Received:
11 August 2015

Revised:
28 November 2016

Accepted:
14 December 2016

<https://doi.org/10.1259/bjr.20150670>

Cite this article as:

Kondo M, Nishie A, Fujita N, Morita K, Shirasaka T, Arimura H, et al. Impact of hybrid iterative reconstruction on unenhanced liver CT. *Br J Radiol* 2017; **90**: 20150670.

FULL PAPER

Impact of hybrid iterative reconstruction on unenhanced liver CT

¹MASATOSHI KONDO, MSc, ²AKIHIRO NISHIE, MD, ²NOBUHIRO FUJITA, MD, ²KOICHIRO MORITA, MD, ¹TAKASHI SHIRASAKA, RT, ¹HISAO ARIMURA, RT, ¹YASUHIKO NAKAMURA, RT and ²HIROSHI HONDA, MD

¹Department of Medical Technology, Kyushu University Hospital, Fukuoka, Japan

²Department of Clinical Radiology, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan

Address correspondence to: Mr Masatoshi Kondo

E-mail: m-kondo@med.kyushu-u.ac.jp

Objective: To clarify the impact of hybrid iterative reconstruction (HIR) and filtered back projection (FBP) on unenhanced liver CT.

Methods: 30 patients with hepatocellular carcinoma (HCC) underwent unenhanced CT. The images were reconstructed with FBP and weak (Level 1), mild (Level 4) and strong (Level 7) levels of HIR (iDose⁴; Philips Medical Systems, Cleveland, OH). Quantitatively, attenuations of the HCC (with the largest lesion in each case), hepatic parenchyma (the average of four segments) and image noise (standard deviation of the attenuations in hepatic parenchyma) were compared between the four kinds of reconstruction using the two-tailed paired *t*-test. Qualitatively, liver lesion conspicuity and characterization were also compared using the Wilcoxon signed-rank test.

Results: Attenuation of the liver lesion with the strong level of HIR was significantly higher than that with FBP ($p = 0.0005$). Attenuations of hepatic parenchyma with all three HIR levels were significantly lower than that with FBP ($p \leq 0.0002$ in all comparisons). Image noise with each of the three HIR levels was significantly smaller than that with FBP ($p < 0.0001$ in any comparison). There was no significant difference in lesion conspicuity and characterization between FBP and each HIR level ($p \geq 0.0819$ in all comparisons).

Conclusion: Although attenuations of the liver lesion and hepatic parenchyma were significantly different between HIR and FBP, HIR had no significant effect on lesion conspicuity and characterization.

Advances in knowledge: Attenuations of liver lesions and hepatic parenchyma differ significantly between HIR and FBP images.

INTRODUCTION

Hybrid iterative reconstruction (HIR) algorithms have been developed for use in contrast-enhanced liver CT.^{1–3} Sagara et al¹ reported a comparison of radiation dose, noise and image quality between a low radiation dose with HIR and routine radiation dose with filtered back projection (FBP) and concluded that a low radiation dose with HIR had diagnostic acceptability comparable with that of a routine radiation dose with FBP. Singh et al² reported on image quality and lesion conspicuity according to different current-time products with HIR and stated that HIR improved the image quality, lesion detection and conspicuity at low radiation doses. Hara et al³ studied the image quality, image noise, low contrast resolution and spatial resolution using a low radiation dose with HIR and confirmed that HIR could achieve a radiation dose reduction of 32–65%. Owing to the image noise reduction induced by HIR, all three reports mentioned above concluded that HIR could achieve radiation dose reduction without compromising the image quality in comparison with FBP.

A previous study⁴ revealed that attenuation of a 15-mm low-contrast cylindrical object at a 1.0% contrast level with HIR (iDose⁴; Philips Medical Systems, Cleveland, OH) was slightly closer to background attenuation, as compared with that with FBP on a Catphan phantom, while background attenuation was unchanged at 10 different radiation dose levels and by scanning 10 times. Consequently, the contrast of the low-contrast object tended to decrease as HIR levels increased in comparison with FBP. However, the impact of the attenuation difference with HIR has yet to be fully investigated in the clinical setting. Therefore, in this study, we focused on unenhanced CT, the attenuation of which is not affected by scan timing after administration of the contrast medium. Yoshida et al⁵ reported that half of the hepatocellular carcinomas (HCCs) are relatively hypodense on unenhanced CT images. We consider that unenhanced CT of HCCs is appropriate for evaluating the effect of HIR in low-contrast objects. Therefore, the purpose of this study was to clarify how the attenuation and visual appearance of solid lesions in unenhanced liver CT is changed by the use of HIR.

In this study, we selected HCC as representative of solid liver lesions.

METHODS AND MATERIALS

Patients

Ethical approval for the conduct of this retrospective study of 60 consecutive patients who underwent dynamic CT for known or suspected HCC at our institution was obtained from the institutional review board of Kyushu University Hospital (approval number: 26–163). Data were collected from September 2010 to February 2014. The diagnosis of HCC was established based on the presence of a combination of the typical enhancing pattern (early enhancement in the arterial phase with washout in the equilibrium phase) on CT and an increase in one of the tumour markers (>20 ng/ml for alpha fetoprotein or >40 nAU/ml for protein induced by vitamin K absence or antagonist II). 50 of the 60 patients satisfied these criteria. The tumour showed iso-attenuation on unenhanced CT in 18 of the 50 patients, and 2 patients had HCC with a portal tumour thrombus and large HCC (>5 cm). These 20 patients were excluded from the study. Finally, a total of 30 patients (21 males, 9 females; mean age, 72 years; age range, 45–91 years) were enrolled in this study. The characteristics of the 30 patients are summarized in Table 1.

Image acquisition and reconstruction

The CT scanner employed in this study was a Brilliance iCT (Philips Medical Systems, Cleveland, OH). Liver dynamic CT scans, including unenhanced CT, arterial, portal venous and equilibrium phases, were obtained during breath-holding for each patient. The scanning parameters were as follows: rotation time 500 ms; 128×0.625 -mm collimator; tube voltage 120 kV;

85–219 mA; field of view 32 cm; and spiral pitch 0.586. The reference tube current–time product of 127 mAs was automatically adapted to patient size and shape using automatic modulation (Dose Right; Philips Medical Systems, Cleveland, OH). The mean current was 156 mA (range, 85–219 mA). A dose of 370 mg ml^{-1} of the non-ionic contrast medium (iopamidol) (Iopamiron 370; Bayer HealthCare, Osaka, Japan) was injected *via* a 22-gauge needle into the right antecubital vein. First, 100 ml of the contrast medium was injected at a speed of 3.0 ml s^{-1} , following which 20 ml of saline solution was injected at the same injection rate as the contrast medium using a dual-head power injector (Dual Shot GX; Nemoto Kyorindo, Tokyo, Japan).

Axial images of 5.0-mm thickness were reconstructed with the abdominal standard convolution kernel for FBP and the three noise reduction levels of HIR (iDose⁴). The three noise reduction levels included weak (iDose⁴ Level 1), mild (iDose⁴ Level 4) and strong (iDose⁴ Level 7) levels. While enhanced (arterial, portal venous and equilibrium phases) liver CT images were only used for confirmation of the enhancing pattern in the liver lesion, unenhanced liver CT images were used for all image assessments.

HIR (iDose⁴) is based on a two-step system for noise reduction. In the first step, HIR optimizes image quality and artefact prevention in the projection space. In the second step, HIR removes noise using model-based noise reduction in the image space.⁶

Image assessment

The liver lesion with the largest diameter was selected in patients with multiple liver lesions. In addition, we assessed the slice in which the target lesion appeared to be the largest.

Table 1. Characteristics of the 30 patients

Characteristics	Number or mean (range)
Background of chronic liver disease	
Chronic viral hepatitis B ^a	2
Chronic viral hepatitis C ^a	23
Alcohol abuse ^a	3
Chronic liver disease without hepatitis virus infection or alcohol abuse ^a	2
AFP (ng/mL) ^b	15.8 (1.6–10150)
PIVKA-II (mAU/mL) ^b	124 (8–35163)
Child–Pugh grade	
A ^a	21
B ^a	7
C ^a	2
Liver lesion location	
Right lobe ^a	23
Left lobe ^a	7
Liver lesion median diameter (mm) ^c	20.1 (20.1, 11.5–42.7)

AFP, alpha fetoprotein; PIVKA-II, vitamin K absence or antagonist II.

^aData are numbers of patients.

^bData are mean with ranges in parentheses.

^cData are mean and median with ranges in parentheses.

Quantitative analysis

A radiology technologist and an abdominal radiologist with 5 and 20 years' experience performed all the measurements consensually using a CT viewer (CT Viewer; Philips Medical Systems, Cleveland, OH). Attenuation of each liver lesion was measured by manually selecting as large a region of interest (ROI) as possible (median area, 73 mm²; range 18–233 mm²). Attenuation of the hepatic parenchyma was defined as the average value of the attenuations in four segments (lateral and medial segments of the left lobe and anterior and posterior segments of the right lobe). Similarly, manual placement of circular ROIs (median area, 180 mm²; range, 104–290 mm²) was performed while carefully avoiding large vessels (Figure 1). Image noise was defined as the average value of the standard deviation of the attenuations in the four segments. Contrast-to-noise ratio (CNR) was calculated using the following formula:

$$\text{CNR} = (\text{MLI} - \text{Mh.p.}) / \text{square root of } (\text{SDI}^2 + \text{SDh.p.}^2), \quad (1)$$

where MLI and Mh.p. are attenuations of the liver lesion and hepatic parenchyma, respectively, and SDI and SDh.p. are standard deviations of attenuation of the liver lesion and hepatic parenchyma, respectively.

Qualitative analysis

We performed image analysis at a window level and width of 100 HU and 500 HU, respectively. To avoid a mismatch between the quantitative and qualitative analyses, the target lesion for each patient was shown with an arrow to indicate the lesion on the FBP image saved on a laptop computer (Let's Note CF-SX1; Panasonic Corporation, Osaka, Japan). The laptop computer was only used to indicate the target lesion in the liver. Two abdominal radiologists, with 4 and 11 years' experience,

respectively, independently assessed the images on a 3 MP medical-grade colour liquid crystal display (Eizo RadiForce RX340; Eizo Corporation, Ishikawa, Japan). These radiologists were blinded to the clinical information. First, liver lesion conspicuity on images obtained using the three HIR levels was compared with that on images obtained using FBP and was assessed using a five-point subjective scale (1, poor; 2, slightly poor; 3, equivalent; 4, slightly better; 5, better). Next, liver lesion characterization was also evaluated. The observers used a five-point subjective scale (1, considered a cyst; 2, suspected cyst; 3, indeterminate; 4, suspected solid lesion; 5, considered a solid lesion) to characterize the lesion. To minimize recall bias, each reading session (FBP vs each HIR level) was performed separately with an interval of at least 2 weeks. For liver lesion conspicuity, we performed pairwise comparisons by placing the two kinds of images side by side on the medical-grade display. For liver lesion characterization, we first evaluated images obtained with the weak level of HIR in all patients, followed by evaluation of images obtained with the mild level of HIR, the strong level of HIR and FBP, in that order.

Statistical analysis

Continuous data are expressed as means $\pm$ standard deviation or median and range, as appropriate. The two-tailed paired *t*-test was used for the comparison of liver lesion and hepatic parenchymal attenuations, image noise and CNR between FBP and each HIR level. The two-tailed paired *t*-test was used for the comparison of liver lesion and hepatic parenchymal attenuations in the four segments between FBP and each HIR level. Wilcoxon signed-rank test was used to compare the scores of liver lesion conspicuity between each pair of the three HIR levels or the scores of liver lesion characterization between FBP and each HIR level. Statistical analyses were performed using commercially available software (JMP Pro, v. 12.0; SAS Institute, Cary, NC). A two-tailed *p*-value of <0.05 was considered to indicate statistical significance.

RESULTS

Quantitative analysis

Table 2 shows a summary of the quantitative analyses (a comparison of liver lesion and hepatic parenchymal attenuations, image noise and CNR is shown in the [Supplementary Table](#)). Attenuation of liver lesions with the strong level of HIR was significantly higher than that with FBP ($p = 0.0005$). There were no significant differences in attenuation of the liver lesion between FBP and weak or mild levels of HIR ($p \geq 0.1904$ in all comparisons). Attenuations of hepatic parenchyma with the three HIR levels were significantly lower than that with FBP ($p \leq 0.0002$ in all comparisons). The actual difference in the attenuation of the liver lesion and hepatic parenchyma between HIR and FBP was <1 HU. Image noise with each of the three levels of HIR was significantly smaller than that with FBP ($p < 0.0001$ in all comparisons). CNRs in the liver lesion with the three HIR levels were significantly higher than that with FBP ($p < 0.0001$ in all comparisons).

Qualitative analysis

Although the scores of liver lesion conspicuity tended to increase as HIR levels increased for both the observers (Table 3), there were no significant differences in the scores of liver lesion

Figure 1. Quantitative analysis: attenuations of the liver lesion and four liver segments (lateral and medial segments of the left lobe and anterior and posterior segments of the right lobe) were measured. SD, standard deviation.

Table 2. Attenuation and attenuation difference between hybrid iterative reconstruction (HIR) and filtered back projection (FBP) of the liver lesions, hepatic parenchyma, image noise and contrast-to-noise ratio (CNR) on unenhanced liver CT

	Attenuation (HU)				Attenuation difference between HIR and FBP (HU)			<i>p</i> -value ^a		
	FBP	Weak-level HIR	Mild-level HIR	Strong-level HIR	Weak-level HIR	Mild-level HIR	Strong-level HIR	FBP vs weak-level HIR	FBP vs mild-level HIR	FBP vs strong-level HIR
Liver lesion	47.4 ± 8.2	47.4 ± 8.3	47.4 ± 8.3	48.0 ± 8.3	0.0 ± 0.1	0.0 ± 0.1	0.6 ± 0.1	0.9220	0.1904	0.0005
Hepatic parenchyma	64.9 ± 4.5	64.8 ± 4.5	64.8 ± 4.5	64.7 ± 4.4	-0.1 ± 0.0	-0.1 ± 0.0	-0.2 ± 0.0	0.0002	0.0002	<0.0001
Image noise	14.8 ± 1.8	13.0 ± 1.5	10.3 ± 1.2	6.4 ± 0.8	-1.8 ± 0.1	-4.5 ± 0.1	-8.4 ± 0.1	<0.0001	<0.0001	<0.0001
CNR	0.9 ± 0.4	1.0 ± 0.5	1.2 ± 0.6	1.8 ± 0.9	0.1 ± 0.1	0.3 ± 0.1	0.9 ± 0.1	<0.0001	<0.0001	<0.0001

Data are mean ± standard deviation.

^aThe two-tailed paired t test.

conspicuity between each pair of HIR levels ($p \geq 0.1607$ in all comparisons).

There were no significant differences in the scores of liver lesion characterization between FBP and each HIR level for both observers, although there seemed to be a slight difference between the two observers in their personal diagnostic standard ($p \geq 0.0819$ in all comparisons) (Table 4). There were no significant differences in the scores of liver lesion characterization between each pair of the three HIR levels ($p \geq 0.1372$ in all comparisons).

A representative case is shown in Figure 2.

DISCUSSION

HIR reduces image noise compared with FBP, as previously reported.^{1-4,6} In addition, a statistically significant difference in attenuation of the liver lesion and hepatic parenchyma between HIR and FBP on unenhanced CT was newly found in this study. Previous reports have stated that there was no significant difference in attenuation of the hepatic parenchyma between HIR and FBP.^{2,7-10} This could be due to shortcomings in relation to the statistical analyses in the previous reports. In the present study, we compared HIR and FBP using appropriate statistical analysis methods for paired samples.¹¹

According to a previous report by Kondo et al,⁴ attenuation of the signal in the Catphan phantom changed, while that of the background remained unchanged. The significant difference in attenuation of liver lesions between HIR and FBP in this study was similar to the signal attenuation observed in the Catphan phantom, while the significant difference in attenuation of the hepatic parenchyma was different from that of the background signal. Although the reason for this is unclear, we propose a plausible hypothesis to explain this difference. We consider that uniformity in attenuation and the beam-hardening effect are potential causes of the changes in attenuation in HIR images. Image noise leads to regional fluctuation in attenuation of objects on CT images.¹² Attenuation of liver lesions might be different in HIR images when compared with FBP images, because this regional fluctuation of attenuation is corrected by HIR, but not by FBP. In our study, subtraction images were generated by subtracting attenuations in images using HIR from those in images using FBP. These subtraction images may demonstrate that not only regional attenuations of the liver parenchyma, but also image attenuation as a whole, changed. Since attenuation of the hepatic parenchyma was defined as the average value measured in four segments, the influence of the beam-hardening effect is likely not negligible when the uniformity in attenuation of the hepatic parenchyma is considered. Hence, HIR might also correct the attenuation difference caused by the beam-hardening effect, resulting in a significant change in attenuation of the hepatic parenchyma. In a previous study, background attenuation in the Catphan phantom was measured by placing a single ROI at locations close to the signal.⁴ Therefore, beam hardening might not have affected attenuation of the background. In this study, we used only CT images with a 5-mm slice thickness. The minimum diameter of circular liver lesions was 11.5 mm, and we only evaluated the image with the

Table 3. Subjective scores of liver lesion conspicuity

Parameter	Reader 1 ^a	Pooled result of Reader 1 ^b	Reader 2 ^a	Pooled result of Reader 2 ^b
HIR with weak	0/0/30/0/0	3.0 (0.0)	0/0/27/3/0	3.1 (0.3)
HIR with mild	0/0/28/2/0	3.1 (0.3)	0/0/24/6/0	3.2 (0.4)
HIR with strong	0/3/20/7/0	3.1 (0.6)	0/6/14/6/4	3.3 (0.9)

HIR, hybrid iterative reconstruction.

^aData are numbers of visual scores given in each category (1, poor; 2, slightly poor; 3, equivalent; 4, slightly better; 5, better) compared with filtered back projection.

^bData are mean scores and standard deviation in parentheses for each reader.

largest lesion in each case. In addition, we used the parameters of acquired slice thickness (0.625 mm) and reconstructed slice thickness (5 mm). Hence, attenuations of the liver lesion and hepatic parenchyma may have been less affected by the partial volume effect.

Although the differences in attenuation of the liver lesion and hepatic parenchyma between HIR and FBP were <1 HU, these differences were statistically significant because the same tendency was observed in most cases. In addition, subtraction images demonstrated that the differences in pixel attenuation between mild or strong levels of HIR and FBP were >5 HU. Since this phenomenon could affect image interpretation by radiologists in daily practice, we investigated whether or not the conspicuity and characterization of liver lesions are different between HIR and FBP. The most important concern when using HIR is whether radiologists can accurately characterize and hence diagnose lesions when their image appearance changes. In addition, in liver lesions in this study, CNRs with the three HIR levels were significantly increased compared with those with FBP. The increased lesion conspicuity might result in the radiologist erroneously diagnosing a solid lesion as cystic. However, no significant differences in liver lesion conspicuity and characterization between HIR and FBP were observed in this study. This result suggests that CT images with HIR can be interpreted using the same diagnostic standard as has been developed for FBP, even when interpreting images handled with HIR alone.

Attenuation of liver lesions with strong levels of HIR was significantly increased compared with that observed with FBP. Furthermore, attenuation of the hepatic parenchyma with all three levels of HIR was significantly decreased compared with

that with FBP. This alteration in attenuation can lead to decreased liver lesion conspicuity. However, the lesion conspicuity with HIR was qualitatively unchanged in this study. This fact might derive from the improvement in the CNR of the liver lesion by HIR due to significant image noise reduction. In other words, the trade-off between the improvement in CNR and the decreased contrast with HIR can explain the lack of difference in liver lesion conspicuity between HIR and FBP. This result itself is in good agreement with the reports of several previous studies.^{9,10,13,14}

During liver lesion characterization, the alteration in attenuation with HIR can also lead to misdiagnosis of a lesion as more “solid-like”. Although Reader 2 tended to evaluate HCCs as being more “solid-like” as the HIR level increased, the difference did not reach statistical significance. In contrast, the judgment of Reader 1 regarding lesion characterization was not at all different between HIR and FBP images. Consequently, we believe that HIR does not remarkably affect lesion characterization.

Limitations

A limitation of this study is that we only performed qualitative analysis with a window width of 500 HU to simplify the assessment. Since this window width is relatively large, the effect of image noise reduction by HIR on lesion conspicuity and characterization may have been underestimated.

CONCLUSION

Attenuations of liver lesions and hepatic parenchyma are significantly different between HIR and FBP images. However, HIR has no significant effect on lesion conspicuity and characterization.

Table 4. Subjective scores of liver lesion characterization

Parameter	Reader 1 ^a	Pooled result of Reader 1 ^b	Reader 2 ^a	Pooled result of Reader 2 ^b
FBP	0/0/7/23/0	3.8 (0.4)	0/6/11/8/5	3.4 (1.0)
HIR with weak	0/0/7/23/0	3.8 (0.4)	0/6/9/10/5	3.4 (1.0)
HIR with mild	0/0/7/23/0	3.8 (0.4)	0/6/8/11/5	3.5 (1.0)
HIR with strong	0/0/7/23/0	3.8 (0.4)	0/5/3/14/8	3.8 (1.0)

FBP, filtered back projection; HIR, hybrid iterative reconstruction.

^aData are numbers of visual scores given in each category (1, considered a cyst; 2, suspected cyst; 3, indeterminate; 4, suspected solid lesion; 5, considered a solid lesion).

^bData are mean scores and standard deviation in parentheses for each reader.

Figure 2. Liver CT images of an 80-year-old male with hepatocellular carcinoma (HCC) in the lateral segment: unenhanced CT images with filtered back projection (FBP) (a) and with weak (b), mild (c) and strong (d) levels of hybrid iterative reconstruction (HIR) are showing the HCC as a low attenuated lesion (arrowhead). Subtraction images, which were generated by subtracting attenuations in images with (e) weak, (f) mild and (g) strong levels of HIR from those in images with FBP are showing the attenuation difference (h) with respect to the original lookup table. In terms of lesion conspicuity, Observer 1 scored the conspicuity as 3, 3 and 2 with weak, mild and strong levels of HIR, respectively, as compared with FBP. Observer 2 scored conspicuity similarly as 3, 3 and 3 with weak, mild and strong levels of HIR, respectively. In terms of lesion characterization, Observer 1 scored characterization as 4, 4, 4 and 4 with FBP and weak, mild and strong levels of HIR, respectively. Observer 2 similarly scored characterization as 3, 4, 4 and 4 with FBP and weak, mild and strong levels of HIR, respectively. Liver lesion conspicuity and characterization with HIR were equivalent to those with FBP. Attenuation of the liver lesion and hepatic parenchyma, image noise and contrast-noise ratio (CNR) were also demonstrated. The subtraction images are also showing that all three levels of HIR have changed not only regional attenuation, but also attenuation as a whole in comparison with the FBP image.

ACKNOWLEDGMENTS

We thank Dr Ken Shirabe, Department of Surgery and Science, Kyushu University, and Dr Kazuhiro Kotoh, Department of Medicine and Bioregulatory Science, Kyushu University, for

providing the clinical information for this article. We also thank Dr Junji Kishimoto, Department of Research and Development of Next Generation Medicine Faculty of Medical Sciences, Kyushu University, for advice on the statistical analysis.

REFERENCES

1. Sagara Y, Hara AK, Pavlicek W, Silva AC, Paden RG, Wu Q. Abdominal CT: comparison of low-dose CT with adaptive statistical iterative reconstruction and routine-dose CT with filtered back projection in 53 patients. *AJR Am J Roentgenol* 2010; **195**: 713–9. doi: <https://doi.org/10.2214/AJR.09.2989>
2. Singh S, Kalra MK, Hsieh J, Licato PE, Do S, Pien HH, et al. Abdominal CT: comparison of adaptive statistical iterative and filtered back projection reconstruction techniques. *Radiology* 2010; **257**: 373–83. doi: <https://doi.org/10.1148/radiol.10092212>
3. Hara AK, Paden RG, Silva AC, Kujak JL, Lawder HJ, Pavlicek W. Iterative reconstruction technique for reducing body radiation dose at CT: feasibility study. *AJR Am J Roentgenol* 2009; **193**: 764–71. doi: <https://doi.org/10.2214/AJR.09.2397>
4. Kondo M, Hatakenaka M, Higuchi K, Fujioka T, Shirasaka T, Nakamura Y, et al. Feasibility of low-radiation-dose CT for abdominal examinations with hybrid iterative reconstruction algorithm: low-contrast phantom study. *Radiol Phys Technol* 2013; **6**: 287–92. doi: <https://doi.org/10.1007/s12194-012-0197-7>
5. Yoshida J, Takayama T, Yamamoto J, Shimada K, Kosuge T, Yamasaki S, et al. Computed tomography of sclerosing hepatocellular carcinoma. *Comput Med Imaging Graph* 1992; **16**: 125–30. doi: [https://doi.org/10.1016/0895-6111\(92\)90126-T](https://doi.org/10.1016/0895-6111(92)90126-T)
6. Scibelli A. iDose4 iterative reconstruction technique. Philips Healthcare Website. Updated 11 March 2011. Available from: <http://acceptance.netforum.healthcare.philips.com/Clinical/global/Explore/White-Papers/CT/iDose4-iterative-reconstruction-technique>
7. Deák Z, Grimm JM, Treitl M, Geyer LL, Linsenmaier U, Körner M, et al. Filtered back projection, adaptive statistical iterative reconstruction, and a model-based iterative reconstruction in abdominal CT: an experimental clinical study. *Radiology* 2013; **266**: 197–206. doi: <https://doi.org/10.1148/radiol.12112707>
8. Suzuki S, Haruyama T, Morita H, Takahashi Y, Matsumoto R. Initial performance evaluation of iterative model reconstruction in abdominal computed tomography. *J Comput Assist Tomogr* 2014; **38**: 408–14. doi: <https://doi.org/10.1097/rct.0000000000000062>
9. Shuman WP, Green DE, Busey JM, Kolokythas O, Mitsumori LM, Koprowicz KM, et al. Model-based iterative reconstruction versus adaptive statistical iterative reconstruction and filtered back projection in liver 64-MDCT: focal lesion detection, lesion conspicuity, and image noise. *AJR Am J Roentgenol* 2013; **200**: 1071–6. doi: <https://doi.org/10.2214/AJR.12.8986>
10. Singh S, Kalra MK, Do S, Thibault JB, Pien H, O'Connor OJ, et al. Comparison of hybrid and pure iterative reconstruction techniques with conventional filtered back projection: dose reduction potential in the abdomen. *J Comput Assist Tomogr* 2012; **36**: 347–53. doi: <https://doi.org/10.1097/RCT.0b013e31824e639e>
11. Gordic S, Desbiolles L, Stolzmann P, Gantner L, Leschka S, Husarik DB, et al. Advanced modelled iterative reconstruction for abdominal CT: qualitative and quantitative evaluation. *Clin Radiol* 2014; **69**: e497–504. doi: <https://doi.org/10.1016/j.crad.2014.08.012>
12. Kalender WA, Klotz E, Kostaridou L. An algorithm for noise suppression in dual energy CT material density images. *IEEE Trans Med Imaging* 1988; **7**: 218–24. doi: <https://doi.org/10.1109/42.7785>
13. Yoon JH, Lee JM, Yu MH, Baek JH, Jeon JH, Hur BY, et al. Comparison of iterative model-based reconstruction versus conventional filtered back projection and hybrid iterative reconstruction techniques: lesion conspicuity and influence of body size in anthropomorphic liver phantoms. *J Comput Assist Tomogr* 2014; **38**: 859–68. doi: <https://doi.org/10.1097/RCT.0000000000000145>
14. Dobeli KL, Lewis SJ, Meikle SR, Thiele DL, Brennan PC. Noise-reducing algorithms do not necessarily provide superior dose optimisation for hepatic lesion detection with multidetector CT. *Br J Radiol* 2013; **86**: 20120500. doi: <https://doi.org/10.1259/bjr.20120500>