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Implementation of ultra-low-dose lung protocols in CT-guided lung biopsies: feasibility and safety in the clinical setting

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Abstract

Objective: To evaluate the use of ultra-low-dose computed tomography (ULDCT) for CT-guided lung biopsy versus standard-dose CT (SDCT).

Methods: CT-guided lung biopsies from 115 patients (50 ULDCT, 65 SDCT) were analyzed retrospectively. SDCT settings were 120 kVp with automatic mAs modulation. ULDCT settings were 80 kVp with fixed exposure (20 mAs). Two radiologists evaluated image quality (i.e., needle artifacts, lesion contouring, vessel recognition, visibility of interlobar fissures). Complications and histological results were also evaluated.

Results: ULDCT was considered feasible for all lung interventions, showing the same diagnostic accuracy as SDCT. Its mean total radiation dose (dose–length product) was significantly reduced to 34 mGy-cm (SDCT 426 mGy-cm). Image quality and complication rates ($P = 0.469$) were consistent.

Conclusions: ULDCT for CT-guided lung biopsies appears safe and accurate, with a significantly reduced radiation dose. We therefore recommend routine clinical use of ULDCT for the benefit of patients and interventionalists.

Keywords

CT-guided biopsy, lung intervention, ultra-low-dose CT protocol, CT dose reduction, iterative reconstruction

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Introduction

Computed tomography (CT)-guided percutaneous lung biopsy is routinely used to establish diagnoses, thereby also strongly influencing the therapeutic regimen and prognosis. They comprise the method of choice for both peripherally located and small lesions (>2 cm) and when bronchoscopic access is limited.[1,2] Multiple CT scans (planning, guiding, and control scans) may be necessary during a single intervention, resulting in considerable radiation exposure to both patient and interventionalist.[3,4] Considerable effort has therefore gone into reducing the radiation dose. Several studies[5–8] have describe improved image quality in ultra-low-dose CT (ULDCT) protocols using iterative reconstruction algorithms (iDose 5, Philips Healthcare, Cleveland, OH, USA). Only limited data are available,[9–11] however, regarding substantially reduced radiation dosages for ULDCT use in interventional procedures. With lung biopsies, the image quality does not have to reach a diagnostic standard, thus allowing the possibility of using ULDCT (Figure 1).

The aim of this retrospective study was to evaluate the interventional accuracy and safety of a standardized ULDCT protocol using image reconstruction via iterative reconstruction in the clinical setting.

Material and methods

Our hospital institutional review board approved this study, waiving the requirement for written informed consent because of its retrospective study design.

A total of 115 patients who had had an indication for a chest intervention were retrospectively enrolled in this study. In August 2012, we established an ULDCT protocol for lung interventions at our institution following the implementation of iterative reconstruction. The tube voltage was reduced from 120 kVp to 80 kVp, and a fixed tube current–time product of 20 mAs was used instead of the dose modulation employed for standard-dose CT (SDCT). A total of 50 patients underwent non-enhanced ULDCT of the chest for biopsy of suspicious pulmonary lesions (study group). The control group included 65 consecutive patients whose non-enhanced SDCT chest scans were reviewed. The data were collected between January 2009 and November 2014, with the interventions performed by two radiologists with more than 3 years of experience in diagnostic and interventional CT. The percutaneous biopsy procedure was standardized in our institution as follows.

(1) A limited (planning) CT scan of the thorax (helical acquisition mode) confirms the location of the nodule and is used to determine the safest approach.
(2) The skin is disinfected, and local anesthetics are applied. A small skin incision is made at the biopsy needle entrance point.
(3) Sequential (procedural CT) images (4×5 mm collimation) are used to guide the needle path to the nodule. Specimens are obtained using an 18-gauge coaxial biopsy needle (Gallini Medical devices, Mantova, Italy).
(4) A postprocedural (control) CT scan (helical acquisition mode) of the thorax is used to rule out complications.
(5) A posteroanterior plain radiographic examination of the chest during expiration is performed 4 h after the intervention.
(6) The patient is discharged from hospital the following day if there are no complications.

All examinations were performed on a Brilliance iCT 256 scanner (Philips Healthcare, Cleveland, OH, USA). The detector collimation was $2 \times 128 \times 0.625$ mm, creating 256 overlapping slices via a dynamic z-flying focal spot for the

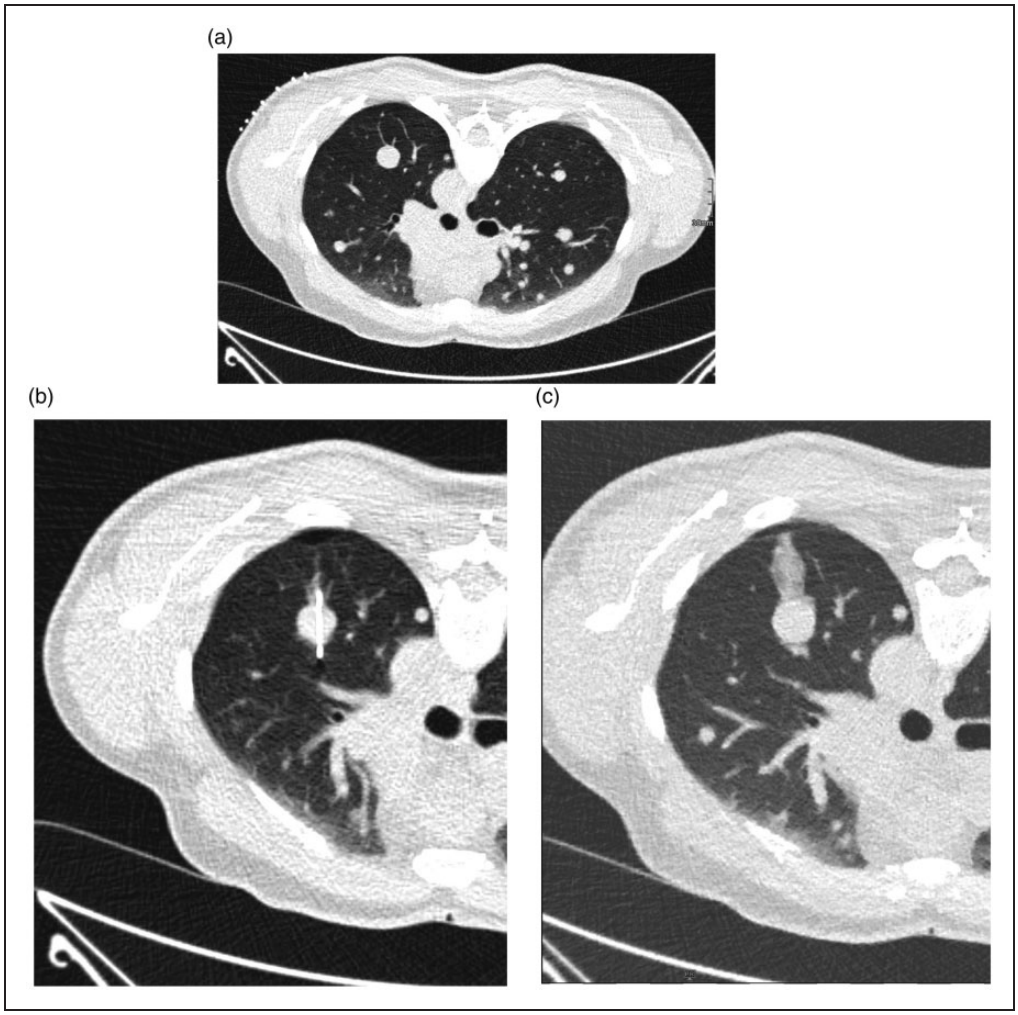

Figure 1. A 65-year-old man (body mass index 28 g/m^2) with suspected pulmonary metastases of malignant melanoma underwent ultra-low-dose computed tomography. Total radiation dose (dose–length product, DLP, 35.1 mGy × cm) with a total effective dose of 0.5 mSv (calculated by CT-Expo: Stamm G, Nagel HD. CT-Expo – a novel program for dose evaluation in CT *Fortschr Roentgenstr* 2002;174:1570–1575). (a) Preinterventional planning sequence. (b) Correct needle position in the lung nodule. (c) Post-puncture hemorrhage in the needle pathway as a physiological consequence and small post-interventional pneumothorax without therapeutic consequence.

planning and control CT scans. The pitch was 0.758 and the rotation speed 0.33 s. The scan protocol for the procedural CT was sequential (axial) acquisition mode and utilized a collimation of 4×5 mm. The "L" (lung) filter was chosen as a reconstruction kernel. For the SDCT protocol, the dose modulation technique DoseRight, including Z-DOM (operating in the z direction), was deployed for helical scans, whereas for the procedural CT a fixed tube current–time product of 50 mAs was used. The tube voltages for the planning, procedural, and control SDCT scans were 120 kV_p. The

examinations were reconstructed with the iterative reconstruction algorithm iDose 5 for SDCT and ULDCT (Philips Healthcare, Cleveland, OH, USA). The reconstruction with iDose level 5 was used for the intervention itself.

The dose–length product (DLP) was recorded from the patient dose report. Histological findings were also recorded on the patients' charts.

Important factors that may have had an influence on radiation dose and image quality were obtained from the radiological information system HIS/RIS and from the patients' charts. Body mass index, intervention time, size of punctured lesions, and complications were evaluated. Complications were categorized using the definitions of the Society of Interventional Radiology (SIR).[12] A minor complication was defined as an event that required no further therapy or only nominal therapy—e.g., overnight admission for observation or SIR classification A (minor bleeding) or B (pneumothorax without the need of a chest tube). Mild bleeding from the puncture site was considered a regular consequence and not counted as a complication. A major complication that required therapy and minor hospitalization (<48 h) was classified as SIR C (pneumothorax with immediately placed chest tube) or SIR D (prolonged hospitalization of >48 h).

Qualitative analysis of image quality

The qualitative analysis was performed on a Picture Archiving and Communication System (Agfa Technical Imaging Systems, Richfield Park, NJ) by two radiologists with more than 3 years of experience in diagnostic/interventional CT. The radiologists worked independently and were blinded to each other's results.

Image quality was assessed for criteria relevant to a safe biopsy, including the visual sharpness of vessels in the proposed needle pathway: 1 = sharp, 2 = limited definition but without impaired interventional confidence, 3 = limited definition with impaired interventional confidence; conspicuity of the lesion: 1 = sharp, 2 = limited definition but without impaired interventional confidence, 3 = limited definition with impaired interventional confidence; and visibility of the interlobar fissures: 1 = good, 2 = doubtful, 3 = nonexistent. Inter-reader variability was then analyzed.

Statistical analysis

Quantitative variables were summarized as the median (interquartile range) and qualitative variables as the count (percentage). Differences between groups were assessed using the Mann–Whitney U test or the χ^2 test, respectively. Comparisons of the radiation dose (DLP) were adjusted for age and scan length in a multivariable log-linear model. Subjective image quality was summarized by relative frequency and compared between raters using the percentage of agreement and kappa statistics. Statistical significance was assumed at $P \leq 0.05$. All calculations were done with IBM SPSS Statistics software (Version 22, IBM Corp., Armonk, NY, USA).

Results

Patient distribution, procedural differences, histological findings

The ULDCT and SDCT differed according to the age of the patients, with the ULDCT group having a mean age of 63 years (51–71 years) and the SDCT group 57 years (48–65 years). Apart from patient age, there were no significant differences between the two groups (Table 1).

Examination of the procedures revealed no significant differences in the intervention time or size of the puncture lesions between the groups, with the average lesion size

Table 1. Patient demographics of the patients in the ULDCT and SDCT groups.

Variable	Total ($n = 115$)	ULDCT ($n = 50$)	SDCT ($n = 65$)	*P*
Male sex	70 (61%)	32 (64%)	38 (59%)	0.546
Age (years)	59 (49–69)	63 (51–71)	57 (48–65)	0.045
BMI	25.1 (22–29)	24.4 (21.5–28.0)	25.4 (22.2–29.4)	0.163
Height (cm)	174 (167–180)	176 (167–181)	172 (166–179)	0.080
Weight (kg)	75 (65–89)	75 (66–89)	76 (65–88)	0.901

ULDCT, ultra-low-dose computed tomography; SDCT, standard-dose computed tomography; BMI, body mass index.

Table 2. Procedural comparison of the ULDCT and SDCT groups.

Parameter	Total	ULDCT	SDCT	*P*- value
Intervention time (min)	26 (22–32)	28 (22–32)	26 (22–31)	0.720
Lesion size (cm^2)	4.1 (2.1–7.8)	3.5 (1.7–7.4)	5.2 (2.6–7.9)	0.111
Scan length (mm)				
Planning	100 (79–157)	79 (79–99)	146 (97–201)	<0.001
Control	295 (259–326)	296 (267–316)	290 (257–332)	0.879

Table 3. Major and minor complications in the ULDCT and SDCT groups.

Complications	ULDCT (n = 50)	SDCT (n = 65)	*P*
Total	21 (42%)	23 (35%)	0.469
Major (SIR C)	4 (8%)	7 (11%)	
Minor (SIR A and B)	17 (34%)	16 (24%)	

SIR, Society of Interventional Radiology.

3.5 cm^2 (1.7–7.4 cm^2) in the ULDCT group and 5.2 cm^2 (2.6–7.9 cm^2) in the SDCT group, with an overall mean lesion size of 4.1 cm^2 (Table 2). The length of the planning scan was significantly different between the two groups, however, and was taken into consideration in the statistical dose calculations.

Pneumothorax was the only peri-interventional and post-interventional complication, of which 17 required insertion of a chest tube (SIR C). No relevant hemorrhage was reported. There were no SIR D complications. The complication rates did not differ significantly between the two groups (Table 3).

Examination of the histological findings revealed three inconclusive results for the ULDCT protocol and one inconclusive result for the SDCT protocol (Table 4).

Radiation dose

For reliable comparisons, we adjusted the DLP for age and scan length. The mean values of the adjusted total DLP were 426 mGy-cm for the SDCT protocol and 34 mGy-cm for the ULDCT scan, indicating a significant difference ($P < 0.001$). DLP values for the planning, puncture, and control scans are summarized in Table 5.

Subjective image quality analysis

Both readers rated the image quality of the ULDCT scans as diagnostically sufficient

Table 4. Histological findings after biopsy in the ULDCT and SDCT groups.

Subtype	ULDCT group	SDCT group	*P*
Malignant histology	36 (72%)	51 (78%)	0.696
NSCLC	6	9	
Adenocarcinoma	17	26	
Squamous cell carcinoma	6	6	
Metastasis	4	7	
Nerve sheath tumor	1	1	
Benign histology	11 (22%)	13 (20%)	
Fibrosis	2	3	
Inflammatory infiltration	8	9	
Tuberculosis	1	1	
Physiological flora	2	2	
No results	3 (6%)	1 (2%)	

NSCLC, non-small cell lung cancer.

Table 5. Dose–length product for the ULDCT and SDCT protocols.

Dose–length product[a]	ULDCT group	SDCT group	*P*
Planning	6.7 (6.7–7.6) *7.1 (6.1–8.3)*	180 (95–299) *168 (148–192)*	<0.001
Guiding	8 (6–10) *7.9 (6.8–9.1)*	57 (44–82) *66 (58–75)*	<0.001
Control	15.3 (14–16) *15.4 (13.6–17.5)*	170 (121–297) *169 (151–188)*	<0.001
Total	34 (31–36) *34.1 (30.5–38.1)*	412 (270–539) *426 (388–469)*	<0.001

ULDCT and SDCT results are expressed as the median (interquartile rate) and the adjusted mean 95% confidence interval (in italics).
[a]Expressed in mGy × cm.

(Table 6). There were no ULDCT cases in which the biopsy could not have been performed. Agreement between the readers was ≥74% for all three evaluation variables. The highest agreement was reached during assessment of the interlobar fissures: 90% (kappa 0.627).

Discussion

The use of ULDCT for CT-guided lung biopsies, which had already been implemented in routine clinical practice, was evaluated. Previous studies demonstrated that iterative reconstruction algorithms allowed the use of ULDCT while maintaining acceptable image quality.[2,13] The results of our study revealed a substantial reduction in radiation exposure—reduced to 34 mGy-cm (80 kVp, 20 mAs) from 412 mGy-cm used for the SDCT intervention. This difference is a more than 10-fold reduction in the radiation dose.

When compared with previous studies,[9,10] we further reduced the tube voltage (80 kV vs. 100 kV) while achieving comparable results. It proved that a dose reduction could produce the same results regarding safety, feasibility, and quality of the biopsy. A numerical comparison of the DLP,

Table 6. Qualitative image evaluation and inter-reader variability.

Variable and score	Reader 1	Reader 2	Agreement	Kappa
Vessel sharpness[a]				
1	42 (84%)	31 (62%)	74%	0.379
2	8 (16%)	19 (38%)		
3	0	0		
Lesion conspicuity[b]				
1	37 (74%)	37 (74%)	74%	0.376
2	13 (26%)	13 (26%)		
3	0	0		
Visibility of interlobar fissures[c]				
1	45 (90%)	40 (80%)	90%	0.627
2	0	4 (8%)		
3	5 (10%)	6 (12%)		

[a]Vessel sharpness in the proposed needle pathway was scored as: 1 = sharp; 2 = limited definition but without impaired interventional confidence; 3 = limited definition with impaired interventional confidence.
[b]Conspicuity of the lesion as scored as: 1 = sharp; 2 = limited definition but without impaired interventional confidence; 3 = limited definition with impaired interventional confidence.
[c]Visibility of the interlobar fissures was scored as: 1 = good; 2 = doubtful; 3 = nonexistent.

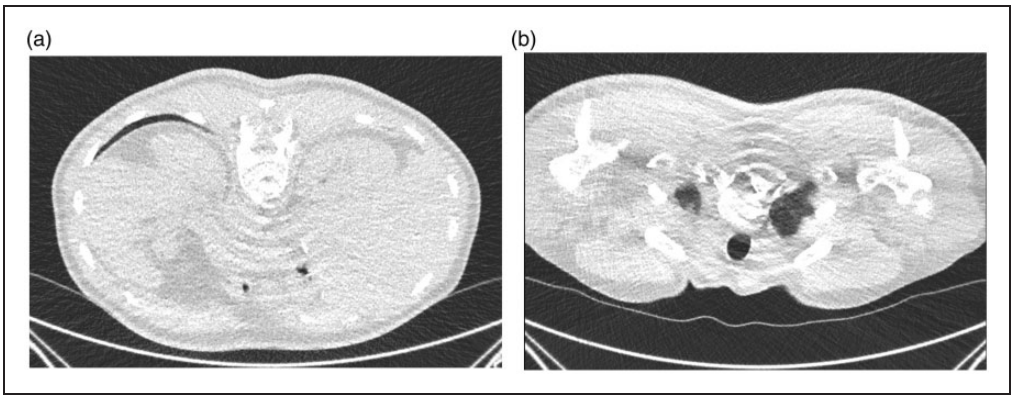

Figure 2. (a, b) Ring artifacts resulting from a reduced dosage of 80 kV_p and 20 mAs.

however, was not possible because of the different study designs, CT scanners, and protocols used (e.g., we routinely perform a complete chest CT scan after puncture, whereas Smith et al. scan only the needle insertion site).

With regard to image quality, we demonstrated that iterative reconstruction post-processing resulted in adequate images, although ring artifacts appeared to be common in the ULDCT group (Figure 2a and b). These artifacts mainly occurred in soft tissue masses, such as in the shoulder area or the abdomen. There were no relevant artifacts reported in the thoracic area that could have interfered with the biopsies. For one of the image quality criteria (the identification of interlobar fissures), one of the readers was unsure of the determination in 8% of cases, which might be the consequence of the lowered image quality. The other reader was positive about a fissure

determination in all cases, so experience may also have to be taken into account.

In terms of the safety and feasibility of ULDCT for lung interventions, the only complication that was recorded was pneumothorax. No relevant hemorrhages or SIR D complications were recorded. No significant difference was found between the complication rates of the ULDCT and the SDCT protocols. Overall, we recorded a complication rate within the documented mean for such interventions.[14]

Examination of the histological results of the biopsies revealed a high percentage of malignancy in both groups (Table 4), indicating correct needle positioning and demonstrating the importance of dose reduction: 20% of the patients had a benign diagnosis and would require further follow-up scans. Inconclusive results were found for specimens from three probes in the ULDCT group, in contrast to specimens from one probe in the SDCT group. This difference may be due to the probe sites (i.e., the specimen obtained from an area of central necrosis). In the ULDCT group, two of three patients with an inconclusive specimen showed inconspicuous clinical and radiological (CT examination) findings between 6 and 14 months after the intervention. The other patients were lost to follow-up.

When considering our results in regard to the clinical setting, the ULDCT scan protocol for interventional lung biopsies was safe and feasible. Thus, the cumulative dose could be significantly reduced without reducing interventional accuracy compared with that achieved with SDCT (Table 5). No increased risk of complications was reported.

Summing up, our results confirm previous study results[2,9,10] and take them one step farther: We could reduce the tube current while maintaining the same high procedural quality and low complication rate.

A limitation of this study is that we did not make intra-individual comparisons of the two scan protocols because it was considered ethically unjustifiable. Moreover, patients in the SDCT group were significantly older than those in the ULDCT group. In addition, the scan length differed between groups (Table 2). As these factors may affect the comparability of the radiation dose between groups, we adjusted the two groups according to age and scan length using a log-scale multivariable linear regression.

Conclusion

The use of ULDCT for performing lung interventions was shown to be feasible in all patients examined. The complication rate for the ULDCT protocol was no higher than that for the SDCT protocol, indicating that the ULDCT is a safe protocol for lung biopsy. In addition, there was a significant reduction in the cumulative radiation dose, from 412 mGy-cm to 34 mG-cm, with no reduction in the accuracy of needle placement.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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References

1. Prosch H, Stadler A, Schilling M, et al. CT fluoroscopy-guided vs. multislice CT biopsy mode-guided lung biopsies: accuracy, complications and radiation dose. *Eur J Radiol* 2012; 81: 1029–1033.
2. Chang DH, Hiss S, Mueller D, et al. Radiation dose reduction in computed tomography-guided lung interventions using an iterative reconstruction technique. *Rofo* 2015; 187: 906–914.

3. Heyer CM, Mohr PS, Lemburg SP, et al. Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: prospective randomized study. *Radiology* 2007; 245: 577–583.
4. Heyer CM, Nusslein TG, Stephan V, et al. [Low-dose CT-guided transthoracic lung biopsy for evaluation of non-infectious chronic interstitial lung disease in children]. *Pneumologie* 2007; 61: 499–508. [in German, English Abstract].
5. Geyer LL, Schoepf UJ, Meinel FG, et al. State of the art: iterative CT reconstruction techniques. *Radiology* 2015; 276: 339–357.
6. Yasaka K, Katsura M, Akahane M, et al. Model-based iterative reconstruction for reduction of radiation dose in abdominopelvic CT: comparison to adaptive statistical iterative reconstruction. *Springerplus* 2013; 2: 209.
7. Yasaka K, Katsura M, Akahane M, et al. Dose-reduced CT with model-based iterative reconstruction in evaluations of hepatic steatosis: how low can we go? *Eur J Radiol. 2014* 83: 1063–1068.
8. Ohno Y, Takenaka D, Kanda T, et al. Adaptive iterative dose reduction using 3D processing for reduced- and low-dose pulmonary CT: comparison with standard-dose CT for image noise reduction and radiological findings. *AJR Am J Roentgenol* 2012; 199: W477–W485.
9. Adiga S and Athreya S. Safety, efficacy, and feasibility of an ultra-low dose radiation protocol for CT-guided percutaneous needle biopsy of pulmonary lesions: initial experience. *Clin Radiol* 2014; 69: 709–714.
10. Smith JC, Jin DH, Watkins GE, et al. Ultra-low-dose protocol for CT-guided lung biopsies. *J Vasc Interv Radiol* 2011; 22: 431–436.
11. Yanagawa M, Gyobu T, Leung AN, et al. Ultra-low-dose CT of the lung: effect of iterative reconstruction techniques on image quality. *Acad Radiol* 2014; 21: 695–703.
12. Sacks D, McClenny TE, Cardella JF, et al. Society of Interventional Radiology clinical practice guidelines. *J Vasc Interv Radiol* 2003; 14: S199–202.
13. Katsura M, Matsuda I, Akahane M, et al. Model-based iterative reconstruction technique for ultralow-dose chest CT: comparison of pulmonary nodule detectability with the adaptive statistical iterative reconstruction technique. *Invest Radiol* 2013; 48: 206–212.
14. Manhire A, Charig M, Clelland C, et al. Guidelines for radiologically guided lung biopsy. *Thorax* 2003; 58: 920–936.