Quality and Dose Optimized CT Trauma Protocol – Recommendation from a University Level-I Trauma Center

Qualitäts- und dosisoptimiertes CT-Polytraumaprotokoll – Empfehlung eines universitären Level-I Traumazentrums

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ZUSAMMENFASSUNG

Hintergrund Als überregionales Level-I Traumazentrum evaluierten wir zu Qualitäts- und Dosisoptimierungszwecken die Computertomographien (CT) polytraumatisierter Patienten. Angewandt wurden dabei iterative Rekonstruktionen sowie Röhrenspannungsreduktion verbunden mit einer Splitbolus-Kontrastmittel-Applikation.

Methoden 61 Patienten wurden in 3 verschiedenen Gruppen untersucht, die sich in der genutzten Röhrenspannung (120 – 140 kVp) und der ASIR Rekonstruktionsstufe (ASIR 20 – 50 %) unterschieden. Das Protokoll beinhaltete einen nativen kranialen und Kontrastmittel (KM) gestützten Ganzkörper-Scan (64-MSCT). Die KM-Gabe (350 mg/ml Iod) erfolgte als Splitbolus 100 ml (2 ml/s), 20 ml NaCl (1 ml/s), 60 ml (4 ml/s), 40 ml NaCl (4 ml/s), scan delay 85 s, um sowohl Verletzungen des arteriellen Gefäßsystems sowie von parenchymatösen Organen in einem Scan darstellen zu können. Die Bildqualität wurde quantitativ (SNR/CNR) und qualitativ (5-Punkte Likert Skala) in häufig von Verletzungen betroffenen Organen evaluiert. Die Strahlendosis wurde ebenfalls untersucht.

Ergebnisse Die Anwendung iterativer Rekonstruktionen zusammen mit einer Verringerung der Röhrenspannung führte zu einer gleichbleibend guten qualitativen und quantitativen Bildqualität sowie zu einer signifikanten Dosisreduktion von mehr als 40 % (DLP 1087 vs. 647 mGyxcm). Durch verschiedene Bildrekonstruktions-Stufen in Abhängigkeit der unterschiedlichen Schichtdicken, des Kernels und des Untersuchungsareals (Kopf, Lunge, Körperstamm, Knochen) konnte die Bildqualität gesteigert und alle Verletzungsmuster zuverlässig beurteilt werden. In Zusammenschau unserer Ergebnisse empfehlen wir die Durchführung eines Polytrauma-Protokolls mit einer Röhrenspannung von 120 kVp und folgenden Iterationsstufen: cCT 5mm: ASIR 20; cCT 0,625 mm: ASIR 40; Lunge 2,5 mm: ASIR 30, Körperstamm 5 mm: ASIR 40; Körperstamm 1,25 mm: ASIR 50; Körperstamm 0,625 mm: ASIR 0.

Schlussfolgerung Die dedizierte Anpassung des CT Protokolls (Grad der Spannungsreduktion und der iterativen Bildrekonstruktionsstufen) an das jeweilige Untersuchungsgebiet (Kopf, Lunge, Körperstamm, Knochen) zusammen mit einem Split-Bolus KM Injektionsprotokoll erlaubt eine gleichbleibend gute Bildqualität bei relevanter Dosisreduktion in der Untersuchung polytraumatisierter Patienten.

Kernaussagen

- Die dedizierte Anpassung des CT Polytraumaprotokolls erlaubt eine optmierte CT Untersuchung.
- Entscheidend sind verschiedene Level der iterativen Rekonstruktion, die Röhrenspannung sowie das KM-Protokoll.
- Es kann eine Dosisreduktion von mehr als 40 % bei guter Bildqualität erreicht werden.

ABSTRACT

Purpose As a supra-regional level-I trauma center, we evaluated computed tomography (CT) acquisitions of polytraumatized patients for quality and dose optimization purposes. Adapted statistical iterative reconstruction [(AS)IR] levels, tube voltage reduction as well as a split-bolus contrast agent (CA) protocol were applied.

Materials and Methods 61 patients were split into 3 different groups that differed with respect to tube voltage (120 – 140 kVp) and level of applied ASIR reconstruction (ASIR 20 – 50 %). The CT protocol included a native acquisition of the head followed by a single contrast-enhanced acquisition of the whole body (64-MSCT). CA (350 mg/ml iodine) was administered as a split bolus injection of 100 ml (2 ml/s), 20 ml NaCl (1 ml/s), 60 ml (4 ml/s), 40 ml NaCl (4 ml/s) with a scan delay of 85 s to detect injuries of both the arterial system and parenchymal organs in a single acquisition. Both the quantitative (SNR/CNR) and qualitative (5-point Likert scale) image quality was evaluated in parenchymal organs that are often injured in trauma patients. Radiation exposure was assessed.

Results The use of IR combined with a reduction of tube voltage resulted in good qualitative and quantitative image quality and a significant reduction in radiation exposure of more than 40 % (DLP 1087 vs. 647 mGyxcm). Image quality could be improved due to a dedicated protocol that included different levels of IR adapted to different slice thicknesses, kernels and the examined area for the evaluation of head, lung, body and bone injury patterns. In synopsis of our results, we recommend the implementation of a polytrauma protocol with a tube voltage of 120 kVp and the following IR levels: cCT 5mm: ASIR 20; cCT 0.625 mm: ASIR 40; lung 2.5 mm: ASIR 30, body 5 mm: ASIR 40; body 1.25 mm: ASIR 50; body 0.625 mm: ASIR 0.

Conclusion A dedicated adaptation of the CT trauma protocol (level of reduction of tube voltage and of IR) according to the examined body region (head, lung, body, bone) combined with a split bolus CA injection protocol allows for a high-quality CT examination and a relevant reduction of radiation exposure in the examination of polytraumatized patients

Key Points

- Dedicated adaption of the CT trauma protocol allows for an optimized examination.
- Different levels of iterative reconstruction, tube voltage and the CA injection protocol are crucial.
- A reduction of radiation exposure of more than 40 % with good image quality is possible.

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Introduction

Whole-body multislice computed tomography (WBCT) has become the standard diagnostic tool in the initial workup of polytrauma patients [1 – 4]. It has been shown that WBCT can increase the probability of survival in patients with severe trauma due to its ability to show the full extent of injuries quickly and accurately for all examined body parts [5]. Although the use of WBCT in the suitable trauma setting is undisputed [6], there is an ongoing debate about the most appropriate CT protocol that strikes the optimal balance between the best possible image quality for different body areas, dose-limiting aspects, speed of examination, and diagnostic confidence. Factors that influence these parameters are mostly of a technical nature, such as tube voltage [7], automated exposure control (AEC), the use of iterative reconstruction (IR) [8, 9], and different ways to inject contrast agent (CA) [10 – 13]. However, nontechnical aspects, such as patient positioning (e. g., placement of arms), play a crucial role in examination optimization [14, 15].

Due to the rising number of CT exams, radiation exposure has become a central concern in research and clinical practice [16]. Especially severely injured trauma patients who are frequently young and often need follow-up CT scans can benefit from dose-limiting techniques. IR has been proven to efficiently reduce radiation exposure in different organ systems [8, 17 – 19]. However, image quality is paramount in multi-trauma patients in order to avoid missing any subtle but potentially life-threating injuries.

The aim of this study is to present a CT trauma protocol that allows both excellent image quality and an adequate reduction of radiation exposure by using dedicated body-region-adapted levels of iterative reconstruction together with a split-bolus CA injection protocol.

Materials and Methods

Study design and patient characteristics

Our institutional ethics board approved this anonymized, retrospective study. Patients were not exposed to additional radiation.

All patients included in this analysis were at least 18 years of age and were announced as “severely injured” by the primary rescue staff. They were admitted to the emergency room of our university level-I trauma center either by ambulance or helicopter accompanied by an emergency physician. All study patients received full radiological diagnostic workup including FAST (focused assessment with sonography for trauma) and WBCT pursuant to the valid guidelines of trauma care [20]. The final decision to perform WBCT was made by the trauma leader. Only patients in a standardized position with their arms up next to their head during body CT were included in the study.

▶ **Table 1** CT examination parameters and iterative reconstruction (IR) settings.

▶ **Tab. 1** CT Untersuchungsparameter und Stufen der iterativen Rekonstruktion (IR).

	group A	group B	group C
technical parameters			
tube voltage head/body (kVp)	120/140	120/140	120/120
mA range head/body	100 – 300/100 – 600	100 – 300/100 – 600	100 – 300/100 – 600
collimation head/body	64 × 0.625 mm	64 × 0.625 mm	64 × 0.625 mm
rotation time (s) head/body	1.0/0.6	1.0/0.6	1.0/0.6
pitch body	1.375	1.375	1.375
noise index head/body	2.8/15.0	2.8/15.0	4/15.0
ASIR dose reduction (DR):			
ASIR DR cCT	–	–	ASIR (DR) 20
ASIR DR body CT	–	ASIR (DR) 40	ASIR (DR) 40
ASIR image reconstruction (REC):			
head 5 mm standard kernel	FBP	FBP	ASIR (REC) 20
head 1.25 mm bone kernel	FBP	FBP	ASIR (REC) 30
head 0.625 mm detail kernel	FBP	FBP	ASIR (REC) 40
lung 2.5 mm lung kernel	FBP	ASIR (REC) 30	ASIR (REC) 30
body 5 mm standard kernel	FBP	ASIR (REC) 40	ASIR (REC) 40
body 1.25 mm detail kernel	FBP	ASIR (REC) 50	ASIR (REC) 50
body 0.625 mm detail kernel	FBP	ASIR (REC) 0	ASIR (REC) 0
2 D reconstructions (all detail kernel)	sinuses cor: 2 mm body sag, cor: 2 mm cervical, thoracal, lumbal spine sag: 2 mm MIP lung: 15 mm		

Note the difference between the ASIR dose reduction (ASIR DR) responsible for lowering the tube current, thus allowing a dose reduction and ASIR image reconstruction (ASIR REC) applicable in raw data reconstruction to modify the image impression.
ASIR dose reduction (ASIR DR) geht mit einer Senkung des Röhrenstroms einher und erlaubt somit eine Dosisreduktion. Im Gegensatz dazu erlaubt ASIR image reconstruction (ASIR REC) eine Änderung des Bildeindruckes durch Rekonstruktion der Rohdaten.

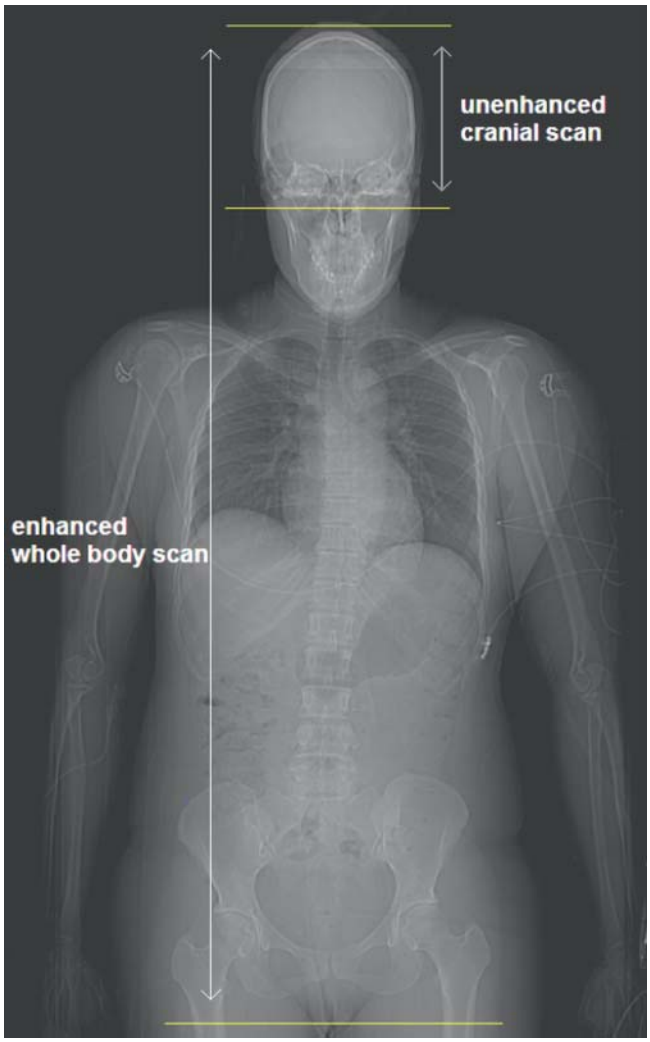
A matched-pair analysis was performed for a total of 61 patients that were assigned to 3 different groups according to the 3 different CT protocols that were used (▶ **Table 1**):

- Group A (n = 21) was examined using a tube voltage of 140 kVp for the body examination and a tube voltage of 120 kVp for the head examination (cCT). Both cCT und the body examination were performed using a filtered back-projection (FBP) algorithm (▶ **Table 1**).
- Group B (n = 20) was examined using a tube voltage of 140 kVp and an adaptive statistical iterative reconstruction (ASIR) algorithm for the body examination. Adapted levels of IR were applied according to the different body regions that were examined. CCT was performed using a tube voltage of 120 kVp and an FBP algorithm (▶ **Table 1**).
- Group C (n = 20) was examined using a tube voltage of 120 kVp and an adapted ASIR protocol for both body and head examinations (▶ **Table 1**).

CT examination

All examinations were performed on a 64-slice multidetector CT scanner (Light Speed VCT, General Electric, Fairfield, USA) using the following protocols:

1. Orbitomeatally oriented unenhanced series of the head for detecting possible intracranial pathologies with the patients' arms positioned next to the body (slice thickness: 0.625 mm; tube voltage: 120 kVp; a predefined noise index (NI) of 2.8 in groups A and B and of 4 in group C was set as the target value; automated tube current modulation was set between 100 and 300 mA (▶ **Table 1**). The scanner automatically modulated the tube current within these borders. The head acquisition ranged from the upper calvarium to the foramen magnum (▶ **Fig. 1**).
2. Administration of a total of 160 ml contrast agent (CA) (Xenetix 350, Guerbet GmbH, Germany) for an acquisition of the whole body with the following technical parameters: slice



▶ **Fig. 1** Scout with illustration of scan range of unenhanced series of the head and contrast-enhanced whole-body series including intracranial vessels.

▶ **Abb. 1** Scout zur Untersuchungsplanung und Demonstration der Scanlänge der nativen Kopfuntersuchung und der kontrastmittelgestützten Ganzkörperuntersuchung inklusive der intrakraniellen Gefäßdarstellung.

thickness: 0.625 mm, tube voltage: 120 – 140 kVp; collimation: 64 × 0.625 mm; pitch:1.375 and a predefined NI of 15. The body acquisition was performed with the patients' arms elevated next to the head. The body acquisition ranged from the upper calvarium to below the symphysis (▶ **Fig. 1**). Automated tube current modulation was set between 100 and 600 mA. The scanner automatically modulated the tube current within these borders according to the preset tube voltage (▶ **Table 1**).

CA was administered in a split bolus technique: 100 ml CA (2 ml/s flow rate), 20 ml saline (1 ml/s flow rate), 60 ml CA (4 ml/s flow rate), 40 ml saline (4 ml/s flow rate), scan delay 85 s. This injection protocol allows concomitant evaluation of the arterial and venous system in a single acquisition.

Data reconstruction

Besides lowering the tube voltage (kVp) (group C), ASIR was applied for lowering image noise (groups B and C). Iterative reconstruction algorithms aim to reduce image noise, which in turn can be exploited to reduce radiation exposure. As previously reported [14, 18], IR uses the information from the acquired raw data for further image processing. Matrix algebra is used to transform each measured pixel (x) into a new estimated pixel value (x'). This newly calculated value (x') is repetitively compared to the measured value and adjusted in each iterative step until both eventually converge. This method results in a selective reduction of image noise.

Raising the noise index (NI) leads to higher noise and reduces tube current. ASIR offers another option to vary tube current. First, the user chooses the desired level of dose reduction by selecting a predefined level of ASIR dose reduction (ASIR DR) from 0 % to 50 %. By default, the use of x% ASIR DR results in a tube current reduction of approximately x% [21]. Due to lower tube currents, the combination of AEC and ASIR DR leads to a significant dose reduction compared to FBP only. Eventually, the acquired raw data are retrospectively reconstructed using both ASIR and FBP. ASIR- and FBP-acquired images are combined at a ratio of X% ASIR and 100-X% FBP. The extent of retrospective ASIR-based reconstruction of the raw data can be adjusted after raw data acquisition according to different slice thicknesses, kernels or examined body areas as shown in ▶ **Table 1** (ASIR image reconstruction [ASIR REC]). The retrospective selection of ASIR REC alters the visual impression of the resulting images but, unlike ASIR DR, it does not influence radiation exposure.

Patients were evaluated with regard to maximum cranial and body diameters in the sagittal and frontal plane on axial images. Scan ranges for both cranial and body acquisitions were compiled from dose reports. Patient age and gender were recorded. Injury severity scores (ISS) of all patients were evaluated on the basis of injury patterns diagnosed in WBCT. The abbreviated injury scale (AIS 2008) was used to assess the ISS [22].

Quantitative image quality

The quantitative image quality was evaluated as signal-to-noise (SNR) and contrast-to-noise (CNR) ratios. Both were calculated using attenuation values (SI) in Hounsfield units (HU) and the standard deviation measured in oval regions of interest (ROI) of at least 1 cm² size in body regions that are often affected by trauma, specifically in the liver, spleen, renal cortex, pancreas, bone marrow (12th vertebral body), in the aorta, and in the portal vein. The standard deviation of background noise (SD) was assessed in the field of view outside the patient's body. ROIs were placed in homogeneous parts of tissue avoiding structures such as liver cysts or parenchymal vessels.

The SNR was determined as the SI of a specific body region divided by the standard deviation of noise:

$$SNR = \frac{SI_{ROIa}}{SD}$$

The CNR was defined as the difference between two compared tissues divided by the standard deviation of background noise:

$$CNR = \frac{\Delta(SI_{ROIa}, SI_{ROIb})}{SD}$$

Qualitative image quality

Qualitative image analysis was performed by two experienced blinded radiologists with 12 and 6 years of image reading experience. Technical information on the image was obscured to reduce the expectation bias. Image quality was evaluated in five categories: noise, contrast, artifacts, detectability of small structures and overall diagnosability. A five-point Likert scale was used to evaluate each category (5 = excellent image quality, no artifacts; 4 = slight blurring with unrestricted diagnostic image evaluation; 3 = moderate blurring with restricted assessment; 2 = severe blurring with uncertainty about the evaluation; 1 = non-diagnostic image quality). Image quality scoring was performed by viewing all CT series with the aforementioned body-region-adapted ASIR levels.

Radiation exposure

The dose length product (DLP), $CTDI_{vol}$ values and scan range were recorded from dose reports for the estimation of radiation exposure. DLP values relate to the 16 cm diameter head phantom for the head scan and to the 32 cm diameter body phantom for the body scan.

Statistical analysis

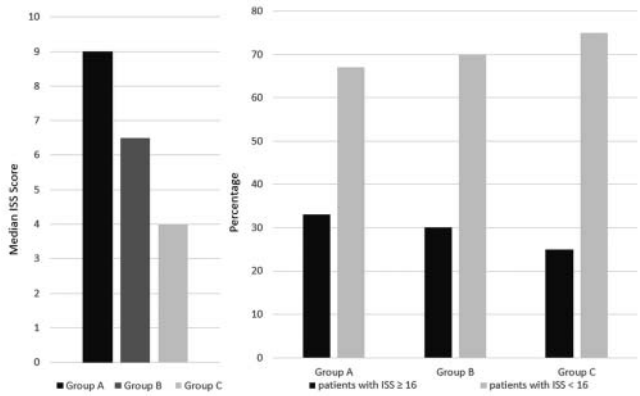
Statistical analysis was performed using SPSS Statistics, version 23 (SPSS Inc, Chicago, IL). Ordinal data were tested for significance using the Mann-Whitney U-test. Interval data were tested using an independent t-test with 95 % confidence intervals. A p-value of < 0.05 was considered statistically significant. Interreader agreement was assessed using the weighted Cohen's kappa test. Normally distributed data were given as mean ± standard deviation, and ordinal data as median and range.

Results

Patient characteristics

The overall results were: mean age: 47.3y ± 17.6y, mean body diameter in sagittal plane: 233.9 mm ± 32.9 mm, mean body diameter in frontal plane: 320.2 mm ± 32.8 mm, mean cranial diameter in sagittal plane: 192.2 mm ± 8.1 mm, and mean cranial diameter in frontal plane: 155.7 mm ± 9.0 mm. None of these data differed significantly among the groups.

The median ISS score was 9 (range: 1 – 57) in group A, 6.5 (range: 1 – 57) in group B and 4 (range: 1 – 29) in group C. The total numbers and percentages of patients with ISS scores of more than 15 were as follows: group A: 7 (33 % of the patients); group B: 6 (30 % of the patients); and group C: 5 (25 % of the patients) (▶ **Fig. 2**).



▶ **Fig. 2** Median ISS scores of groups A–C and percentages of patients with ISS scores ≥ 16.

▶ **Abb. 2** Mediane ISS Werte der Gruppen A–C und prozentuale Verteilung der Patienten mit einem ISS Wert ≥ 16.

Quantitative image quality

The signal-to-noise ratios (SNR) in the liver, spleen, pancreas and bone differed significantly between groups A and C. The SNR in the liver, spleen and pancreas differed significantly between groups B and C. There were no statistically significant differences in SNR between groups A and B (▶ **Table 2**). The contrast-to-noise ratios (CNR) only differed significantly in the evaluation of the liver and pancreas parenchyma between groups A and C and groups B and C. All other CNRs did not show significant differences (▶ **Table 2**). Attenuation in the aorta and portal vein was significantly higher in group C compared to group A and group B (▶ **Table 2**).

Split bolus administration of the CA in all groups allowed a single-phase CT examination that combines the advantages of an arterial and a venous CA phase.

Qualitative image quality

There were no significant differences among groups A-C regarding qualitative image grading. Interreader agreement was fair to good (Cohen's kappa value ranging from 0.48 to 0.84) (▶ **Table 3**). Both reviewers rated the overall diagnosability as good or excellent (grades 4 – 5) for all images that were analyzed. Subgroup ratings for the analysis of small structures or the impairment of image quality due to artifacts ranged from fair to excellent (grades 3 – 5).

Diagnostic image quality was maintained after a reduction of tube voltage in conjunction with adaption of ASIR levels. Image examples show clear depiction of arterial vessel injuries (▶ **Fig. 3, 4**), parenchymal injuries (▶ **Fig. 5**) and complex fractures (▶ **Fig. 5, 6**).

Radiation exposure

Group A showed a significantly higher mean DLP value (1113.1 mGy cm ± 317.7; $CTDI_{vol}$: 11.5 mGy ± 3.0) than group B (824.7 mGy cm ± 246; $CTDI_{vol}$: 8.8 mGy ± 2.5) and group C (647.3 mGy cm ± 179.8; CTDIvol: 6.9 mGy ± 1.8) in the body

▶ **Table 2** Quantitative image grading.

▶ **Tab. 2** Quantitative Bildbeurteilung.

	group A	group B	group C	p-values group A vs. B	p-values group A vs. C	p-values group B vs. C
SNR liver	15.7 ± 4.2	17.8 ± 7.7	22.5 ± 4.8	p > 0.05	p < 0.01	p = 0.02
SNR renal cortex	24.3 ± 6.9	26.6 ± 9.6	27.6 ± 10.4	p > 0.05	p > 0.05	p > 0.05
SNR spleen	20.5 ± 5.8	20.2 ± 8.0	26.4 ± 5.7	p > 0.05	p < 0.01	p < 0.01
SNR pancreas	15.9 ± 5.1	16.2 ± 5.9	20.5 ± 5.4	p > 0.05	p < 0.01	p = 0.02
SNR bone	32.6 ± 12.4	38.7 ± 13.5	42.3 ± 12.5	p > 0.05	p = 0.02	p > 0.05
CNR liver parenchyma – fat tissue	31.7 ± 8.5	33.3 ± 11.2	40.5 ± 7.6	p > 0.05	p < 0.01	p = 0.02
CNR renal cortex – fat tissue	40.7 ± 11.1	42.1 ± 13.1	45.0 ± 12.3	p > 0.05	p > 0.05	p > 0.05
CNR splenic tissue – fat tissue	36.3 ± 9.1	35.7 ± 41.6	41.6 ± 7.6	p > 0.05	p > 0.05	p > 0.05
CNR pancreatic tissue – fat tissue	32.2 ± 9.2	31.7 ± 9.3	38.1 ± 8.3	p > 0.05	p = 0.04	p = 0.03
CNR bone – fat tissue	49.6 ± 15.3	54.2 ± 16.1	56.4 ± 13.9	p > 0.05	p > 0.05	p > 0.05
CNR muscle – fat tissue	25.7 ± 7.5	25.8 ± 8.4	29.9 ± 5.9	p > 0.05	p > 0.05	p > 0.05
HU aorta	219.9 ± 50.9	210.0 ± 61.2	271.0 ± 69.6	p > 0.05	p = 0.01	p = 0.01
HU portal vein	137.5 ± 25.1	138.0 ± 35.2	213.4 ± 41.0	p > 0.05	p < 0.01	p < 0.01

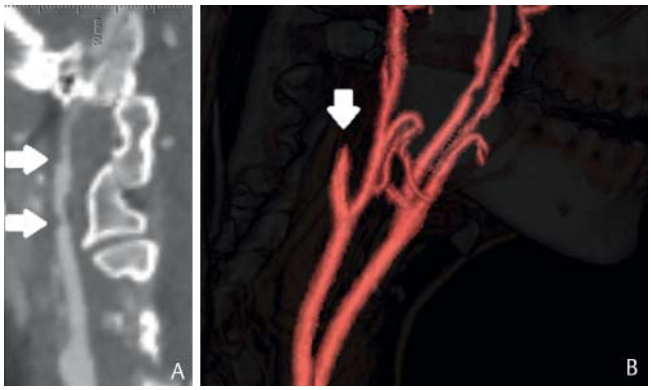
ASIR images show no statistically significant differences in signal-to-noise ratios (SNR) compared to FBP when using the same tube voltage (group A vs. B). Group C (ASIR 120 kVp) shows the highest SNR. Contrast-to-noise ratios (CNR) only differ significantly in the evaluation of the liver and pancreas parenchyma between groups A and C and groups B and C.
ASIR Bilder zeigen keine signifikant unterschiedlichen Signal zu Rausch Verhältnisse (SNR) verglichen mit FBP Bildern derselben Röhrenspannung (Gruppe A vs. B). Gruppe C (ASIR 120 kVp) zeigt im Vergleich die höchsten SNR Werte. Kontrast zu Rausch Verhältnisse (CNR) zeigen nur in der Evaluation des Leber- und Pankreasparenchyms zwischen Gruppe A und C sowie B und C signifikante Unterschiede.

▶ **Table 3** Qualitative image grading.

▶ **Tab. 3** Qualitiative Bildbeurteilung.

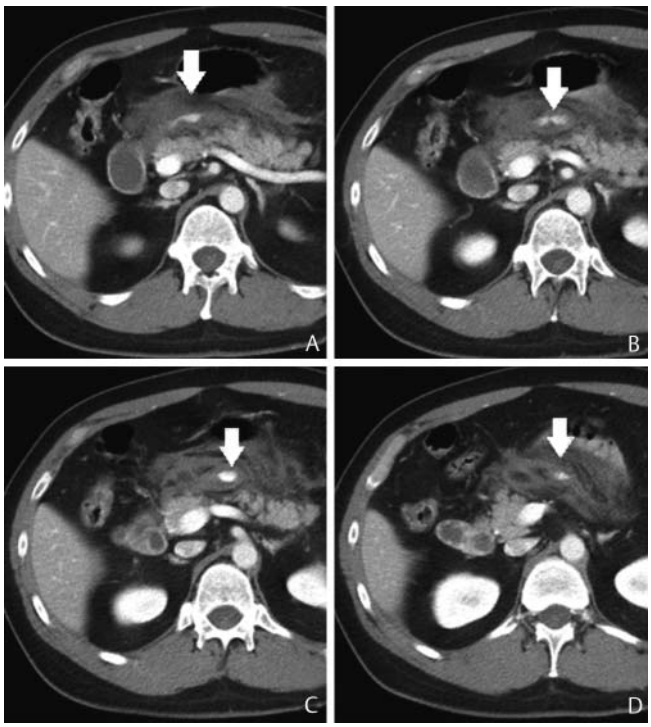
	reader 1			reader 2			interreader agreement
	group A	group B	group C	group A	group B	group C	weighted kappa value
noise	4.75 (4 – 5)	4.75 (4 – 5)	4.70 (4 – 5)	4.85 (4 – 5)	4.90 (4 – 5)	4.80 (4 – 5)	0.61
contrast	4.91 (4 – 5)	4.85 (4 – 5)	4.90 (4 – 5)	4.91 (4 – 5)	4.85 (4 – 5)	4.90 (4 – 5)	0.50
small structures	4.91 (3 – 5)	4.90 (4 – 5)	4.95 (3 – 5)	4.86 (3 – 5)	4.85 (3 – 5)	4.95 (3 – 5)	0.70
artifacts	4.41 (3 – 5)	4.15 (3 – 5)	4.20 (3 – 5)	4.50 (3 – 5)	4.45 (3 – 5)	4.60 (4 – 5)	0.48
overall diagnosability	4.86 (4 – 5)	4.85 (4 – 5)	4.95 (4 – 5)	4.90 (4 – 5)	4.85 (4 – 5)	4.90 (4 – 5)	0.84

5 = excellent image quality – 1 = non-diagnostic image quality. Scores given by the two readers [median (range)]. There are no differences among the different groups. Interreader agreement was fair to good.
Bildqualitätsbeurteilung der beiden Auswerter. Es zeigen sich keine Unterschiede zwischen den Gruppen. Die Übereinstimmung zwischen den Auswertern war ausreichend bis gut.



▶ **Fig. 3** Protocol C (120 kVp, adapted ASIR for both body and head examinations): Curved MIP display **A** of the left internal carotid artery in a 27-year-old patient suffering from a whiplash injury after being hit by a car. Split bolus CA administration enabled clear identification of the diameter irregularity of the artery, suggesting dissection. This finding was confirmed by subsequent MRI and angiography. 3 D reconstruction **B** of ASIR images also shows diameter variations of the left ICA and trauma-related complete occlusion of the right ICA (arrow).

▶ **Abb. 3** Protokoll C (120 kVp, adaptiertes ASIR Level für Körperstamm- und Kopfuntersuchung): Curved MIP Darstellung **A** der linken Arteria carotis interna bei einer 27 jährigen Patientin, die ein Schleudertrauma nach PKW Unfall erlitten hat. Die mehrzeitige Kontrastmittelinjektion ermöglichte eine sichere Detektion der Kaliberunregelmäßigkeiten der Arterie, die auf eine Dissektion hindeuten. Diese konnte nachfolgend auch in der MRT und der Angiographie nachgewiesen werden. 3 D Rekonstruktion **B** der ASIR Bilder zeigen ebenfalls die Kaliberunregelmäßigkeiten der linken ACI sowie einen traumaassozierten Komplett-Verschluss der rechten ACI (Pfeil). ASIR 120 kVp: DLP 498 mGy × cm.



▶ **Fig. 4** Mesenteric hematoma with active bleeding in a 43-year-old patient involved in a car accident. **A–D** successive axial slices. The split bolus CA protocol yields excellent arterial contrast allowing reliable detection of active bleeding. Subsequent angiography identified a branch of the gastroepiploic artery as the source of bleeding.

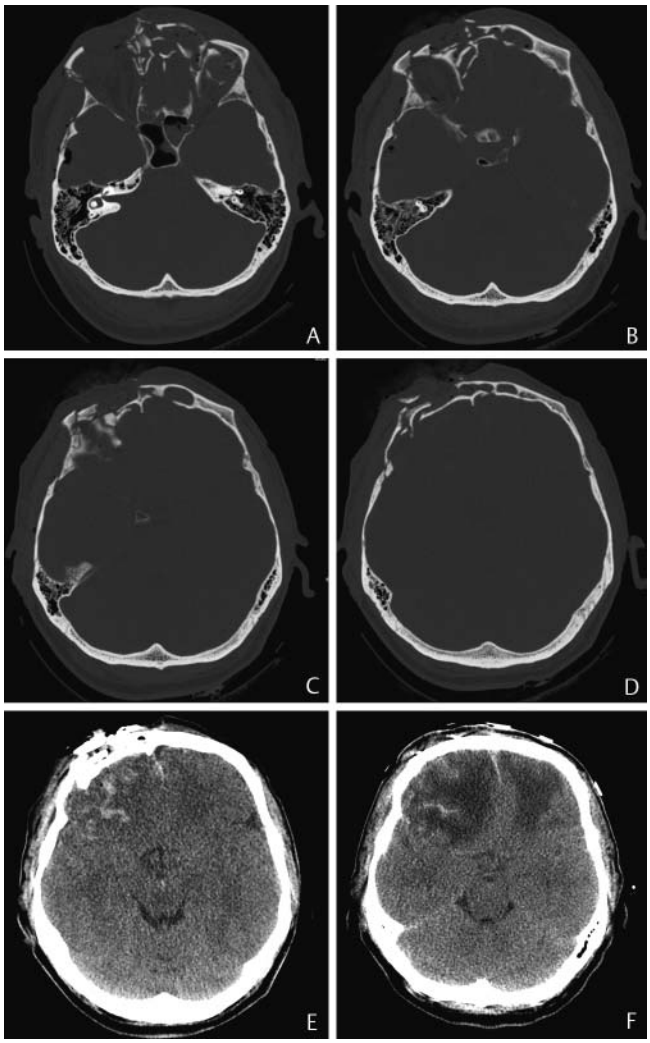
▶ **Abb. 4** Mesenteriales Hämatom mit aktiver Blutung bei einem 43 - jährigen Patienten, der in einen Autounfall verwickelt war. **A–D** aufeinanderfolgende axiale Schichtungen. Der arterielle Kontrast im Split-Bolus KM-Protokoll ist von ausgezeichneter Qualität und ermöglicht eine zuverlässige Diagnose der aktiven Blutung. Die nachfolgende Angiographie zeigte den Ursprung der Blutung in einem Ast der A. gastro-epiploica. ASIR 120 kVp: DLP 602 mGy × cm.

acquisitions. Group B showed a significantly higher mean DLP value compared to group C in the body acquisitions. Regarding cCT, group A showed a significantly higher mean DLP value (851.7 mGy cm ± 72.1; $CTDI_{vol}$: 55.4 mGy ± 2.9) than group C (543.0 mGy cm ± 106.6; $CTDI_{vol}$: 37.0 mGy ± 4.0). The DLP in group B (773.3 mGy cm ± 190.3; $CTDI_{vol}$: 52.8 mGy ± 1.9) was significantly higher than in group C. The DLP between group A and B did not differ significantly when comparing head acquisitions (▶ **Fig. 7**). The mean acquisition range was 878.1 mm ± 50.2 mm for body examinations and 146.9 mm ± 7.9 mm for head examinations. The acquisition ranges did not differ significantly among the groups.

Discussion

Aspects of limiting radiation exposure have become a focus in CT imaging. Especially in the collective of young trauma patients with the frequent need for subsequent follow-up CT examinations, reduction of radiation exposure plays a crucial role. There have been few studies examining ASIR in polytrauma CT [9, 23] and abdominal and thoracic CT imaging. Mueck et al. have suggested an implementation of 30 – 50 % ASIR for an optimal examination of the thorax and the abdomen, acknowledging the need for further individual optimization of imaging parameters with respect to certain examination and/or institutional requirements [18, 19].

While there is no consensus on how to best examine patients suffering from multiple trauma in CT, it is undisputed that WBCT plays a significant role in the treatment of patients with multiple injuries [1 – 5]. On the other hand, there is a concern about possible overtriage of whole-body CT imaging in polytraumatized patients [24, 25]. It was shown that selective CT scanning of body regions with clinically suspected injuries can be beneficial especially in young patients with minor injuries to reduce radiation exposure and to save medical resources [26, 27]. In our retrospective analysis, only 25 – 33 % of the study patients had multiple trauma with an ISS > 15. ISS scores differed among groups A-C; however, this is most likely attributable to the small numbers of patients in the subgroups. These results show that there is a thin line between overtriage and the need for reliable diagnosis, e. g., in patients exposed to high-risk mechanisms of injury. Even negative CT findings may be very valuable in patients who are unconscious or intubated.



▶ **Fig. 5** 32-year-old patient injured by a home-made explosion kit that detonated while he was bending over it on New Year's Eve. **A–D** show detailed bone injury patterns of the skull; **E** shows intracranial brain injury with parenchymal and subarachnoid bleeding. **F** shows extensive frontal brain injury with brain edema in the frontal lobe at 8-day follow-up.

▶ **Abb. 5** 32 jähriger Patient der sich in der Silvesternacht über einen selbstgebauten Sprengsatz beugte, als dieser detonierte. **A–D** zeigen detailliert das Frakturmuster der Kalotte. **E** zeigt im Weichteilfenster die intrakraniellen Hirnverletzungen mit parenchymalen und subarachnoidalen Hämorrhagien. **F** zeigt den Verlauf nach 8 Tagen mit ausgedehnter Frontallappen-Verletzung und konsekutivem Hirnödem. ASIR 120 kV: DLP 521 mGy × cm. **A–D**: ASIR DR 20; head 1.25 mm bone kernel ASIR REC 30, **E, F**: ASIR DR 20; head 0.625 mm detail kernel ASIR REC 40.

The present study addresses the issue of a comprehensive CT polytrauma protocol including different steps in protocol modification: first, reduction of radiation exposure by (a) lowering tube voltage together with (b) iterative reconstruction (low mA) for body examination and cCT, and (c) an optimized split-bolus CA protocol that provides for single-phase acquisition, thus reducing radiation exposure significantly; second, image optimization using body-region-adapted levels of ASIR reconstruction. From protocol A to B to C, our study shows an escalation in the potential for radiation exposure reduction for CT of the head and the whole body.

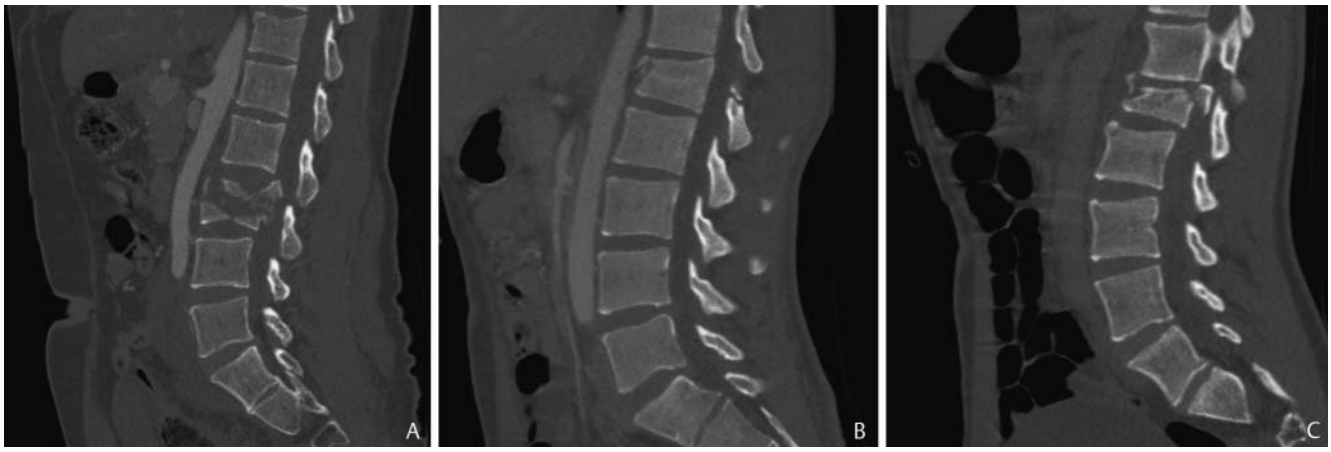
Our former standard CT protocol was acquired using a tube voltage of 140 kVp for the body and 120 kVp for the head, both reconstructed with an FBP algorithm (group A). In a first step to reduce radiation exposure and to evaluate the safety of IR implementation, we kept the tube voltage constant and only changed the reconstruction algorithm to ASIR including mA reduction for body acquisition (group B). These modifications did not degrade the quantitative or qualitative image quality. In a second step, we decreased the tube voltage to 120 kVp for body CT and also introduced 20 % IR blending (ASIR DR) in acquisitions of the cranium based on the results of a recent study that evaluated optimal blending of IR in cerebral CT [21] (group C). To detect the full extent of injuries in the different body regions, we selectively adapted the level of ASIR image reconstruction (ASIR REC) for different body regions.

These steps led to a radiation exposure of 647 mGy cm (mean DLP body) and 543 mGy cm (mean DLP head) that are well below the dose reference levels (1000 mGy cm for whole-body CT and 850 mGy cm for cranial CT) of the German Federal Office for Radiation Protection in 2016 [28]. The DLP values of the present study are also below those of other recently published studies reporting a mean DLP of 594 – 909 mGy cm for body CT [29], 1298 – 1338 mGy cm for the body scan and 850 – 1306 mGy cm for the cranial scan [30].

The quantitative and qualitative image quality in group C was stable compared to former protocols, indicating that the tube voltage can be safely lowered to 120 kVp using IR while achieving a reduction of radiation exposure of about 40 % for the body region. This reduction is attributable to the combined use of a lower tube voltage (from 140 kVp in group A to 120 kVp in group C) and IR. Although both parameters influence radiation exposure, it is reasonable to assume that IR is responsible for a large percentage of the reduction in radiation exposure since switching from FBP (group A) to IR (group B) while using the same tube voltage of 140 kVp resulted in a 26 % reduction in radiation exposure.

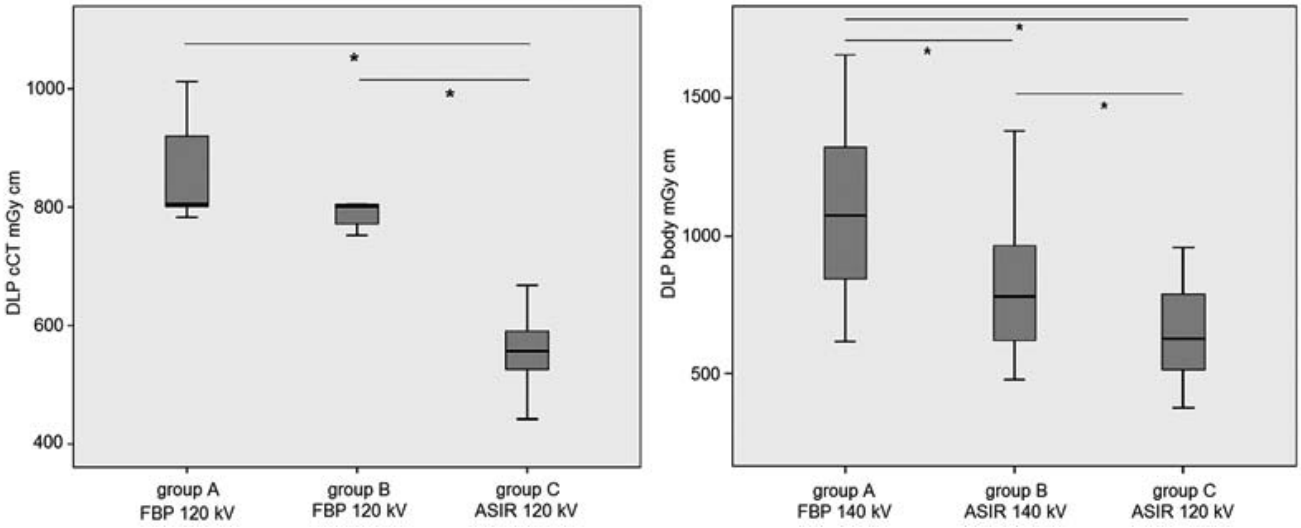
The CT trauma protocol presented here is characterized by the use of dedicated body-region-adapted levels of iterative reconstruction and allows considerable dose reduction of more than 40 % in trauma patients undergoing WBCT while maintaining diagnostic image quality. We recommend IR blending together with a multiphasic contrast agent injection as described for group C in ▶ **Table 1**. This protocol allowed evaluation of both the arterial system and the parenchymal organs. During cCT, the arms should be positioned next to the torso and, whenever possible, repositioned next to the head for the body acquisition. If the upper arm position is not possible, the arms should not be positioned alongside the torso but in front of the upper abdomen to avoid beam hardening artifacts [14].

Our study has some limitations. First, the practical recommendation for body-region-adapted levels of ASIR is applicable to one vendor only. However, our results show that a dedicated adaption of technical parameters improves the CT trauma protocol and may be beneficial for CT examinations on scanners from other manufacturers as well. Second, our data analysis was retrospec-



▶ **Fig. 6** Traumatic vertebral body fractures in groups **A–C**. All protocols allow for reliable detection of fracture details.

▶ **Abb. 6** Darstellung traumatischer LWK Frakturen in den verschiedenen Gruppen **A–C**. Alle Protokolle erlaubten die zuverlässige Charakterisierung der Frakturdetails. **A**: FBP, 140 kVp; DLP 1076 mGy × cm. **B**: ASIR 40, 140 kVp; DLP 889 mGy × cm. **C**: ASIR 40, 120 kVp; DLP 720 mGy × cm.



▶ **Fig. 7** Radiation exposure for whole-body CT and cranial CT. Significant differences between groups are indicated by an * ($p < 0.05$). [central line: median; box: interquartile range (IQR); whisker: 1.5 × IQR].

▶ **Abb. 7** Vergleich der Dosiswerte für Ganzkörper-CT und Kopf CT. Signifikante Unterschiede sind mit einem * gekennzeichnet ($p < 0.05$). [mittlere Linie: median; box: interquartile range (IQR); whisker: 1,5 × IQR].

tive without explicit patient group matching. However, patient parameters matched well and showed no significant differences. Third, qualitative image quality evaluation may not have been fully blinded, since the image impression of ASIR usually differs from that of FBP. Fourth, only 61 patients were included in this study. Therefore, our findings should be validated in larger patient groups in future studies. Fifth, we only obtained one scout with lowered arms to plan both cranial and body examinations although the body scan was performed with elevated arms. This affects the AEC of the CT scanner which uses the scout to define the applied tube current. Hence, arms within the field of view in the scout raise the applied tube current that leads to an elevated radiation exposure and better image quality, which was found to be crucial in this patient collective. However, the applied level of ASIR lowers the dose significantly, resulting in examinations that show a radiation exposure below the given reference levels and recently published studies as discussed above. This workflow might have systemically influenced dose modulation for all examined patients but guaranteed comparability among the different groups since dose-influencing variables were limited to tube voltage and level of applied ASIR. If the AEC of the used CT manufacturer depends on the acquired scout, using separate scouts for head and body examinations (with elevated arms) is reasonable in future examinations to ensure correct adjustment of the mA modulation.

Conclusion

The comparison of different CT polytrauma protocols has shown that the dedicated adjustment of the amount of IR and tube voltage according to the specific body region, slice thickness and kernel allows for a reduction of radiation exposure of more than 40 %, while maintaining quantitative and qualitative image quality in the examination of polytraumatized patients.

CLINICAL RELEVANCE

- Dedicated adaption of the CT trauma protocol including adjustments of the level of IR and tube voltage as well as split bolus contrast agent administration allows for an optimized examination.
- Using body-region-adapted levels of ASIR, radiation exposure can be reduced by more than 40 %, while maintaining diagnostic image quality.

Conflict of Interest

The authors declare that they have no conflict of interest.

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