Original Investigation

Feasibility of Respiratory-gated High-pitch Spiral CT: Free-breathing Inspiratory Image Quality

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Abbreviations and Acronyms

BMI
body mass index

CT
computed tomography

$CTDI_{vol}$
volume CT dose index

DLP
dose length product

DSCT
dual-source CT

E
effective dose

ECG
electrocardiogram

HPM
high-pitch mode

Rationale and Objectives: This study aimed to develop and implement a respiratory-gated setup for dual-source computed tomography (CT) at high pitch to examine patients in a reproducible inspiratory phase.

Materials and Methods: Twenty-one patients underwent free-breathing respiratory-gated chest CT using a high-pitch scan mode no more than 6 months after inspiratory breath-held nongated CT, which serves as reference. Scan parameters were as follows: pitch = 3.4, 128 × 0.6 mm collimation, 0.28 s gantry rotation time, and 150 ref.mAs per tube at 120 kV. The examinations were triggered using the tidal wave provided by a respiratory-gating system as input signal. Image quality was assessed focusing on artifacts and delineation of the anatomical and pathological structures. Lung volumes were measured on both free-breathing and reference examinations.

Results: All examinations were performed without complications. Image quality was high with both protocols. Significantly less motion artifacts were recorded with the high-pitch mode compared to the reference ($P = 0.02$). Most of the artifacts were located in the peripheral parts of the lower lobes for the study group and in the central part of the left lower lobe for the reference. Average total lung volume was 4.5 ± 1.5 L in respiratory-gated examinations and 5.8 ± 0.9 L in examinations with breath-hold in inspiration.

Conclusions: High-pitch chest CT scanning during free breathing minimizes motion artifacts, improving image quality in patients with limited breath-holding abilities. To assure scanning in an inspiratory phase, data acquisition should be triggered with a respiratory-gating system.

Key Words: CT; thorax; lung; adults; artifacts.

INTRODUCTION

Computed tomography (CT) has an important role to play in thoracic imaging (1,2). Isotropic imaging of the chest is possible with modern multislice spiral CT systems in less than 10 s, a breath-hold time that can be managed by the majority of patients. As a consequence of the shorter scan times, respiratory motion artifacts decreased and image quality improved significantly. Shorter CT rotation times also enabled higher temporal resolution and significantly reduced cardiac motion artifacts, which are not only known to alter the image quality near the heart, but also responsible for pulsation artifacts around the aorta and central pulmonary vessels (3).

However, there is a group of patients that cannot comply with breathing commands, for example ventilated patients, sedated patients, mentally impaired patients, or pediatric patients. Hence, image quality is commonly degraded from motion artifacts in these patient groups.

To reduce scan time and to increase temporal resolution, it is recommended to select the shortest rotation time available and the highest pitch. On current state-of-the-art CT

Acad Radiol 2016; ■:■■–■■

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http://dx.doi.org/10.1016/j.acra.2015.12.018

scanners using a single X-ray source, the rotation times vary between 250 and 350 ms, resulting in a temporal resolution per image not better than half the rotation time, and the pitch values usually do not exceed 1.5. The introduction of dual-source CT (DSCT) technology offered the possibility to improve the temporal resolution and to increase the scan speed using high-pitch modes (HPM) (4).

Electrocardiogram (ECG)-triggered HPM spiral CT in cardiac (5,6) and chest (7) imaging has been reported with 128-slice DSCT systems, allowing a motion-free depiction of the heart and coronary arteries, as it provides an effective temporal resolution of 75 ms. Sub-second chest imaging can be performed, fast enough to avoid motion artifacts even if the scan is performed without respiratory commands, with 64-slice DSCT (8), and with 128-slice DSCT systems (9,10). A drawback of such an approach is that the scan is commenced at a random respiratory phase, probably end-expiration, which may degrade the diagnostic value (11).

Our hypothesis was that instead of triggering the scan to a specific heart phase, scanning could also be triggered to a specific respiratory phase to meet a predefined respiratory state. The aim of this study was to develop and test a setup for respiratory-gated CT of the chest using HPM to acquire motion-free images of the lung during free breathing at end-inspiration.

MATERIALS AND METHODS

Study Population

High-pitch spiral CT imaging was performed in 21 consecutive patients referred to chest CT, who had at least one conventional CT chest examination within the last 6 months. To avoid selection bias, patients who underwent surgery within the interval and patients with large atelectasis or significant pleural effusion in one of the examinations were excluded from the study to obtain comparable lung volumes. The patients were composed of 14 men and seven women; mean age was 64 ± 12 years (range 36–84 years). The patients' body mass index was 26 ± 3 kg/m^2 (range 21–31 kg/m^2). None of the patients received breathing instructions for the examination. Written informed consent was obtained from each patient. The study was performed under an institutional review board-approved protocol and complies with the Declaration of Helsinki.

CT Technique

CT examinations were performed on a DSCT system (SOMATOM Definition Flash, Siemens Healthcare, Forchheim, Germany) with the following parameters: 0.28 s gantry rotation time, 128 × 0.6 mm slice acquisition, 150 ref.mAs, 120 kV tube voltage, 0.28 s rotation time, and 460 mm/s table speed (pitch 3.4). Contrast agent (50 mL, 370 mg iodine/mL, Ultravist, Bayer HealthCare, Leverkusen, Germany) was injected with a power injector at a delivery rate of 2.5 mL/s followed by a saline chaser bolus (30 mL); three patients did not receive contrast material. After a delay of 30 s, the scan was triggered by the respiratory-gating system. To trigger the scan, patients were connected to a gating system (AZ-733V, Anzai Medical Co, Tokyo, Japan). A load cell was fixed to the patients' chest with a Velcro band, which was connected to a sensor port and a personal computer as shown in Figure 1. After calibration of the system, the gate point and gate width were set and the gate signal was then transferred to a converter, which connected the external gating system to the ECG port of the CT scanner. To perform the spiral scan during inspiration, a threshold at 80% of the inspiratory curve was used. Because approximately 1 s is necessary to accelerate the CT table and to initiate the scan, the trigger point needs to be predicted prospectively, based on the last breathing cycles before the actual scan (Fig 2).

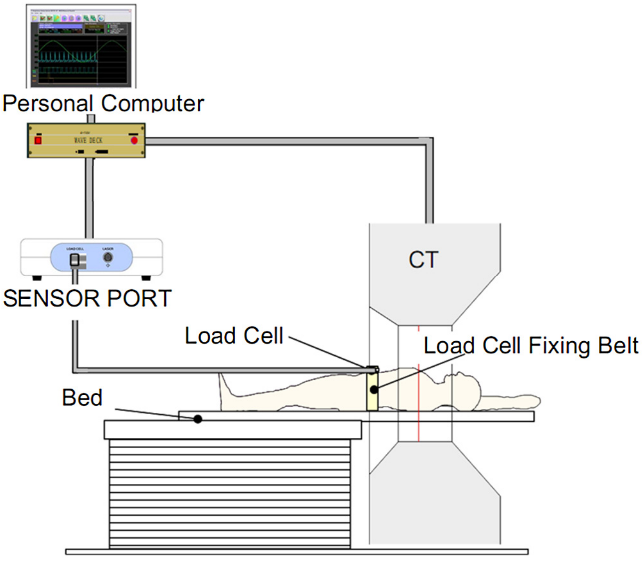

Figure 1. Experimental setting: Tidal wave signal, recorded by a load cell, was used as input signal to trigger the examination.

From the raw data, axial images were reconstructed with a slice thickness of 0.75 mm and 0.4 mm increment using a standard- (B30 f) and high-resolution (B70f) kernel for multiplanar evaluation.

Control Group and Image Evaluation

All patients had a standard CT examination with regular pitch settings of the chest ($n = 10$) or a thoracoabdominal scan range ($n = 11$) in deep inspiration following automated respiratory commands on a 64-slice ($n = 15$, SOMATOM Sensation 64, Siemens Healthcare), a 128-slice ($n = 3$, SOMATOM Definition AS+, Siemens Healthcare), or a 128-slice dual-source system ($n = 2$, SOMATOM Definition Flash, Siemens Healthcare). These examinations were used as an intra-individual reference for image quality. Two board experienced radiologists (17 and 5 years) interpreted the images on a three-dimensional workstation (syngo 3D MMWP, Siemens Healthcare, Erlangen, Germany) after removal of all identifying