Radiology

ORIGINAL RESEARCH ■ THORACIC IMAGING

Optimal Scan Parameters for CT Fluoroscopy in Lung Interventional Radiologic Procedures: Relationship between Radiation Dose and Image Quality[1]

Yoshikazu Yamao, RT, MSc
Koichiro Yamakado, MD, PhD
Haruyuki Takaki, MD
Tomomi Yamada, PhD
Shuichi Murashima, MD, PhD
Junji Uraki, MD, PhD
Hiroshi Kodama, MD
Naoki Nagasawa, RT, PhD
Kan Takeda, MD, PhD

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.

[1] From the Department of Radiology, Mie University Hospital, 2-174 Edobashi, Tsu 514-8507, Japan (Y.Y., N.N.); and Departments of Radiology (K.Y., H.T., S.M., J.U., H.K., K.T.) and Translational Medical Science (T.Y.), Mie University School of Medicine, Tsu, Japan. Received April 28, 2009; revision requested July 2; final revision received September 27; accepted October 5; final version accepted October 26. **Address correspondence to** Y.Y. (e-mail: *yamao@clin.medic.mie-u.ac.jp*).

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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 Mie 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 hypothesis that there was a 40% difference between the percentage of acceptable CT fluoroscopic images achieved with one scan parameter that provides the best image quality and the percentage achieved with at least one of the other scan parameters. The power analysis was performed by using a two-sided McNemar test with a power of 80%. A significance level of .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 × $10^3/\mu L$ (50 × $10^9/L$), 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-a-radiation-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).

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Abbreviations:
CNR = contrast-to-noise ratio
IR = interventional radiology
RF = radiofrequency
ROI = region of interest
SNR = signal-to-noise ratio

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Guarantors of integrity of entire study, Y.Y., K.Y., H.T.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, Y.Y., K.Y., H.T., T.Y.; clinical studies, Y.Y., K.Y., H.T., S.M., J.U., H.K., K.T.; experimental studies, Y.Y., N.N.; statistical analysis, Y.Y., H.T., T.Y.; and manuscript editing, Y.Y., K.Y., H.T., T.Y., J.U., N.N.

See Materials and Methods for pertinent disclosures.

Figure 1

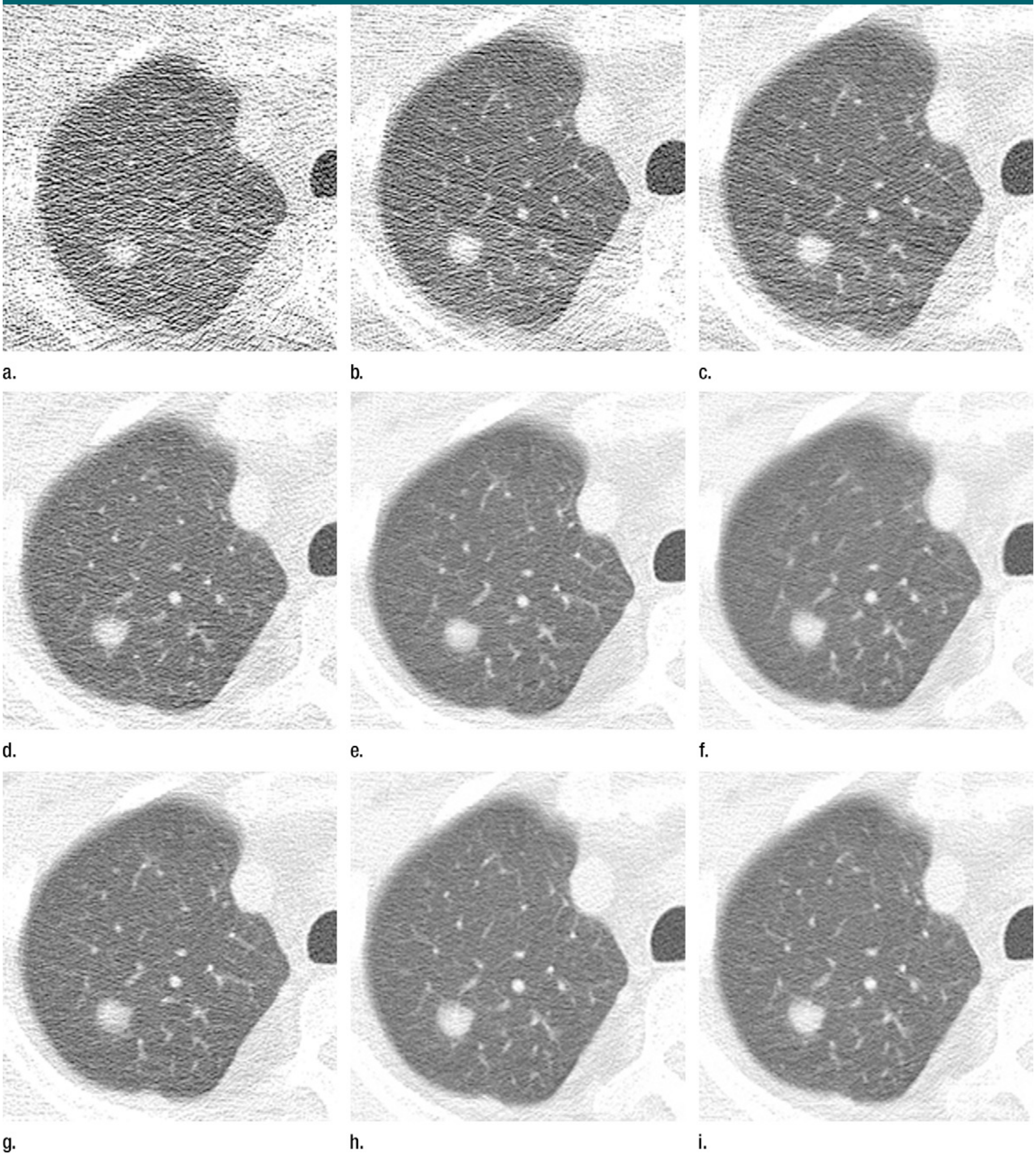

Figure 1: Axial CT fluoroscopic images obtained with **(a)** 80 kV and 10 mA, **(b)** 80 kV and 20 mA, **(c)** 80 kV and 30 mA, **(d)** 120 kV and 10 mA, **(e)** 120 kV and 20 mA, **(f)** 120 kV and 30 mA, **(g)** 135 kV and 10 mA, **(h)** 135 kV and 20 mA, and **(i)** 135 kV and 30 mA scan parameters.

30 mA; parameter G, 135 kV and 10 mA; parameter H, 135 kV and 20 mA; and parameter I, 135 kV and 30 mA (Fig 1, Table 1). Other scan parameters were fixed and were as follows: image thickness, 6 mm; gantry rotation time, 0.75 seconds per rotation; field of view, large; and reconstruction filter algorithm, FC50. We generally used kernel for the lung.

Radiation Dose Measurement

Measurements of the radiation dose for each scan parameter were performed by using a polymethyl methacrylate phantom (model 660–7; Radcal, Monrovia, Calif), with a cylinder diameter of 32 cm for the body, and a CT probe (model 10 × 5-3CT; Radcal). Radiation doses were calibrated secondarily by using a national standard dosimeter

Table 1

Radiation Dose for Each Scan Parameter

Scan Parameter	Tube Voltage on Console (kV)	Tube Current (mA)	Weighted CT Dose Index per Second (mGy/sec)*
A	80	10	0.42 ± 0.07
B	80	20	0.84 ± 0.09
C	80	30	1.27 ± 0.11
D	120	10	1.18 ± 0.16
E	120	20	2.35 ± 0.20
F	120	30	3.55 ± 0.20
G	135	10	1.48 ± 0.32
H	135	20	2.98 ± 0.50
I	135	30	4.46 ± 0.46

* Data are the mean ± standard deviation.

(model A-5 Exradin ion chamber; Standard Imaging, Middleton,Wis) (15). The CT dose index advocated by the recent International Electrotechnical Commission standard (16) was measured. Measurements were repeated five times at the central and peripheral positions of the phantom, with an exposure time of 7.5 seconds. Mean weighted CT dose index per second was used as an index of the radiation dose.

Quantitative Analysis

Two radiologic technologists (Y.Y. and N.N., with 11 and 8 years of experience in CT study, respectively) measured the signal-to-noise ratios (SNRs) of the lung parenchyma and the tumor. Regions of interest (ROIs) were in the lung parenchyma, excluding lung vessels. The ROIs were also in the largest part of the tumor. ROIs were placed sequentially as large as possible both in the lung parenchyma and in the tumor, with the consensus of two radiologic technologists. The same ROIs were placed in nine images obtained with different scan parameters in each patient. The SNR was calculated as follows: SNR = $|C|/\mathrm{SD}$, where C is the CT number and SD is the standard deviation (17,18). The contrast-to-noise ratio (CNR) of each CT image was calculated as follows: CNR = $(|C_{\mathrm{tum}} - C_{\mathrm{lp}}|)/\mathrm{SD}_{\mathrm{lp}}$, where C_{tum} is the CT number of the tumor, C_{lp} is the CT number of lung parenchyma, and $\mathrm{SD}_{\mathrm{lp}}$ is the standard deviation of lung parenchyma (19).

Qualitative 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 interrater 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. 0in 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.

Table 2

Patients' Background according to Sex

Characteristic	Female Patients	Male Patients	*P* Value
No. of patients	13	19	...
Age (y)*	64.2 ± 13.0	66.7 ± 15.1	.707
Body height (cm)*	151.7 ± 4.8	167.2 ± 5.1	<.001
Body weight (kg)*	49.4 ± 8.1	60.1 ± 12.4	.01
Body mass index*	21.6 ± 4.1	21.5 ± 5.1	.963
Maximum tumor diameter (cm)*	1.5 ± 0.5	1.9 ± 0.8	.124
Tumor type†			.427
Primary	5	4	
Metastatic	8	15	
Tumor location†			.96
Upper	2	4	
Middle	7	9	
Lower	4	6	

* Data are the mean ± standard deviation.

† Data are numbers of patients.

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: $Y = 38.80 + 48.39\langle X - 0.42\rangle - 19.13\langle X - 0.84\rangle - 23.30\langle X - 1.48\rangle - 3.95\langle X - 2.98\rangle$, where Y was the visual image score (feasibility to perform the lung IR procedure), and $\langle X\rangle$ was the max $\{0, X\}$ of the radiation dose.

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 (ie, the visual score improvement per one weighted CT dose index per second) was 48.4 per milligray per second from 0.42 mGy/sec (80 kV, 10 mA) to 0.84 mGy/sec (80 kV, 20 mA), and it was 29.3 per milligray per second from 0.84 mGy/sec to 1.48 mGy/sec (135 kV, 10 mA). When the radiation dose was greater than 1.48 mGy/sec (135 kV, 10 mA), improvement in image quality became more gradual. The improvement rate of image quality was only 6.0 per

Figure 2

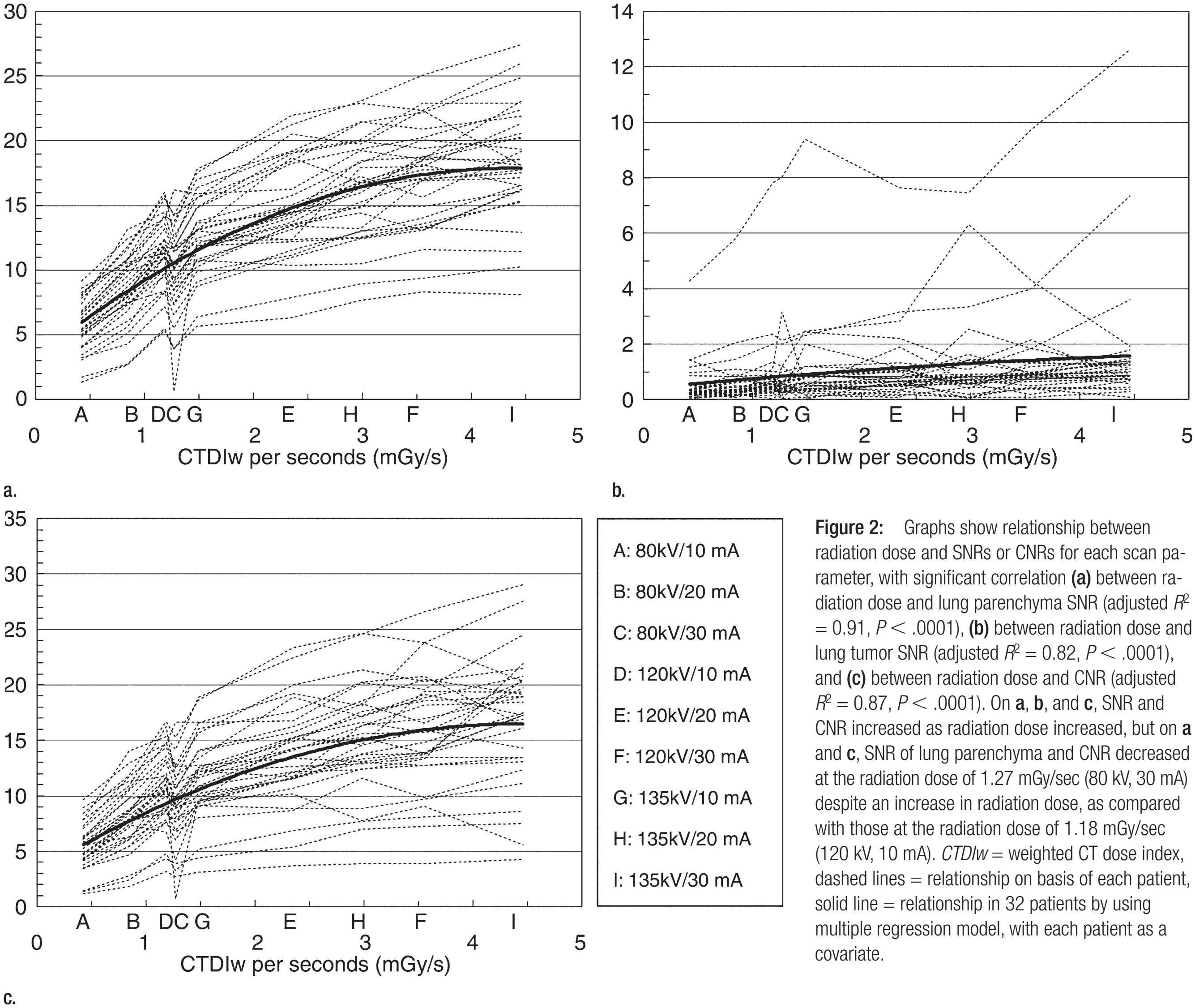

Figure 2: Graphs show relationship between radiation dose and SNRs or CNRs for each scan parameter, with significant correlation **(a)** between radiation dose and lung parenchyma SNR (adjusted $R^2 = 0.91$, $P < .0001$), **(b)** between radiation dose and lung tumor SNR (adjusted $R^2 = 0.82$, $P < .0001$), and **(c)** between radiation dose and CNR (adjusted $R^2 = 0.87$, $P < .0001$). On **a**, **b**, and **c**, SNR and CNR increased as radiation dose increased, but on **a** and **c**, SNR of lung parenchyma and 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). *CTDIw* = weighted CT dose index, dashed lines = relationship on basis of each patient, solid line = relationship in 32 patients by using multiple regression model, with each patient as a covariate.

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

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Figure 3

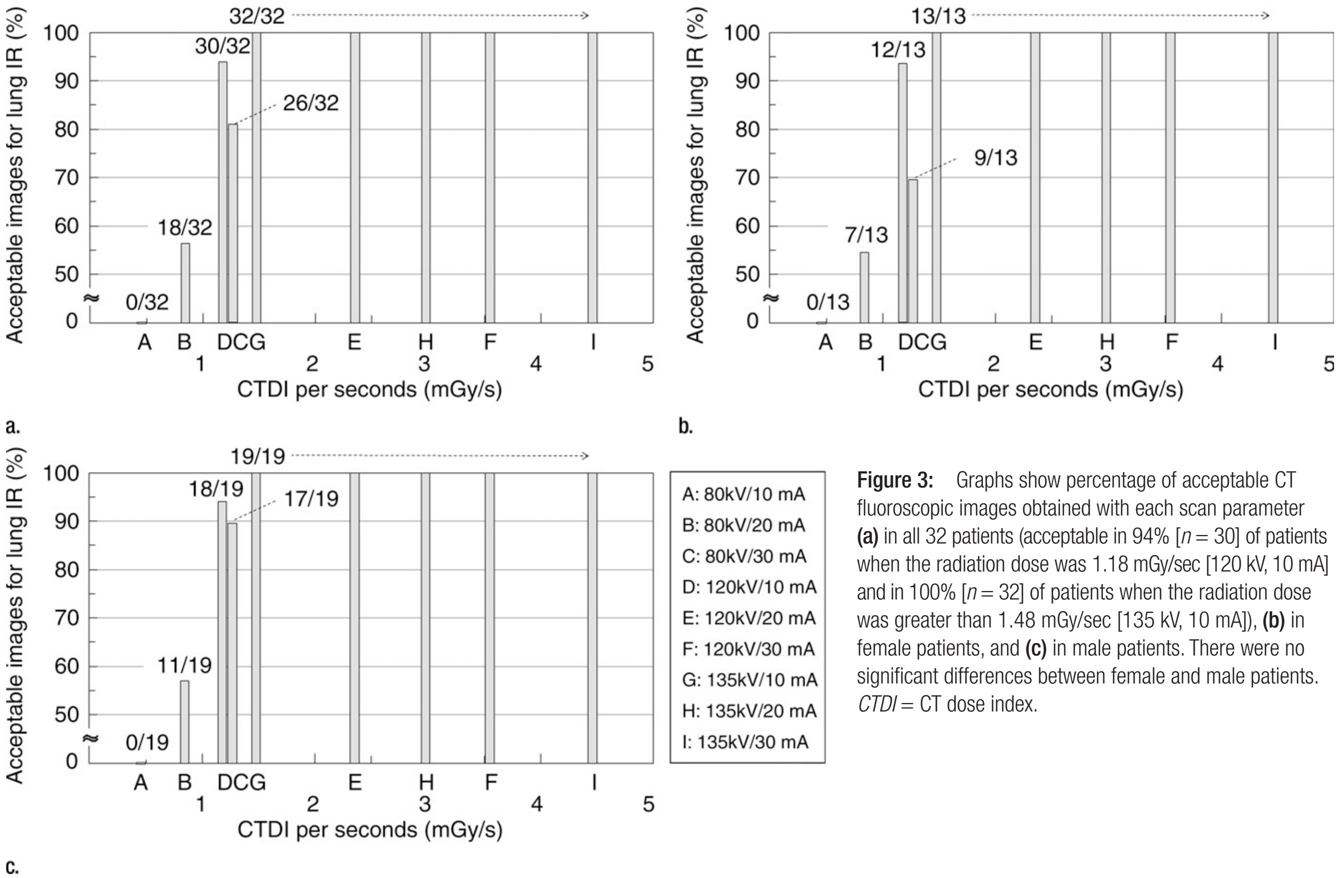

Figure 3: Graphs show percentage of acceptable CT fluoroscopic images obtained with each scan parameter **(a)** in all 32 patients (acceptable in 94% [$n = 30$] of patients when the radiation dose was 1.18 mGy/sec [120 kV, 10 mA] and in 100% [$n = 32$] of patients when the radiation dose was greater than 1.48 mGy/sec [135 kV, 10 mA]), **(b)** in female patients, and **(c)** in male patients. There were no significant differences between female and male patients. *CTDI* = CT dose index.

Figure 4

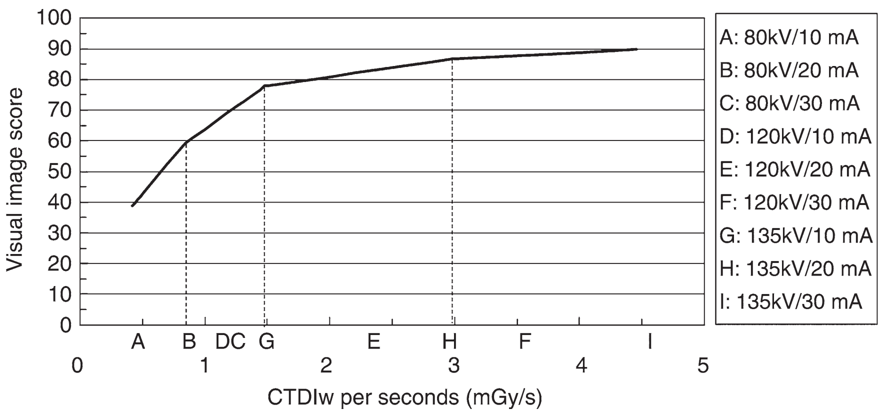

Figure 4: Graph shows relationship between radiation dose and visual image score (piecewise linear regression equation). Piecewise linear regression equation showed improvement in image quality as the radiation dose increased. Three flexion points existed for scan parameters B (80 kV, 20 mA), G (135 kV, 10 mA), and H (135 kV, 20 mA). Piecewise linear regression equation 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). Improvement rate of image quality was 48.4 per mGy/sec from 0.42 mGy/sec (80 kV, 10 mA) to 0.84 mGy/sec (80 kV, 20 mA) and 29.3 per mGy/sec from 0.84 mGy/sec (80 kV, 20 mA) to 1.48 mGy/sec (135 kV, 10 mA). In contrast, irrespective of increase in radiation dose greater than 1.48 mGy/sec (135 kV, 10 mA), the improvement rate in image quality became gradual. Improvement rate of image quality was 6.0 per mGy/sec from 1.48 mGy/sec (135 kV, 10 mA) to 2.98 mGy/sec (135 kV, 20 mA) and 2.0 per mGy/sec from 2.98 mGy/sec (135 kV, 20 mA) to 4.46 mGy/sec (135 kV, 30 mA). *CTDIw* = weighted CT dose index.

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

1. Ambrogi MC, Lucchi M, Dini P, et al. Percutaneous radiofrequency ablation of lung tumours: results in the mid-term. Eur J Cardiothorac Surg 2006;30(1):177–183.
2. Fernando HC. Radiofrequency ablation to treat non-small cell lung cancer and pulmonary metastases. Ann Thorac Surg 2008;85(2):S780–S784.
3. Lencioni R, Crocetti L, Cioni R, et al. Response to radiofrequency ablation of pulmonary tumours: a prospective, intention-to-treat, multicentre clinical trial (the RAPTURE study). Lancet Oncol 2008;9(7):621–628.
4. Simon CJ, Dupuy DE, DiPetrillo TA, et al. Pulmonary radiofrequency ablation: long-term safety and efficacy in 153 patients. Radiology 2007;243(1):268–275.
5. Suh RD, Wallace AB, Sheehan RE, Heinze SB, Goldin JG. Unresectable pulmonary malignancies: CT-guided percutaneous radiofrequency ablation—preliminary results. Radiology 2003;229(3):821–829.
6. Wolf FJ, Grand DJ, Machan JT, Dipetrillo TA, Mayo-Smith WW, Dupuy DE. Microwave ablation of lung malignancies: effectiveness, CT findings, and safety in 50 patients. Radiology 2008;247(3):871–879.
7. Yamakado K, Hase S, Matsuoka T, et al. Radiofrequency ablation for the treatment of unresectable lung metastases in patients with colorectal cancer: a multicenter study in Japan. J Vasc Interv Radiol 2007;18(3):393–398.
8. Lucey BC, Varghese JC, Hochberg A, Blake MA, Soto JA. CT-guided intervention with low radiation dose: feasibility and experience. AJR Am J Roentgenol 2007;188(5):1187–1194.
9. Kim TJ, Lee JH, Lee CT, et al. Diagnostic accuracy of CT-guided core biopsy of ground-glass opacity pulmonary lesions. AJR Am J Roentgenol 2008;190(1):234–239.
10. Meyer CA. "Transthoracic needle aspiration biopsy of benign and malignant lung lesions": a commentary. AJR Am J Roentgenol 2007;188(4):891–893.
11. Meyer CA, White CS, Wu J, Futterer SF, Templeton PA. Real-time CT fluoroscopy: usefulness in thoracic drainage. AJR Am J Roentgenol 1998;171(4):1097–1101.
12. Katada K, Kato R, Anno H, et al. Guidance with real-time CT fluoroscopy: early clinical experience. Radiology 1996;200(3):851–856.
13. The 2007 recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007;37(2–4):1–332.
14. Oken MM, Creech RH, Tormey DC, et al. Toxicity and response criteria of the Eastern Cooperative Oncology Group. Am J Clin Oncol 1982;5(6):649–655.
15. Japanese Standards Association. Japanese Industrial Standards. Methods of calibration for exposure meters, air kerma meters, air absorbed dose meters and dose-equivalent meters [in Japanese]. JIS Z 4511. Tokyo, Japan: Japanese Standards Association, 2005.
16. International Electrotechnical Commission. Medical electrical equipment: part 2-44—particular requirements for the safety of x-ray equipment for computed tomography. Document no. 60601-2-44. 3rd ed. Geneva, Switzerland: International Electrotechnical Commission, 2009.

17. Kalra MK, Maher MM, Sahani DV, et al. Low-dose CT of the abdomen: evaluation of image improvement with use of noise reduction filters—pilot study. Radiology 2003;228(1):251–256.

18. Nakayama Y, Awai K, Funama Y, et al. Abdominal CT with low tube voltage: preliminary observations about radiation dose, contrast enhancement, image quality, and noise. Radiology 2005;237(3):945–951.

19. Gupta AK, Nelson RC, Johnson GA, Paulson EK, Delong DM, Yoshizumi TT. Optimization of eight-element multi-detector row helical CT technology for evaluation of the abdomen. Radiology 2003;227(3):739–745.

20. Metz CE, Herman BA, Shen JH. Maximum likelihood estimation of receiver operating characteristic (ROC) curves from continuously-distributed data. Stat Med 1998;17(9):1033–1053.

21. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psychol Bull 1979;86(2):420–428.

22. Fleiss JL. The design and analysis of clinical experiments. New York, NY: Wiley, 1986.

23. Nakamura T. BMDP program for piecewise linear regression. Comput Methods Programs Biomed 1986;23(1):53–55.

24. Teeuwisse WM, Geleijns J, Broerse JJ, Obermann WR, van Persijn van Meerten EL. Patient and staff dose during CT guided biopsy, drainage and coagulation. Br J Radiol 2001;74(884):720–726.

25. Tsalafoutas IA, Tsapaki V, Triantopoulou C, Gorantonaki A, Papailiou J. CT-guided interventional procedures without CT fluoroscopy assistance: patient effective dose and absorbed dose considerations. AJR Am J Roentgenol 2007;188(6):1479–1484.

26. White CS, Templeton PA, Hasday JD. CT-assisted transbronchial needle aspiration: usefulness of CT fluoroscopy. AJR Am J Roentgenol 1997;169(2):393–394.

27. Itoh S, Ikeda M, Arahata S, et al. Lung cancer screening: minimum tube current required for helical CT. Radiology 2000;215(1):175–183.

28. Lee JY, Chung MJ, Yi CA, Lee KS. Ultra-low-dose MDCT of the chest: influence on automated lung nodule detection. Korean J Radiol 2008;9(2):95–101.

29. Mayo JR, Hartman TE, Lee KS, Primack SL, Vedal S, Müller NL. CT of the chest: minimal tube current required for good image quality with the least radiation dose. AJR Am J Roentgenol 1995;164(3):603–607.

30. Zhu X, Yu J, Huang Z. Low-dose chest CT: optimizing radiation protection for patients. AJR Am J Roentgenol 2004;183(3):809–816.

31. Rusinek H, Naidich DP, McGuinness G, et al. Pulmonary nodule detection: low-dose versus conventional CT. Radiology 1998;209(1):243–249.

32. Schindera ST, Nelson RC, Toth TL, et al. Effect of patient size on radiation dose for abdominal MDCT with automatic tube current modulation: phantom study. AJR Am J Roentgenol 2008;190(2):W100–W105.

33. Huda W, Scalzetti EM, Levin G. Technique factors and image quality as functions of patient weight at abdominal CT. Radiology 2000;217(2):430–435.

34. Moore WH, Bonvento M, Olivieri-Fitt R. Comparison of MDCT radiation dose: a phantom study. AJR Am J Roentgenol 2006;187(5):W498–W502.

35. Theocharopoulos N, Perisinakis K, Damilakis J, Karampekios S, Gourtsoyiannis N. Dosimetric characteristics of a 16-slice computed tomography scanner. Eur Radiol 2006;16(11):2575–2585.

36. Martin CJ. Radiation dosimetry for diagnostic medical exposures. Radiat Prot Dosimetry 2008;128(4):389–412.

37. Tsapaki V, Aldrich JE, Sharma R, et al. Dose reduction in CT while maintaining diagnostic confidence: diagnostic reference levels at routine head, chest, and abdominal CT—IAEA-coordinated research project. Radiology 2006;240(3):828–834.