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EMERGENCY RADIOLOGY SPECIAL FEATURE: FULL PAPER

Dose reduction in 64-row whole-body CT in multiple trauma: an optimized CT protocol with iterative image reconstruction on a gemstone-based scintillator

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Objective: Evaluation of potential dose savings by implementing adaptive statistical iterative reconstruction (ASiR) on a gemstone-based scintillator in a clinical 64-row whole-body CT (WBCT) protocol after multiple trauma.

Methods: Dose reports of 152 WBCT scans were analysed for two 64-row multidetector CT scanners (Scanners A and B); the main scanning parameters were kept constant. ASiR and a gemstone-based scintillator were used in Scanner B, and the noise index was adjusted (head: 5.2 vs 6.0; thorax/abdomen: 29.0 vs 46.0). The scan length, CT dose index (CTDI) and dose-length product (DLP) were analysed. The estimated mean effective dose was calculated using normalized conversion factors. Student's *t*-test was used for statistics.

Results: Both the mean CTDI (mGy) (Scanner A: 53.8 ± 2.0, 10.3 ± 2.5, 14.4 ± 3.7; Scanner B: 48.7 ± 2.2, 7.1 ± 2.3,

9.1 ± 3.6; *p* < 0.001, respectively) and the mean DLP (mGy cm) (Scanner A: 1318.9 ± 167.8, 509.3 ± 134.7, 848.8 ± 254.0; Scanner B: 1190.6 ± 172.6, 354.6 ± 128.3, 561.0 ± 246.7; *p* < 0.001, respectively) for the head, thorax and abdomen were significantly reduced with Scanner B. There was no relevant difference in scan length. The total mean effective dose (mSv) was significantly decreased with Scanner B (24.4 ± 6.0, 17.2 ± 5.8; *p* < 0.001).

Conclusion: The implementation of ASiR and a gemstone-based scintillator allows for significant dose savings in a clinical WBCT protocol.

Advances in knowledge: Recent technical developments can significantly reduce radiation dose of WBCT in multiple trauma. Dose reductions of 10–34% can be achieved.

INTRODUCTION

Since its introduction, multidetector CT (MDCT) use has dramatically risen as the first-line imaging tool in emergency radiology, mostly because of its wide availability, short scan time, duration, robust technique, and high spatial and temporal resolution due to isotropic voxels. The number of CT scans has exceeded 70 million per year in the USA in recent years.¹ Although the emergency department patient volumes grew in the USA at about 13% between 2000 and 2005, the number of CT examinations had increased from 51% to 463%, depending on the institution and the relevant body region.² MDCT is widely accepted as the whole-body imaging procedure in multiple trauma and is indisputably the imaging modality of choice.^{3,4} A detailed analysis in a clinical outcome study has proven that standardized whole-body CT (WBCT) clearly improves the survival rate after severe trauma.⁵ Despite this strong benefit, the trauma patient is still exposed to a considerable

radiation dose of about 10–20 mSv, with some published reports of >30 mSv for a single WBCT scan.⁵

Concerns about radiation dose and its potentially harmful and carcinogenic effects are being widely discussed.^{6–8} There is evidence that cumulative doses to an organ of 30–90 mSv or more can increase the risk of developing cancer.⁹ Consequently, several technical approaches to dose reduction have already been established and implemented successfully in clinical practice, such as tube current modulation and automatic exposure control.^{10–12}

High computational power now also offers improved techniques of image reconstruction. Filtered back projection (FBP) has been the standard mathematical reconstruction algorithm since the beginning of CT. Its main advantage is the fast calculation, even of CT images, which is essential for routine CT scanning; the main disadvantage

is a limited potential of dose reduction. There is a well-known trade-off between radiation dose and image noise: the lower the dose, the higher the image noise, which is considered as deterioration of image quality. This was an indisputable fact in clinical practice for a long time.

Recently, iterative image reconstructions have become available, such as adaptive statistical iterative reconstruction (ASiR). The main advantage of these algorithms is that they assume a far more realistic data model than conventional FBP to reduce radiation dose by decreasing image noise.¹³ Despite its higher mathematical complexity, the use of ASiR does not result in longer reconstruction times than FBP.¹⁴ Therefore, it is also suited for emergency conditions when time is of the essence.

The purpose of this retrospective controlled and blinded clinical study was to evaluate the potential dose savings by combining ASiR and a new gemstone-based scintillator, in a clinical 64-row WBCT protocol of patients sustaining major and multiple trauma.

METHODS AND MATERIALS

Patients

The institutional review board has waived the need for informed consent due to the retrospective nature of the study. All patients who fulfilled the clinical criteria of multiple trauma and underwent a WBCT examination according to an advanced routine CT protocol between December 2008 and October 2010 were included. The indication of WBCT is based on widely accepted modified Advanced Trauma Life Support® criteria referring to vital signs, injury pattern and mechanism of trauma (Table 1).³ Patients who underwent a different CT protocol based on specific clinical indication or had an incomplete dose report were excluded.

Table 1. Established clinical indication rule for whole-body CT

Impaired vital signs
Pattern of injury
Open thoracic injury
Unstable thorax
Unstable pelvic fracture
Fractures of at least two major long bones
Macroamputation
Mechanism of trauma
Explosion
Entrapment or entombment
Fall >3 m height
Death of the codriver
Rollover of the vehicle
Ejection out of the vehicle
Accident with (motor-)cyclist, pedestrian
High-velocity accident

CT technique

The WBCT examinations were performed on two different 64-row MDCT scanners from one manufacturer. Scanner A (LightSpeed® VCT® XT; GE Healthcare, Waukesha, WI) was replaced by Scanner B (Discovery® CT750 HD; GE Healthcare) in November 2009. Scanner A was only capable of FBP, whereas Scanner B was capable of ASiR for image reconstruction also using a new CT detector. Both scanners were otherwise technically comparable, and the use of Scanner B was an upgrade on the platform of Scanner A using the same technique of tube current modulation in both *xy*-plane (Auto mA) and the *z*-direction (Smart mA). However, there was also a different detector in Scanner B; the gemstone-based scintillator has a low afterglow and a primary decay of about 0.03 μ s, which is reported to be 100 times faster than conventional scintillator material.¹⁵ The newly introduced dedicated high-definition mode on Scanner B with 2.5 more projections per rotation was not used for this study to keep further parameters constant.

Whole-body CT protocol

Both protocols used have been the routine examination standard for each particular CT device at our emergency radiology department and have not been altered for study purposes.

The main scanning parameters were kept constant for all CT examinations (Table 2). The head, which also includes the mid-face, was scanned in helical mode without gantry tilt (Phase 1, non-contrast). The helical MDCT scans of the thorax and abdomen were conducted separately from each other. The cervical spine was included in the chest volume during the arterial contrast medium phase (Phase 2, arterial); the abdomen, including the pelvis, was examined during the portovenous phase (Phase 3, portovenous). The arms were placed crosswise on the trunk during the examination in order to reduce artefacts, following a long-established institutional protocol. Prior to this study, in order to make the results of both scanners comparable, the protocol for the CT scanner replacing the first one was modified with the help of the manufacturer to preserve the same constant clinical image quality and allow for a objective comparison: based on prior experience, noise index was adapted and increased from 5.2 to 6.0 (head) and from 29.0 to 46.0 (thorax and abdomen). The ASiR level was set at 30% (head) and 50% (thorax and abdomen).

Image reconstruction

FBP has been used as a standard reconstruction method for almost 30 years. Owing to the limited processing capabilities, CT images were reconstructed from measured attenuation profiles by using the analytic Radon transformation. By contrast, modern CT systems provide an impressive improved processing power for statistical reconstruction algorithms. The ASiR generates CT images by taking photon statistics into account in addition to measured attenuation data. Consecutively, the mean image noise decreases correlating to the applied ASiR level from 0% to 100%. Two strategies could now be used: improving image quality or, as desired by our study concept, reducing the radiation dose by maintaining the accustomed image quality at the same time. We refer to previous publications for a detailed description of the ASiR algorithm.^{16,17}

Table 2. CT scan parameters for two whole-body CT scan protocols each of 64-row multidetector CT (VCT 64 and HD 750; GE Healthcare, Waukesha, WI)

CT parameters	
Two plane scout	
Tube voltage	120 kV
Tube current	40 mA (anteroposterior), 80 mA (lateral)
Head	
Time of rotation	0.5 s
Collimation	64 × 0.625 mm
Slice thickness	2.5 mm
Tilt	0°
Tube voltage	120 kV
Tube current, mAs product	100–320 mA, modulated
Table feed/rotation	19.4 mm
Contrast medium injection	
Volume	140 ml
Saline chaser	40 ml
Flow rate	3.5 ml s ⁻¹
Bolus tracking (monitoring)	Thoracic aorta
Cervical spine/thorax	
Rotation time	0.5 s
Collimation	64 × 0.625 mm
Slice thickness	1.25 mm
Tube voltage	120 kV
Tube current	100–700 mA, modulated
Table feed	55 mm
Delay	3 s, after monitoring
Abdomen/pelvis	
Rotation time	0.5 s
Collimation	64 × 0.625 mm
Slice thickness	1.25 mm
Tube voltage	120 kV
Tube current	100–700 mA, modulated
Table feed	55 mm
Delay	ca. 50 s after thorax

Radiation dose

The scan length (mm), CT dose index (CTDI, mGy) and dose-length product (DLP, mGy cm) of the head, thorax and abdomen were retrieved and calculated on the basis of the dose reports. The calculation of the mean effective dose (mSv) was carried out by conversion of the DLP with the normalization

coefficient corresponding to the European guidelines on quality criteria for CT (Table 3).¹⁹ As radiation dose is dependent on the patient's constitution among other things, the coronal and sagittal diameters were measured at the level of the first vertebral body of the lumbar spine.

Image quality

As various instruments, for example, rib spreaders, chest tubes, electrocardiography and monitoring cables, are present depending on the clinical situation, the occurrence of artefacts is very variable during an emergency CT examination. Therefore, we did not perform a detailed assessment of image quality. However, we distinguished between diagnostic and non-diagnostic overall image quality, the latter of which was defined indication for a repeat CT scan without specific medical indication.

Statistical analysis

Statistical analysis was performed using SPSS® v. 18 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). An *a priori* estimation of the sample size was conducted resulting in a minimum need of 38 patients (one-sided, alpha error 0.025, power 0.95). Significant differences in age distribution, patients' diameters, dose parameters and mean effective dose were tested by the student's *t*-test. The gender distribution was analyzed by the χ^2 -test. The significance level was $p < 0.05$.

RESULTS

The data from 76 patients (54 males, 22 females; mean age 44 ± 19 years) who were examined on Scanner A were compared with the data of 76 patients (49 males, 27 females; mean age 46 ± 19 years) who were examined on Scanner B. There was no significant difference between both the groups in terms of gender ($p = 0.386$), age distribution ($p = 0.510$), sagittal diameter (23.2 ± 4.6 vs 23.6 ± 3.8 cm; $p = 0.580$) and coronal diameter (32.4 ± 4.3 vs 32.7 ± 3.4 cm; $p = 0.580$).

There was no significant difference in scan length in all examined body regions, comparing Scanners A and B, which would have had influence on the following results.

Table 4 gives an overview of the dose characteristics. The mean CTDI and mean DLP for the head, thorax and abdomen were statistically significantly lower for all regions using Scanner B including ASiR than using Scanner A without ASiR. The largest differences in CTDI (mGy) were for the thorax (reduction of 31.1%; 10.3 ± 2.5 vs 7.1 ± 2.3) and abdomen (reduction of 36.8%; 14.4 ± 3.7 vs 9.1 ± 3.6), whereas in the head section

Table 3. Effective dose per dose-length product (DLP); normalized values of over various body regions¹⁹

Body region	Normalized effective dose, E_{DLP} (mSv mGy ⁻¹ cm ⁻¹)
Head	0.0023
Thorax	0.017
Abdomen	0.015

(reduction of 9.5%; 53.8 ± 2.0 vs 48.7 ± 2.2), dose reduction effects were only minor. Considering the CTDI as an indicator for the radiation dose applied per slice, without taking into account the scan length, there were dose savings of 9.5–36.8%, depending on the anatomical region (Table 4).

Again, the largest differences with DLP (mGy cm) were found in the thorax (reduction of 30.0%; 509.3 ± 134.7 vs 354.6 ± 128.3) and abdomen (reduction of 33.8%; 848.8 ± 254.0 vs 561.0 ± 246.7); however, the differences in the head section were only small (reduction of 9.7%; 1318.9 ± 167.8 vs 1190.6 ± 172.6).

The resulting estimated effective dose was reduced by about 10% in the head, 30% in the thorax and 34% in the abdomen. The mean effective dose calculated for the entire WBCT examination was reduced by about 30% from 24.4 mSv with Scanner A down to 17.2 mSv with Scanner B (Table 5).

DISCUSSION

MDCT is considered as the modality of choice in the imaging of patients with polytrauma.²⁰ Despite its proven effect on survival rate,⁵ the radiation dose applied is not only a major concern only for radiologists but also widely discussed with many alert clinical partners. The popular media in many countries is also focusing on radiation dose issues and the possible medical risks for the patients.

As the use of MDCT has also risen in other radiological sub-specialties such as cardiac imaging, recent developments have focused on strategies of dose reduction, including tube current modulation and automatic exposure control.^{10,11,18} The main limitation of dose reduction so far has been that by lowering the dose, the resulting higher noise level has impaired the image quality. Modern highly capable CT systems offer dose savings using iterative image reconstructions, such as ASiR™ (GE Healthcare), iDose⁴ (Philips Healthcare) and IRIS (Siemens Healthcare). According to Silva et al,¹⁷ ASiR allows for a significant reduction in radiation dose without losing image quality compared with FBP. The study by Hara et al¹⁶ showed a significant reduction in the CTDI of 32–65% by using ASiR in 12

abdominal CT scans. Two studies by Prakash et al^{21,22} showed a significant dose reduction of 27.6% for thorax scan and about 25.1% for the abdomen scan. In our study, the dose reduction has been evaluated for a dedicated WBCT protocol in patients with multiple injuries.

Using a trauma protocol with ASiR, the radiation dose decreased significantly from 24.4 to 17.2 mSv, which means a dose reduction of 30% for the entire CT examination. The mean effective dose of WBCT in the literature is estimated between 10 and 30 mSv.^{5,23} The different scan parameters and different patient positions applied make an important contribution. Ptak et al²⁴ and Fanucci et al²⁵ have shown that a monophasic examination provides a significant dose reduction and shorter duration of the scan than a segmented scan protocol owing to missing overlap. Neither of these studies were conducted with 64-row MDCT scanners. Moreover, 64-row MDCT has markedly reduced the duration of the scan compared with former MDCT scanners.²⁶ The scan protocols published have been heterogeneous in terms of scan parameters, which have been adjusted to the institutional needs of image quality and patients' characteristics. However, comparable scan protocols resulted in a drop of the mean effective dose of 21.2–24.69 mSv,^{27,28} which is similar to our result of 24.4 mSv with FBP.

Our results could show in detail that there was a decrease for each anatomical body region. Although the dose reduction of the head CT was only 10%, there was a marked decrease of about 30–34% for the chest and abdominal CT, respectively. The different ASiR levels of 30% for head CT and 50% for thorax and abdomen CT, respectively, might explain these different capabilities of dose reduction. Moreover, the potential dose savings are limited by the higher noise caused by the skull, which has to be penetrated by photons in head CT. Although the scan length influences the DLP with the number of rotations, the CTDI is considered a more accurate parameter correlating with the applied radiation dose per standardized slice thickness. A detailed analysis showed that the dose reduction per slice was at a maximum of 36.8% for the abdomen and 31.1% for the thorax, and lower dose savings of 9.5% in the head CT section.

Table 4. Results concerning radiation dose parameters: scan length, CT dose index (CTDI) and dose-length product (DLP); mean values $\pm$ standard deviation

CT parameters	Head	Thorax	Abdomen
Scan length (mm)			
Scanner A	225.3 ± 30.8	430.1 ± 40.7	520.5 ± 51.2
Scanner B	221.6 ± 33.3	434.1 ± 52.0	540.6 ± 87.0
CTDI (mGy)			
Scanner A	53.8 ± 2.0	10.3 ± 2.5	14.4 ± 3.7
Scanner B	48.7 ± 2.2^a	7.1 ± 2.3^a	9.1 ± 3.6^a
DLP (mGy cm)			
Scanner A	1318.9 ± 167.8	509.3 ± 134.7	848.8 ± 254.0
Scanner B	1190.6 ± 172.6^a	354.6 ± 128.3^a	561.0 ± 246.7^a

^a $p < 0.001$.

Table 5. Mean estimated effective dose $\pm$ standard deviation (mSv)

Radiation dose	Head	Thorax	Abdomen	Total
Scanner A	3.0 ± 0.4	8.7 ± 2.3	12.7 ± 3.8	24.4 ± 6.0
Scanner B	2.7 ± 0.4^a	6.0 ± 2.2^a	8.4 ± 3.7^a	17.2 ± 5.8^a

^a $p < 0.001$.

In addition to the patients' dose exposure, there are medicolegal aspects that have to be taken into account. The European Guidelines, as well as national agencies such as the Federal Office of Radiation Protection in Germany, regulate the application of radiation by publishing dose reference levels.¹⁹ In view of this background, all radiological institutions aim to stay within these reference values, based on the analysis of an average European patient of about 70 kg weight. In particular in this context, the dose indicators (CTDI and DLP) that are displayed on the CT workstation are regarded as reference values. As the European Guidelines also state a good correspondence between the displayed and measured dose values,²⁹ we did not perform further analysis of radiation exposure by CT dosimetry software. However, the authors would like to communicate that the CTDI and DLP in this study (as in others) do not represent the exact radiation dose of an individual patient but serve as a valid and reliable reference point of a clinical CT protocol for estimation.

The retrospective study design has to be put into context. However, even without randomization, the biometric characteristics (mean age and gender distribution) were comparable in both study groups and match epidemiological data. Owing to normal distribution, it can be assumed that the patients' size and height did not affect the considerations about radiation exposure in both cohorts. Moreover, a prospective study design should be well considered in terms of ethical aspects, in particular with respect to possible non-diagnosed injuries using a low-dose CT protocol without adjusting the scanner's capabilities.

As both scan protocols were established as routine WBCT protocols in a large Level 1 trauma centre, there were no non-diagnostic CT examinations, and none of the CT examinations had to be repeated because of insufficient image quality. In general, the evaluation of image quality using a multiple trauma CT protocol differs from dose studies, which focus on a single body region. Besides artefacts that can be caused by technical applications, such as electrocardiography cables, the arm positioning influences the image quality.²⁸ With respect to the factor time, patient's safety and standardization of procedures, the

arms were positioned in front of the trunk according to our institutional WBCT protocol for trauma patients.

We cannot clearly separate the single effects of ASiR from other technical components, such as the scintillator, as we used two different CT scanners in this study; both scanners were otherwise widely comparable as Scanner B was an upgrade on the platform of Scanner A.

The potential dose savings by the use of ASiR is supported by recent studies, which have shown similar results: dose reduction of about 30% in chest CT²² and about 33% in abdominal CT.³⁰ On the other hand, Jiang et al¹⁵ also state that the gemstone-based detector allows for dose savings. However, a recent study by Yanagawa et al³¹ did not confirm a significant influence of the gemstone-based detector using a standard dose and a very low dose protocol (10 mA, 120 kVp), particularly if the high-definition mode was not enabled. They hypothesize that the detector characteristics could contribute more effectively in a moderate to low dose protocol. Further analysis is needed to clarify this topic. Apart from that, the aim of this study was not to evaluate a single parameter but the capability of the complete CT system for a clinical purpose. Namely, to introduce the new technique safely into clinical practice and make it available for patients with complex WBCT scans that benefit best from this new dose-reduced scan technique.

CONCLUSION

In conclusion, it is essential to keep the dose of the examination as low as reasonably achievable. In routine WBCT of patients with multiple injuries, it is possible to reduce the radiation dose by a combination of recent technical developments, such as ASiR, tube current modulation and a gemstone-based scintillator.

CONFLICTS OF INTEREST

LLG was on the speaker's bureau for GE Healthcare from 2010 to 2012.

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