Signature: © Pol J Radiol, 2016; 81: 593-597
DOI: 10.12659/PJR.899502

Polish Journal of Radiology
www.PolRadiol.com
ORIGINAL ARTICLE

Received: 2016.05.10
Accepted: 2016.06.06
Published: 2016.12.10

Quality Improvement of Dual-Energy Lung Perfusion Image by Reduction of Low-Energy X-Ray Spectrum: An Evaluation on Clinical Images

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background: The effects of the reduction of low-energy X-ray spectrum on lung perfusion images created by dual-energy CT have not been well evaluated. The aim of this study is to investigate the reliability of lung perfusion blood volume (PBV) images created by dual-energy CT (DECT) equipped with or without a tin filter, focusing on its accuracy adjacent to high-attenuation areas.

Material/Methods: Among 176 patients who underwent DECT for suspicion of pulmonary embolism, 38 patients (mean age, 64; range, 16 to 83 years) without apparent evidence of pulmonary embolism were evaluated in this study. They underwent DECT at 100/140 kVp with a tin filter on 140 kVp tube (Group A; n=18) or at 80/140 kVp without the filter (Group B; n=20). On the lung PBV images, the degrees of artifacts – pulmonary enhancement defect (PED) and pseudo-enhancement in the trachea (PTE) adjacent to the vena cava were evaluated using a four-point scale (0=minimal to 3=prominent).

Results: The mean degrees of artifact in Group A were significantly lower than those in Group B (0.8 *vs.* 1.9; P<0.0001 for PED, respectively, and 1.1 *vs.* 2.2; P<0.0001 for TPE, respectively). The mean CTDIvols were 4.90±1.14 and 12.98±3.15 mGy (P<0.0001) for Group A and Group B, respectively.

Conclusions: The quality and accuracy of dual-energy lung perfusion image will be improved by using the tin filter technique.

MeSH Keywords: **Perfusion Imaging • Radiography, Dual-Energy Scanned Projection • Tomography Scanners, X-Ray Computed**

PDF file: http://www.polradiol.com/abstract/index/idArt/899502

Background

The dual-energy CT is one of the most interesting techniques using the dual-source CT and enables it to create novel images not obtained using conventional CT scanners, such as virtual unenhanced image [1,2], bone-removed CT angiography [3,4], component analysis of urinary stones [5,6], and quantitative analysis in contrast enhancement of pulmonary ground-glass attenuation lesions [7,8].

Lung PBV (pulmonary blood volume) is an application software available on the workstation provided by the manufacturer. By using this application, iodinated contrast material in the lung parenchyma can be overlaid on the post-contrast images obtained by the dual-energy (DE) technique based on the 3-material decomposition theory, consequently creating lung perfusion images [9]. A previous study showed that Lung PBV images might replace pulmonary perfusion scintigraphy in particular clinical situations such as pulmonary arterial embolism, chronic thromboembolic pulmonary hypertension, etc. [10]. However, Kang et al. [11] reported that focal iodine defects not related to pulmonary embolism (PE) were observed. They suggested that a higher range of iodine concentration in the superior vena cava and a beam-hardening effect might contribute to the inaccuracy.

Although changes in radiation quality induced by the beam-hardening effect are considered to influence the accuracy [12], a new system equipped with a 'selective photon shield' using a tin filter was introduced in 2009 to reduce the effect by removing low-energy photons from the high-energy X-ray tube. This technique could also achieve better separation of the two different kVp images and is expected to improve the ability to distinguish different substances in the biological structures such as calcium, iodine and iron [13]. Kawai et al. [14] reported on the efficacy of a tin filter for improving the error of iodine removal on virtual unenhanced images in a phantom study. We hypothesized it could also be expected to produce more accurate and reliable lung perfusion images even in the area adjacent to structures with high-concentration contrast material; however, the precise investigation of this technique using the tin filter has not been performed so far.

In this study, we conducted a clinical study to investigate the influence of high-attenuation materials and the efficacy of the tin filter on lung perfusion images, focusing on the effectiveness for artifact reduction.

Material and Methods

IRB approval

Approval for the clinical study was obtained from the local institutional review board.

Patients

Written informed consent was obtained from all patients. Between February 2012 and September 2013, 176 patients suspected to have PE from their present clinical history underwent dual-energy CT scans. Among them, 85 patients with apparent enhancement defects in the pulmonary artery at 2.0-mm thickness, past history of PE and/or deep venous thrombosis (DVT), past history of malignant tumor, or elevated plasma D-dimer (>250 ng/mL), 51 patients with parenchymal abnormalities (inflammatory change, tumor, post-operative change), a patient with a pacemaker on her left thoracic wall, and a patient who could not hold her arms extended during the scanning were excluded. Therefore, the rest, 38 patients (29 women and 9 men; median age, 67 years) without any evidence of PE were evaluated in the study (Figure 1).

CT scanning

Each patient underwent a contrast enhanced CT scan with SOMATOM Definition Flash (Siemens Medical Solutions, Forchheim, Germany) in a dual energy (DE) mode with (n=18; Group A) or SOMATOM Definition (Siemens Medical Solutions) without (n=20; Group B) the tin filter 30 seconds after administration of iodinated contrast material (300 mgI/mL) at a rate of 3.0 mL/sec. The scanning parameters were as follows: tube voltages/reference mAs, 100 kVp/89 mAs and 140 kVp/76 mAs with the filter or 80 kVp/525 mAs and 140 kVp/105 mAs without the filter for Group A or Group B, respectively; beam collimation, 32×2×0.6 mm with z-flying focal spot; rotation time, 0.5 second; tube current was variable and automatically regulated by body thickness and surrounding tissue using a built-in dose-modulating system CARE Dose 4D technique (Ref). The images were reconstructed at 2.0-mm thickness and 2.0-mm intervals using a reconstruction kernel of D30f.

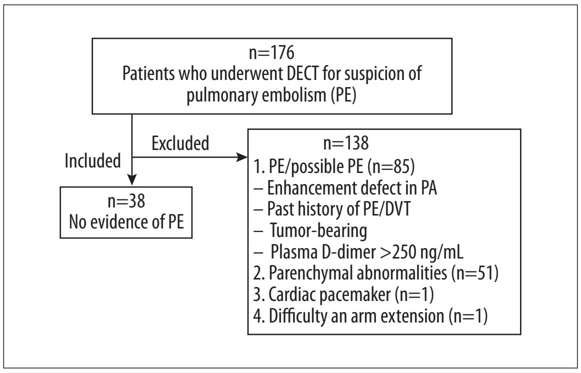

Figure 1. Schema for patient selection.

Calculation of lung perfusion images

The concept of material decomposition using DECT has already been reported [15]. For both patient groups, lung perfusion images were obtained from the datasets acquired by two different kilovolt scans using the 'Lung PBV' application of Syngo Dual Energy originally installed on the workstation. The parameters required for material decomposition followed the manufacturer's default settings and lung perfusion images were displayed with a color-coded scale.

Image evaluation

We supposed two different indicators of artifacts; 1) pulmonary enhancement defect (PED) as an artifact for potential pseudo-positivity and 2) tracheal pseudo-enhancement (TPE) as another artifact for potential pseudo-negativity. PED and TPE adjacent to the brachiocephalic vein ipsilateral to the injection site were evaluated using a four-point scale (0=minimal to 3=prominent) in consensus by two diagnostic radiologists (10 and 7 years of experience) not informed of their scanning conditions according to the following criteria: for PED, Score 0; no/very slight defect, Score 1; defect more than Score 0 but less than Score 2, Score 2; defect reaching the thoracic wall, Score 3; broad defect which might be judged as PE (Figure 2A). For TPE, Score 0; enhancement less than 5% area in the trachea on a transverse sectional image, Score 1; 5–24%, Score 2; 25–49%, Score 3; 50% and more (Figure 2B). Concurrently, attenuations at the brachiocephalic vein of the injection side were measured at three regions on weighted averaged images, simulated 120 kVp images generated from the two different kilovolt image sets.

Statistical analysis

All calculations were performed using statistical software Prism 5 ver. 5.0 (GraphPad Software, La Jolla, USA). To assess the differences in the artifact scores between images with and without a tin filter, the Mann-Whitney U test was used. To assess the correlation between the artifact

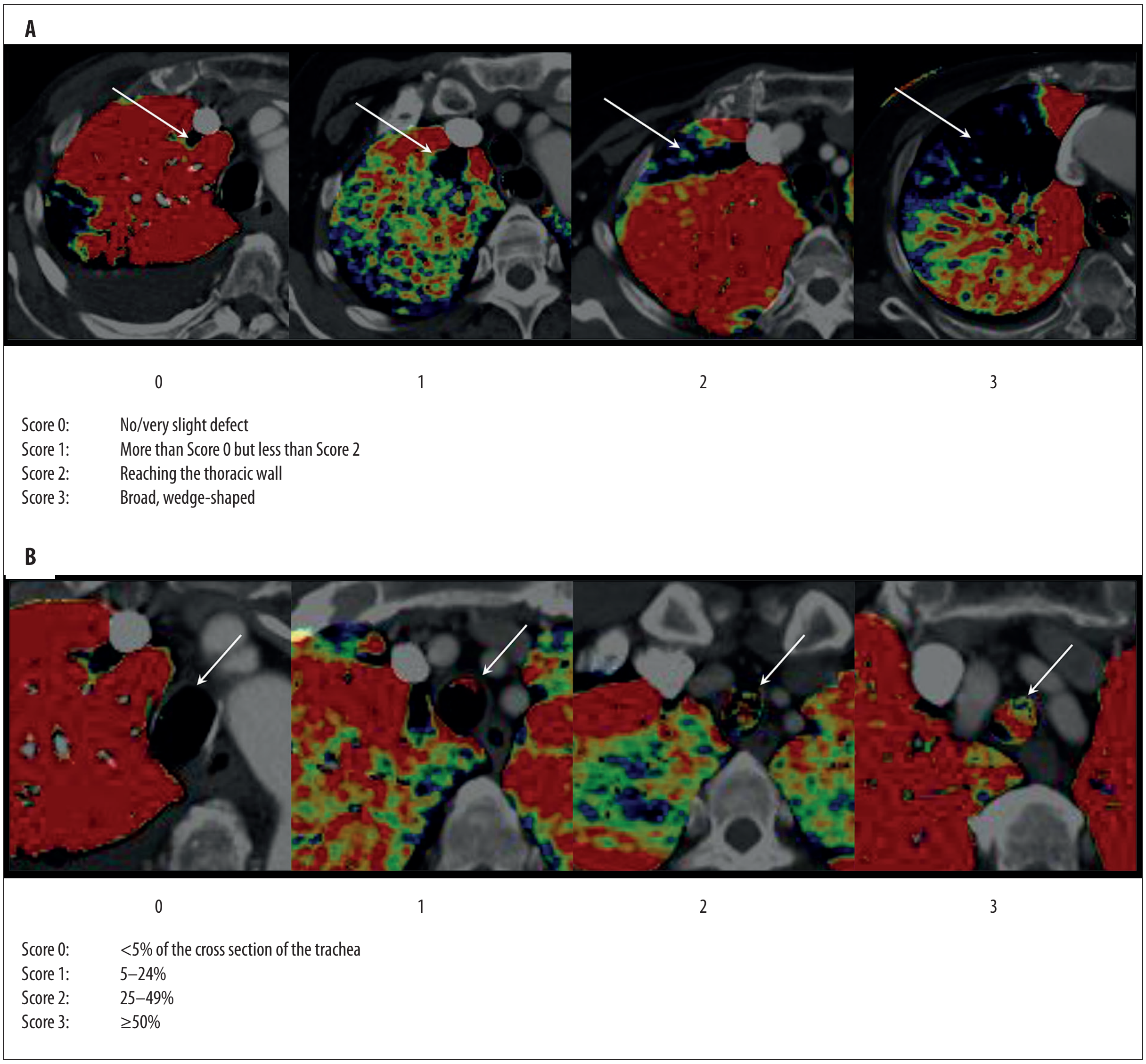

Figure 2. Scoring criteria of pulmonary enhancement defect (PED) (**A**) and tracheal pseudo-enhancement (TPE) (**B**). For PED, score 0 was defined as no or very slight defect, score 3 was broad defect which might be judged as pulmonary embolism. TPE was classified into 4 grades dependent on its area in the cross-sectional trachea.

scores and the attenuation of the brachiocephalic vein, Spearman's rank correlation was used.

Results

The mean PED scores were 0.8 and 1.9 ($P<0.0001$) for group A and B, respectively. The mean TPE scores were 1.1 and 2.2 ($P<0.0001$), respectively. The mean CTDIvol were 4.90±1.14 (SD) and 12.98±3.15 mGy ($P<0.0001$), respectively. There were no significant differences in the age, gender, contrast injection side, and attenuation of the brachiocephalic vein (BCV) between the two groups (Table 1). There was a positive correlation between the CT number of the BCV and PED in Group A ($P=0.038$) (Figure 3).

Discussion

In this study, we hypothesized the iodine distribution in the lung parenchyma was almost homogeneous as long as there was no evidence of pulmonary thromboembolism on contrast-enhanced CT pulmonary arteriography, parenchymal abnormalities, other clinical findings, nor past history of DVT. In many cases, however, the iodine concentration was displayed relatively low on the lung PBV images especially just around the intensively enhanced vessels (e.g. brachiocephalic vein, superior vena cava). We considered this artifact as an indicator of the potential pseudo-positivity for thromboembolism; pulmonary enhancement defect (PED). The fact that PED was observed only on the side ipsilateral to the injection site of the contrast media might strongly support this hypothesis. On the other hand, the intra-tracheal space was enhanced on some lung PBV images and was also dominantly observed adjacent to high-attenuation vessels. This type of artifact – namely, tracheal pseudo-enhancement (TPE) – indicated a possibility of pseudo-negativity in lung perfusion images. In the past literature dealing with virtual unenhanced images by using phantom models, insufficient iodine removal occurred adjacent

Table 1. Summary of the results.

	Group A (n=18)	Group B (n=20)	*P* value
Age (years, mean)	62	66	0.42*
Gender (F/M)	12/6	17/3	0.18**
Injection side (R/L)	15/3	19/1	0.24**
Attenuation of BCV on WAI* (HU, mean ±SD)	1165±357	1424±401	0.09***
PED score (mean)	0.8	1.9	<0.0001***
TPE score (mean)	1.1	2.2	<0.0001***
CTDI volume (mGy, mean ±SD)	4.90±1.14	12.98±3.15	<0.0001*

WAI – weighted average image (a mixed two-kilovolt image equivalent to 120-kVp image). * Student's t-test; ** Chi-square test; *** Mann-Whitney u test.

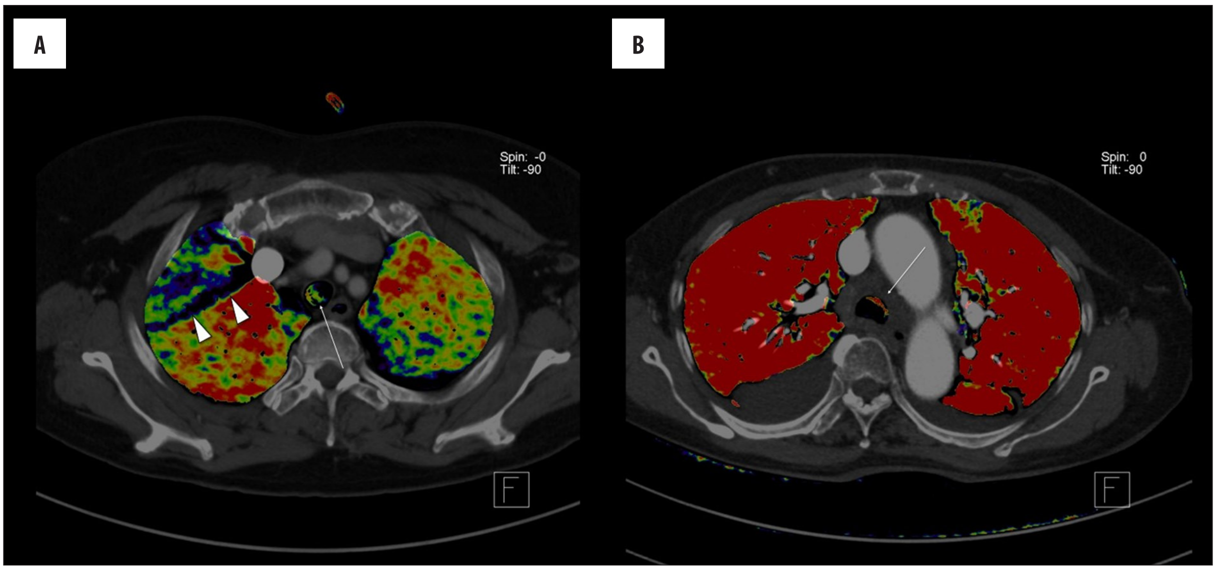

Figure 3. Correlations between the artifact score and attenuation of the brachiocephalic vein ipsilateral to the injection site of the contrast medium. (**A**) Group A and (**B**) Group B. A positive correlation was observed for PED in Group A (P=0.038).

to high-concentration iodine, especially in areas with low iodine concentration on the images scanned without the tin filter [14]. This phenomenon was considered consistent with the appearance of PED in terms of 'underestimation' of iodine concentration. In contrast, TPE may lead to 'overestimation' of iodine concentration in the lung parenchyma. Although these two types of artifacts seem inconsistent with each other, we believe beam hardening and scatter might contribute to this phenomenon. Beam hardening and scatter both produce not only dark but also bright streaks around high-attenuation objects and therefore may also cause 'pseudo-enhancement' as well as enhancement defect [16,17]. Especially, low-energy components of the X ray spectra are more susceptible to irregular scattering; they tend to cause uncertainty in measurement of attenuation [18]. Some reports have also shown that this is one of the most important factors affecting the accuracy of material decomposition [12,19]. In the present study, we applied a new technique using a tin filter to a 140 kVp tube in combination with a 100 kVp tube in place of 80 kVp and the radiation exposure was significantly lower in Group A. Without the filter, the overlap of X-ray spectra between the two tubes was larger when using the 100 kVp tube and, in general, the difference in attenuation of certain tissues between two different kilovolt images was larger. Therefore, it is considered favorable to use two X-ray tubes with more different voltages for material decomposition in a conventional equipment [20]. However, the lower the energy of the low-kilovolt tube is, the more prominent the artifacts are. For the lung BPV images, the results of this study indicated the tin filter solved these problems by intercepting only the low-energy spectra of high-kilovolt X-rays and achieved better separation of the two X-ray spectra suppressing artifacts without increasing radiation exposure. Nevertheless, the extent was small compared to Group B, and relatively severe PED was also observed in Group A when the CT number of the brachiocephalic vein was high. This indicates pseudo-positivity for PE is likely to occur when the concentration of iodinated contrast media is high even if using the filter. Conversely, it implies optimization of the contrast injection protocol and scanning timing would diminish this artifact.

There are some limitations of our study. First, possible incomplete exclusion of PE patient: Although perfusion and ventilation lung scintigraphy is considered the gold standard examination for pulmonary embolism, we employed only clinical findings and contrast enhancement of the pulmonary artery visible on 2.0-mm-slice CT to rule out PTE. This might have missed microembolism in the peripheral vessels. Second, limitation of evaluated areas: Only apexes and their periphery in the lung parenchyma were evaluated and other parts of the lung were not covered in this study. This was because enhancement defect on Lung PBV images was mainly observed in these areas and to make systematic classification of the artifacts easier for the two readers. Third, there might be some effects other than the tin filter and tube voltages. In this study, two different CT scanners were used. SOMATOM Definition Flash was the latest one equipped with some new reconstruction algorithms including a modern technique, Advanced Modeled Iterative Reconstruction [21]. Although this technique might reduce beam hardening effect to a certain extent, noise reduction in low-radiation-dose scan is considered relatively dominant [16].

Conclusions

In conclusion, although further investigation to support the results is needed, this study demonstrated that tin filter might improve lung perfusion images generated using DECT by reducing the influence of adjacent high-attenuation materials without increasing the radiation dose.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References:

1. Graser A, Johnson TR, Hecht EM et al: Dual-energy CT in patients suspected of having renal masses: Can virtual nonenhanced images replace true nonenhanced images? Radiology, 2009; 252: 433–40
2. Ferda J, Novák M, Mírka H et al: The assessment of intracranial bleeding with virtual unenhanced imaging by means of dual-energy CT angiography. Eur Radiol, 2009; 19: 2518–22
3. Watanabe Y, Uotani K, Nakazawa T et al: Dual-energy direct bone removal CT angiography for evaluation of intracranial aneurysm or stenosis: Comparison with conventional digital subtraction angiography. Eur Radiol, 2009; 19: 1019–2.
4. Uotani K, Watanabe Y, Higashi M et al: Dual-energy CT head bone and hard plaque removal for quantification of calcified carotid stenosis: Utility and comparison with digital subtraction angiography. Eur Radiol, 2009; 19: 2060–65
5. Matlaga BR, Kawamoto S, Fishman E. Dual source computed tomography: A novel technique to determine stone composition. Urology, 2008; 72: 1164–68
6. Primak AN, Fletcher JG, Vrtiska TJ et al: Noninvasive differentiation of uric acid versus non-uric acid kidney stones using dual-energy CT. Acad Radiol, 2007; 14: 1441–47
7. Pontana F, Remy-Jardin M, Duhamel A et al: Lung perfusion with dual-energy multi-detector row CT: Can it help recognize ground glass opacities of vascular origin? Acad Radiol, 2010; 17: 587–94
8. Kawai T, Shibamoto Y, Hara M et al: Can dual-energy CT evaluate contrast enhancement of ground-glass attenuation? Phantom and preliminary clinical studies. Acad Radiol, 2011; 18: 682–89
9. Sueyoshi E, Tsutsui S, Hayashida T et al: Quantification of lung perfusion blood volume (lung PBV) by dual-energy CT in patients with and without pulmonary embolism: preliminary results. Eur J Radiol, 2011; 80: e505–9
10. Nakazawa T, Watanabe Y, Hori Y et al: Lung perfused blood volume images with dual-energy computed tomography for chronic thromboembolic pulmonary hypertension: Correlation to scintigraphy with single-photon emission computed tomography. J Comput Assist Tomogr, 2011; 35: 590–95
11. Kang MJ, Park CM, Lee CH et al: Focal iodine defects on color-coded iodine perfusion maps of dual-energy pulmonary CT angiography images: A potential diagnostic pitfall. Am J Roentgenol, 2010; 195: W325–30
12. Maass C, Baer M, Kachelriess M: Image-based dual energy CT using optimized precorrection functions: A practical new approach of material decomposition in image domain. Med Phys, 2009; 36: 3818–29
13. Primak AN, Ramirez Giraldo JC, Liu X et al: Improved dual-energy material discrimination for dual-source CT by means of additional spectral filtration. Med Phys, 2009; 36: 1359–69
14. Kawai T, Takeuchi M, Hara M et al: Accuracy of iodine removal using dual-energy CT with or without a tin filter: An experimental phantom study. Acta Radiol, 2013; 54: 954–60
15. Johnson TR, Krauss B, Sedlmair M et al: Material differentiation by dual energy CT: Initial experience. Eur Radiol, 2007; 17: 1510–17
16. Boas FE, Fleischmann D: CT artifacts: Causes and reduction techniques. Imaging Med, 2012; 4: 229–40
17. Maki DD, Birnbaum BA, Chakraborty DP et al: Renal cyst pseudoenhancement: Beam-hardening effects on CT numbers. Radiology, 1999; 213: 468–72
18. Kyriakou Y, Meyer E, Prell D et al: Empirical beam hardening correction (EBHC) for CT. Med Phys, 2010; 37: 5179–87
19. Dinkel J, Khalilzadeh O, Phan CM et al: Technical limitations of dual-energy CT in neuroradiology: 30-month institutional experience and review of literature. J Neurointerv Surg, 2015; 7: 596–602
20. Avrin DE, Macovski A, Zatz LE: Clinical application of Compton and photo-electric reconstruction in computed tomography: Preliminary results. Invest Radiol, 1978; 13: 217–22
21. Gordic S, Desbiolles L, Stolzmann P et al: Advanced modelled iterative reconstruction for abdominal CT: Qualitative and quantitative evaluation. Clin Radiol, 2014; 69: e497–504