast material (CM) [1]. An accurate three-dimensional tissue characterization is essential to perform many interventional procedures, locate anatomical structures, blood vessels and embedded parenchymal lesions [2]. Many clinical studies have shown the usability of diagnostic CBCT during interventional procedures [2–6].

Truncated projections and beam hardening effects are common problems associated with CBCT imaging that significantly affects reconstruction of the acquired image data. Several studies have

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shown that the production of scatter radiation in the imaging field directly affects image quality and patient dose [7–9]. The scatter radiation increased patient dose and reduced image quality during CBCT patient imaging. Higher radiation doses during CBCT imaging and increased frequency of examinations performed increases the need to reduce radiation dose to the patient and working staff. To maintain consistent performance of CBCT equipment, the European Federation of Organizations for Medical Physics (EFOMP) working group conducted discussions since 2014 and formulated certain guidelines [10]. These guidelines provided a minimum number of quality tests which needed to be performed in order to ensure safety, reliability, and consistency in the operation of the device.

Recent CBCT imaging devices are capable of being used for multiple image acquisition protocols with different rotation angles and frame numbers for patient examinations during image-guided interventional procedures. To our knowledge there are few publications available that discuss several clinical CBCT image acquisition protocols. Image quality improvement, and lesion detection using multiple acquisition protocol increases the concern regarding patient dose. Present study evaluated several CBCT image acquisition protocols and its impacts on lesion detection, delineation, image quality and patient dose during image-guided hepatic transarterial chemoembolization (TACE) therapy.

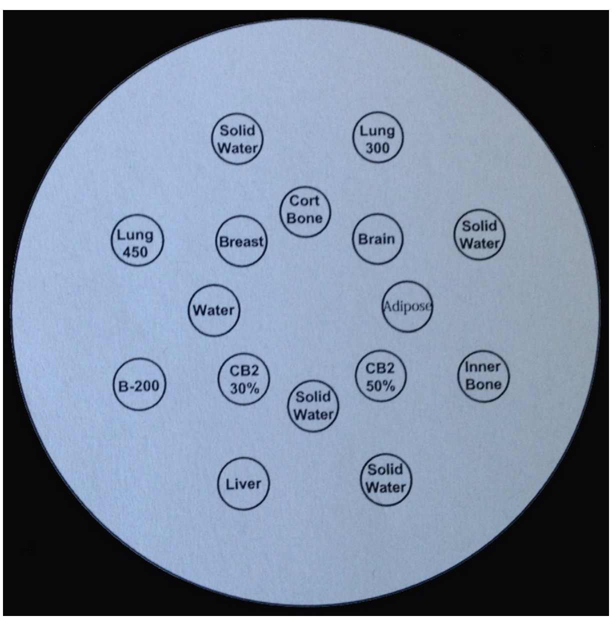

Fig. 1. (A) Pictorial representation of the phantom cross-section used for cone-beam CT imaging to assess radiation dose and image quality with different image data acquisition protocols.

Material and methods

Study design

Patients and phantom imaging were performed in our University hospital using a robotic multi-axis Artis zeego CBCT imaging system from Siemens Healthcare, Forchheim, Germany. Institutional review board approval was obtained prior to beginning the study. The CBCT protocols were first investigated using a phantom. Next, the protocols that were found to be clinically appropriate in terms of image quality and radiation dose were then assessed on patients.

Phantom imaging and protocols

Phantom imaging was used to evaluate different image acquisition protocols, which are available with the CBCT imaging system to demonstrate patient radiation dose optimization and safety. A 32 cm diameter computed tomographic dose index (CTDI) body phantom (14 cm length; PTW, Freiburg, Germany) combined with an electron density phantom (5 cm length; Gammex, model 467, Middleton, USA; Fig 1) to cover longitudinal axis of the exposure field, was used for CBCT imaging. Specifications of the electron density phantom and inserted rod materials can be obtained from the [11]. The imaging was performed using a single rotation X-ray tube-detector system around the phantom in a pre-determined software controlled angle. The phantom imaging was repeated five times for each acquisition protocol to generate and report stable results.

The protocols used for phantom imaging were as follows: protocol-1 (6 s imaging time, 360° rotation angle), protocol-2 (5 s, 300°), protocol-3 (4 s, 240°) and protocol-4 (3 s, 180°). Furthermore, additional information regarding the acquisition protocols used for imaging is provided in Table 1. A modified FDK (Feldkamp-Davis-Kress) algorithm was used to reconstruct the cross-sectional image data. Reconstructed image slice thickness was 0.7 mm and the software version used for imaging was VC 21A (Siemens Healthcare, Forchheim, Germany).

Patient selection

One hundred patients' imaging data acquired in the past two years was retrospectively analyzed. Patient CBCT examinations were performed exclusively for image-guidance purpose during real-time TACE therapy and the selection of patients was random. Patients with hepatic lesions contraindicated for surgery or unresponsive lesions to chemotherapy were included in this study. Patients with lesion sizes less than 1 cm diameter and appearance of >5 hepatic lesions in hepatic parenchyma were excluded from the present investigation.

Table 1
Description of the cone-beam CT image acquisition protocols used for the phantom imaging.

Imaging parameters	Phantom imaging			
	Protocol-1	Protocol-2	Protocol-3	Protocol-4
Kilo-voltage (kV)	124	124	124	124
Tube current (mA)	333 ± 3 (329–335)	340 ± 3 (331–347)	360 ± 4 (357–363)	377 ± 4 (375–379)
Exposure time (s)	6	5	4	3
Imaging start position (°)	0	0	0	0
Imaging end position (°)	360	300	240	180
Rotation speed (°/s)	60	60	60	60
Total rotation angle (°)	360	300	240	180
Frame rate (s)	60	60	60	60
Number of frames	397	248	248	166

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