Performance of half-dose chest CT in lung malignancy using a new iterative reconstruction technique

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Purpose

To evaluate the performance of half-dose chest CT using a new iterative reconstruction technique based on the raw data named Sinogram Affirmed Iterative Reconstruction (SAFIRE) and to determine the optimal strength images in patients with primary or metastatic lung malignancies.

Materials and Methods

Patients

From March to July 2013, we enrolled 38 consecutive patients (22 men and 16 women, mean age 60.2 years, range 37-78 years) who underwent follow-up chest CT examinations for therapeutic evaluation of primary lung cancer or metastatic pulmonary lesions. The underlying malignancies were located in the lung (n=8), colon (n=7), head and neck (n=4), stomach (n=3), kidney (n=3), bladder (n=3), breast (n=2) and other locations (n=8). The mean body mass index (BMI) of the patients was 23.15 ±3.88 kg/m² (range, 17.0-36.5 kg/m²). They all had solitary or multiple pulmonary lesions which were solid nature. The mean size of the lesions was 23±5.24mm (range 5-62mm).

CT Data Acquisition

All CT scans were obtained in the supine position after IV contrast administration with a dual-source Flesh 128-slice multi-detector CT system. The standard-dose CT scans were performed under automated dose modulation using two tubes in dual-source modes with the following settings: 120 kVp, 100-230 mA; tube rotation time, 0.5 seconds; pitch 1.2. The half-dose data sets (50-115 mA) were obtained using projection data from only one of the two x-ray detectors in this dual-source CT system.

Image Reconstruction

From each CT image, 6 image serials were reconstructed. First a standard-dose image serial was reconstructed using a conventional filtered back projection algorithm to evaluate the lung and mediastinal images using kernel B60f. Scanned raw data were exported to an external hard drive and 5 half-dose SAFIRE image serials (strength 1-5; S1-S5) were reconstructed on an offline workstation provided by the vendor (Siemens) using kernel B50f. In order to compare standard-dose and half-dose SAFIRE images at a radiation dose ratio of 2:1, SAFIRE reconstructions used the data acquired from only one tube of the dual-source CT system. All data sets were reconstructed with a slice thickness of 3 mm in increments of 3 mm. Consecutive CT examinations were dicomized
and displayed with a window level of -700 Hounsfield units (HU) and width of 1500 HU for lung images, as well as a window level of 25 HU and width of 400 HU for mediastinal images.

**Image Analysis and Evaluation**

**Subjective analysis**

Two independent radiologists evaluated the CT scans. They were blinded to image strength and independently compared the half-dose SAFIRE images with corresponding standard-dose images in the same patient at a similar level in a side-by-side manner on two monitors using a digital picture-archiving and communicating system diagnostic workstation. The radiologists reviewed the images at a constant window width and level to simulate both lung and mediastinal window settings. Images were assessed for the following 10 factors: lung noise, lung contrast, central vessel and airway sharpness, peripheral vessel and airway sharpness (i.e., within 2 cm of the parietal pleura), mediastinal noise, mediastinal contrast, mediastinal sharpness, chest wall noise, chest wall contrast and chest wall sharpness. In comparison with the corresponding baseline images, the factors were graded as better than (score 2), equal to (score 1), or worse than (score 0) the standard-dose images. In addition, the conspicuity of pulmonary lesions was analyzed using 5-point scale (1= no lesion seen, 2= questionable lesion or an artifact mimicking a lesion, 3= subtle lesion with ill-defined margin, 4= well-visualized lesion with ill-defined margins, 5= well-visualized lesion with sharp margins). Diagnostic confidence was evaluated using 3-point scale (1= unacceptable for diagnostic interpretation, 2= confidence limited to only large or well-defined lesions, 3= fully confident).

**Quantitative analysis**

We obtained the quantitative measurements on all 228 images (6 images x 38 patients) of attenuation values (in Hounsfield units) and image noise (SD of attenuation coefficients) in the descending thoracic aorta and chest wall muscle of subscapularis at the level of inferior pulmonary vein with a region-of-interest (ROI) of a constant size and shape. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the descending thoracic aorta with respect to the chest wall muscle were calculated for all images according to the following standard equations:

\[
\text{SNR} = \frac{\text{mean HU of Aorta in ROI}}{\text{SD of Aorta in ROI}} \\
\text{CNR} = \frac{(\text{mean HU of Aorta in ROI} - \text{mean HU of chest wall in ROI})}{\text{SD of Aorta in ROI}}
\]

**Statistical Analysis**

For each subset of standard-dose and reconstructed half-dose images, subjective image noise, sharpness and contrast scores for all 10 factors and lesion assessments
(conspicuity and diagnostic confidence) were reported as the mean±standard error of the mean. Individual scores of subjective image factors were compared using the Wilcoxon signed-rank test. Objective image noise including SNR and CNR was compared using the paired t-test. The correlation between subjective factors and objective image noise (SNR and CNR) was determined using the Spearman correlation test. Significant correlation was defined as a difference with a 2-sided p-value less than 0.05. The Cohen # test was used to assess the degree of inter- and intra-observer agreement between the two readers. The # coefficient value was considered as follows: slight (< 0.20), fair (0.21 - 0.40), moderate (0.41 - 0.60), substantial (0.61 - 0.80); or near-perfect (0.81 - 1.00).

Results

Subjective analysis

Moderate inter-observer agreement was noted between the two independent radiologists (simple # coefficient, 0.51 ; p<0.05). Intra-observer agreement was moderate (simple # coefficient, 0.48; p<0.05).

The mean subjective image noise, sharpness, contrast, and lesion assessment scores of standard-dose and five subsets of half-dose images reconstructed with SAFIRE are summarized in Table 1. The score above 1 means the subjective factor is better and the score less than 1 means the subjective factor is worse than the corresponding standard dose image. There was significantly less subjective image noise in the lung, mediastinum and chest wall of the half-dose images reconstructed with strengths 1 to 5 compared to the corresponding standard-dose images (p<0.05). Subjective image noise was positively correlated with strength (p<0.05) (Figure 1). Compared to standard-dose images, there was significantly less central and peripheral lung sharpness in the S4 and S5 half-dose images, mediastinal sharpness in the S3-S5 half-dose images, and chest wall sharpness in the S2-S5 half-dose images (p<0.05). The reduction in sharpness was correlated with strength (p<0.05) (Figure 2). There was a statistically significant improvement in lung contrast of the half-dose images of all strengths, as well as in mediastinum and chest wall contrast in S2-S5 images (p<0.05). Image contrast was positively correlated with strength (p<0.05). Lesion conspicuity and diagnostic confidence of reconstructed half-dose images are demonstrated in Table 2. Lesion conspicuity was significantly decreased in the S4-S5 half-dose images (p<0.05). However, the diagnostic confidence was fully confident in all half-dose image strengths. In particular, S2 and S3 reconstructed images had the lowest subjective image noise while maintaining sharpness of the lung parenchyma and lesion conspicuity.

Quantitative analysis
The SNR and CNR of standard-dose and reconstructed half-dose images are presented in Table 3. CNR and SNR, which were both positively correlated with strength (p<0.05), were significantly higher in reconstructed half-dose images of all strengths compared to standard-dose images (p<0.05). There was a statistically significant correlation between the subjective image noise assessment and the quantitative image noise, including SNR and CNR, of the descending thoracic aorta (Spearman correlation coefficient, 1.0 in lung, 0.99 in mediastinum and chest wall; p<0.01).

Images for this section:
Fig. 1: 52-year-old woman with stomach cancer. The reconstructed half-dose CT images with 5 strengths (b to f) show decreased image noise in the aorta and mediastinal fat compared to the standard-dose image (a). Image noise was inversely correlated with strength.
Fig. 2: 53-year-old woman with rectal cancer. The reconstructed half-dose CT images with strength 3, 4 and 5 (d, e and f) show poor visualization of the small vascular structures in the peripheral 2 cm of the lung compared to the standard-dose image (a). Image sharpness was inversely correlated with strength. However, the conspicuity of the small metastatic pulmonary nodules is comparable to the standard-dose image.
### Table 1: Scores of subjective factors in the lung, mediastinum and chest wall in each half-dose image reconstructed with different strengths of SAFIR

Note: values are expressed as mean ± standard error of the mean. *Value shows a statistically significant difference with a two-sided p-value less than 0.05, compared with the value of the corresponding standard-dose CT images.

<table>
<thead>
<tr>
<th></th>
<th>Lung Noise</th>
<th>Lung Contrast</th>
<th>Central Lung Sharpness</th>
<th>Peripheral Lung Sharpness</th>
<th>Mediastinal Noise</th>
<th>Mediastinal Contrast</th>
<th>Mediastinal Sharpness</th>
<th>Chest wall Noise</th>
<th>Chest wall Contrast</th>
<th>Chest wall Sharpness</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>*1.18±0.24</td>
<td>*1.34±0.33</td>
<td>1±0</td>
<td>*1.26±0.34</td>
<td>1.01±0.22</td>
<td>0.97±0.11</td>
<td>*0.34±0.33</td>
<td>1.01±0.08</td>
<td>0.97±0.11</td>
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<tr>
<td>S2</td>
<td>*1.61±0.24</td>
<td>*1.84±0.24</td>
<td>1±0</td>
<td>*1.81±0.24</td>
<td>*1.12±0.32</td>
<td>0.96±0.14</td>
<td>*1.84±0.24</td>
<td>*1.17±0.24</td>
<td>0.95±0.16</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>*1.83±0.24</td>
<td>*1.97±0.11</td>
<td>0.99±0.81</td>
<td>*1.97±0.11</td>
<td>*1.38±0.38</td>
<td>0.92±0.18</td>
<td>*1.97±0.11</td>
<td>*1.34±0.24</td>
<td>0.88±0.25</td>
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<tr>
<td>S4</td>
<td>*1.92±0.18</td>
<td>2±0</td>
<td>0.93±0.17</td>
<td>*0.45±0.25</td>
<td>2±0</td>
<td>*1.54±0.36</td>
<td>0.86±0.26</td>
<td>2±0</td>
<td>*1.45±1.56</td>
<td>0.71±0.34</td>
</tr>
<tr>
<td>S5</td>
<td>*1.95±0.16</td>
<td>2±0</td>
<td>0.71±0.30</td>
<td>*0.22±0.30</td>
<td>2±0</td>
<td>*1.62±0.32</td>
<td>0.68±0.34</td>
<td>2±0</td>
<td>*1.55±0.23</td>
<td>0.46±0.34</td>
</tr>
</tbody>
</table>

### Table 2: Scores of the lesion conspicuity and diagnostic confidence in each half-dose image reconstructed with different strengths of SAFIR

Note: values are expressed as mean ± standard error of the mean.

<table>
<thead>
<tr>
<th></th>
<th>Lesion conspicuity</th>
<th>Diagnostic confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>5±0</td>
<td>3±0</td>
</tr>
<tr>
<td>S2</td>
<td>5±0</td>
<td>3±0</td>
</tr>
<tr>
<td>S3</td>
<td>5±0</td>
<td>3±0</td>
</tr>
<tr>
<td>S4</td>
<td>4.81±0.88</td>
<td>3±0</td>
</tr>
<tr>
<td>S5</td>
<td>4.65±0.11</td>
<td>3±0</td>
</tr>
</tbody>
</table>
Table 3: Mean SNR and CNR of descending thoracic aorta in standard-dose and reconstructed half-dose images with different 5 strengths. Note: values are expressed as mean ± standard error of the mean.

<table>
<thead>
<tr>
<th></th>
<th>Standard-dose</th>
<th>Half-dose S1</th>
<th>Half-dose S2</th>
<th>Half-dose S3</th>
<th>Half-dose S4</th>
<th>Half-dose S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNR</td>
<td>3.28 ± 0.69</td>
<td>4.56 ± 1.03</td>
<td>5.25 ± 1.03</td>
<td>6.09 ± 1.25</td>
<td>8.17 ± 1.85</td>
<td>10.67 ± 2.71</td>
</tr>
<tr>
<td>SNR</td>
<td>2.25 ± 0.63</td>
<td>3.2 ± 0.93</td>
<td>3.68 ± 0.95</td>
<td>4.28 ± 1.13</td>
<td>5.74 ± 1.60</td>
<td>7.42 ± 2.27</td>
</tr>
</tbody>
</table>
Conclusions

In conclusion, half-dose chest CT images using SAFIRE can improve image quality, as evidenced by decreased noise and increased contrast, while resulting in diagnostic confidence comparable to standard-dose images. In addition, image reconstruction with strength levels 2 and 3 appear to be the optimal choice in clinical practice by maintaining lung parenchyma sharpness and lesion conspicuity.

Personal Information