Feasibility of low dose chest computed tomography using a high-pitch dual source system: image quality and radiation dose reduction

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Aims and objectives

Lung cancer is a leading cause of cancer death (1). Since early stage lung cancer can be managed curably, screening is appropriate for reducing lung cancer related morbidity and mortality. Over the past 10 years, low dose chest computed tomography (LDCT) scanning has detected up to 85% of stage I lung cancers, offering promise in increasing the cure rate. In addition, use of CT has reduced lung cancer mortality by 20% (2). Despite these contributions to lung cancer treatment, recent concern has focused on the increased radiation exposure during screening CT scans (3-5). The mean radiation dose of LDCT scan is approximately 1.5 mSv (6). However, repeated scans for screening result in an accumulated radiation dose.

Since radiation-related carcinogenesis is a stochastic effect, the reduction of radiation dose is a major concern in modern radiology. Several approaches to reduce radiation dose have been developed and put into routine practice. These approaches include lowering the tube voltage, automatic tube current modulation, new hardware development such as selective in-plane shielding, and an iterative reconstruction algorithm (7-11). Among them, the high helical pitch scan has re-emerged as a tenable option with the development of the dual-source CT scanner (12-15). The conventional single-source CT scanner is limited in its increased pitch factor because of an interpolation artifact problem (16). The recently introduced dual-source CT scanner allows increased pitch values up to 3.2 without the interpolation artifact. This high-pitch factor scan has a major advantage of reducing total scanning time (17). Many published reports using the dual source CT scanner have provided optimism that high-pitch CT scans can reduce the radiation dose.

The thorax is suitable for reducing radiation dose because of its relatively lower composition of soft tissue and high contrast between air and pulmonary parenchyma. We assumed that reduction of radiation dose using high-pitch CT scan would be better in the thorax than in other body parts. Thus, the purpose of this study was to assess the effectiveness of a high-pitch pre-enhancement LDCT (HP-LDCT) scan protocol in reducing radiation dose without deterioration of image quality compared with standard LDCT.
Methods and materials

Our retrospective clinical study was approved as HIPPA-compliant by our institutional review board and informed consent was waived. Our chest CT scan protocol for the surveillance of breast cancer metastasis consisted of pre- and post-enhancement CT scans. To reduce the total radiation exposure, a decision of a CT protocol committee was made to change the protocol with consensus of chest radiologists and a referring breast surgeon after dual-source CT scanner installation in November, 2012. The changed CT scan protocol for breast cancer patient consisted of HP-LDCT and standard-pitch post-enhancement scans. After the change and set-up of the chest CT protocol, 51 consecutive patients who underwent chest CT for surveillance of breast cancer from December 2012 to February 2013 were considered for inclusion in this study. A patient was excluded due to free breathing during the CT scan. Finally, 50 female patients with a mean age of 53±9.6 years were enrolled in the HP-LDCT group. Another 50 consecutive patients (23 males, 27 females; mean age 51±15 years) underwent LDCT for routine health screening in the same period and were enrolled in the LDCT group. Patients' height, weight, and body mass index (BMI; weight in kilograms divided by the height in meter squared) were recorded in an Excel (Microsoft, Redmond, WA) tracking template by medical records survey.

CT protocols

All CT examinations were performed on a second generation 128-slice dual-source CT system (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany). No contrast medium was used in the LDCT protocol. Iodine contrast medium (300-350 mg I/ml) was injected at a rate of with 1-2 ml/sec in standard-pitch post-enhancement CT scan in the breast cancer patients. The CT scan protocol is summarized in Table 1. Patients were examined with a collimation of 64x0.6 mm and a slice acquisition of 128x0.6 mm by means of a z-flying focal spot. Tube voltage and current was fixed at 120 kVp and 40 mAs, respectively, in the HP-LDCT and LDCT protocols. HP-LDCT was examined with a gantry rotation time of 0.28 s and a pitch of 3.0. LDCT was examined with a gantry rotation time of 0.5 s and a pitch of 1.2. Standard-pitch post-enhancement CT scan was examined with gantry rotation time of 0.5 s and a pitch of 0.6. Difference of gantry rotation time was because of pre-fixed setting value by the manufacturer's software at the high pitch scan mode. The manufacturer's software application designed to minimize radiation dose (CARE Dose or CARE kV) was not used in pre-contrast HP-LDCT and LDCT protocols. Post-contrast chest CT scan was obtained with a gantry rotation time of 0.5 s and a pitch of 0.6 with a manufacturer's software application designed to minimize radiation dose (CARE Dose or CARE kV).

The CT volume dose index (CTDIvol) and the dose-length product (DLP) were obtained from the patient protocol from each CT scan. The DLP was measured in units of mGy·cm and reflected the absorbed dose by the participant from the entire series of images in a
CT scan examination. The effective dose (ED) was calculated by multiplying the DLP by a commonly accepted adult lung conversion coefficient of 0.014 mSv·mGy\(^{-1}\)·cm\(^{-1}\) (18).

Image reconstruction

All scans were reconstructed with a 3-mm slice thickness and a standard filter back projection algorithm using a B40 spatial resolution kernel. We did not evaluate an advanced iterative reconstruction algorithm known as iterative reconstruction in image space (IRIS) or Sinogram Affirmed Iterative Reconstruction (SAFIRE). All CT examinations were sent to a picture archiving and communication system (PACS, PiviewSTAR; Infinite Healthcare, Seoul, Korea) and reviewed.

Image analysis

Objective image analysis

Image noise (standard deviation of the CT number) was measured for all 100 patients at five areas on the PACS by an independent reader (C. Park). For all areas, 10-20 mm diameter circular regions of interest (ROIs) were drawn without touching the adjacent wall, vessels or fascia. For the lung images, ROIs were located in the outside air and lung parenchyma of the right lower lobe. For the mediastinum images, ROIs were located in the left infraspinatus muscle, subcutaneous fat layer and descending thoracic aorta without touching the adjacent wall, vessels or fascia. Signal-to-noise ratio (SNR) of lung parenchyma, aorta, subcutaneous fat layer and muscle were calculated by dividing the mean CT number of each area by the corresponding standard deviation (19).

Subjective image analysis

All CT images were randomized and evaluated in a blinded manner using the aforementioned PACS for assessment of the subjective image quality. Two thoracic radiologists (H.H and H.H with 5 and 6 years of experience in chest imaging, respectively) independently evaluated the lung and mediastinum image quality at the level of humerus head, azygos arch, bronchus intermedius, inferior pulmonary vein and the lung base just above right hemidiaphragm.

Subjective image quality was assessed in terms of image noise, artifacts, cardiac motion artifact and overall diagnostic acceptability. Image noise was scored on a five-point scale: 1, minimum to no image noise; 2, less than average; 3, average; 4, more than average; 5, unacceptable noise. Artifacts were ranked on a four-point scale: 1, no or minimum; 2, artifacts showing a part of the segment without interfering diagnostic decision; 3, artifacts occupying the entire segment, but diagnosis still possible; 4, artifacts affecting diagnosis. Windmill artifacts, streak artifacts and beam hardening artifacts were assessed (20). Cardiac motion artifact with respect to pulmonary vessels and bronchial wall in the lung...
images and with respect to the vascular wall and the borders of organ in the mediastinal images was assessed on a five-point scale: 5, sharpest and no blurring; 4, minimal blurring and less than 3 mm in length of borderline motion artifact; 3, any blurring of bronchi and pulmonary vessels with equal or more than 3 mm and less than 5 mm in length of borderline motion artifact; 2, any blurring of bronchi and pulmonary vessels with equal or more than 5 mm and less than 10 mm in length of borderline motion artifact; 1, tram track artifact with any length of borderline motion artifact (Figure 1). The overall diagnostic acceptability was graded on a five-point scale: 5, superior; 4, above average; 3, average; 2, less than average; 1, unacceptable (20).

All images sets were displayed on the default preselected lung window setting (window width 1500HU; window level, -600HU) and mediastinum setting (window width 400HU; window level, 45HU) that did not allow any change.

Statistical analyses

BMI, objective image noise, SNR and scan length showed normal distribution. Thus, the independent sample t-test was used for the statistical analysis. The Mann-Whitney U test was used for the DLP analysis because DLP of HP-LDCT did not show normal distribution. The difference in the scores for the subjective image qualities between HP-LDCT and LDCT were analyzed by the Mann-Whitney U test. Interobserver agreement was evaluated by measuring the $k$ statistics. The significance level for all tests was 5% (two-sided). All data were analyzed using the statistical software (Medcalc, version 12.7.0, Medcalc software bvba, Belgium).
Fig. 1: Scores of cardiac motion artifacts. (A) Inferior pulmonary vein region image shows clear demarcation of cardiac border and no blurring of pulmonary vessels, bronchi and fissure (5-point). (B) Basal lung region image shows minimal blurring of cardiac margin (less than 3mm) and pulmonary vessels (4-point). (C) Inferior pulmonary vein region image shows moderated blurring of cardiac margin (equal or more than 3mm and less than 5mm) although relatively less blurring of pulmonary vessels or bronchi (3-point). (D) Cardiac margin shows marked blurring (more than 5mm) (2-point). (E) Cardiac margin blurring is 7mm, and pulmonary vessels shows double or tram track artifacts (1-point).

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Results

Patient and radiation dose characteristics

Descriptions of the patient groups and radiation doses in patients who underwent HP-LDCT and LDCT are summarized in Table 2. There was no significant difference in BMI between the 50 female patients (24.5±2.9 kg/m$^2$) who underwent HP-LDCT and the 50 patients (23.2±3.0 kg/m$^2$) who underwent LDCT ($P=0.07$) (Figure 2). Scan length was significantly longer in males (37.1±0.4 cm) than in females (34.8±0.4 cm) ($P<0.01$). However, scan length of females was not different between HP-LDCT and LDCT (35.2±2.4 cm; $P=0.51$; Figure 2). DLP of standard-pitch post-enhancement CT was 268.22±75.71 mGy·cm [95% confidence interval (CI), 243.14-293.3 mGy·cm] and DLP of HP-LDCT was 90.22±4.34 mGy·cm [95% CI, 88.65-91.78 mGy·cm] ($P<0.01$). There was a mean 66.4% reduction in radiation dose. Overall DLP of LDCT was 106.14±6.48 mGy·cm [95% CI, 103.6-107.3 mGy·cm]. DLP of LDCT was further analyzed according to sex because of scan length difference. Females' DLP of LDCT was 103.1±6.4 mGy·cm [95% CI, 100.6-105.6 mGy·cm]. Mean females' DLP of HP-LDCT was significantly lower than mean females' DLP in the LDCT group ($P<0.01$). The effective dose was determined by the DLP measurements and the appropriate normalized coefficients were found in the literature for chest CT (0.014 mSv/mGy·cm); estimate for HP-LDCT and LDCT was 1.26±0.06 mSv and 1.49±0.09 mSv, respectively ($P<0.01$; Figure 3).

Objective image noise and SNR

HP-LDCT images showed significantly reduced objective image noise only in the infraspinatus muscle ($P=0.04$) and subcutaneous fat regions ($P<0.01$). Objective image noises of other regions did not show significant differences between HP-LDCT and LDCT (Table 3). There was no significant difference of SNR (Table 3).

Subjective image quality assessment

The interobserver agreement between the two readers was ranged from fair to good for lung and mediastinum window setting analysis of HP-LDCT and LDCT ($k=0.22~0.68$). Figure 4 shows HP-LDCT images of apex and inferior pulmonary vein level on lung and mediastinum window setting. The subjective image quality scores are summarized in Table 4 (lung window setting) and Table 5 (mediastinal window setting). Artifacts were rare in both groups. On analysis of the lung window setting, reader 1 showed better subjective image quality scores of noise and cardiac pulsation artifact at all regions, and reader 2 showed only better image quality scores of noise at humeral head and azygos vein regions, and scores of cardiac pulsation artifact at inferior pulmonary vein and basal lung regions on HP-LDCT compared with LDCT. On analysis of the mediastinum window setting, reader 1 showed better subjective image quality scores of noise at
humerus head and azygos vein levels, and scores of cardiac pulsation artifact at bronchus intermedius, inferior pulmonary vein, and basal lung zone regions. Reader 2 did not show any significant differences of noise and cardiac pulsation artifact image scores between HP-LDCT and LDCT. Mean overall diagnostic acceptability of HP-LDCT of each reader was 3.2±0.4 and 3.1±0.4, respectively. Overall diagnostic acceptability of HP-LDCT was significantly better than that of LDCT in both readers (P<0.05)
Fig. 2: Distribution of BMI and scan length (sl) between HP-LDCT and LDCT groups (P>0.05).

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Fig. 3: Comparison of the overall and females' DLP between HP-LDCT and LDCT. Mean radiation dose of females' DLP in HP-LDCT (90.2 mGy·cm) is significantly reduced that of LDCT (103.1 mGy·cm) (P<0.01).

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Fig. 4: HP-LDCT images of a 50-year-old female. On the lung window setting analysis (width: 1500, level: -600), noise scores is average (3-point) and score of cardiac motion artifact is 5-point at all regions. On the mediastinum window setting analysis (width: 400,
level: 45) and the noise score is more than average (4-point). But, the score of cardiac motion artifact is 5-points at all regions. Five regions are level of apex (A & F), azygos vein (B & G), bronchus intermedius (C & H), inferior pulmonary vein (D & I) and above diaphragm (E & J). (A & F) Image of apex on lung and mediastinum window settings shows no beam hardening, and clear demarcation of soft tissues of lower neck area such as major vessels, thyroid gland, muscles and subcutaneous fat layer. (D & I) Image of inferior pulmonary vein level on lung and mediastinum window settings shows sharp edge of pulmonary vessels, bronchi and mediastinum structures such as aortic root.

Table 1: Scan parameters of HP-LDCT, LDCT and standard post-enhancement CT scans.

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Table 2: Descriptions of study population and radiation dose between HP-LDCT and LDCT groups. Data are presented as range or mean±standard deviation (95%, confidence interval). * P value is from the Mann-Whitney U test. Other P values are from independent t-test.

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Table 3: Description of objective image noise and signal to noise ratio (SNR) between HP-LDCT and LDCT groups. Standard deviation of CT number measured at infraspinatus muscle and subcutaneous layer areas show significant decrease in HP-LDCT group. SNR was not difference between the HP-LDCT and LDCT groups. P-values were obtained by independent t-test.

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**Table 4:** Summarization of subjective image quality score on lung window setting analysis between HP-LDCT and LDCT groups. P-values were obtained by Mann-Whitney U test.

<table>
<thead>
<tr>
<th>Lung window setting</th>
<th>Reader 1</th>
<th>Reader 2</th>
<th>P-value</th>
<th>Reader 1</th>
<th>Reader 2</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HP-LDCT</td>
<td>LDCT</td>
<td></td>
<td>HP-LDCT</td>
<td>LDCT</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Humeral head</td>
<td>3.41±0.61</td>
<td>2.88±0.41</td>
<td>&lt;0.01</td>
<td>3.09±0.36</td>
<td>3.03±0.00</td>
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<td>Azygos vein</td>
<td>3.32±0.47</td>
<td>2.94±0.12</td>
<td>&lt;0.01</td>
<td>3.09±0.36</td>
<td>3.03±0.00</td>
<td>0.04</td>
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<td>Bronchus intermedius</td>
<td>3.26±0.45</td>
<td>2.91±0.38</td>
<td>&lt;0.01</td>
<td>3.09±0.36</td>
<td>3.03±0.00</td>
<td>0.31</td>
</tr>
<tr>
<td>Inferior pulmonary vein</td>
<td>3.26±0.45</td>
<td>2.94±0.34</td>
<td>&lt;0.01</td>
<td>3.09±0.36</td>
<td>3.03±0.00</td>
<td>0.36</td>
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<tr>
<td>Basal lung</td>
<td>3.26±0.45</td>
<td>2.94±0.34</td>
<td>&lt;0.01</td>
<td>3.09±0.36</td>
<td>3.03±0.00</td>
<td>0.36</td>
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<tr>
<td>Sharpness</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Humeral head</td>
<td>5.00±0.00</td>
<td>4.77±0.56</td>
<td>0.02</td>
<td>5.00±0.00</td>
<td>5.00±0.00</td>
<td>1.00</td>
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<tr>
<td>Azygos vein</td>
<td>4.86±0.22</td>
<td>4.54±0.51</td>
<td>0.01</td>
<td>5.00±0.00</td>
<td>4.91±0.30</td>
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<td>Bronchus intermedius</td>
<td>4.80±0.40</td>
<td>4.40±0.59</td>
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<td>5.00±0.00</td>
<td>4.86±0.48</td>
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<td>Inferior pulmonary vein</td>
<td>4.60±0.59</td>
<td>3.77±1.03</td>
<td>&lt;0.01</td>
<td>4.94±0.00</td>
<td>4.40±0.98</td>
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<td>Basal lung</td>
<td>4.40±0.51</td>
<td>3.51±1.24</td>
<td>&lt;0.01</td>
<td>4.71±0.44</td>
<td>4.03±1.02</td>
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Table 5: Summarization of subjective image quality score on mediastinum window setting analysis between HP-LDCT and LDCT groups. P-values were obtained by Mann-Whitney U test.

<table>
<thead>
<tr>
<th>Mediastinum setting</th>
<th>Reader 1</th>
<th>Reader 2</th>
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<tr>
<td></td>
<td>HP-LDCT</td>
<td>LDCT</td>
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<tr>
<td>Noise</td>
<td></td>
<td></td>
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<td>Humeral head</td>
<td>3.26±0.56</td>
<td>2.89±0.36</td>
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<td>Azygos vein</td>
<td>3.23±0.46</td>
<td>2.97±0.22</td>
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<tr>
<td>Bronchus intermedius</td>
<td>3.06±0.30</td>
<td>3.00±0.00</td>
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<tr>
<td>Inferior pulmonary vein</td>
<td>3.06±0.30</td>
<td>3.00±0.00</td>
</tr>
<tr>
<td>Basal lung</td>
<td>3.06±0.30</td>
<td>3.00±0.00</td>
</tr>
<tr>
<td>Sharpness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humeral head</td>
<td>5.00±0.00</td>
<td>4.97±0.22</td>
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<tr>
<td>Azygos vein</td>
<td>4.86±0.30</td>
<td>4.60±0.44</td>
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<tr>
<td>Bronchus intermedius</td>
<td>4.91±0.30</td>
<td>4.29±0.75</td>
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<tr>
<td>Inferior pulmonary vein</td>
<td>5.00±0.00</td>
<td>4.66±0.59</td>
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<tr>
<td>Basal lung</td>
<td>5.00±0.00</td>
<td>4.49±0.48</td>
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</table>
Conclusion

In conclusion, although the concern of reduction of radiation dose derived from fast scan time could degrade the image quality because of the decrease in effective x-ray photon, there was no image quality deterioration on HP-LDCT. Above all, the most important point of our study was that more than 13% reduction of radiation dose and better image quality based on suppression of cardiac pulsation artifact were achievable using HP-LDCT protocol.
References


18.


