Eur Radiol (2011) 21:636–643
DOI 10.1007/s00330-010-1991-4

CHEST

Chest computed tomography using iterative reconstruction vs filtered back projection (Part 2): image quality of low-dose CT examinations in 80 patients

François Pontana · Alain Duhamel · Julien Pagniez · Thomas Flohr · Jean-Baptiste Faivre · Anne-Lise Hachulla · Jacques Remy · Martine Remy-Jardin

Received: 1 July 2010 / Revised: 13 September 2010 / Accepted: 8 October 2010 / Published online: 16 November 2010

Abstract
Purpose To evaluate the image quality of an iterative reconstruction algorithm (IRIS) in low-dose chest CT in comparison with standard-dose filtered back projection (FBP) CT.
Materials and methods Eighty consecutive patients referred for a follow-up chest CT examination of the chest, underwent a low-dose CT examination (Group 2) in similar technical conditions to those of the initial examination, (Group 1) except for the milliamperage selection and the replacement of regular FBP reconstruction by iterative reconstructions using three (Group 2a) and five iterations (Group 2b).
Results Despite a mean decrease of 35.5% in the dose-length-product, there was no statistically significant difference between Group 2a and Group 1 in the objective noise, signal-to-noise (SNR) and contrast-to-noise (CNR) ratios and distribution of the overall image quality scores. Compared to Group 1, objective image noise in Group 2b was significantly reduced with increased SNR and CNR and a trend towards improved image quality.
Conclusion Iterative reconstructions using three iterations provide similar image quality compared with the conventionally used FBP reconstruction at 35% less dose, thus enabling dose reduction without loss of diagnostic information. According to our preliminary results, even higher dose reductions than 35% may be feasible by using more than three iterations.

Keywords Radiation dose · CT · Chest · Iterative reconstruction · Image quality

Introduction

Over the last decade, chest radiologists have considerably modified their CTprotocols and thus, reduced the radiation dose distributed from CT examinations with no loss in the diagnostic quality of examinations [1–3]. These changes started with the understanding that high-quality examinations, devoid of perceptible image noise, could be obtained at lower doses by selecting weight-adapted protocols and/or using automatic tube current modulation systems [4–6]. A further step in the dose saving direction was the acceptance that diagnostic images could tolerate a certain amount of noise, as reported for screening purposes or follow-up examinations of benign diseases [7, 8]. However, there is no consensus in the medical community on the noise level tolerable in specific clinical situations and there has been no attempt, so far, to design CT protocols according to the diagnostic task of the examination. Therefore, an ideal approach would be to examine patients with low-dose CT

F. Pontana · J. Pagniez · J.-B. Faivre · A.-L. Hachulla · J. Remy · M. Remy-Jardin
Department of Thoracic Imaging, Hospital Calmette (EA 2694),
University Lille Nord de France,
F-59000 Lille, France

A. Duhamel
Department of Medical Statistics, University Lille Nord de France,
59000 Lille, France

T. Flohr
Computed Tomography Division, Siemens Healthcare,
D-91301 Forchheim, Germany

M. Remy-Jardin (✉)
Department of Thoracic Imaging, Hospital Calmette,
Boulevard Jules Leclercq,
59037 Lille cedex, France
e-mail: martine.remy@chru-lille.fr

protocols while systematically getting rid of the image noise generated by the low-dose acquisition protocol, a situation made clinically realistic by the recent introduction of iterative reconstructions in CT practice.

Iterative reconstruction is not a new image reconstruction technique, routinely used for emission tomography such as positron emission tomography (PET) or single photon emission computed tomography (SPECT) [9–11] and recently re-introduced to CT as a method to improve image quality, enhance image resolution and lower image noise [12]. Having previously investigated the magnitude of noise reduction achievable with an iterative reconstruction technique (IRIS) [13], the purpose of the present study was to evaluate the image quality of low-dose chest CT examinations reconstructed with IRIS in comparison with standard-dose filtered backprojection (FBP) images.

Materials and methods

Patient population

Over a 3-month period (January 2010–March 2010), 80 consecutive adult patients (56 male; 24 female; mean age: 57.4±11.5 years) referred for chest CT follow-up were prospectively enrolled in this study based on the following criteria: (a) the previous chest CT examination (Group 1) had been obtained on the same CT system as that used for the follow-up examination (Group 2); (b) there were no significant changes in the patient's weight (less than 3 kg) nor in the extent of the underlying chest disease (less than 10% of changes in lung infiltrative and/or destructive changes) between the initial and follow-up CT examinations to ensure the lack of patient-related causes of image noise modification; (c) the follow-up CT examination had to be obtained in strictly similar technical conditions to those of the initial examination, except for the milliamperage selection and the image reconstruction technique, as described in the CT evaluation section.

The number of patients necessary for this evaluation was calculated as follows. The main objective of the study was to demonstrate that the quality of low-dose images reconstructed with three iterations at GROUP 2 was at least as good as the image quality of standard-dose examinations reconstructed with a standard reconstruction technique at GROUP 1. We used a non inferiority hypothesis for computing an estimated sample size. The non inferiority limit was fixed at 7.5% of the mean of the noise obtained with the standard reconstruction which was estimated at 22.6±6 (mean±standard deviation) by analyzing previous examinations at our institute. Assuming a correlation value of 0.5 between the two measures of noise according to the two reconstruction techniques, an estimated number of 80 patients was necessary for 80% power with significance at 5%.

The mean body mass index of our study group was 25.3 (±4.3) kg/m2, including four underweight patients (BMI <18.5 kg/m2; category I), 34 normal patients (BMI between 18.5 and 24.9 kg/m2; category II), 30 overweight patients (BMI between 25 and 29.9 kg/m2; category III) and 12 obese patients (BMI >30 kg/m2; category IV). The clinical indications for CT follow-up examinations included therapeutic evaluation of bronchopulmonary carcinoma treated by chemotherapy (*n*=36; 45%) or surgery (*n*=5; 6.25%), indeterminate lung nodules (*n*=16; 20%), idiopathic interstitial pneumonias (*n*=8; 10%), mesothelioma (*n*=4; 5%), infectious lung diseases (*n*=4; 5%) and miscellaneous causes (*n*=7; 8.75%). The median interval of time between GROUP 1 and GROUP 2 examinations was 108.6 days, ranging from 6 to 227 days (mean value: 116 days).

CT evaluation

CT parameters

GROUP 1 and GROUP 2 examinations, including 49 contrast-enhanced and 31 unenhanced CT examinations, were performed on the same dual-source 128-slice MDCT system (Somatom Definition Flash; Siemens; Germany). Apart from the reference tube current-time product (i.e., reference mAs) which was decreased by 30% (Table 1) according to the results of our preliminary study [13], CT parameters for Group 1 and Group 2 examinations were kept constant, including: (a) the same number, orientation(s) and kilovoltage selections for the GROUP 1 and GROUP 2 scout-views (topograms) to ensure a similar contribution of the automatic exposure control on both examinations; (b) non-ECG-gated acquisition over the entire thorax with the following parameters: collimation: 64×2×0.6 mm with z-flying focal spot for the simultaneous acquisition of 128

Table 1 Kilovoltage and milliamperage selections at T1 and T2

Patients' body weight (b.w.)	T1 protocols	T2 protocols
<50 kg (*n*=1)	80 kVp–120 ref mAs	80 kVp–80 ref mAs
50 kg–79 kg (*n*=36)	100 kVp–90 ref mAs	100 kVp–60 ref mAs
80–100 kg (*n*=40)	120 kVp–90 ref mAs	120 kVp–60 ref mAs
>100 kg (*n*=3)	140 kVp–120 ref mAs	140 kVp–80 ref mAs

overlapping 0.6 mm slices with both measurement systems; rotation time: 0.28 s with 75 ms temporal resolution; pitch: 3.0; weight-adapted selection of the kilovoltage for both tubes (ranging between 80 and 140 kVp) with adapted milliamperage setting at GROUP 1 (ranging between 90 and 120 ref mAs, reduced by 30% in the GROUP 2 examination); 4D dose modulation (Care Dose 4D; Siemens, Germany). When GROUP 1 and GROUP 2 examinations consisted of CT angiographic examinations, the injection protocols were similar at GROUP 1 and GROUP 2, consisting of the administration of 80 mL of a 35% iodinated contrast agent (Xenetix 350, Guerbet) at flow rate of 4 mL/sec, using a dual-headed pump injector (Stellant Medrad France, Rungis, France) without saline flush. The threshold of the bolus tracking system (Care Bolus, Siemens) was set at 150 HU with the region-of-interest positioned within the ascending aorta. For every patient, the GROUP 1 examination represented the standard-dose chest CT examination in our routine clinical practice while the GROUP 2 examination was the low-dose CT examination.

CT image reconstruction

Lung and mediastinal images of GROUP 1 examinations (Group 1 images), reconstructed using the CT system's built in reconstruction computer at the time of each patient's initial referral, were available on a CD-ROM at the time of the follow-up CT examination. They consisted of images reconstructed with a standard FBP algorithm using a high spatial resolution kernel (B50; lung images) and a soft kernel (B20, mediastinal images), respectively. Lung and mediastinal images of GROUP 2 examinations (Group 2 images) were reconstructed with an iterative reconstruction technique (IRIS algorithm; Siemens) using a high spatial resolution kernel (I50, lung images) and a soft resolution kernel (I20; mediastinal images), respectively. At the time of this evaluation, there was no commercially-available product enabling creation of iterative reconstructions; the overall process, namely the off-line reconstruction of five series of lung and medisatinal images on a prototype workstation, needed 50 to 60 min.The assessment of image quality on GROUP 2 examinations was made on images reconstructed with three iterations (Group 2a) and five iterations (Group 2b). All images were viewed using standard mediastinal (window width, 400 HU, window center, 40 HU) and lung parenchymal (window width, 1,600 HU; window center, −600 HU) window settings.

CT parameters analyzed

Assessment of subjective and objective image noise and overall image quality at GROUP 1 and GROUP 2 followed the same methodology as that described in the first part of the present study [13]. On CT angiographic examinations, the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were also calculated using the methodology described by Szucs-Farkas et al. [14], based on the following equations: $\mathrm{SNR} = \mathrm{SI}_{\mathrm{vessel}}/\mathrm{noise}$ and $\mathrm{CNR} = (\mathrm{SI}_{\mathrm{vessel}} - \mathrm{SI}_{\mathrm{muscle}})/\mathrm{noise}$, where $\mathrm{SI}_{\mathrm{vessel}}$ is the mean signal intensity (SI) of pulmonary vessels. $\mathrm{SI}_{\mathrm{vessel}}$ was calculated as the average of the vascular enhancement measurements (in HU) obtained at five different levels (the main pulmonary artery, right pulmonary artery, left pulmonary artery, right lower lobe artery and left lower lobe artery) and noise was defined as the mean of the standard deviation of these measurements. The ROIs used for these measurements were chosen to be as large as the vessels. $\mathrm{SI}_{\mathrm{muscle}}$ was calculated as the average of the attenuation of the central parts of the pectoral muscles and the deep paraspinal muscles, on both sides.

Conditions of image analysis

The image quality assessment was performed by the two subspecialty thoracic radiologists (JP and FP) also involved in the part-1 study. They evaluated the CT parameters by consensus on a clinical workstation to which the lung and mediastinal images of the GROUP 1 and GROUP 2 examinations were systematically transferred. The GROUP 1 images were imported from the patient's CD-ROM. For GROUP 2 examinations, the raw data were first transferred to an offline PC provided by the vendor to reconstruct the two sets of iterative reconstructions, i.e., the images reconstructed with three iterations and the images reconstructed with five iterations. The GROUP 2 images were analyzed as previously reported [13].

Statistical analysis

Results were expressed as means and standard deviations (SD) for continuous variables; frequencies and percentages for categorical variables. For the continuous variables, the comparisons between the techniques were performed using a paired Student *t*-test. For categorical parameters, the comparisons were performed by using the McNemar Chi-Square test. The statistical significance was defined as $p<0.05$. The statistical analyses were performed using the SAS software (SAS Institute Inc Cary, NC 25513).

Results

Radiation doses at GROUP 1 and GROUP 2

The mean value of effective mAs, taking into account the effect of automatic exposure control, was 73.9±30.1

(range: 30–199) at GROUP 1 and 47.7±20.1 (range: 20–143) at GROUP 2; the mean dose-length-product (DLP) was 162.2±102.1 mGy.cm (range: 24–611) at GROUP 1 and 104.6±63.8 mGy.cm (range: 23–365) at GROUP 2, with a mean DLP reduction of 35.5% between GROUP 1 and GROUP 2.

Comparison of image quality between Group 2a and Group 1

Table 2 summarizes the mean values of objective noise at GROUP 2 in comparison with GROUP 1. There was no statistically significant difference between the objective noise on lung (p=0.3768) and mediastinal (trachea: p=0.0510; aorta: p=0.2343) images between Group 2a and Group 1. Comparing the SNR and CNR at GROUP 1 and GROUP 2 in the 49 contrast-enhanced CT examinations (Table 2), we did not find any statistically significant difference in the SNR (p=0.6332) and CNR (p=0.5530) ratios between the two groups. As shown in Table 2, subjective image noise in Group 2a was not found to be significantly different on lung images (p=0.1025) but more pronounced on mediastinal images (p=0.0047). The distribution of overall image quality scores (Table 2) was not found to be statistically significant in Group 2a compared with Group 1 (p=0.1256).

Comparison of image quality between Group 2b and Group 1 (Table 2)

Objective noise was significantly reduced on both lung and mediastinal images of Group 2b compared with Group 1 (p <0.0001). Compared to Group 2a, the mean noise reduction on Group 2b images was 14.4% at the level of the trachea and 13.1% at the level of the aorta on mediastinal images and 21.9% on lung imagesThe SNR (p<0.0001) and CNR (p<0.0001) ratios were significantly increased in Group 2b compared with Group 1. In Group 2b, subjective image noisewas similar on mediastinal images (p=1) but signif-

Table 2 Comparison of image quality at T1 and T2

	Group 1 Standard-dose CT examinations reconstructed with FBP	Group 2a Low-dose follow-up CT examinations reconstructed with three iterations	Group 2b Low-dose follow-up CT examinations reconstructed with five iterations
Objective image noise			
Objective noise at the level of the trachea on mediastinal images mean (SD), HU	18.37 (5.17)	17.39 (4.92)	14.74 (4.41)*
Objective noise at the level of the aorta on mediastinal images mean (SD), HU	31.51 (9.10)	32.19 (9.41)	28.08 (8.74)*
Objective noise at the level of the trachea on lung images, mean (SD), HU	45.70 (12.48)	44.81 (12.09)	34.82 (10.09)*
Signal-to-noise (SNR) and contrast-to-noise (CNR) ratios			
SNR	11.13 (2.78)	11.38 (3.59)	12.89 (3.26)*
CNR	9.78 (2.66)	10.08 (3.50)	11.39 (3.31)*
Subjective image quality			
Subjective image noise on mediastinal images	-score 1: 34 (42.5%)	-score 1: 26 (32.5%)*	-score 1: 34 (42.5%)
	-score 2: 46 (57.5%)	-score 2: 54 (67.5%)	-score 2: 46 (57.5%)
	-score 3: 0	-score 3: 0	-score 3: 0
Subjective image noise on lung images	-score 1: 41 (51%)	-score 1: 45 (56%)	-score 1: 55 (69%)**
	-score 2: 39 (49%)	-score 2: 35 (44%)	-score 2: 25 (31%)
	-score 3: 0	-score 3: 0	-score 3: 0
Distribution of overall image quality scores			
Excellent image quality (score 1)	27 (34%)	24 (30%)	32 (40%)
Good image quality (score 2)	53 (66%)	56 (70%)	48 (60%)
Nondiagnostic image quality (score 3)	0	0	0

FBP filtered back projection

NB: For objective image noise, comparisons between Group 2a and Group 1 and between Group 2b and Group 1 were made using the paired Student t test. * refers to statistically significant differences with Group 1 (*= p<0.0001). Comparisons of SNR and CNR between Group 2a and Group 1 and between Group 2b and Group 1 were made using the paired Student t test. * refers to statistically significant differences with Group 1 (*= p<0.0001). Comparison of subjective image quality between Group 2a and Group 1 and between Group 2b and Group 1 were obtained with a McNemar test. * refers to statistically significant differences with Group 1 (*: p<0.01; **= p<0.0001). Comparison of overall image quality scores between groups were obtained with a McNemar test icantly reduced on lung images (p=0.0002). There was a trend towards improved image qualityin Group 2b compared to Group 1 (p=0.0588).

Figures 1, 2 and 3 illustrate the image quality achievable with three and five iterations according to the patient's BMI, including one normal (Fig. 1), one overweight (Fig. 2) and one obese (Fig. 3) patient.

Discussion

From the present investigation, we can demonstrate that iterative reconstruction using a newly developed algorithm (iterative reconstruction in image space; IRIS) with three iterations provides similar image quality to that achievable with FBP at 35% less dose. Comparing examinations acquired in similar conditions apart from the milliamperage setting, we found no statistically significant difference in the objective evaluation of image noise, as provided by the measurements of image noise, SNR and CNR between Group 2a and Group 1. While subjective noise on lung images did not differ between Group 2a and Group 1, it was found to be more pronounced on mediastinal images, a situation very likely to be due to difficulties in rating minimal image noise. Despite these differences, the overall image quality scores did not differ between Group 2a and Group 1, confirming our hypothesis that iterative reconstructions could provide comparable image quality despite the 35% dose reduction applied to each follow-up examination. The technical conditions of data acquisitions, namely a systematic selection of weight-adapted CT parameters, explain that the majority of examinations in Group 2a were rated with a good image quality whereas 30% of the examinations were considered with an excellent image quality. These figures confirm that radiologists can integrate image noise in clinical routine inasmuch as the examinations remain of diagnostic quality, as always observed in our study group.

Comparing image quality of GROUP 1 images and GROUP 2 images reconstructed with five iterations, the objective image noise on lung and mediastinal images was found to be significantly reduced with five iterations. While not reaching a statistically significant difference, there was also a trend towards improved image quality in Group 2b compared to Group 1, suggesting that the overall image quality of low-dose examinations reconstructed with five iterations can be superior to that of standard-dose CT examinations. These results suggest that higher dose reductions than 35% may be feasible by using more than three iterations which opens further improvement in dose saving protocols for chest imaging.

The clinical implementation of iterative reconstructions in routine clinical practice requires significant hardware efforts to avoid excessive image reconstruction times. The objectives of all commercially available approaches to iterative image reconstruction in CT aim at reducing the computational complexity of the algorithms while maintaining the potential to lower image noise without degrading spatial resolution. The iterative reconstruction in image space (IRIS) applies the regularization procedure, which is

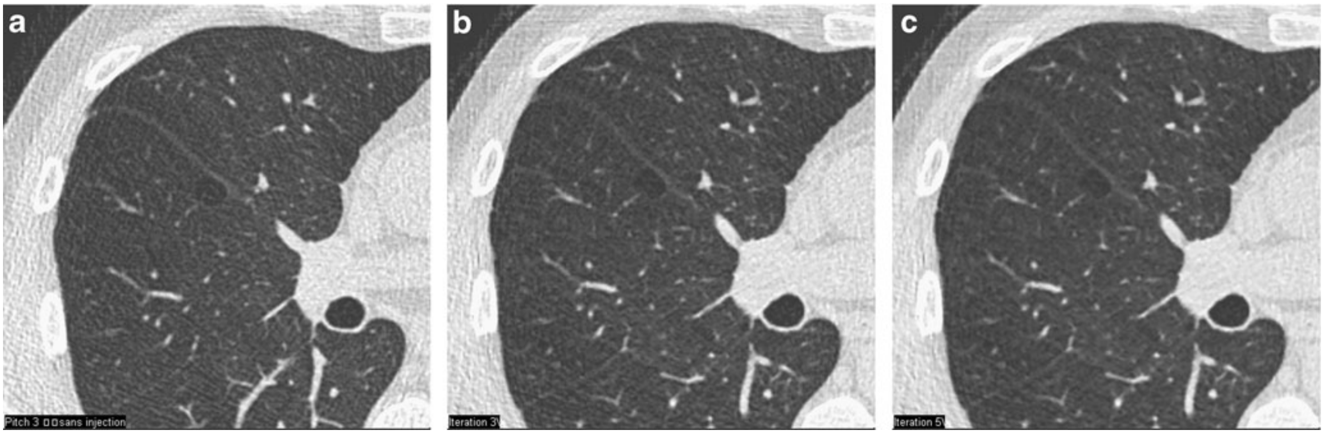

Fig. 1 Comparison of GROUP 1 and GROUP 2 examinations obtained 6 months apart in a 56 year-old man referred for COPD follow-up (normal BMI: 22.6 kg/m2). **a** Filtered back projection-reconstructed lung image of the initial standard dose CT examination (100 kVp; 90 eff mAs; DLP: 80 mGy.cm), obtained at the level of the right bronchus intermedius, illustrating the reference image quality (objective noise at the level of the trachea: 29.3 HU; subjective image noise rated as moderate [score 2]). **b** IRIS-reconstructed lung image of the follow-up low-dose CT examination (100 kVp; 60 eff mAs; DLP: 51 mGy.cm), obtained at the same level as that of **a**, reconstructed with three iterations. Despite dose reduction, there was similar objective (noise measured at the level of the trachea: 28.6 HU) and subjective (score 2) image noise at GROUP 2. **c** IRIS-reconstructed lung image of the follow-up low-dose CT examination obtained at the same level as that of **a**, reconstructed with five iterations. Compared with **b**, the objective (noise measured at the level of the trachea: 22.2 HU) and subjective (score 1) noise is reduced

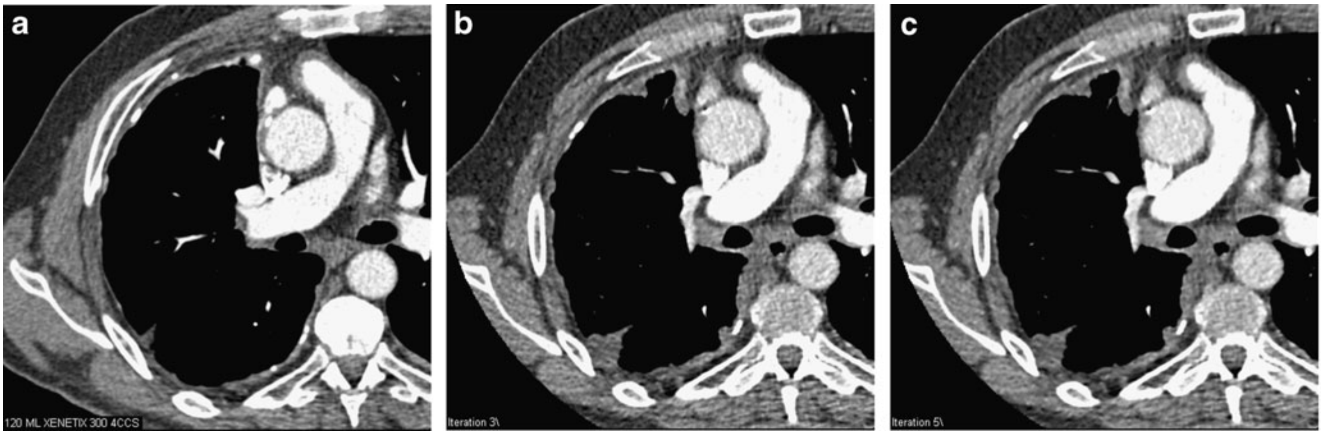

Fig. 2 Comparison of GROUP 1 and GROUP 2 CT angiographic examinations obtained 4 months apart in a 64 year-old man referred for follow-up of mesothelioma under chemotherapy (overweight patient; BMI: 27.8 kg/m2). **a** Filtered back projection-reconstructed mediastinal image of the initial standard dose CT examination (120 kVp; 90 eff mAs; DLP: 196 mGy.cm), obtained at the level of the left main bronchus, illustrating the reference image quality (objective noise at the level of the aorta: 28.8 HU; subjective image noise rated as minimal [score 1]). **b** IRIS-reconstructed mediastinal image of the follow-up low-dose CT examination (120 kVp; eff 60 mAs; DLP: 158 mGy.cm), obtained at the same level as that of **a**, reconstructed with three iterations. Compared with **a**, there was similar objective noise (noise measured at the level of the aorta: 29.3 HU) and a higher score for subjective noise (score 2). **c** IRIS-reconstructed mediastinal image of the follow-up low-dose CT examination, reconstructed with five iterations (same level as that of **a**). Compared with **b**, the objective noise is reduced (noise measured at the level of the aorta: 24.7 HU) with lower rating of subjective noise (score 1)

essential for noise reduction, to the image data in an iterative loop without forward projection and calculation of correction projections [15]. Since this study, a slightly modified version of the evaluated IRIS algorithm with five iterations has been installed on our CT system as a commercially available product, allowing reduction of the radiation dose in chest CT examinations in clinical routine.

To our knowledge, this is the first clinical study comparing image quality of examinations reconstructed with different algorithms in the same patient. Despite methodological differences, our results can only be compared to those of Prakash et al. [16], the only group having already reported an experience with iterative reconstructions applied to chest CT. Investigating a different iterative

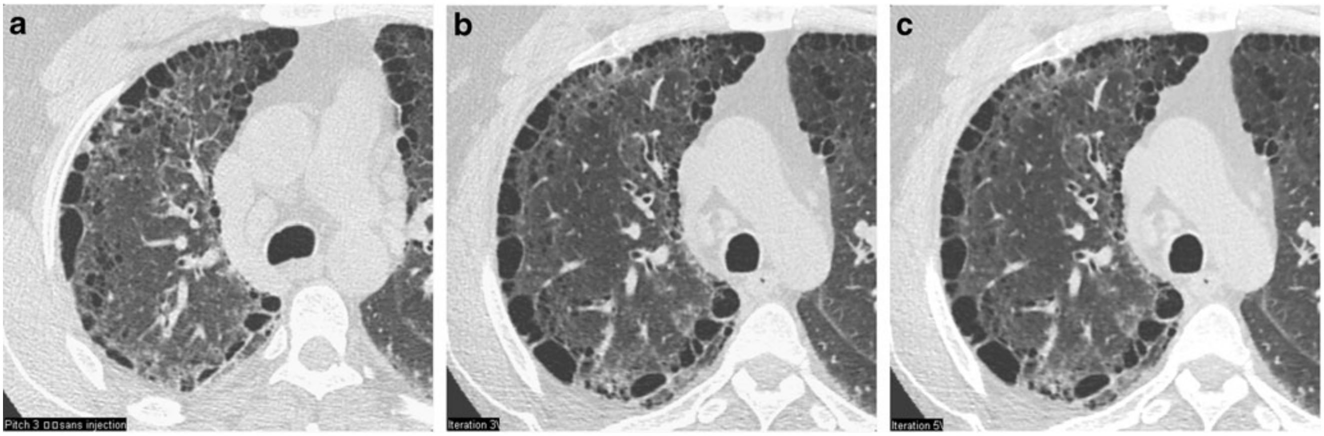

Fig. 3 Comparison of GROUP 1 and GROUP 2 CT examinations, obtained 6 months apart, in a 55 year-old man referred for follow-up of lung fibrosis (obese patient; BMI: 33.9 kg/m2). **a** Filtered back projection-reconstructed lung image of the initial standard dose CT examination (140 kVp; 120 eff mAs; DLP: 284 mGy.cm), obtained at the level of the aortic arch, illustrating the reference image quality (objective noise at the level of the trachea: 35 HU; subjective image noise rated as minimal [score 1]). **b** IRIS-reconstructed lung image of the follow-up low-dose CT examination (140 kVp; 80 eff mAs; DLP: 209 mGy.cm), obtained at the same level as that of **a**, reconstructed with three iterations. Compared with **a**, the objective noise is slightly reduced (noise measured at the level of the trachea: 33.5 HU) with similar rating of subjective noise (score 1). **c** IRIS-reconstructed lung image of the follow-up low-dose CT examination reconstructed with five iterations (same level as that of **a**). Compared with **b**, the objective noise is reduced (noise measured at the level of the trachea: 26.5 HU) with similar rating of subjective noise (score 1)

reconstruction algorithm, i.e. the adaptive statistical iterative reconstruction (ASIR) technique, these authors compared two paired groups of patients, matched by weight but not by underlying disease which may also interfere with the level of objective noise of CT examinations. They reported the possibility of reducing patient dose by 27.6% by using ASIR, while image noise was simultaneously reduced by 24.1%. This is comparable to the results reported here (35% dose reduction with simultaneous reduction of image noise when using IRIS with five iterations). It should be kept in mind, however, that Prakash et al. used a CT technique with significantly higher radiation dose. Whereas our GROUP 1 examinations were acquired with a mean DLP of 162.2 mGy.cm, corresponding to an average effective patient dose of 2.76 mSv, the mean radiation dose in their study before application of ASIR was 12.2 mSv. With the use of IRIS, the mean DLP in our study was reduced to 104.6 mGy.cm, corresponding to an average effective patient dose of 1.78 mSv, whereas Prakash et al. applied 8.8 mSv with the use of ASIR.

A few limitations of this investigation have to be pointed out. First, we did not have strict similarities in the patients' status, i.e. body weight and/or chest abnormalities, at the time of the initial and follow-up examinations, which may have influenced image noise. However, we paid attention to these potential biases when selecting our population, restricting the inclusion of patients with minimal changes in body weight and/or disease extent between GROUP 1 and GROUP 2. Because body weight thresholds had been defined to select the kilovoltage of each examination, changes in the patient's body weight at GROUP 2 might have theoretically led to the selection of a different kilovoltage for the follow-up examination. However, because a minimal body-weight change between GROUP 1 and GROUP 2 was an inclusion criterion, we arbitrarily maintained the same kilovoltage at GROUP 1 and GROUP 2. Secondly, there was no evaluation of lesion conspicuity between GROUP 1 and GROUP 2 as any change in the morphological aspect of individual small-sized lesions at GROUP 2 could have also been attributable to changes over time. Lastly, the readers simultaneously analyzed the three series of lung then mediastinal images and thus, were not blinded to the acquisition and reconstruction parameters. Because the visual appearance of iterative reconstruction is very different from that resulting from filtered back projection,, we considered that a blinded review of images would be very artificial. We could have considered a blinded analysis of the two series of iterative reconstructions; however, given to the complexity of ananymization of images in the technical conditions of our study and because this comparative analysis was not the main objective of our study, we did not attempt to do it. Moreover, this study design was found to be well adapted for the rating of subjective noise on the two series of iterative reconstructions, mainly observed as minimal.

In conclusion, our results confirm that it is possible to provide similar image quality on low-dose CT examinations reconstructed with three iterative reconstructions compared to standard-dose CT examinations reconstructed with FBP. The 35% dose reduction investigated in the present study has the potential to be improved by using more than three iterations.

Acknowledgements M. Rémy-Jardin received research funding from Siemens Healthcare.

J. Rémy is consultant at Siemens Healthcare.

T. Flohr is an employee of Siemens Healthcare.

The remaining authors (F. Pontana, J Pagniez, J.B. Faivre, A. Duhamel) have no financial disclosures and had complete unrestricted access to study data at all stages of the study.

References

1. Tsapaki V, Aldrich JE, Sharma R et al (2006) Dose reduction in CT while maintaining diagnostic confidence: Diagnostic reference levels at routine head, chest, and abdominal CT- IAEA-coordinated Research Project. Radiology 240:828–834
2. Kubo T, Lin PJP, Stiller W, Takahashi M, Kauczor HU, Ohno Y, Hatabu H (2008) Radiation dose reduction in chest CT: a review. AJR 190:335–343
3. Mayo JR (2009) CT evaluation of diffuse infiltrative lung disease: dose considerations and optimal technique. J Thorac Imaging 24:252–259
4. Das M, Mahnken AH, Mühlenbruch G et al (2005) Individually-adapted examination protocols for reduction of radiation exposure for 16-MDCT chest examinations. AJR 184:1437–1443
5. De Maertelaer TD, Gevenois PA V (2003) Dose reduction in multidetector CT using attenuation-based online tube current modulation. AJR 181:331–334
6. Mulkens TH, Bellinck P, Baeyaert M, Ghysen D, Van Dick X, Mussen E, Venstermans C, Termote JL (2005) Use of an automatic exposure control mechanism for dose optimization in multidetector row CT examinations: clinical evaluation. Radiology 237:213–223
7. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard JO, Saini S (2004) Strategies for CT radiation dose optimization. Radiology 230:619–628
8. Long FR (2007) High-resolution computed tomography of the lung in children with cystic fibrosis. Technical factors. Proc Am Thorac Soc 4(4):306–309
9. Shepp LA, Vardi Y (1982) Maximum likelihood reconstruction for emission tomography. IEEE Trans Med Imaging 1:113–122
10. Lange K, Carson R (1984) EM reconstruction algorithms for emission and transmission tomography. J Comput Assist Tomogr 8:306–16
11. Lewitt RM, Matej S (2003) Overview of methods for image reconstruction from projections in emission computed tomography. Proc IEEE 91:1588–1611
12. Thibault JB, Sauer KD, Bouman CA, Hsieh J (2007) A three-dimensional statistical approach to improved image quality for multislice helical CT. Med Phys 34:4526–4544
13. Pontana F, Pagniez J, Flohr T, Faivre JB, Duhamel A, Remy J, Remy-Jardin M (2010) Chest computed tomography using

iterative reconstruction vs filtered back projection (Part 1): evaluation of image noise reduction in 32 patients. Eur Radiol

14. Szucs-Farkas Z, Strautz T, Patak MA, Kurmann L, Vock P, Schindera ST (2009) Is body weight the most appropriate criterion to select patients eligible for low-dose pulmonary CT angiography? Analysis of objective and subjective image quality at 80 kVp in 100 patients. Eur Radiol 19:1914–1922
15. Bruder H, Raupach R, Sedlmair M, Sunnegardh J, Stierstorfer K, Flohr TG (2010) Reduction of radiation dose in CT with an FBP-based iterative reconstruction technique. ECR B-568
16. Prakash P, Kalra MK, Digumarthy SR, Hsieh J, Pien H, Singh S, Gilman MD, Shepard JAO (2010) Radiation dose reduction with chest computed tomography using adaptive statistical iterative reconstruction technique: initial experience. J Comput Assist Tomogr 34:40–45