Optimal Scan Parameters for CT Fluoroscopy in Lung Interventional Radiologic Procedures: Relationship between Radiation Dose and Image Quality

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Purpose:
To evaluate the relationship between radiation doses and lung computed tomographic (CT) fluoroscopic scan parameters and to determine optimal scan parameters for performance of lung interventional radiologic (IR) procedures.

Materials and Methods:
The institutional review board approved this prospective study, which included 32 patients with a single lung tumor; written informed consent was obtained. CT fluoroscopic images were obtained with three tube voltages (80, 120, 135 kV) and three tube currents (10, 20, 30 mA) in each patient. The signal-to-noise ratios (SNRs) and the contrast-to-noise ratios (CNRs) were measured quantitatively. To evaluate the feasibility of performing lung IR procedures, four readers visually scored the image quality. Acceptable CT fluoroscopic images were determined by using agreement of at least three of the four readers. The weighted CT dose index for each CT scan parameter was measured. A piecewise linear regression equation was obtained from the relationship between radiation doses and visual image scores.

Results:
Both the SNR and the CNR improved as the radiation dose increased, leading to improvement in the image quality. Acceptable image quality was achieved in 94% (30 of 32) of patients when the radiation dose was 1.18 mGy/sec (120 kV, 10 mA) and in all patients when it was greater than 1.48 mGy/sec (135 kV, 10 mA). The piecewise linear curve showed rapid improvement in image quality until the radiation dose increased to 1.48 mGy/sec (135 kV, 10 mA). When the radiation dose was increased greater than 1.48 mGy/sec, improvement in the image quality became more gradual.

Conclusion:
Results of this study can be used to guide the determination of optimal scan parameters in lung CT fluoroscopy.
Computed tomographic (CT) fluoroscopy is widely used in lung interventional radiologic (IR) procedures, including radiofrequency (RF) ablation (1–7), biopsy (8–10) of tumors, and drainage of fluid (8,11). Because CT fluoroscopy enables real-time monitoring of target lesions, surrounding organs, and the passage of a needle (12), it makes lung IR procedures easier and safer than conventional CT-guided lung IR procedures.

A major problem of real-time CT fluoroscopy is radiation exposure. Excessive radiation exposure to patients undergoing IR procedures can occur during CT fluoroscopy because of continuous exposure at a single anatomic location. On the other hand, excessively low radiation doses provide inferior image quality and result in interference with IR procedures.

When lung IR procedures are performed, it is ideal to obtain reasonable image quality with low radiation exposure: as low a radiation dose as reasonably practicable (13). However, no consensus has been reached in regard to optimal scan parameters when CT fluoroscopy-guided lung IR procedures are performed. Furthermore, the relationship between the radiation dose to the patient and image quality has not been well evaluated.

We evaluated the relationship between radiation doses and lung CT fluoroscopic scan parameters, and we determined optimal scan parameters for the performance of lung IR procedures.

Materials and Methods

Study Design

The institutional review board of Meie University School of Medicine (Tsu, Japan) approved this prospective study. Written informed consent was obtained from each patient. This study was not supported by any grants. There were no conflicts of financial interests for any authors. No authors are employees of the related companies.

The sample size required for this prospective study was derived from the institutional normalized ratio (15). A significance level of 0.05 was used, with Bonferroni correction. The power analysis showed that 30 subjects were required. Given the deviation for patients who cannot hold their breath, the sample size was determined to be 32 subjects.

Patients and CT Scan Parameter

Patients who had a single lung tumor of 3.5 cm or less in diameter who also underwent lung RF ablation or lung biopsy were included. Exclusion criteria were as follows: Eastern Cooperative Oncology Group performance status of 2–4 (14), a platelet count of less than 50 × 10^8/µL (50 × 10^8/L), and an international normalized ratio higher than 1.5.

In all patients, axial CT fluoroscopic images were obtained at the level of the maximum tumor diameter by using a four–detector row CT scanner (Asteion; Toshiba Medical Systems, Otawara, Japan). In regard to CT scan parameters, three tube voltages (80, 120, and 135 kV) and three tube currents (10, 20, and 30 mA) were used. In total, nine CT fluoroscopic images were obtained with different CT scan parameters before lung RF ablation or lung biopsy. These CT scan parameters were as follows: parameter A, 80 kV and 10 mA; parameter B, 80 kV and 20 mA; parameter C, 80 kV and 30 mA; parameter D, 120 kV and 10 mA; parameter E, 120 kV and 20 mA; parameter F, 120 kV and

Advances in Knowledge

- Acceptable image quality was achieved in 94% (30 of 32) of patients when the radiation dose was 1.18 mGy/sec (120 kV, 10 mA) and in 100% (32 of 32) of patients when the radiation dose was greater than 1.48 mGy/sec (135 kV, 10 mA).
- CT fluoroscopic image quality improved as the radiation dose increased.
- Although image quality rapidly improved until the radiation dose increased from 0.42 mGy/sec (80 kV, 10 mA) to 1.48 mGy/sec (135 kV, 10 mA), improvement in image quality became more gradual when the radiation dose was greater than 1.48 mGy/sec (135 kV, 10 mA).

Implications for Patient Care

- On the basis of the as-low-as-reasonable-dose-as-reasonably-practicable principle, we suggested that the starting CT fluoroscopic parameter and adjusted CT scan parameters in the performance of lung interventional radiologic procedures form a relationship between radiation dose and image quality, as follows: 120 kV, 10 mA; 135 kV, 10 mA; 120 kV, 20 mA; and 135 kV, 20 mA.
- To prevent excessive radiation exposure, it is noteworthy that improvement in image quality becomes gradual, irrespective of an increase in radiation dose, when the radiation dose becomes greater than 1.48 mGy/sec (135 kV, 10 mA).
Optimal Scan Parameters at Lung CT Fluoroscopy

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Radiation Dose Measurement

Measurements of the radiation dose for each scan parameter were performed by using a polymethyl methacrylate phantom (model 600–7; Radcal, Monrovia, Calif), with a cylinder diameter of 32 cm for the body, and a CT probe (model 10 X 5-3CT; Radcal). Radiation doses were calibrated secondarily by using a national standard dosimeter.
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Table 1

<table>
<thead>
<tr>
<th>Radiation Dose for Each Scan Parameter</th>
<th>Tube Voltage on Console (kV)</th>
<th>Tube Current (mA)</th>
<th>Weighted CT Dose Index per Second (mGy/sec)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80</td>
<td>10</td>
<td>0.42 ± 0.07</td>
</tr>
<tr>
<td>B</td>
<td>80</td>
<td>20</td>
<td>0.84 ± 0.09</td>
</tr>
<tr>
<td>C</td>
<td>80</td>
<td>30</td>
<td>1.27 ± 0.11</td>
</tr>
<tr>
<td>D</td>
<td>120</td>
<td>10</td>
<td>1.16 ± 0.16</td>
</tr>
<tr>
<td>E</td>
<td>120</td>
<td>20</td>
<td>2.35 ± 0.20</td>
</tr>
<tr>
<td>F</td>
<td>120</td>
<td>30</td>
<td>3.55 ± 0.20</td>
</tr>
<tr>
<td>G</td>
<td>135</td>
<td>10</td>
<td>1.48 ± 0.32</td>
</tr>
<tr>
<td>H</td>
<td>135</td>
<td>20</td>
<td>2.98 ± 0.50</td>
</tr>
<tr>
<td>I</td>
<td>135</td>
<td>30</td>
<td>4.46 ± 0.46</td>
</tr>
</tbody>
</table>

* Data are the mean ± standard deviation.

Quantitative Analysis

Four interventional radiologists (H.T., S.M., J.U., and H.K., who had experience in IR procedures for 5, 10, 15, and 20 years, respectively) evaluated the nine CT images obtained with different scan parameters in each patient. The four readers interpreted the images independently, without knowledge of the patient’s name, sex, age, and clinical outcome and the CT scan parameter used. Nine reading sessions were performed by each reader. In each reading session, 32 images were evaluated: one image in each patient. A liquid crystal display (RadiForce RX210; EIZO Nanao, Ishikawa, Japan) was used for image reading; a change in the window setting (width, levels) was allowed. No limit in reading time was imposed. To avoid a learning-curve bias, images for the order of patients and scan parameters were presented in a random fashion. Randomization was performed by one author (Y.Y.) by using a random number list (Microsoft Office Excel; Microsoft, Mountain View, Calif). At least a 1-week interval separated each reading session.

Qualitative analyses were visually performed by each reader by using continuously distributed scales (20). Each image was assigned a score in terms of feasibility of performing lung IR procedures on a scale of zero (not acceptable image quality) to 100 (acceptable image quality). When each reader had judged that the CT image was acceptable for lung IR procedures, a score of 51 or more was assigned. Acceptable CT fluoroscopic images were determined comprehensively by using the agreement of at least three readers (score of 51 or greater). The percentage of acceptable CT fluoroscopic images was then calculated for each scan parameter.

Statistical Analysis

Data related to the radiation dose of each CT scan parameter were expressed as the mean ± standard deviation. Patient demographic characteristics and tumor backgrounds were compared between men and women. The mean values for age, body height, body weight, body mass index, and the maximum tumor diameter were compared by using the Student t test. The proportions of primary and metastatic tumors and tumor location were compared by using the Fisher exact test.

Relationships between the radiation dose and the SNR or CNR were analyzed by using a multiple regression model, with each patient as a covariate. Interobserver agreement was assessed by using the intrarater reliability in evaluating acceptable CT fluoroscopic image quality for lung IR procedures (21,22). The percentages of acceptable CT fluoroscopic images were evaluated. They were also evaluated on the basis of sex. These percentages for each scan parameter were compared between men and women by using the Fisher exact test. The relationship between the radiation dose and the visual image score was analyzed by using a piecewise linear regression model (23), which included the readers and patients as covariates.

All statistical analyses were performed by using software (SAS, release 9.1; SAS Institute, Cary, NC); a P value of less than .05 was considered to indicate a significant difference.

Results

Patients

During May 1 through October 31, 2008, 50 patients underwent CT fluoroscopy–guided lung IR procedures,
including lung RF ablation (n = 47) and lung biopsy (n = 3). Among them, 32 patients met the inclusion criteria and were included in this study (Table 2). Eighteen patients were excluded from this study because they had multiple lung tumors (n = 17) or a large tumor that was more than 3.5 cm in diameter (n = 1). All 32 patients underwent lung RF ablation for the treatment of lung tumor. All patients could hold their breath during CT fluoroscopy.

The mean age of 32 patients was 65.7 years ± 14.1 (standard deviation), and the age range was 23–87 years. There were 13 women and 19 men. There was no significant difference in age between women (mean age, 64.2 years ± 13.0; range, 40–83 years) and men (mean age, 66.7 years ± 15.1; range, 23–87 years) (P = .707). Twenty-three patients had metastatic lung cancer. The other nine patients had primary lung cancer. The mean maximum diameter of the target lung tumor was 1.7 cm (range, 0.7–3.4 cm). Lung tumors were located in the right lobe in 23 patients and in the left lobe in nine patients. Six tumors were located above the aortic arch, 10 tumors were located below the right inferior pulmonary vein, and 16 tumors were located between the aortic arch and the right inferior pulmonary vein. The mean body weight of these patients was 55.7 kg ± 12.0 (range, 38.1–91.5 kg).

Although there were significant differences in body height (P < .001) and weight (P = .01) between men and women (Table 2), the body mass index was almost equal between the two patient groups. On the mean maximum tumor diameter (P = .124), the proportion of primary and metastatic tumors (P = .427), and tumor location (P = .96).

### Radiation Dose Measurement

The results with regard to radiation dose (weighted CT dose index per second) for each scan parameter are presented in Table 1. The value of the weighted CT dose index per second increased as tube voltage and tube current increased.

#### Quantitative Analysis: SNR and CNR

A significant correlation was found between the radiation dose and the SNR of both the lung parenchyma (adjusted \( R^2 = 0.91, P < .0001 \)) and the tumor (adjusted \( R^2 = 0.82, P < .0001 \)). The SNRs of both the lung parenchyma and the tumor increased as the radiation dose increased (Fig 2a, 2b). The CNR, which was also correlated with the radiation dose (adjusted \( R^2 = 0.87, P < .0001 \)) showed almost the same curve as the SNR (Fig 2c). The SNR of lung parenchyma and the CNR decreased at the radiation dose of 1.27 mGy/sec (80 kV, 30 mA) despite an increase in radiation dose, as compared with those at the radiation dose of 1.18 mGy/sec (120 kV, 10 mA) (Fig 2a, 2c).

#### Qualitative Analysis and Acceptable CT Fluoroscopic Images

Acceptable image quality was achieved in 94% (30 of 32) of patients when the radiation dose of 1.18 mGy/sec (120 kV, 10 mA) was used and in 100% (32 of 32) of patients when the radiation dose was greater than 1.48 mGy/sec (135 kV, 10 mA) (Fig 3a). The percentage of patients in whom acceptable image quality was achieved decreased at the radiation dose of 1.27 mGy/sec (80 kV, 30 mA). There were no significant differences between women and men in the percentage of patients in whom acceptable image quality was achieved for each scan parameter (Fig 3b, 3c). The interrater reliability of visual image scores assigned by four readers was 0.77.

From the radiation dose and visual image score (Fig 4), the piecewise linear regression equation was calculated, as follows: \( Y = 38.80 + 48.39X - 0.42X^2 \). Plotting the radiation dose against the number of patients in whom acceptable image quality was achieved, the piecewise linear regression curve showed rapid improvement in image quality until the radiation dose increased from 0.42 mGy/sec (80 kV, 10 mA) to 1.48 mGy/sec (135 kV, 10 mA). The improvement rate of image quality, as calculated by the visual image score (feasibility to perform the lung IR procedure), was 23.30%/mGy/sec when the radiation dose was increased from 0.42 mGy/sec (80 kV, 10 mA) to 1.48 mGy/sec (135 kV, 10 mA). The rate of image quality was only 6.0 per

#### Table 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Female Patients</th>
<th>Male Patients</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>13</td>
<td>19</td>
<td>.07</td>
</tr>
<tr>
<td>Age (y)*</td>
<td>64.2 ± 13.0</td>
<td>66.7 ± 15.1</td>
<td>.707</td>
</tr>
<tr>
<td>Body height (cm)*</td>
<td>151.7 ± 4.8</td>
<td>167.2 ± 5.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Body weight (kg)*</td>
<td>49.4 ± 8.1</td>
<td>60.1 ± 12.4</td>
<td>.01</td>
</tr>
<tr>
<td>Body mass index*</td>
<td>21.6 ± 4.1</td>
<td>21.5 ± 5.1</td>
<td>.963</td>
</tr>
<tr>
<td>Maximum tumor diameter (cm)*</td>
<td>1.5 ± 0.5</td>
<td>1.9 ± 0.8</td>
<td>.124</td>
</tr>
</tbody>
</table>

† Data are the mean ± standard deviation.
* Data are numbers of patients.
milligray per second from 1.48 mGy/sec (135 kV, 10 mA) to 2.98 mGy/sec (135 kV, 20 mA), and it was 2.0 per milligray per second from 2.98 mGy/sec to 4.46 mGy/sec (135 kV, 30 mA).

Discussion
CT fluoroscopy–guided and CT-guided images for lung IR procedures are usually obtained with tube voltage of 120–140 kV and lower tube current rotation time of 25–50 mAs than are usual CT studies (8,11,12,24–26). However, researchers in few reports describe optimal scan parameters for lung CT fluoroscopy.

Lucey et al (8) retrospectively evaluated technical success rates and complications in CT-guided IR by using various CT scan parameters and concluded that the CT scan parameter of 120 kV and 30 mAs is optimal in the performance of lung IR procedures.

Our results showed that, as the radiation dose increased, the SNR and CNR improved, leading to improvement in image quality (27–31). Our results also support the results described by Lucey et al (8). By using the CT scan parameter of 120-kV tube voltage and 30-mA tube current, image quality was acceptable in all patients. However, on the basis of examination of the radiation dose of this parameter, the radiation dose generated from this scan parameter is not small (weighted CT dose index per second, 3.55 mGy/sec). Acceptable image quality can be achieved with a lower radiation dose, as shown in our study. Acceptable CT fluoroscopic images were obtained in all patients.
when the CT scan parameter of 135-kV tube voltage and 10-mA tube current (weighted CT dose index per second, 1.48 mGy/sec) was used. Moreover, acceptable images were obtained in 94% of the patients by using the CT parameter of 120-kV tube voltage and 10-mA tube current (weighted CT dose index per second, 1.18 mGy/sec).
The body structures of patients are known to affect CT images (32,33). For that reason, we cannot come to a conclusion in regard to which CT scan parameter is recommended for all patients. On the basis of the as-low-a-radiation-dose-as-reasonably-practicable principle, we should try to obtain lung CT fluoroscopic images with the scan parameter that provides the least amount of radiation exposure and then change those images to obtain an acceptable image quality. Our results can be a guideline to changing CT scan parameters. In this study, 1.18 mGy/sec (120 kV, 10 mA) was considered the minimum dose to obtain acceptable CT fluoroscopic images for lung IR procedures. We assume that we should start obtaining CT fluoroscopic images at 120 kV and 10 mA and adjust CT scan parameters as follows: 120 kV and 10 mA, 135 kV and 10 mA, 120 kV and 20 mA, and 135 kV and 20 mA. Furthermore, to prevent excessive radiation exposure, it is noteworthy that improvement in image quality becomes gradual, irrespective of an increase in radiation dose, when the radiation dose becomes greater than 1.48 mGy/sec (135 kV, 10 mA).

In our study, the lung parenchyma SNR and CNR and visual image quality were reduced, irrespective of an increase in the radiation exposure, when the radiation dose was 1.27 mGy/sec (80 kV, 30 mA). The lower x-ray transmission energy of 80 kV (effective energy, 34 keV) rather than that of 120 kV (effective energy, 42 keV) might be the cause. When the x-ray transmission energy is low, x-rays are absorbed by the subcutaneous tissues and bone despite an increased radiation dose. Therefore, we cannot recommend the use of a tube voltage of 80 kV when lung IR procedures are performed.

Our study had limitations. First, our results might not be applicable to CT scanners of different manufacturers. Moore et al (34) have reported that radiation doses differed among various manufacturers’ CT scanners. Second, we measured the weighted CT dose index by using the polymethyl methacrylate phantom, not human bodies. Although no consensus exists as to which measurement accurately reflects the radiation dose to the patient, the use of the weighted CT dose index may be just a method problem that leads to an overestimation of the patient’s dose for CT fluoroscopy. However, the use of the weighted CT dose index is a widely accepted method for calculating the index of the CT radiation dose (35). Aside from the use of the weighted CT dose index, other methods exist for CT dose measurement, such as the absorbed dose, the surface dose, the dose-length product, and the effective dose (16,25,36,37). Further evaluation by using these indexes is necessary.

Third, the respective body structures and tumor locations of the patients were not considered in our study because of the small patient series.

Finally, image interpretation was performed by using static images, not real-time images, during lung IR procedures. Further study is required to investigate whether an increase in radiation dose is needed owing to artifacts from IR devices and stress during IR procedures.

In summary, the results of our study indicate that image quality at CT fluoroscopy improves as the radiation dose increases; however, improvement in image quality becomes gradual when the radiation dose is greater than 1.48 mGy/sec (135 kV, 10 mA).

References


