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ORIGINAL ARTICLE

Iterative reconstruction does not substantially delay CT imaging in an emergency setting

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Abstract
Objectives To evaluate the effects of iterative reconstruction (IR) on reconstruction time and speed in two commonly encountered acquisition protocols in an emergency setting: pulmonary CT angiography (CTA) and total body trauma CT.
Methods Twenty-five patients underwent a pulmonary CTA for evaluation of pulmonary embolisms and 15 patients underwent a total body CT after a traumatic event on a 256-slice CT. Images were reconstructed with filtered back-projection (FBP) and two IR levels. Reconstruction time and speed were quantified using custom written software.
Results Mean reconstruction time delays for pulmonary CTAs were 10±10 s and 12±12 s for IR levels 2 and 4, respectively, and 44±8 s and 45±7 s for total body trauma CTs for IR levels 1 and 6, respectively. Mean reconstruction times and speeds for pulmonary CTAs were 26±7 s, 36±9 s and 38±12 s, and 26.7±5.6 slices/s, 18.7±2.3 slices/s and 18.0±2.8 slices/s for FBP, IR levels 2 and 4, respectively. For total body trauma CTs these values were 87±15 s, 132±17 s and 132±18 s, and 20.1±1.6 slices/s, 13.2±0.8 slices/s and 13.2±0.6 slices/s for FBP, IR levels 1 and 6, respectively.
Conclusions IR does not result in clinically important CT image reconstruction delays in an emergency setting. No substantial differences in reconstruction time and speed were found between different IR levels.
Main Messages
- *IR delayed total pulmonary CTA reconstruction with 10–12 s and total-body trauma CT with 44–45 s*
- *IR is not substantially delaying reconstruction in emergency CT imaging*
- *Reconstruction time and speed are similar for different levels of IR*

Keywords Computed tomography · Iterative reconstruction · Computed tomography angiography · Trauma · Emergency imaging

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Introduction

Iterative reconstruction (IR) for computed tomography (CT) is a promising noise reducing technique with the potential to substantially reduce radiation dose while preserving study interpretability [1–7]. Currently, reconstruction algorithms for CT data use filtered back projection (FBP). Image reconstruction with FBP is fast and robust, since it is based on simple mathematical assumptions concerning the CT system. However, with low-dose CT and with obese patients this algorithm leads to noisy images which are susceptible to artefacts [8–10]. All major vendors have recently introduced noise- and artefact-reducing IR algorithms for CT data. IR has been used for many years in nuclear medicine [11], but complexity of CT data impeded the introduction of IR for CT image reconstruction until recently. Improvements in computational power of CT workstations has allowed the recent introduction of IR for CT as well [12]. IR algorithms filter in the raw data domain, image data domain, or both. Measured raw data or image data are iteratively optimised based on the noise reducing model. Since iterative filtering is more computationally demanding compared with conventional filtering methods, they are associated with longer reconstruction times, especially when iterative filtering takes place in the raw data domain [9]. These longer reconstruction times are one of the major drawbacks of IR. The delay in image reconstruction can be especially problematic in the emergency setting, where it is imperative that CT images are available for analysis rapidly after image acquisition. The noise reducing effect and potential decrease of radiation dose with IR have been studied before [1–7]; however, the impact of IR on reconstruction time in clinical CT procedures has not been investigated in detail yet.

The aim of this study was to evaluate the effects of IR on CT image reconstruction time and speed compared with FBP in two commonly encountered acquisition protocols in an emergency setting: pulmonary CT angiography (CTA) and total body trauma CT.

Materials and methods

Subjects

Twenty-five adults (mean age ± standard deviation [SD)] 58.4±14.9 years) underwent pulmonary CTA for evaluation of pulmonary embolism and 15 patients (13 adults and 2 children, mean age ± SD 49.3±24.2 years) underwent total body CT after a traumatic event on a 256-slice CT. Our local institutional review board approved this study and waived the need for informed consent since anonymised data were obtained from routine care image acquisition and patients were not exposed to additional radiation dose.

Pulmonary CTA protocol

Pulmonary CTA examinations were performed on a 256-slice CT (Brilliance iCT; Philips Healthcare, Best, The Netherlands) at end-inspiration in the cranio-caudal direction ranging from above the lung apices to below the diaphragm to include the entire lungs. A circular region of interest was drawn within the pulmonary trunk on the locator image. A dose of 80 ml non-ionic iodinated contrast material (Ultravist, 300 mg iopromide/ml; Schering Nederland, Weesp, The Netherlands) was injected intravenously to patients weighing 65 kg or more at a rate of 6 ml/s. For patients weighing less than 65 kg, the dose was 65 ml and the injection rate was 5 ml/s. At the time the region of interest reached a mean signal density of 150 Hounsfield units (HU), the patient was instructed to maintain a breath-hold and image acquisition started after 8 s. The following parameters were used: detector collimation 128×0.625 mm; pitch 1.0; rotation time 0.5 s; matrix size 512×512. Routine clinical care tube voltage and tube current-time product with automatic current selection (Automatic DoseRight ACS; Philips Healthcare) and z-axial dose modulation were used that depended on individual patients' weight and were 80 kVp and approximately 350 mAs, respectively for patients <60 kg; 100 kVp and approximately 250 mAs, respectively for patients ≥60 and <100 kg, and 120 kVp and approximately 200 mAs, respectively for patients ≥100 kg.

Trauma CT protocol

CT trauma examinations were performed on the same 256-slice CT in cranio-caudal direction ranging from the skull base to the ischium. A circular region of interest was drawn within the descending aortic arch at the locator image. Non-ionic iodinated contrast material (Ultravist, 300 mg iopromide/ml; Schering Nederland, Weesp, The Netherlands) was administered intravenously using a split bolus technique. The first bolus of 100 ml was injected with a rate of 4 ml/s and the second bolus of 50 ml was injected with a rate of 3 ml/s. For children, a single bolus with a volume of 2 ml/kg was administered with a rate of 2 or 3 ml/s. Image acquisition started at the time the region of interest reached a mean signal density of 160 HU. The following parameters were used: detector collimation 128×0.625 mm; pitch 1.0; rotation time 0.5 s; matrix size 512×512. Routine clinical care tube voltage and tube current-time product with automatic current selection (Automatic DoseRight ACS; Philips Healthcare) and z-axial dose modulation were used: 120 kVp and approximately 300 mAs for adults, and 80 and 100 kVp and 90 and 160 mAs for children, depending on their weight.

Image reconstruction

The IR algorithm iDose^4 is the fourth version by Philips, which filters in both raw data and image data domain. The noisiest raw CT data are identified and corrected with a Poisson-statistics-based maximum likelihood denoising algorithm [13]. Subsequently, reconstructed images are propagated to the image domain where uncorrelated noise is decreased by iterative filtering. The noise reducing strength can be selected by choosing one of seven levels. According to the manufacturer, levels 1, 2, 4 and 6 correspond to 10.6 %, 16.3 %, 29.3 % and 45.2 % noise reduction, respectively [13].

All CTAs and total body CTs (including cervical, thoracic and abdominal region) were reconstructed on an Extended Brilliance Workstation (Philips Healthcare) from the raw data. Both FBP and two IR levels (iDose^4; Philips Healthcare) were used. For pulmonary CTA, levels 2 and 4 were used, and for trauma CT, levels 1 and 6 were used.

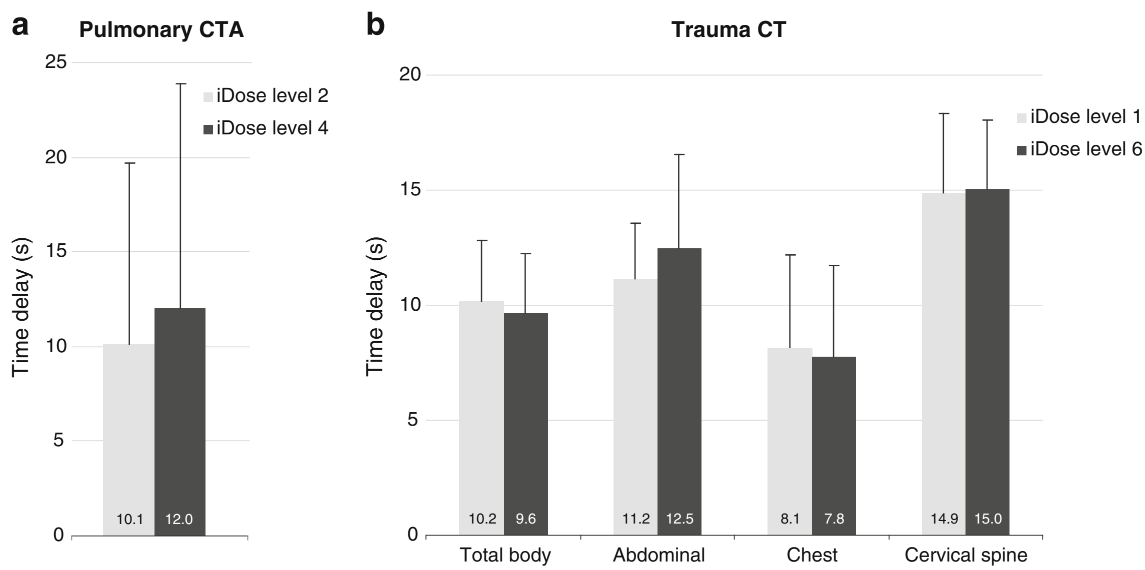

Fig. 1 Mean reconstruction time delay of the pulmonary CTAs (**a**) and the total body trauma CTs (**b**) with iterative reconstruction compared with filtered back projection

Levels 1 and 6 were evaluated because we expected that differences in reconstruction time and speed would be most evident between two extreme noise reducing levels. Levels 2 and 4 were evaluated to assess differences between two less extreme noise reduction levels. Pulmonary CTAs were reconstructed with 0.9-mm-thick axial slices (slice-increment 0.45 mm). Total body CTs were reconstructed with 5-mm-thick axial slices (slice-increment 4 mm) over the total region of image acquisition (total body) and additional 0.7 mm thick axial slices (slice-increment 0.5 mm) for the cervical region and 0.9-mm-thick axial slices for the abdominal and thoracic region (both slice-increment 0.7 mm). Thus, in total four datasets were reconstructed for the trauma scans (entire scan range, cervical spine, thorax and abdomen). Eight total body trauma CTs were reconstructed twice in order to evaluate the reproducibility of our method and mean values of these two measurements in these eight patients are used for analysis.

Assessment of reconstruction time and speed

Reconstruction time and speed of these emergency setting CT protocols with thick and thin slices and overlapping reconstructions were quantified based on Digital Imaging and Communications in Medicine (DICOM) information using a self-written plug-in for ImageJ (US National Institutes of Health, Bethesda, Maryland, USA, http://imagej.nih.gov/ij, version 1.46e) for all scans. This plug-in identified the date and time of reconstruction of each slice. Reconstruction time was calculated as the time difference between the first and the last slice of each acquisition. Reconstruction speed was calculated by dividing the reconstruction time by the number of reconstructed images.

Data analysis

The Kolmogorov-Smirnov test showed that data were normally distributed. Statistical differences were therefore analysed with the parametric dependent *t*-test and all values were described by mean ± standard deviation (SD), unless otherwise stated. Statistical analyses were performed with SPSS version 15.0 (SPSS, Chicago, IL, USA).

Results

Compared with FBP reconstruction, the time delay for reconstruction of an entire pulmonary CTA was on average 10±10 s (40 %) and 12±12 s (47 %) for iDose^4 levels 2 and level 4, respectively (Fig. 1a). For the four datasets of an entire total body trauma CT the combined time delay was 44±8 s (51 %) and 45±7 s (51 %) for iDose^4 levels 1 and 6, respectively, compared with FBP (Fig. 1b).

Mean reconstruction time and speed are listed in Tables 1 and 2. The mean reconstruction time was significantly longer with IR compared with FBP for pulmonary CTAs as well as for total body trauma CTs (all $P<0.001$), whereas differences between IR levels were not significant (all $P>0.05$). Mean reconstruction speed was significantly slower with IR compared with FBP for pulmonary CTAs as well as for total body trauma CTs (all $P<0.001$), and differences between IR levels were not significant for total body trauma CTs (all $P>0.05$). However, mean reconstruction speed for pulmonary CTAs with iDose^4 level 4 was slightly slower compared with level 2 (18.0 slices/s versus 18.7 slices/s for iDose^4 levels 4 and 2, respectively, $p=0.04$).

Table 1 Mean reconstruction time for filtered back projection and iterative CT reconstructions

	Time (s)					*P* value[a]			Slices (N)
	FBP	L2	Percentual delay	L4	Percentual delay	FBP vs L2	FBP vs L4	L2 vs L4	
CTA [b]	25.5±1.4	35.6±1.8	+40 %	37.6±2.4	+47 %	<0.001	<0.001	0.057	647.8±16.6
	FBP	L1	Percentual delay	L6	Percentual delay	FBP vs L1	FBP vs L6	L1 vs L6	
Total body [c]	18.1±0.9	28.3±1.0	+56 %	27.8±1.1	+54 %	<0.001	<0.001	0.255	200.2±6.6
Abdominal [c]	33.2±1.7	44.3±1.8	+33 %	45.7±2.1	+38 %	<0.001	<0.001	0.139	674.1±21.8
Chest [c]	20.1±1.1	28.2±1.4	+40 %	27.8±1.5	+38 %	<0.001	<0.001	0.633	389.6±16.3
Cervical [c]	15.9±0.6	30.8±0.9	+94 %	31.0±0.9	+95 %	<0.001	<0.001	0.780	476.2±16.1
Total trauma CT	87.3±14.6	131.7±16.7	+51 %	132.2±17.9	+51 %	<0.001	<0.001	0.921	1740.1±213.5

FBP filtered back projection, *L2* iDose[4] level 2, *L4* iDose[4] level 4

[a] Based on dependent *t*-test

[b] n=25

[c] n=15

Table 2 Mean reconstruction speed for filtered back projection and iterative CT reconstructions

	Speed (slices/s)					*P* value[a]			Slices (N)
	FBP	L2	Percentual delay	L4	Percentual delay	FBP vs L2	FBP vs L4	L2 vs L4	
CTA [b]	26.7±1.1	18.7±0.5	−30 %	18.0±0.6	−33 %	<0.001	<0.001	0.040	647.8±16.6
	FBP	L1	Percentual delay	L6	Percentual delay	FBP vs L1	FBP vs L6	L1 vs L6	
Total body [c]	11.2±0.3	7.1±0.1	−37 %	7.3±0.2	−35 %	<0.001	<0.001	0.237	200.2±6.6
Abdominal [c]	20.7±0.6	15.3±0.3	−26 %	14.9±0.3	−28 %	<0.001	<0.001	0.103	674.1±21.8
Chest [c]	19.9±0.6	14.0±0.3	−30 %	14.2±0.3	−29 %	<0.001	<0.001	0.475	389.6±16.3
Cervical [c]	30.0±0.3	15.5±0.5	−48 %	15.4±0.4	−49 %	<0.001	<0.001	0.683	476.2±16.1
Total trauma CT	20.1±1.6	13.2±0.8	−34 %	13.2±0.6	−34 %	<0.001	<0.001	0.753	1740.1±213.5

FBP filtered back projection, *L2* iDose[4] level 2, *L4* iDose[4] level 4

[a] Based on dependent *t*-test

[b] n=25

[c] n=15

Table 3 Mean overall reconstruction time and speed for the first and second total body trauma CT reconstructions ($n=8$)

		First reconstructions	Second reconstructions	Difference (%)	*P* value[a]
Reconstruction time (s)	FBP	85.1±18.5	88.5±20.0	3.4 (4 %)	0.024
	L1	131.6±23.8	131.0±23.2	0.6 (<1 %)	0.687
	L6	132.4±25.8	128.8±24.4	3.6 (3 %)	0.289
Reconstruction speed (slices/s)	FBP	20.0±1.6	19.3±1.8	0.7 (4 %)	0.030
	L1	12.8±0.8	12.9±0.6	0.1 (<1 %)	0.756
	L6	12.8±0.6	13.2±0.8	0.4 (3 %)	0.263

FBP filtered back projection, *L1* iDose[4] level 1, *L6* iDose[4] level 6

[a] Based on dependent *t*-test

Eight total body trauma CTs were reconstructed twice, and the total average reconstruction time differed slightly by 3 s (4 %), 1 s (<1 %) and 4 s (3 %), and speed differed 0.7 slices/s (4 %), 0.1 slices/s (<1 %), 0.4 slices/s (3 %) for FBP, iDose[4] levels 1 and 6, respectively (Table 3). For both reconstruction time and speed, differences between the two FBP reconstructions were significant ($P<0.05$) and differences between the IR reconstructions were not significant ($P>0.05$).

Discussion

The principle result of this study is that IR causes an increase in CT image reconstruction time, but this difference is clinically insignificant. IR is a promising technique which allows CT image acquisition with lower radiation dose and similar or better image quality [1–7]. One of the major drawbacks of IR is the longer reconstruction time, which can theoretically be problematic in the emergency setting. It is well established that survival rate of traumatic patients is greatest if care is given within a short time period, especially the first "golden" hour. Thus, it is important not to lose time in the diagnostic process of these patients. Currently, CT image acquisition is essential for the triage of haemodynamically stable trauma patients. A substantial delay in reconstruction time of CT data can therefore theoretically decrease the survival rate of traumatic patients. Furthermore, lowering the CT radiation dose is important for traumatic patients since they are often relatively young. Therefore our findings are important and reassuring.

The effects of IR on reconstruction time and speed in clinical CT procedures have not been evaluated in detail yet. Some studies reported limited data on reconstruction time and/or speed. The reported reconstruction times and speed values are listed in Table 4. This table shows that reported values have a wide variety, which is presumably caused by the different application areas and IR techniques. Especially long reconstruction times were reported with the model-based IR algorithm (MBIR; GE Healthcare), which are

Table 4 Reported IR reconstruction time and speed in literature

Author	Year	Application	IR technique	Reconstruction time (s)		Time delay (%)	Reconstruction speed (slices/s)		Speed delay (%)
				FBP	IR		FBP	IR	
Kligerman [14]	2012	Pulmonary CTA	iDose[4]	–	–	–	31	22	29
Funama [15]	2011	Coronary CTA	iDose[4]	–	–	–	22	16	27
Moscariello [2]	2011	Coronary CTA	SAFiRE	–	–	–	40	20	50
Scheffel [16]	2011	Coronary CTA	ASIR	–	–	40–60	–	–	–
Marin [17]	2010	Abdominal CT	ASIR	–	–	–	15	10	33
May [18]	2011	Abdominal CT	IRIS	–	–	–	5.4	0.9	83
Korn [19]	2011	Head CT	IRIS	25 (22–27)	68 (61–74)	172	–	–	–
Gervaise [20]	2012	Lumbar spine CT	AIDR 3D	33	35	6	14.1	13.3	6
Yamada [21]	2012	Chest CT	MBIR	<60	3,600	5900	9.2	0.2	98

FBP filtered back projection; *IR* iterative reconstruction; *IRIS* Iterative Reconstruction in Image Space, Siemens Medical Solutions; *AIDR 3D* Adaptive Iterative Dose Reduction, Toshiba Medical Systems; *ASIR* Adaptive Statistical Iterative Reconstruction, GE Healthcare; iDose[4], Philips Healthcare; *SAFiRE* Sinogram Affirmed Iterative Reconstruction, Siemens Medical Solutions; *MBIR* Model-Based Iterative Reconstruction, GE Healthcare probably explained by the fact that this is the most advanced IR algorithm currently available These studies did not investigate reconstruction time and/or speed systematically, but mostly relied on a single measurement. Because of this lack of systematic evaluation of the effects of IR on reconstruction time in clinical CT procedures we have investigated the impact of IR on reconstruction time and speed in emergency CT imaging, and found that IR is not a substantial delaying factor for pulmonary CTA and total body trauma CT imaging. Furthermore, we found no substantial differences in reconstruction time and speed between different IR levels.

The total delay in reconstruction time due to IR of both pulmonary CTAs (approximately 10–12 s) and total body trauma CTs (approximately 44–45 s) was short and will not be problematic in the emergency setting. In clinical practice the first reconstruction of a trauma total body scan in our institution that is processed is the entire scan range with 5 mm-thick-slices for immediate evaluation to detect acute pathology such as tension pneumothorax or haemorrhage. On average this reconstruction took 10 s longer with IR compared with FBP. During assessment of this dataset the cervical spine, chest and abdominal reconstructions are performed. Reconstruction time and speed were significantly longer and slower with both IR levels compared with FBP. However, these differences are still very small and not clinically relevant, since they would not delay CT imaging in an emergency setting. One should note that CT image reconstruction is only one link in the emergency time chain. Besides the direct effect of IR on reconstruction time IR may also influence reading time; for example, due to a potential reduction in artefacts. Differences between both IR levels were not significant, except for the pulmonary CTA reconstruction speed (P=0.04). The iDose^4 level 4 reconstructed slower compared with level 2; however, a difference of 0.7 slices/s is very small and certainly not clinically relevant.

Kligerman et al. [14] also evaluated pulmonary CTAs with iDose^4 and measured a reconstruction speed of 31 slices/s with FBP and 22 slices/s with IR, resulting in a 29 % speed delay. These results are similar to our measured mean reconstruction speed of 27 slices/s with FBP and 18 slices/s with IR, resulting in a 33 % speed delay.

To evaluate the reproducibility of our method, eight total body trauma CTs were reconstructed twice. Differences between both reconstruction times and speed were small (ranging from <1 % to 4 %). Differences were significant for FBP measurements, however, differences of 3 s and 0.7 slices/s are small and certainly not clinically relevant. One would expect identical reconstruction times and speed at first and second reconstructions using the same raw CT data and reconstruction parameters. This discrepancy is probably caused by the computational power. Reconstruction time and speed depend on the computational power of the workstation. With more queued reconstruction tasks, greater computational power is demanded and reconstruction speed may decrease.

The most important limitation of this study is the fact that only a single IR algorithm of a single vendor was used, and therefore it is unknown whether our results apply to IR algorithms of other vendors. Thus, future research concerning the reconstruction time and speed of different IR algorithms is recommended. This study shows that IR is not substantially delaying reconstruction time, but future research on the effects of IR on the total emergency time chain (including reading time) is recommended.

In conclusion, this study showed that IR is not a clinically important delaying factor for CT image reconstruction in an emergency setting. No substantial differences in reconstruction time and speed were found between iDose^4 levels 2 and 4, and between levels 1 and 6.

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