Implementation of Dose Monitoring Software in the Clinical Routine: First Experiences

Einführung einer Dosis-Monitoring-Software in den klinischen Alltag: Erste Erfahrungen

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Zusammenfassung
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Ziel: Die Strahlenbelastung der Bevölkerung durch medizinische Bildgebung hat in den letzten Jahrzehnten deutlich zugenommen. Um die Strahlenbelastung der Patienten systematisch aufzeichnen und kontrollieren zu können, wurde in unserem Institut eine Dosis-Monitoring-Software installiert und zunächst mit den Computertomografen (CTs) verbunden.

Material und Methoden: Mithilfe der Dosis-Monitoring-Software wurden die Dosisdaten von zwei CTs zwischen Juli 2014 und Februar 2015 retrospektiv ausgewertet. Das eine CT befindet sich neben der Notaufnahme („Notfall-CT"), das andere CT wird überwiegend für stationäre und ambulante Patienten verwendet („Routine-CT"). Die Daten wurden im Hinblick auf die Anzahl der Untersuchungen mit Dosiswerten oberhalb festgelegter Schwellenwerte („Alerts") ausgewertet und die Ursachen für diese für beide CTs analysiert. Um signifikante Unterschiede zwischen beiden Geräten festzustellen, wurden Chi-Quadrat-Tests durchgeführt.

Ergebnisse: Insgesamt wurden 8883 Untersuchungen akquiriert (Routine-CT: 3415, Notfall-CT: 5468). Hierbei wurden 316 Alerts registriert (Quote: 4 %). Die Quote der Alerts schwankte zwischen 2 und 5 % zwischen den Monaten und Geräten, wobei am Routine-CT signifikant mehr Alerts nachgewiesen wurden. Ursachen für die Alerts waren hoher BMI (51 %), ungenaue Lagerung der Patienten im Isozenter (24 %), Untersuchungswiederholungen (11 %), Artefakte durch einliegendes Osteosynthesematerial (9 %) oder andere Gründe (5 %). Scanwiederholungen waren signifikant häufiger am Notfall-CT notwendig (p = 0,019), während hoher BMI, ungenaue Patientenlagerung oder einliegendes Osteosynthesematerial öfter Alerts am Routine-CT verursachten (für alle p < 0,05). Es zeigte sich eine gute Korrelation zwi-

Abstract
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Purpose: Radiation exposure of the public as a result of medical imaging has significantly increased during the last decades. To have a tool to register and control patient dose exposure, we implemented dose monitoring software at our institution and first connected our computed tomography (CT) scanners.

Materials and Methods: CT dose data from July 2014 to February 2015 was retrospectively analyzed using dose monitoring software. We evaluated a number of scans above predefined dose thresholds ("alerts"), assessed reasons for alerts and compared data of two CT scanners, one located close to the emergency room ("emergency CT scanner") and one mainly used on an outpatient basis ("clinical routine CT scanner"). To check for statistically significant differences between scanners, chi-square-tests were performed.

Results: A total of 8883 scans were acquired (clinical routine CT scanner, n = 3415; emergency CT scanner, n = 5468) during which 316 alerts were encountered (alert quota, 4 %). The overall alert quota ranged from 2 – 5 % with significantly higher values for the clinical routine CT scanner. Reasons for alerts were high BMI (51 %), patient off-centering (24 %), scan repetition (11 %), orthopedic hardware (9 %), or other (5 %). Scan repetition was necessary significantly more often with the emergency CT scanner (p = 0.019), while high BMI, off-centering and orthopedic hardware were more frequently seen with the clinical routine CT scanner (for all, p < 0.05). There was a good correlation between high body weight and dose above threshold (r = 0.585).

Conclusion: Implementation of dose monitoring software in the clinical routine was successfully accomplished and provides important information regarding patient radiation protection.

schen dem BMI und den Dosiswerten über dem Schwellenwert (r = 0,585).

Schlussfolgerung: Eine Dosis-Monitoring-Software kann erfolgreich in den klinischen Alltag eingeführt werden und liefert wichtige Informationen betreffend den Strahlenschutz der Patienten.

Kernaussagen:
1. Eine Dosis-Monitoring-Software kann erfolgreich in den klinischen Alltag eingeführt werden.
2. Dosiswarnungen sind entweder durch menschliche Fehler oder patientenspezifische Faktoren bedingt.
3. Durch eine Dosis-Monitoring-Software werden wichtige Informationen betreffend den Strahlenschutz der Patienten gewonnen.

Key Points:
1. Implementation of dose monitoring software in the clinical routine can be successfully accomplished.
2. Dose notifications are due to human error or patient-specific factors.
3. Dose monitoring software provides important information regarding radiation protection of patients.

Citation Format:

Introduction
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Radiation exposure of the public due to medical imaging has dramatically increased during the last decades, which is stressed by the fact that the number of computed tomography scans performed increased by 1900 % in the United States from 1980 to 2005 [1, 2]. Despite the introduction of multiple new technologies such as dose modulation, low-dose protocols, and reconstruction algorithms, annual radiation exposure due to medical imaging currently makes up almost 50 % of the yearly background radiation exposure per capita [2]. As a consequence, reasonable dose management has become more and more important and has gained public visibility [3]. To account for this, the American College of Radiology (ACR) has introduced the Dose Index Registry (DIR) as part of the National Radiology Data Registry [4] and has initiated campaigns to increase awareness of radiation protection ("Image Wisely" for adults [5]; "Image Gently" for pediatrics [6, 7]) with similar projects existing in Europe ("EuroSafe" [8]).

With regard to computed tomography (CT), important radiation dose quantities are the volumetric CT dose index ($CTDI_{vol}$) and the dose length product (DLP), which are routinely displayed on every CT console. They are measured using cylindrical phantoms [4, 9]. In most countries the DLP is the quantity used for setting national dose reference levels (DRLs).

To account for an increasing demand of dose control, several dose monitoring programs have been launched. This software allows for in-house quality assurance by analysis of dose levels, by identification of dose outliers as well as by reviewing the radiation exposure of different scanners. Moreover, this software enables comparison of one's own dose data with national DRLs [4, 10] and aggregation of data for a national dose registry based on exam type and body part [4]. However, so far little is known about the feasibility of introducing dose monitoring software in the clinical routine. Therefore, the aim of the present study was to report on first experiences gained in a large public hospital after connection of dose monitoring software to two computed tomography scanners and the software's implementation in the daily clinical routine. Furthermore, analysis of excess dose notifications was performed to assess the most frequent sources of radiation exposure above predefined thresholds.

Methods
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Our local ethics committee approved analysis of the dose monitoring software's data as part of the hospital's quality assurance. Informed consent was waived.

Dose monitoring software

GE's (GE Healthcare Systems, Buc, France) dose management solution DoseWatch® was implemented at our institution to improve radiation protection, while maintaining high diagnostic quality of images. DoseWatch® is web-based software that allows for capturing, tracking, and reporting radiation dose information directly from any imaging device and was first connected to our computed tomography (CT) scanners. The software offers detailed analysis on the dose delivered to the patients and can be adapted to one's own preferences. Dose data analysis is possible for all scanners together as well as separately for each scanner, thereby allowing for comparison of dose data between different scanners. Moreover, the software inherits a notification system that transmits messages when dose levels exceed predefined thresholds ("alerts"). At the time as the installation of the software, national dose reference levels (DRLs) for 21 indication-based CT examinations, which were set as dose thresholds, were available in our country. For all other protocols we decided to derive DRLs by determining the 75th percentile of the distribution of a defined dosimetric quantity [11]. The software received dose information as a separate file based on the dose protocol of the scanners, which included scout images for the assessment of patient diameter and positioning.

Study setup

The dose monitoring software was installed on a virtual server. ⊙ **Fig. 1** illustrates the standard dose monitoring workflow as currently practiced in our institution. A dose team consisting of two radiographers, one board certified radiologist, and the institution's IT specialist supervises the workflow. They meet once a month to discuss dose data and coordinate tasks associated with the dose monitoring software.

In our institution each CT examination is justified by either a board certified radiologist or a radiology resident. Justification encompasses choosing the adequate CT protocol in order to address the clinical question. As no national standards exist, CT protocols are specific for our institution and are not mapped to the RadLex [4]. Given that our CT scanners are from the same vendor, protocol names are identical for all scanners.
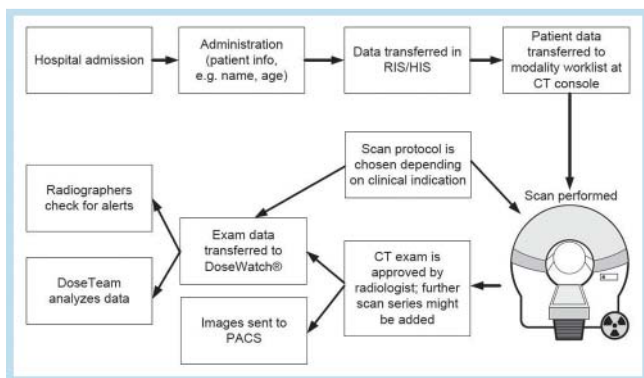
Fig. 1   Scheme of the standard dose monitoring workflow as practiced in our institution. HIS = Hospital Information System. RIS = Radiology Information System

Abb. 1   Zusammenstellung der Standardabläufe betreffend der Dosisüberwachung an unserem Institut. HIS = Krankenhausinformationssystem. RIS = Radiologie-Informationssystem.
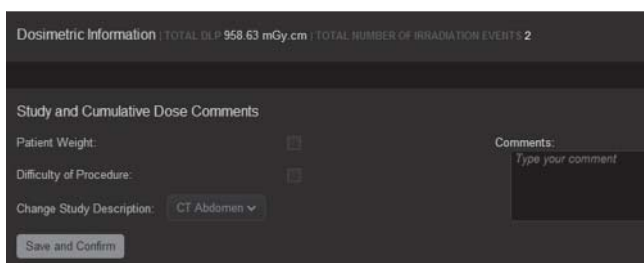
Fig. 2   Illustration of the alert answering window. Radiographers can either click on one of the predefined comments as seen on the left (e. g. patient weight) or can type their comment in the box on the right site.

Abb. 2   In dem dargestellten Fenster können die Röntgenassistenten die Dosiswarnungen beantworten, indem sie entweder einen vorgegebenen Kommentar (z. B. Patientengewicht) auswählen oder eine Bemerkung in das entsprechende Feld auf der rechten Seite schreiben.

Our workflow includes approval of every CT scan by a board certified radiologist or a radiology resident before the patient is allowed to leave the CT bed. For that reason it is possible for further scan series to be added (e. g. a delayed phase), although they were not part of the initially planned CT protocol. Because contextual integration between our Radiology Information System (RIS) and the dose monitoring software is not established yet, the software cannot register any change of protocol made after the scan has already started. To avoid dose data being linked to the wrong CT protocol, radiographers were advised to make a note in the comment box of the software, whenever the protocol differed from the initially chosen protocol. The correct study name was then manually selected within the dose monitoring software, before data analysis began.

As part of our dose monitoring policy, the dose monitoring software continuously runs on a separate computer next to the CT scanning console and radiographers are advised to check for alerts after each scan. In case of a dose notification, radiographers are trained to answer them by either clicking on predefined answers (e. g. patient weight) or giving short explanations (e. g. repetition of scan due to severe movement artifacts) within the software's comment box (○ **Fig. 2**).

The radiographers involved in the present study had an average working experience of 8.32 years after certification (range: 1 – 41 years).

CT scans

CT data sets were acquired on our two multidetector-row CT scanners. One of these two CT scanners is mainly used on an outpatient basis (Discovery HD 750, GE Healthcare Systems, Milwaukee, WI, USA) and therefore is called clinical routine CT. The second CT scanner is installed close to the emergency room ("emergency CT"; LightSpeed VCT, GE Healthcare Systems, Milwaukee, WI, USA) and is primarily used for the imaging of patients from the emergency room or the intensive care units as well as for CT-guided percutaneous interventions. Both CT scanners are equipped with the latest reconstruction algorithms such as the iterative reconstruction algorithm.

Depending on clinical indication, protocols were chosen and scans were performed native or after contrast media application (intravenous, oral and/or rectal), adhering to the as low as reasonably achievable (ALARA) principle. The applied study protocols, their scan parameters as well as the set dose thresholds are summarized in ○ **Table 1**.

Statistical analysis
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Data analysis was done by a board certified radiologist with 10 years of experience in CT and with a special interest in radiation protection. For the purpose of this study, data from July 2014 until February 2015 was retrospectively evaluated with a focus on the volumetric CT dose index (CTDI$_{vol}$; milli-Gray (mGy)) and the dose length product (DLP; mGy*cm). Moreover, study description, patient gender and age as well as body mass index (BMI; kg/m^2) were recorded. A BMI ≥ 25 kg/m^2 was deemed to represent excess BMI.

The radiologist revised all alerts gained during the investigation period, analyzed reasons for notifications and compared data of the emergency and clinical routine scanner. Besides high BMI, one possible cause of alert was the patient being positioned not perfectly in the isocenter of the scanner ("patient off-centering"), which was assumed if aberrations in vertical position exceeded 2 cm.

To check for statistically significant differences between the two scanners, chi-square-tests (χ^2-test) were done with a p-value > 0.05 considered to represent statistical significance. If high BMI caused the alert, the relative DLP value above the threshold was calculated and correlated with the BMI by means of the Pearson correlation coefficient.

Data was exported from the dose monitoring software as Excel spreadsheets and further analysis was then performed using either Microsoft Excel 2010 (Redmond, WA, USA) or IBM SPSS Version 22 (Amonk, NY, USA).

Results
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A total of 8883 CT scans were acquired during July 1, 2014 and February 28, 2015 (5468 on emergency CT scanner; 3415 on clinical routine CT scanner) and dose data of all examinations was successfully transferred to the dose monitoring software. CT scans were performed on 7914 different patients, of whom 695 underwent 2 examinations, 96 got 3 scans, 20 had 4 CTs,

Table 1 Summary of protocol names with scan parameters and dose thresholds (dose-length product; mGy[1]cm).

Tab. 1 Zusammenfassung der Protokollnamen mit den Untersuchungsparametern sowie den Dosisschwellenwerten (Dosislängenprodukt; mGy[1]cm).

CT protocol	tube voltage (kV)	tube current (mA)	pitch	noise index	DLP threshold (mGy[1]cm)
skull/brain	120	120 – 165	0.75	9.0	1000[1]
brain (vascular)	120	120 – 335	0.531	25.30	1000[1]
skull/brain/cervical spine	120	120 – 500	0.531	9.00 – 32.00	1250
sinus	120	10 – 290	0.531	27.00	350[1]
skull/brain/neck/chest/ abdomen	120	100 – 335	0.531	9.00 – 28.20	1800
skull/brain/chest/abdomen	120	100 – 335	0.531	9.00 – 28.20	1650
trauma (skull/brain/cervical spine/ chest/abdomen/pelvis)	120	100 – 335	0.531	9.00 – 32.00	2300
cervical spine	120	120 – 500	0.969	32.00	600[1]
neck	120	170 – 500	1.375	28.20	600[1]
neck/chest	120	120 – 350	1.375	28.00	500
neck/chest/abdomen (vascular)	120	120 – 450	1.375	49.50	1300
chest (vascular)	120	80 – 450	1.375	49.50	375
chest/abdomen (vascular)	120	120 – 450	1.375	49.50	1000
chest/epigastrium	120	80 – 450	1.375	49.50	600[1]
heart	100	500	0.16	15.03	1000[1]
chest	120	80 – 135	1.375	37.25	400[1]
chest/abdomen	120	120 – 450	1.375	28.00	1000
thoracic spine	120	160 – 560	0.984	25.30	300
shoulder	120	120 – 350	0.969	27.00	500[1]
elbow	100	80 – 300	0.531	14.00	200
wrist	80	50 – 200	0.531	13.50	100
lumbar spine	120	160 – 560	0.984	25.30	850[1]
abdomen/pelvis	120	100 – 550	1.375	35.00	650[1]
pelvis/lower extremity (vascular)	120	100 – 550	1.375	14.14	1000[1]
pelvis	100	80 – 350	0.984	35.00	500[1]
knee/lower leg	120	80 – 300	0.531	13.30	300
ankle	100	80 – 250	0.531	13.30	225

[1] national dose reference level.
nationaler Dosisreferenzwert.

and 2 patients received 6 and 7 scans, respectively. The patient group consisted of 4511 men (57 %) and 3403 women (43 %) with a mean age of 58.6 ± 23.9 years, (range: 0 to 101 years). The most frequently applied CT protocols were CT of the skull/brain (either alone or in combination with sinus and/or cervical spine; n = 2658), CT of the chest (n = 1546), CT of the chest and abdomen (n = 2043), and CT of the abdomen (n = 1918).

During the investigation period a total of 316 alerts were encountered: clinical routine CT scanner, n = 145; emergency CT scanner, n = 171. The mean alert quota was 4 % with a range from 2 – 5 % between the months. The alert quota was significantly higher on the clinical routine CT scanner in total for all months together (χ^2-value = 7668, p = 0.006) and in September 2014 (χ^2-value = 4674, p = 0.031) (● **Table 2**). For all other months no considerable difference was detected between the scanners (for all, p > 0.05).

Most alerts were seen when performing CT of the abdomen (n = 136), CT of the skull/brain (n = 64), and CT of the chest-abdomen (n = 60). Causes of alerts were high BMI (n = 160; 51 %), patient off-centering (n = 77; 24 %), scan repetition (n = 36; 11 %), orthopedic hardware in the scanning area (n = 28; 9 %), or other causes such as examination on a spine board (n = 15; 5 %) (● **Table 3**). While most scans with alerts due to high BMI occurred in the case of CT of the abdomen (n = 117; 73 %) or CT of the chest-abdomen (n = 27; 17 %), scan repetition was most often necessary in CT of the skull/brain (n = 29; 81 %).

When comparing both scanners, analysis revealed that patient off-centering and orthopedic hardware significantly more frequently caused notifications on the clinical routine CT scanner versus the emergency CT scanner: patient off-centering, 27 % vs. 22 %, χ^2-value = 4831, p = 0.028; orthopedic hardware, 11 % vs. 7 %, χ^2-value = 4.15, p-value = 0.042. Although values varied noticeably between the months, overall alerts due to high BMI were significantly more often encountered on the clinical routine CT scanner: χ^2-value = 6453, p = 0.011. In contrast, scan repetition led to an alert considerably more frequently on the emergency CT scanner compared to the clinical routine CT scanner: 17 % vs. 5 %, χ^2-value = 5514, p = 0.019. No considerable differences were detected with regard to other reasons (χ^2-value = 0.015, p = 0.901).

If the alert was triggered by high BMI, the threshold was exceeded by 58 % on average (range, 1 – 171 %). There was a good correlation of the BMI and the relative dose value above the threshold (r = 0.585; ● **Fig. 3**).

Discussion
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Due to the versatile use of CT [12, 13], the number of CT studies has continuously increased during the last decades [1, 2, 14, 15]. At the same time radiation exposure of the public from medical sources has grown by approximately 600 % to reach 3.0 mSv per capita per year [16, 17] and it is expected that 1 – 2 % of all can-

		no. of alerts	no. of scans	alert quota	routine vs. emergency CT	
					χ^2-value	p-value
july 2014	routine CT	20	457	4%	0.106	0.744
	emergency CT	24	604	4%		
	both	44	1061	4%		
august 2014	routine CT	13	431	3%	0.004	0.951
	emergency CT	18	610	3%		
	both	31	1041	3%		
september 2014	routine CT	24	417	6%	4.674	0.031[1]
	emergency CT	21	680	3%		
	both	45	1097	4%		
october 2014	routine CT	25	487	5%	3.279	0.07
	emergency CT	22	716	3%		
	both	47	1203	4%		
november 2014	routine CT	18	416	4%	0.91	0.34
	emergency CT	23	713	3%		
	both	41	1129	4%		
december 2014	routine CT	15	348	4%	2.71	0.1
	emergency CT	17	695	2%		
	both	32	1043	3%		
january 2015	routine CT	7	435	2%	1.878	0.171
	emergency CT	22	766	3%		
	both	29	1201	2%		
february 2015	routine CT	23	424	5%	2.365	0.124
	emergency CT	24	684	4%		
	both	47	1108	4%		
total	routine CT	145	3415	4%	7.668	0.006[1]
	emergency CT	171	5468	3%		
	both	316	8883	4%		

Table 2 Comparison of alert quota of the clinical routine and the emergency CT scanner during July 2014 and February 2015.

Tab. 2 Vergleich der Quote der Dosiswarnungen am Routine-CT und am Notfall-CT zwischen Juli 2014 und Februar 2015.

no. = number, χ^2-value = chi-square value
no. = Anzahl, χ^2-Wert = Chi-Quadrat-Wert
[1] indicates statistical significance (p < 0.05).
   statistisch signfikanter Unterschied (p < 0,05).

cers in the United States will be attributable to CT scans in the future [18 – 20]. Although there is little doubt that in most cases the benefits of CT scans far outweigh the risks [5, 18] and that dose may not be reduced at the expense of needed diagnostic information [13, 21], the high number of unjustified, inappropriate and clinically unnecessary CT studies has garnered considerable media attention and has created substantial public anxiety [3, 13]. For these reasons radiation protection is more and more in the focus of interest. To address this, some manufacturers have introduced dose monitoring computer programs, which enable tracking and reporting of ionizing radiation exposure for patients [10, 22] and which may potentially induce dose reduction actions [21, 23]. The present study showed on the basis of 8883 CT scans that dose monitoring software can be successfully implemented in the clinical routine and that dose data can be reliably transferred from the imaging devices to the software. Our analysis revealed that computed tomography dose values exceeded predefined thresholds on average in 4% of examinations. Reasons were high BMI (51%), patient off-centering (24%), scan repetition (11%), orthopedic hardware within the scanning area (9%), or other causes (5%), thus a mixture of patient-specific and user-specific reasons. Comparison of alert reasons on the clinical routine scanner and the emergency CT scanner showed that scan repetition was more frequently found on the latter. This may be explained by severe motion artifacts caused by oftentimes confused and agitated emergency patients requiring examination of the skull/brain to exclude intracerebral bleeding or stroke. In contrast, patient off-

centering was more often encountered on the clinical routine CT scanner, although we assumed that time pressure would play a major role in correct patient centering. We therefore expected more patient off-centering alerts on the emergency CT scanner with its usually more hectic working environment. The importance of proper patient positioning at the isocenter and its considerable influence on both image quality and radiation dose distribution was demonstrated in several studies [24 – 26]. Reasons are changes in tube current-time product (e.g. by affecting the function of the automatic exposure control system), an increase of radiation dose absorbed by sensitive surface tissues, or an altered projection of organs onto the bowtie filter [24, 27]. It was shown that already relatively small aberrations in vertical position of 2 – 6 cm may result in dose increases of up to 51% [25, 26]. As patient centering is a user-specific factor and therefore controllable, we performed an in-service training for our radiographers pointing out the importance of proper patient positioning and the need to refresh their skills.

On both scanners the majority of alerts were caused by high BMI (BMI ≥ 25 kg/m^2). Based on probability distribution, we expected no significant differences in alerts due to high BMI between both scanners, but nonetheless found alerts on the clinical routine CT scanner considerably more often. One explanation might be that examinations of the abdomen are usually conducted on the clinical routine CT scanner and predominantly cause high BMI alerts due to the marked fat accumulation at the abdomen. The influence of BMI on absorbed dose and image quality is well-known

Table 3 Sources of alerts (absolute and relative numbers) as encountered on clinical routine and emergency CT during July 2014 and February 2015.

Tab. 3 Ursachen der Dosiswarnungen (relative und absolute Werte) am Routine- und Notfall-CT zwischen Juli 2014 und Februar 2015.

		BMI		off-centering		repetition		orth. hardware		other	
		abs	rel	abs	rel	abs	rel	abs	rel	abs	rel
july 2014	routine CT	12	60 %	5	25 %	1	5 %	2	10 %	0	0 %
	emergency CT	11	46 %	8	33 %	4	17 %	0	0 %	1	4 %
	both	23	52 %	13	30 %	5	11 %	2	5 %	1	2 %
august 2014	routine CT	6	46 %	3	23 %	1	8 %	1	8 %	2	15 %
	emergency CT	7	39 %	4	22 %	3	17 %	3	17 %	1	6 %
	both	13	42 %	7	23 %	4	13 %	4	13 %	3	10 %
september 2014	routine CT	13	54 %	5	21 %	2	8 %	4	17 %	0	0 %
	emergency CT	10	48 %	2	10 %	6	29 %	1	5 %	2	10 %
	both	23	51 %	7	16 %	8	18 %	5	11 %	2	4 %
october 2014	routine CT	15	60 %	6	24 %	1	4 %	3	12 %	0	0 %
	emergency CT	13	59 %	4	18 %	3	14 %	1	5 %	1	5 %
	both	28	60 %	10	21 %	4	9 %	4	9 %	1	2 %
november 2014	routine CT	9	50 %	3	17 %	2	11 %	3	17 %	1	6 %
	emergency CT	14	61 %	4	17 %	3	13 %	2	9 %	0	0 %
	both	23	56 %	7	17 %	5	12 %	5	12 %	1	2 %
december 2014	routine CT	10	67 %	5	33 %	0	0 %	0	0 %	0	0 %
	emergency CT	9	53 %	0	0 %	3	18 %	2	12 %	3	18 %
	both	19	59 %	5	16 %	3	9 %	2	6 %	3	9 %
january 2015	routine CT	3	43 %	3	43 %	0	0 %	1	14 %	0	0 %
	emergency CT	10	45 %	5	23 %	4	18 %	2	9 %	1	5 %
	both	13	45 %	8	28 %	4	14 %	3	10 %	1	3 %
february 2015	routine CT	9	39 %	9	39 %	0	0 %	2	9 %	3	13 %
	emergency CT	9	38 %	11	46 %	3	13 %	1	4 %	0	0 %
	both	18	39 %	20	43 %	3	6 %	3	6 %	3	6 %
total	routine CT	77	53 %	39	27 %	7	5 %	16	11 %	6	4 %
	emergency CT	83	49 %	38	22 %	29	17 %	12	7 %	9	5 %
	both	160	51 %	77	24 %	36	11 %	28	9 %	15	5 %

abs = absolute value, BMI = body mass index; alert due to high body weight (≥ 25 kg/m²), off-centering = patient was not positioned properly in isocenter, orth. hardware = orthopedic hardware; alert was caused by dose up-regulation due to orthopedic hardware, other = causes for alerts not covered by the aforementioned reasons; e. g. dose up-regulation because of scan on spine-board, rel = relative value.

abs = absoluter Wert, BMI = Body-Mass-Index; die Dosiswarnung ist durch ein hohes Patientengewicht bedingt (≥ 25 kg/m²), off-centering = ungenaue Patientenlagerung im Isozenter des Scanners, orth. Hardware = die Dosiswarnung ist durch einliegendes Osteosynthesematerial und dadurch bedingter Dosis-Hochregulierung verursacht, other = die Dosiswarnung ist die Folge anderer Gründe wie beispielsweise durch Untersuchung auf einem Spineboard. rel = relativer Wert.
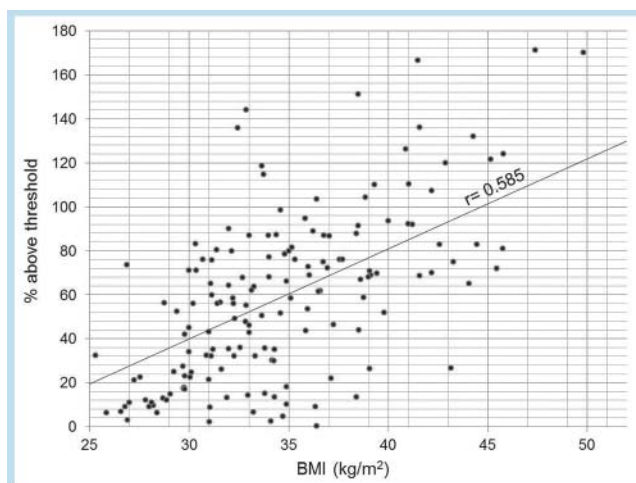
Fig. 3 Correlation of high body weight (BMI ≥ 25 kg/m²) and dose above threshold (relative number). The Pearson coefficient (r = 0.585) shows a good correlation of both metrics.

Abb. 3 Die Höhe des Patientengewichts (BMI ≥ 25 kg/m²) korreliert gut mit dem relativen Dosiswert oberhalb des Schwellenwertes (Pearson-Korrelationskoeffizient r = 0,585).

and has led to the introduction of BMI-dependent tube voltage/current selection at many sites [9, 28], which is now evaluated at our institution, too.

Furthermore, up-regulation of the tube current may be caused by orthopedic hardware within the scanning area, which was also more frequently detected on the clinical routine CT scanner. This is due to the fact that most patients with orthopedic hardware undergo scans on an outpatient basis. Irrespective of this, we now increasingly acquire orthopedic hardware examinations with the dual-energy technology due to fewer metal artifacts [29], which often involves dose reduction and a possible decline of alerts.

Our study has some limitations: (1) The training and experience of radiographers significantly influence the radiation exposure of patients [3, 14, 21] and the quality of data depends on the accuracy of tagging, which might have skewed our results. However, a mean working experience of 8.32 years indicates that most radiographers involved in the study were well versed. (2) We used scanners from a single vendor, which may have affected dose values as, for example, tube current modulation techniques and bowtie filters vary among different vendors [25]. (3) In some patients alerts may have been caused by more than one source or an interaction of several causes (e. g. high BMI and off-centering). In these cases we tried to estimate which of the causes might have been the principal reason. However, we cannot exclude that our appraisal was

inaccurate. (4) National DRLs have been introduced in many countries, but show considerable ranges [11, 13], so that our thresholds may not have been perfect, although they are lower than most published DRLs. (5) Finally, we based our analyses on CTDI$_{vol}$ and DLPs, although they have several disadvantages such as measurements done on phantoms that are much shorter than the average adult patient or inaccuracy when radiation dose-saving technologies are applied [3, 4, 9]. To account for these drawbacks, the size-specific dose estimate (SSDE), which also considers patient anatomy, is used more and more [30] and should be included in further studies.

In summary, our study shows that dose monitoring software can be successfully implemented in clinical practice and provides important information on a patient's radiation dose. Besides being a tool for internal and external quality control, dose monitoring software can be used to improve awareness and knowledge of radiation doses. It will be the task of future research to assess longer-term effects of dose monitoring software in terms of dose reduction and decrease of alerts caused by human error as well as to evaluate the impact of adaptation of scanning parameters to patient-specific factors.

Clinical relevance

▶ Increasing radiation exposure of patients due to medical imaging has made the registration and control of radiation dose more and more a topic of interest.
▶ Dose monitoring software is an important tool to collect and analyze radiation dose data and allows for internal and external quality control.
▶ By revealing sources of a radiation dose above predefined thresholds, dose monitoring software not only increases radiation awareness but may also lead to an improvement in radiation protection.

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