Original article

Effect of iterative reconstruction on image quality of low-dose chest computed tomography

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Summary. *Aim:* To assess quality and radiologists' preference of low-dose computed tomography (LDCT) reconstructed with filtered back projection (FBP) or Iterative Reconstruction. *Methods:* Thin-section LDCTs (1-mm thick contiguous images; 120 kVp; 30 mAs) of 38 consecutive unselected patients, evaluated for various clinical indications, were reconstructed by four different reconstruction algorithms: FBP and Sinogram-AFfirmed Iterative Reconstruction (SAFIRE) with three different strengths, from 2 to 4 (*i.e.* S2, S3, S4). The image noise was recorded. Two thoracic radiologists visually compared both anatomic structures (interlobular septa, lung fissures, centrilobular artery, bronchial wall, and small vessels) and lung abnormalities (intralobular reticular opacities, nodules, emphysema, cystic lung disease, decreased-attenuation areas related to constrictive obliterans bronchiolitis, patchy ground-glass opacity, consolidation, and bronchiectasis) using a qualitative four-point scale grading system of the image quality. *Results:* A lower amount of noise was recorded for LDCTs reformatted with any SAFIRE algorithm, as compared to FBP ($P < 0.0001$). The noise levels decreased as the SAFIRE strength increased from S2 to S4. The visual score of the subsegmental/segmental bronchial wall was greater for the FBP datasets compared to any SAFIRE dataset ($P < 0.0001$ for reviewer 1; $P < 0.02$ for reviewer 2). The decreased lung attenuation pattern score was lower on the S4 images for one reviewer, as compared to the other LDCT datasets ($P = 0.003$). No other differences in terms of radiologists' preference were recorded among FBP, S2, S3, and S4. Interobserver agreement was moderate only for fissures and bronchial wall, and good to excellent for the remainders. *Conclusion:* Iterative reconstructions showed lower image noise but did not provide any real improvement for the radiologists' evaluation of thin-section LDCT of the lung. (www.actabiomedica.it)

Key words: filtered back projection, image quality, low-dose chest computed tomography, iterative reconstruction, screening

Introduction

Computed tomography (CT) is the key imaging technique used in clinical practice for evaluation of chest disease. The associated exposure to ionizing radiation, however, counters the diagnostic benefit of CT (1). As a consequence, radiologists, physicists, and manufacturers of CT scanners are putting substantial efforts towards reducing the radiation exposure to patients during CT examinations (2-9). The high degree of contrast that exists between air and the pulmonary parenchyma makes lung assessment via low-dose computed tomography (LDCT) suitable. Indeed, LDCT has emerged as the standard technique used in lung cancer screening trials (10-13). Furthermore, LDCT has been shown to allow consistent assessment of parenchymal abnormalities related to either chronic obstructive pulmonary disease (COPD) (14, 15) or interstitial lung diseases (16, 17).

Several tools have been developed to reduce the radiation dose for chest CT (18). Notably, usage of low kilovolt (kV) or reduced tube current yields a lower patient dose, but with the drawback of lower image quality. Although vendor-specific variation exists, application of an iterative reconstruction algorithm (IRA) may reduce the image noise associated with LDCT images (10, 19). The first-generation IRAs provided reduced-dose images with a similar quality to that of standard dose filtered back projection (FBP)-reconstructed images. However, these reconstruction algorithms (*i.e.* image domain-based IRAs) modified the visual appearance of images that appeared smooth (IRIS) (20, 21) or pixelated (ASIR) (22, 23), raising concerns about their utility.

A more recently developed domain-based iterative reconstruction method, the Sinogram-AFfirmed Iterative REconstruction (SAFIRE) technique, is based on a noise-modelling technique supported by raw data. The SAFIRE model incorporates the known propagation of noise in projection data into the image domain, and the noise content is then subtracted during each iteration. The resulting noise-subtracted image is compared with the initial data to generate an updated image, which is then added to the previous dataset before the next iteration is carried out; this technique improves the sharpness-to-noise ratio and helps to eliminate artefacts (24). It is known that noise is reduced as the strength of the iteration is increased, and five different strengths of iteration may be used to reduce noise in SAFIRE.

Yang *et al* (25) demonstrated the ability of SAFIRE to substantially improve image quality of LDCT in lung cancer screening. Furthermore, Christe *et al* (26) showed in a phantom-study that for diagnosing ground-glass or reticular opacities, iterative reconstruction is advantageous. However, no conclusive data on radiologists' preference between SAFIRE- and FBP-LDCT images exists in the literature to date (20, 21, 23, 27-30). Therefore, the purpose of this study was to evaluate the effect of SAFIRE settings on a lung cancer screening LDCT protocol with respect to the amount of image noise and the radiologists' preference in the assessment of defined anatomical structures and abnormal findings through a side-by-side comparison of the LDCT datasets.

Material and methods

Ethics statement

All data from study subjects were anonymized prior to analysis. Retrospective studies of anonymized data are exempted from approval by the Institutional Review Board of the University Hospital of Parma, Italy, and no informed consent is required.

Study population

The study included a series of 38 consecutive patients (13/25 male/female; age (years): mean 60.0 ± 17.6, range 21-86) who underwent non-contrast thin-section LDCT of the chest between January 2013 and April 2013 at the University Hospital of Parma (Parma, Italy) for various clinical indications, such as assessment of lung nodules, idiopathic interstitial pneumonia, infectious lung diseases, and miscellaneous disorders.

CT acquisition

A dual-source 2´128-slice CT system (SOMATOM Definition Flash; Siemens Healthcare, Erlangen, Germany) was used with single-source setting. LDCT scans of the whole lung were acquired during deep inspiratory breath-hold, without contrast medium. The scanner was regularly calibrated to allow for reliable measurements and comparison between examinations. Standard low-dose acquisition parameters were as follows: 0.6 mm collimation, 120 kV, 30 mAs, 0.5 s gantry rotation time, and 1.5 pitch. Neither the CARE-dose nor CARE-kV automated systems were used. The radiation exposure was quantified by means of computed tomography dose index (CTDI), dose length product (DLP), and effective dose.

Image datasets

Each LDCT dataset was reconstructed with continuous sections of 1-mm thickness at 1-mm intervals.

For each LDCT scan, four datasets were reconstructed by different algorithms as follows: FBP using sharp-medium kernel (B50), and SAFIRE 2 (S2), SAFIRE 3 (S3), SAFIRE 4 (S4) using an iterative reconstruction kernel (I50). LDCT images were viewed using a standard lung window setting (*i.e.* window centre of -600 HU and window width of 1600 HU).

A total of 152 anonymized LDCT datasets were transferred to a clinical workstation (syngoÒ.via; Siemens Healthcare) for review.

Qualitative analysis

Two radiologists (PB and NS, respectively with 10 and 11 years of experience in interpreting high-resolution lung CT) independently evaluated the LDCT scans. The evaluators simultaneously compared the four LDCT datasets (*i.e.* FBP, S2, S3, S4) of each patient on a single screen by using the workstation's synchronization tool. Reviewers were not allowed to change the window level nor width while scoring the LDCT images, and they were blinded to both patient and CT technical details. Furthermore, each study case was randomly selected for uploading of the LDCT dataset to the screen's quarters.

The reviewers evaluated the following normal lung structures for each LDCT scan: interlobular septa, lung fissures, centrilobular artery, bronchial wall, and small vessels. A third reviewer (ER, with 10 years of experience in chest imaging), not involved in the study analysis, assessed and grouped the LDCTs for the presence of the following abnormalities: intralobular reticular opacities (n = 4) (Figure 1), nodules (n = 7), emphysema (n = 9) (Figure 2), cystic lung disease (n = 2), decreased-attenuation areas related to constrictive obliterans bronchiolitis (n = 2), patchy ground-glass opacity (n = 5), consolidation (n = 7), and bronchiectasis (n = 14). The reviewers were asked to specifically score any of these abnormalities for corresponding LDCTs.

Both normal structures and abnormal findings were visually scored using a four-point scale system, as follows: 4, excellent image quality with demarcation of structures; 3, moderate blurring with slightly restricted image evaluation; 2, severe blurring or poorly defined structures with uncertainty about the evaluation; 1, severely reduced image quality making reliable interpretation impossible (23, 24, 31).

Image noise

Objective assessment of the image noise was realized by measuring the standard deviation of voxel values in homogeneous regions-of-interest (ROI) within the tracheal lumen above the carina (20). The size (20 mm), shape, and position of the ROI were kept

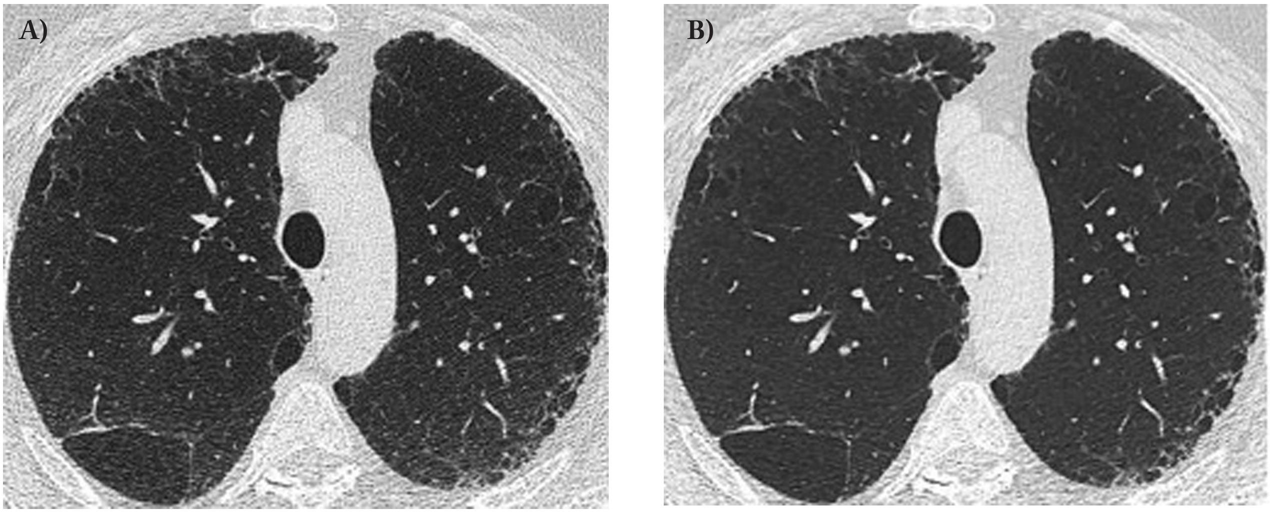

Figure 1. Intralobular reticular opacities in transverse CT image reconstructed with A: filtered back projection and B: SAFIRE 4

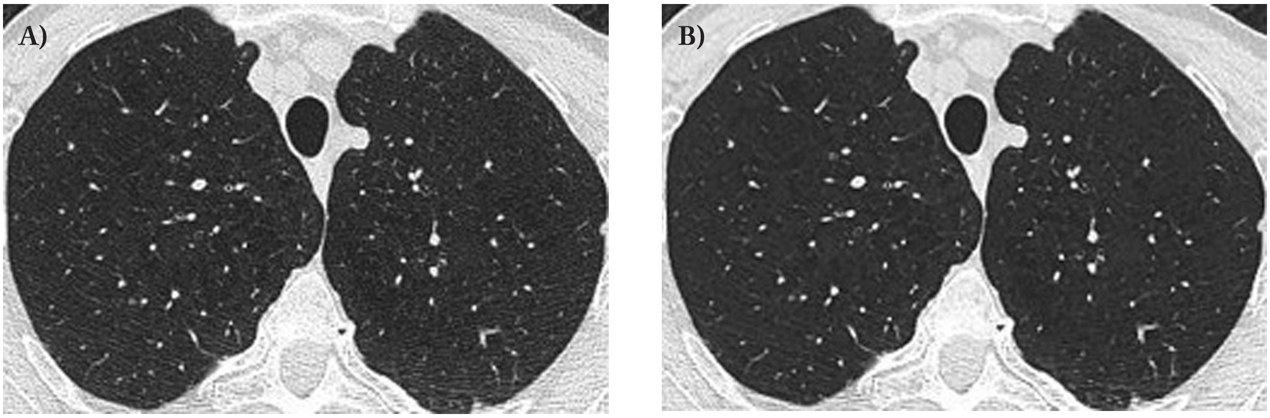

Figure 2. Centrilobular emphysema in transverse CT image reconstructed with A: filtered back projection and B: SAFIRE 4

constant in each LDCT dataset by applying the copy-and-paste function of the workstation.

Statistical analysis

For statistical analysis, data from subjects with cystic lung disease or decreased-attenuation areas related to constrictive obliterans bronchiolitis were grouped together with data from subjects who had emphysema (representing a group of subjects with areas of decreased attenuation), whereas data from subjects with ground-glass opacity were combined with data from subjects who had reticular opacity (representing a group of subjects with areas of interstitial lung disease). The chi-square and analysis of variance (ANOVA) testing methods were used for comparison of variables among the LDCT datasets, as appropriate. A *P* value of less than 0.05 was deemed statistically significant. Interobserver agreement was assessed using the Cohen's weighted kappa coefficient (K_w) and classified as: poor, 0.00-0.20; fair, 0.21-0.40; moderate, 0.41-0.60; good, 0.61-0.80; excellent, 0.81-1.00 (32). The statistical analysis was performed using the MedCalc software, version 12.7.0.0 (Broekstraat, Mariakerke, Belgium).

Results

The mean CTDI was 2.51 ± 0.58 mGy, with a mean per-patient DLP of 90.7 ± 19.3. The effective dose was 1.27 ± 0.27 mSv.

There were significant differences in image noise among the LDCT datasets ($P < 0.001$) (Figure 3). The noise levels decreased as the SAFIRE strength increased from S2 to S4. A reduction of 62% of the noise level was observed for S4, as compared to the FBP.

The qualitative scores for *normal lung structures* are summarized in Table 1. Three LDCTs scored between 1-2 (*i.e.* sub-optimal non-diagnostic findings) for the visualization of interlobular septa and bronchial wall by an observer. *Bronchial wall* qualitatively scored 1 or 2 for S4, whereas all other reconstruction algorithms were significantly better ($P < 0.001$ for reviewer 1, and $P < 0.02$ for reviewer 2). The visual score of the interlobular septa, fissures, centrilobular artery and small vessels was similar among the LDCT datasets for both reviewers ($P = 0.3$).

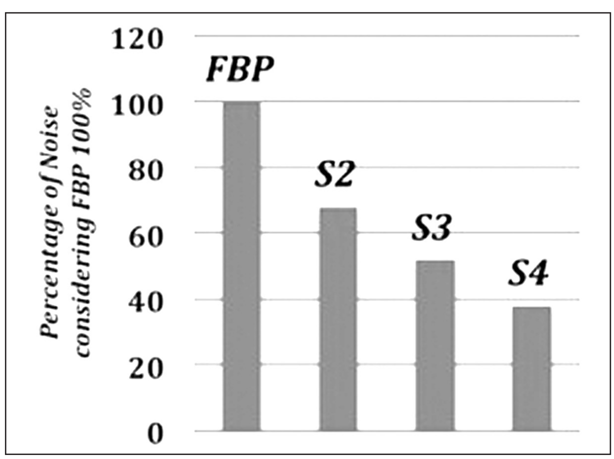

Figure 3. Effects of the different reconstruction methods on noise percentage

The qualitative scores of *lung abnormalities* (50 pulmonary abnormalities in 30 patients) are summarized in Table 2. All series of images scored 4 to 2. For one reviewer, the decreased lung attenuation pattern score was lower on the S4 images, as compared to the other LDCT datasets ($P = 0.003$). The visual score of the remainders was similar among the LDCT datasets for both reviewers.

Interobserver agreement was moderate only for fissures ($K_w = 0.4$) and bronchial wall ($K_w = 0.59$), and good to excellent for the remainders ($K_w = 0.65$ to 1.0) (Table 1 and Table 2).

Discussion

This retrospective study of clinical data was undertaken to determine whether the recent iterative reconstruction algorithm SAFIRE improves the diagnostic value of LDCT scanning, a technique that is increasingly performed at our institution and in routine clinical practice. Our LDCT protocol is similar to that used in some on-going lung cancer screening trials, with radiation dose as low as 1/10 of standard high-resolution CT. Our findings, presented herein, are in line with those reported by prior studies that emphasized the utility of the iterative reconstruction to reduce image noise, as compared to FBP (20-24, 27-30, 33-37). Furthermore, side-by-side comparison of the LDCT datasets allowed our reviewers to make direct comparisons and, therefore, to choose the preferable dataset for visual assessment of both normal lung structures and abnormal findings. The results from the scoring system used in our study suggest that use of SAFIRE strength higher than 3 may negatively influence the visual assessment of both bronchial wall and abnormalities with decreased attenuation.

The obtained average effective dose <2 mSv for our LDCTs is in line with that reported from lung cancer screening trials (12, 38, 39). Our findings expand

Table 1. Qualitative evaluation of normal lung structures

Normal lung structures *	Reviewer	B70, FBP A	B70, FBP B	S2 A	S2 B	S3 A	S3 B	S4 A	S4 B	Interobserver agreement
Interlobular septa										
	4	38/38	35/38	35/38	37/38	35/38	33/38	34/38	30/38	
	3	0	3/38	3/38	1/38	2/38	5/38	2/38	8/38	Kw = 0.62
	2	0	0	0	0	1/38	0	1/38	0	
	1	0	0	0	0	0	0	1/38	0	
Lung fissures										
	4	38/38	34/38	38/38	38/38	37/38	37/38	36/38	37/38	
	3	0	4/38	0	0	1/38	1/38	2/38	1/38	Kw = 0.4
	2	0	0	0	0	0	0	0	0	
	1	0	0	0	0	0	0	0	0	
Centrilobular artery										
	4	38/38	36/38	37/38	38/38	36/38	35/38	35/38	33/38	
	3	0	2/38	1/38	0	2/38	3/38	3/38	5/38	Kw = 0.7
	2	0	0	0	0	0	0	0	0	
	1	0	0	0	0	0	0	0	0	
Bronchial wall										
	4	38/38	35/38	37/38	38/38	37/38	32/38	26/38	30/38	
	3	0	3/38	1/38	0	1/38	6/38	11/38	8/38	Kw = 0.59
	2	0	0	0	0	0	0	1/38	0	
	1	0	0	0	0	0	0	0	0	
Small vessels										
	4	38/38	38/38	38/38	38/38	38/38	38/38	38/38	38/38	
	3	0	0	0	0	0	0	0	0	Kw = 1.0
	2	0	0	0	0	0	0	0	0	
	1	0	0	0	0	0	0	0	0	

*4, Excellent image quality with demarcation of structures; 3, Moderate blurring with slightly restricted image evaluation; 2, Severe blurring or poorly defined structures with uncertainty about the evaluation; 1, Severely reduced image quality making reliable interpretation impossible.

Table 2. Qualitative evaluation of lung abnormalities

Qualitative evaluation of lung abnormalities	Reviewer	B70, FBP		S2		S3		S4	
		A	B	A	B	A	B	A	B
Reticular Opacities									
4		4/4	2/4	4/4	3/4	3/4	4/4	3/4	4/4
3		0	1/4	0	1/4	1/4	0	1/4	0
2		0	1/4	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0
Nodules									
4		7/7	7/7	7/7	7/7	7/7	7/7	6/7	7/7
3		0	0	0	0	0	0	1/7	0
2		0	0	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0
Areas of decreased lung attenuation									
4		12/13	10/13	9/13	13/13	9/13	11/13	7/13	9/13
3		1/13	3/13	4/13	0	4/13	2/13	1/13	4/13
2		0	0	0	0	0	0	5/13	0
1		0	0	0	0	0	0	0	0
Areas of increased lung attenuation									
4		12/12	11/12	12/12	12/12	12/12	12/12	12/12	12/12
3		0	1/12	0	0	0	0	0	0
2		0	0	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0
Bronchiectasis									
4		14/14	14/14	14/14	14/14	14/14	14/14	14/14	14/14
3		0	0	0	0	0	0	0	0
2		0	0	0	0	0	0	0	0
1		0	0	0	0	0	0	0	0

*4, Excellent image quality with demarcation of structures; 3, Moderate blurring with slightly restricted image evaluation; 2, Severe blurring or poorly defined structures with uncertainty about the evaluation; 1, Severely reduced image quality making reliable interpretation impossible.

on those reported by Yang *et al* (25), who undertook a similar study using thicker section LDCT images (*e.g.* 3-mm) and a different visual scoring system (random *vs* side-by-side evaluation). We believe that our scoring methodology might further clarify a radiologist's preference for optimal reconstruction algorithm in clinical practice. Despite having greater objectively assessed image noise, FBP-LDCT images gave similar diagnostic scores as those reconstructed with any SAFIRE algorithm. Christe *et al* (40) demonstrated that for discrimination of subtle pulmonary abnormalities, such as subsolid nodules that occur in fungal pulmonary infections, standard FBP-CT scanning acquired with dose levels of at least 30 mAs was sufficient. In our experience, the use of a sharp-medium kernel to FBP-LDTC may be sufficient to reduce the image noise, making the images more similar to those obtained by standard dose CT. Although recent studies proved that the noise frequency curve is important in conditioning the radiologist's eye, we suggest that noise reduction does not constitute the sole criterion for diagnostic quality of CT images.

We showed that increasing the SAFIRE strength may reduce the image noise, by up to two-thirds as compared to FBP. However, it should be acknowledged that good image quality does not always come from the strongest IRA strength. As suggested by other studies, the texture pattern of the images may represent less familiar images to radiologists, confounding their impression during evaluation. These artefacts, called "blotchy pixelated appearances", result in excessive smoothing and in pixilation or different textures. In fact, the study by Yang *et al* (25) showed that datasets of S5 had lower quality scores and more artefacts, despite having the lowest image noise. Therefore, we did not evaluate the S5 setting in the present study.

The S1 setting was also not included in our study as its effect on the images' appearance was arbitrarily regarded as marginal compared to the FBP.

We showed that artefact appearance negatively influenced visualization of the segmental/subsegmental bronchial walls. Notably, this was true for both the reviewers. However, this limitation might be overcome through the use of software-based quantitation of bronchial metrics, which has been shown to be uninfluenced by an IRA of a single vendor (15).

The worsening in visualization observed in our study for the low-attenuation areas in the S4 dataset may be of relevance as the assessment of emphysema can be used to accurately estimate the probability that lung nodules detected on screening LDCTs are malignant. This observation is in line with findings reported by Mets *et al* (15), who showed that the use of an IRA may influence quantitative CT measures in the assessment of emphysema and air trapping. In contrast, Pontana *et al* (20, 21) showed an improved depiction of emphysema through a first-generation IRA as compared to FBP. In a recent study, Hague *et al* (41) demonstrated that ASIR substantially altered the identification and characterization of respiratory bronchiolitis.

Nevertheless, in keeping with other studies (20, 26, 42, 43), we observed that SAFIRE did not influence the assessment of pulmonary nodules, which is the main task of radiologists in a lung cancer screening setting. The pivotal assessment of nodule detection and volume measurement was beyond the scope of the present study.

This study has two key limitations that must be considered when interpreting our data. First, the study population size was not large enough to draw conclusions for individual lung disorders. Second, the number of reviewers may not be sufficient to fully reveal the radiologists' preference. Nevertheless, the good to excellent interobserver agreement strengthens the study's observations.

In conclusion, we showed that iterative reconstructions increase the LDCT-related image quality, but the contribution might be trivial or even detrimental for visual characterization of bronchial wall and pulmonary areas with decreased attenuation.

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