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APPLICATION OF SUBSECOND ROTATION SCAN TO HELICAL CT FOR LUNG CANCER SCREENING

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ABSTRACT

Purpose: To clarify whether the benefit of a reduced effective scan width obtained using a smaller pitch outweighs the disadvantage of increased noise in the application of a subsecond helical CT to mass screenings for lung cancer.

Materials and Methods: Twenty-two helical CT scans of the lung were obtained in 11 healthy subjects using the following parameters: 1) scan 1 was performed at 120 kVp, 50 mA, 10-mm collimation, 1-second/rotation, helical pitch of 2.0; and 2) scan 2 was performed at 120 kVp, 50 mA, 10-mm collimation, 0.75-second/rotation, helical pitch of 1.5. Computer-generated nodules measuring 10 mm and 6 mm in diameter showing ground-glass opacity were superimposed on these images. The detectability of each nodule was evaluated by six blinded readers using ROC analysis.

Results: Detectability of the 6-mm nodules was significantly higher in scan 2 than in scan 1. Detectability of the 10-mm nodules was not significantly different between scans 1 and 2.

Conclusion: The use of a smaller pitch by employing a subsecond rotation scan in a helical CT for lung cancer screenings improves the detection of small lesions without increasing either the scanning time or radiation dose.

Key Words: Computed tomography (CT), Cancer screening, Lung neoplasm

INTRODUCTION

Lung cancer is now the leading cause of cancer deaths in Japan. In general, its prognosis is poor, and the most effective treatment is surgical resection. Peripheral lung cancers usually produce no symptoms until the disease reaches a fairly advanced stage. Although in Japan mass screenings for lung cancer are currently performed using chest radiography, previous studies have demonstrated that this method is ineffective reducing the mortality rate.[1,2)] Recently, attempts have been made to apply helical CT to mass screenings for lung cancer.[3-5)] At the beginning of this screening, the scan speed in helical CT was 1 second for a 360° rotation, and such screening CT examinations are currently performed using scan parameters of 120 kVp, 50 mA, 10-mm collimation, and a helical pitch of 2.0 at most institutions in Japan in order to reduce the radiation dose and to scan the entire lung easily during a single breath-hold.

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Helical CT examinations of the lung are usually performed at a pitch of less than 1.5 in a clinical setting.[6,7] Although the lung parenchyma may be a suitable tissue for helical CT with an increased pitch due to the high inherent contrast between normal lung parenchyma and soft-tissue-density lesions,[8] the use of a relatively large pitch such as 2.0 leads to a degradation of image quality due to an increase in the effective scan width and may increase the risk of missing small lesions showing ground-glass opacity. Subsecond rotation helical CT scanners make it possible to employ a smaller pitch, such as 1.5, without prolonging the scanning time. However, one disadvantage is that, at the same tube current, noise is increased due to the reduction in dose in each rotation. Therefore, the purpose of this study was to determine whether the benefit of the reduced effective scan width obtained using a smaller pitch outweighs the disadvantage of increased noise in a subsecond rotation helical CT for lung cancer screenings.

MATERIALS AND METHODS

We randomly selected 11 subjects (9 men and 2 women; age range, 39–61 years; mean age, 56 years) from about seventy subjects who underwent lung cancer screenings using helical CT in both 1997 and 1998 at Nagoya Memorial Hospital and who showed no abnormal findings on their CT images. All scans were obtained with a helical CT scanner (Xvigor Toshiba Co., Ltd., Tokyo, Japan). Helical CT for lung cancer screening was performed with fixed scan parameters of 120 kVp, 50 mA, and 10-mm collimation in both years. In 1997 (scan 1), a helical pitch of 2.0 was employed with a scan time of 1 second/rotation (table feed speed, 20 mm/second). In 1998 (scan 2), the CT scanner was upgraded to permit a scan time of 0.75 second/rotation, and the helical pitch was reduced to 1.5 (table feed speed, 20 mm/second). Both the scan time and total radiation dose in each examination were the same using the two sets of scan parameters. The entire lung was scanned during a single breath-hold at maximal inspiration. Images were reconstructed at 10-mm intervals with 180° linear interpolation using lung window settings (window width, 1600 HU; window level, –600 HU). The images in this study were viewed only at lung window settings. Computer-generated nodules measuring approximately 10 mm and 6 mm in diameter were synthesized by increasing the CT number in areas 12 pixels and 8 pixels in diameter, respectively, and these simulated nodules were superimposed on the images.[9,10] Increases in the CT numbers of these nodules relative to the CT number of the background lung tissue were distributed exponentially as described in our previous study.[10] Since a larger pitch results in an increase in the effective scan width, the increase in the CT number at the center of the simulated nodules was specified relative to the height of the CT profile curve obtained by scanning acrylic balls measuring 10 mm and 6 mm in diameter embedded in a piece of styrofoam. Accordingly, the differences in CT number between the centers of the nodules and the lung parenchyma were as follows: 147 HU and 174 HU at pitches of 2.0 and 1.5, respectively, for nodules 8 pixels in diameter, and 186 HU and 200 HU at pitches of 2.0 and 1.5, respectively, for nodules 12 pixels in diameter. Sixteen to 20 nodules were added to the images obtained in each examination, and nodules location were equalized with regard to the following region of the lung: a) level of the nodules, as defined by dividing the scanned images into an upper zone (above the aortic arch), middle zone, and lower zone (below the right inferior pulmonary vein); b) central or peripheral distribution of the nodules, in which the peripheral area was defined as the outer 2 cm of lung parenchyma along the chest wall; and c) ventral and dorsal distribution of the nodules, in which the border was defined as the midpoint of the anteroposterior diameter of the thorax. In the present study, any region of the lung did not have two or more than two nodules. In each examination performed on the same subject, the simulated nodules were placed at the same locations in order to permit the effects of the scan parameters on the images to be evaluated without any interference due to differences in the nodule locations. Six experienced radiologists who were blinded to the location of the nodules as well as the scan parameters used to acquire the CT images, reported the location of each suspected nodule and indicated their confidence level that a nodule was actually present at that location using a continuous rating scale from 0 to 1. In this rating scale, 0 and 1 corresponded to the definite absence and the definite presence of a nodule, respectively. In order to prevent the readers from learning where the nodules were located, the CT images obtained from the same subject were not evaluated successively in the reading order, i.e., they were mixed with images from other subjects, with more than two other images interpreted. Each reader's performance in the detection of simulated nodules was evaluated by using receiver operating characteristic (ROC) analysis. The influence of the scan parameters on the detectability of simulated nodules was also analyzed for the following region of the lung: a) all lung; b) upper zone, middle zone and lower zone; c) central and peripheral. A value of $p<0.05$ was considered statistically significant.

RESULTS

Results for the detectability of simulated nodules are summarized in Tables 1 and 2. The detectability of nodules measuring 6 mm in diameter in scan 2 (at a helical pitch of 1.5 and 0.75 second/rotation) was significantly higher than that in scan 1 (at a helical pitch of 2.0 and 1 second/rotation) (Table 1, Fig. 1). On the other hand, there was no significant difference

Table 1 Detectability results for simulated nodules 6 mm in diameter.

	Scan 1	Scan 2	P
all lung	0.8685 ±0.0281	0.9741 ±0.0060	<0.05
upper	0.8990 ±0.0304	0.9754 ±0.0052	<0.05
middle	0.8265 ±0.0533	0.9595 ±0.0149	<0.05
lower	0.8895 ±0.0276	0.9741 ±0.0069	<0.05
central	0.8653 ±0.0340	0.9768 ±0.0067	<0.05
peripheral	0.8817 ±0.0402	0.9657 ±0.0077	<0.05

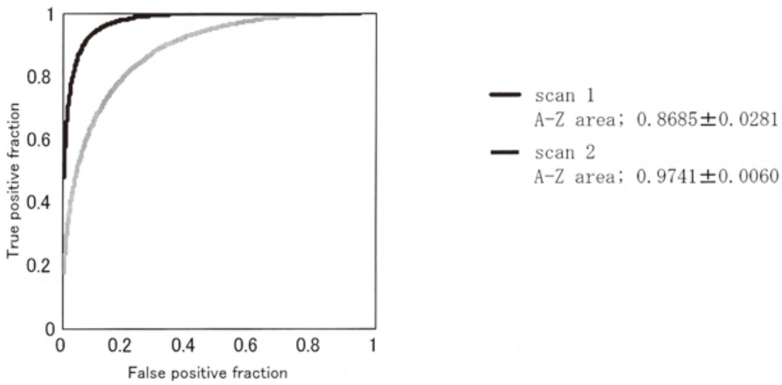

Fig. 1 Detectability of simulated nodules 6 mm in diameter.
Detectability of nodules measuring 6 mm in diameter in scan 2 at helical pitch of 1.5 and 0.75 sec/rotation is significantly higher than in scan 1 at helical pitch of 2.0 and 1 sec/rotation.

between scans 1 and 2 in the detectability of nodules measuring 10 mm in diameter (Table 2). Furthermore, with regard to the 6-mm nodules, the detectability in scan 2 was significantly higher than that in scan 1 in all regions of the lung, while there was no significant difference between scans 1 and 2 in the detectability of the 10-mm nodules in any region (Fig. 2).

Table 2 Detectability results for simulated nodules 10 mm in diameter.

	Scan 1	Scan 2	P
all lung	0.9900 ±0.0063	0.9967 ±0.0032	NS
upper	0.9851 ±0.0103	0.9939 ±0.0042	NS
middle	0.9439 ±0.0360	0.9534 ±0.0273	NS
lower	0.9888 ±0.0064	0.9724 ±0.0117	NS
central	0.9887 ±0.0043	0.9896 ±0.0032	NS
peripheral	0.9479 ±0.0359	0.9639 ±0.0146	NS

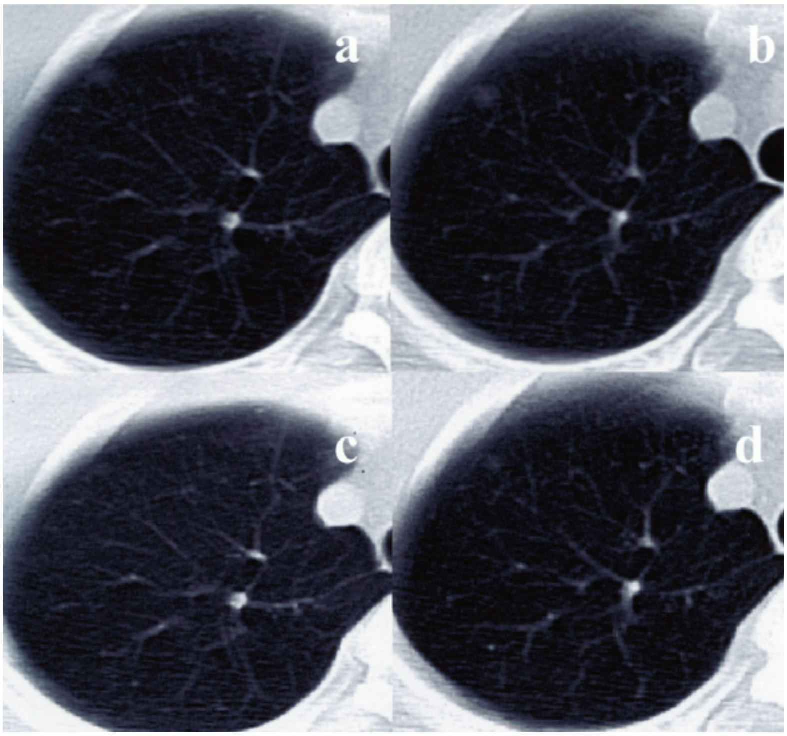

Fig. 2 Upper zone of the lung in case 6.
a) Simulated nodule 10 mm in diameter scanned with a helical pitch of 2.0 and a scan speed of 1 sec/rotation.
b) Simulated nodule 10 mm in diameter scanned with a helical pitch of 1.5 and a scan speed of 0.75 sec/rotation.
c) Simulated nodule 6 mm in diameter scanned with a helical pitch of 2.0 and a scan speed of 1 sec/rotation.
d) Simulated nodule 6 mm in diameter scanned with a helical pitch of 1.5 and a scan speed of 0.75 sec/rotation. Simulated nodules are superimposed at the same locations in all figures. It is possible to detect all 10-mm nodules (a, b), but the 6-mm nodules are less conspicuous in c than in d.

DISCUSSION

Helical CT in mass screening for lung cancer at most institutions in Japan is currently performed with scan parameters of 120 kVp, 50 mA, 1 second/rotation, 10-mm collimation, and a helical pitch of 2.0 in order to minimize both the scan time and radiation dose.[3)] Advances in technology permitting a scan speed of 0.75 second/rotation have made it possible to cover the entire lung using a helical pitch of 1.5 in the same scan time. Based on the results of previous studies,[11-13)] there are some differences in physical performance characteristics between a helical pitch of 2.0 at a scan speed of 1 second/rotation and a helical pitch of 1.5 at a scan speed of 0.75 second/rotation. A reduction in pitch from 2.0 to 1.5 results in a decrease of about 12% in full width at half maximum in the Z-axis with 180° linear interpolation. On the other hand, it is necessary to use the same tube current in both scans because a helical CT with a subsecond rotational scan for lung cancer screening must avoid any increase in the radiation dose. Since noise is inversely proportional to the square root of amperage × scan speed (mAs), the noise at a helical pitch of 1.5 at 0.75 second/rotation is about 18% greater than that at a helical pitch of 2 at 1 second/rotation. Therefore, this study was conducted to clarify the effects of such differences in physical performance characteristics on the diagnostic capabilities of helical CT for lung cancer screenings.

Previous studies have shown that computer-generated nodules can be used to assess a large number of imaging variables.[14)] This method allowed us to manipulate the nodules characteristics, such as their location, attenuation, and size, to achieve the acceptable image quality required for helical CT in lung cancer screening and to assess the influence of the scan parameters on diagnostic capabilities more objectively than is possible with the simple assessment of image quality.

The objective of helical CT for lung cancer screening is to detect potentially curable cancers with a high degree of certainty. With regard to the prognosis of lung cancers, various findings have been reported. Some studies have shown better long-term survival in patients with tumors measuring less than 10 or 20 mm in diameter.[15,16)] The invasion into lymphatic vessels by peripheral lung cancers has been closely related to the prognosis.[17)] The frequency of such invasions is increased in proportion to the tumor size, and more than 40% of tumors over 10 mm in diameter have already invaded the lymphatic vessels.[18)] Patients with adenocarcinomas of the lung with little fibrosis tend to have a good prognosis.[19)] Thus, it is speculated that potentially curable lung cancers appear as focal areas less than 10 mm in diameter showing ground-glass opacity on CT images. Therefore, in the present study, computer-generated nodules were synthesized using such potentially curable cancers as a model.

The present study has demonstrated that scanning with a helical pitch of 1.5 at 0.75 second/rotation is significantly superior to scanning with a helical pitch of 2.0 at 1 second/rotation in the detection of nodules measuring 6 mm in diameter, although no significant difference was observed between the two scanning methods in the detection of nodules measuring 10 mm in diameter. These results indicate that, despite the increase in noise, a decrease in full width at half maximum in the Z axis improves the detection, especially of small, faint lesions. The main reason is that a smaller pitch results in a narrower section-sensitivity profile, which will tend to increase the contrast due to a reduction in partial volume artifacts. This improvement is expected to be useful to avoid missing early curable cancers.

Wright *et al.* also reported that a bias toward the undercounting of pulmonary nodules was noted in scans performed using a helical pitch of 1.5 or 2.0; however, this finding was not statistically significant.[8)] In their study, the targeted nodules varied in terms of their characteristics, such as attenuation and size, and the detectability of nodules in the two scanning methods was compared to that with a helical pitch of 1.0. In order to more precisely assess the differences in the detectability of nodules between helical pitches of 1.5 and 2.0, we conducted a study in the following manner. Simulated nodules modeled after potentially curable lung cancers were generated based on the CT profile curve obtained at the same helical pitch as the CT images. The nodules were then superimposed at the same locations for each examination performed on the same subject in order to minimize any possible effects of differences among individual nodules and/or subjects. Furthermore, the detectability of the nodules was directly compared between helical pitches of 1.5 and 2.0 based on the confidence level assessed using a continuous rating scale by a sufficiently large number of readers. Thus, the findings of the present study have demonstrated that the detectability of small nodules is significantly improved by using a helical pitch of 1.5 in a subsecond rotational helical CT.

Previous studies have demonstrated that use of a helical CT for lung cancer screening enables detection of a large number of pulmonary nodules, the majority of which are found to be benign.[20,21] Further studies are required to establish the proper protocol for the management of these nodules. Henschke *et al.* recommended that nodules smaller than 5 mm in diameter detected on the initial CT images do not justify an immediate work-up but only call for an annual repeat screening to determine whether interim growth has occurred.[21] Yankelevitz *et al.* reported that the growth rate from CT volumetric measurements could be used to distinguish benign from malignant nodules.[22] As to the protocols, it is critical to adopt scan parameters that allow the depiction of small nodules with more reliability on screening CT. The results of this study have proved that reducing a pitch is suitable for that purpose, and that those results would be applicable when multislice CT is used.

In conclusion, the use of a lower pitch by employing a subsecond rotational scan in helical CT for lung cancer screening helps to improve the detection of small lesions without increasing either the scanning time or radiation dose.

REFERENCES

1) Flehiger B.J., Kimmel M. and Melamed M.R.: Natural history of adenocarcinoma-large cell carcinoma of the lung. *J. Natl. Cancer Inst.*, 80, 37–344 (1988).
2) Soda H., Tomita H., Kohno S. and Oka M.: Limitations of annual screening chest radiography for the diagnosis of lung cancer; a retrospective study. *Cancer*, 72, 2341–2346 (1993).
3) Kaneko M., Eguchi K., Ohmatsu H., Kakinuma R., Naruke T., Suemasu K. and Moriyama N.: Peripheral lung cancers; screening and detection with low-dose spiral CT versus radiography. *Radiology*, 201, 798–802 (1996).
4) Sone S., Takashima S., Li F., Yang Z., Honda T., Maruyama Y., Hasegawa M., Yamanda T., Kubo K., Hanamura K. and Asakura K.: Mass screening for lung cancer with mobile spiral computed tomography scanner. *Lancet*, 351, 1242–1245 (1998).
5) Henschke C.I., McCauley D.I., Yankelevitz D.F., Naidish D.P., McGuinness G., Miettinen O.S., Libby D.M., Pasmantier M.W., Koizumi J., Altorki N.K. and Smith J.P.: Early Lung Cancer Action Project; overall design and findings from baseline screening. *Lancet*, 354, 99–105 (1999).
6) Remy-Jardin M., Remy J., Girayd F. and Marquette C.H.: Pulmonary nodules: detection with thick-section spiral CT versus conventional CT. *Radiology*, 187, 513–520 (1993).
7) Kalender W.A., Seisser W., Klotz E. and Vock P.: Spiral volumetric CT with single-breath-hold technique, continuous transport and continuous scanner rotation. *Radiology*, 176, 181–183 (1990).
8) Wright A.R., Collie D.A., Williams J.R., Hashemi-Malayeri B., Stevenson A.J. and Turnbull C.M.: Pulmonary nodules; effect on detection of spiral CT pitch. *Radiology*, 199, 837–841 (1996).
9) Itoh S., Ikeda M., Isomura T., Endo T., Yamakawa K., Itoh K., Naganawa S., Maruyama K. and Ishigaki T.: Screening helical CT for mass screening of lung cancer; application of low-dose and single-breath-hold scanning. *Radiat. Med.*, 16, 75–83 (1998).
10) Itoh S., Ikeda M., Arahata S., Kodaira T., Isomura T., Kato T., Yamakawa K., Maruyama K. and Ishigaki T.:

Lung cancer screening; minimum tube current required for helical CT. *Radiology*, 215, 175–183 (2000).
11) Polacin A., Kalender W.A. and Marchal G.: Evaluation of section sensitivity profiles and image noise in spiral CT. *Radiology*, 185, 29–35 (1992).
12) Kalender W.A. and Polacin A.: Physical performance characteristics of spiral CT scanning. *Med.Phys*., 18, 910–915 (1991).
13) Reynolds M.D., Heuscher D.J. and Vembar M.: Evaluation of spiral CT on a fourth generation system. *Eur. Radiology*, 5, 102–109 (1995).
14) Rusinek H., Naidich D., McGuinness G., Leitman B.S., McCauley D.I., Krinsky GA., Clayton K. and Cohen H.: Pulmonary nodule detection; low-dose versus conventional CT. *Radiology*, 209, 243–249 (1998).
15) Martini N., Bains M.S., Burt M.E., Zakowski M.F., McCormack P., Rusch V.W. and Ginsberg R.J.: Incidence of local recurrence and second primary tumors in resected stage I lung cancer. *J. Thorac. Cardiovasc. Surg.*, 109, 120–129 (1995).
16) Suzuki K., Nagai K., Yoshida J., Nishimura M., Takahashi K., Yokose T. and Nishiwaki Y.: Conventional clinicopathologic prognostic factors in surgically resected nonsmall cell lung carcinoma; a comparison of prognostic factors for each pathologic TNM stage based on multivariate analyses. *Cancer*, 86, 1976–1984 (1999).
17) Kurokawa T., Matsuno Y., Noguchi M., Mizuno S. and Shimosato Y.: Surgically curable "early" adenocarcinoma in the periphery of the lung. *Am. J. Surg. Pathol.*, 18, 431–438 (1994).
18) Ichinose Y., Yano T., Yokoyama H., Inoue T., Asoh H. and Katsuda Y.: The correlation between tumor size and lymphatic vessel invasion in resected peripheral stage I non-small-cell lung cancer; a potential risk of limited resection. *J. Thorac. Cardiovasc. Surg.*, 108, 684–686 (1994).
19) Noguchi M., Morikawa A., Kawasaki M., Matsuno Y., Yamada T., Hirohashi S., Kondo H. and Shimosato Y.: Small adenocarcinoma of the lung. *Cancer*, 75, 2844–2852 (1995).
20) Swensen S.J., Jett J.R., Hartman T.E., Midthun D.E., Sloan J.A., Sykes A.M., Aughenbaugh G.L. and Clemens M.A.: Lung cancer screening with CT; Mayo clinic experience. *Radiology*, 226, 756–761 (2003).
21) Henschke C.I., Yankelevitz D.F., Naidich D.P., McCauley D.I., McGuinnes G., Libby D.M., Smith J.P., Pasmantier M.W. and Miettinen O.S.: CT screening for lung cancer; suspiciousness of nodules according to size on baseline CT. *Radiology*, 231, 164–168 (2003).
22) Yankelevitz D.F., Reeves A.P., Kostis W.J., Zhao B. and Henschke C.I.: Small pulmonary nodules; volumetrically determined growth rates based on CT evaluation. *Radiology*, 217, 251–256 (2000).