Radiation Protection Dosimetry (2020), Vol. 189, No. 1, pp. 35–47
Advance Access publication 15 February 2020
doi:10.1093/rpd/ncaa010

DIAGNOSTIC IMAGING AND IONIZING RADIATION EXPOSURE IN A LEVEL 1 TRAUMA CENTRE POPULATION MET WITH TRAUMA TEAM ACTIVATION: A ONE-YEAR PATIENT RECORD AUDIT

Anna Bågenholm[1,2,*], Pål Løvhaugen[3], Rune Sundset[2,3] and Tor Ingebrigtsen[2,4]
[1]Department of Radiology, University Hospital of North Norway, Tromsø N-9038, Norway
[2]Department of Clinical Medicine, Faculty of Health Science, UiT—The Arctic University of Norway, Tromsø N-9037, Norway
[3]PET-Imaging Center, University Hospital of North Norway, Tromsø N-9038, Norway
[4]Department of Neurosurgery, ENT and Ophthalmology, University Hospital of North Norway, Tromsø N-9038, Norway

*Corresponding author: Anna.Bagenholm@unn.no

Received 16 October 2020; revised 10 January 2020; editorial decision 13 January 2020; accepted 15 January 2020

This audit describes ionizing and non-ionizing diagnostic imaging at a regional trauma centre. All 144 patients (males 79.2%, median age 31 years) met with trauma team activation from 1 January 2015 to 31 December 2015 were included. We used data from electronic health records to identify all diagnostic imaging and report radiation exposure as dose area product (DAP) for conventional radiography (X-ray) and dose length product (DLP) and effective dose for CT. During hospitalization, 134 (93.1%) underwent X-ray, 122 (84.7%) CT, 92 (63.9%) focused assessment with sonography for trauma (FAST), 14 (9.7%) ultrasound (FAST excluded) and 32 (22.2%) magnetic resonance imaging. One hundred and sixteen (80.5%) underwent CT examinations during trauma admissions, and 73 of 144 (50.7%) standardized whole body CT (SWBCT). DAP values were below national reference levels. Median DLP and effective dose were 2396 mGycm and 20.42 mSv for all CT examinations, and 2461 mGycm (national diagnostic reference level 2400) and 22.29 mSv for a SWBCT.

INTRODUCTION

The introduction of conventional radiography (X-ray) in 1895 and computer tomography (CT) in 1971 has increased the burden of manmade ionizing radiation to humans[1]. In Norway, radiation from medical imaging adds an extra 1.1 mSv to the natural background of 4.1 mSv per year[2]. The use is considered acceptable if the expected health gain from an examination exceeds the possible harms[3, 4]. The risk for harm, especially cancer, after use of X-ray and CT, is under debate[5].

Improved availability and recommendations for CT use in trauma patients[6–8] contribute to the increased radiation exposure[9–11]. During the last decade, radiologists and surgeons have debated the use of standardized whole body CT (SWBCT) in trauma patients[12]. Evidence-based guidelines for use of CT in severely injured trauma patients are not available. Some retrospective register studies advocate immediate SWBCT[6, 13], while one prospective study[14] and some reviews[15–17] argue that mortality is not reduced with this method. The majority of patients with severe trauma are between 20 and 60 years[6, 9, 13, 14, 18, 19]. For this patient group, a high ionizing radiation dose can be more harmful than the injuries, if injuries are not severe or life threatening. Optimization of patient dose is therefore important[3, 4]. Age, body size, irradiated body area, machine protocol parameters and use of non-ionizing methods influence the dose the patient receives[2, 20–22].

Numerous studies report radiation exposure risk for subgroups of trauma populations, admissions and/or hospitalizations[9–11, 18, 19, 23, 24]. To our knowledge, no previous study describes all ionizing and non-ionizing diagnostic imaging and the total dose delivered for trauma patients in all age groups, from the accident until the start of rehabilitation. Therefore, the aims of this study were to describe all diagnostic imaging and report the dose delivered during trauma-associated hospitalization at a Level 1 trauma centre.

MATERIAL AND METHODS

Study type and inclusion criteria

This is a retrospective clinical quality audit focused on diagnostic imaging[25, 26]. We included all patients admitted to a Level 1 trauma centre with trauma team activation (TTA) from 1 January 2015 to 31 December 2015. There were no exclusion criteria.

© The Author(s) 2020. Published by Oxford University Press.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Study region

This Norwegian health region is a rural area (257 450 km^2, 1.9 inhabitants per km^2)[27]. The regional Level 1 trauma centre, as defined by the Norwegian trauma system, admits approximately 150 TTA's per year and supports 10 referring hospitals. The region has one common digital picture archiving and communication system (PACS). Thus, all diagnostic examinations are digitally available at the other hospitals immediately after an examination.

The region has predefined criteria for TTA[28] and follows the Advance Trauma Life Support system[29]. Decision on the use of diagnostic imaging, such as choice of modalities, number of examinations and timing is on discretion of the trauma surgeon in charge. The technical protocol for SWBCT in adults (>16 years) is standardized. Patients may undergo diagnostic imaging during four phases: pre-hospital (Phase 1); trauma admission 1, at a referring hospital or at the trauma centre for patients transported directly to the Level 1 trauma centre (Phase 2); trauma admission 2 for referred patients (Phase 3) and the subsequent hospital stay following the trauma admissions (Phase 4). We refer to all phases as the total hospitalization.

Data collection

Trauma registrars continuously survey emergency admissions and prospectively register all trauma patients fulfilling predefined criteria in the national trauma registry. In the present study, we included all patients registered with a TTA in 2015, registered in the national trauma registry. The first author thereafter manually retrieved and registered all study data from pre- and intra-hospital electronic health records, including the radiology information system and the radiology examinations (and logs) in the PACS. Injury severity was reported as injury severity score (ISS)[30] and new ISS[31]. The first author and another AIS certified physician employed at UNN as trauma registry coder scored the injuries in a consensus process[32]. Study data entry continued until death, discharge home or to rehabilitation.

The Regional Medical Ethic Committee defined the study as quality control (case number 2014/1883), and therefore, the data protection officer approved analysis of anonymized data (case number 0446) without approved consent from the patients.

Ionizing radiation units

We registered delivered dose from X-ray examinations as the dose area product (DAP) in Gray-centimetre squared. Dose from CT was registered as the dose length product (DLP) in milliGray centimetre. DLP is the volume CT dose index ($CTDI_{vol}$) in mGy multiplied with the scan length in cm. The $CTDI_{vol}$ expresses the weighted average dose in an infinitesimal slice in a polymethyl methacrylate phantom.

The estimated long time risk (for cancer) is assumed to be associated with the delivered dose. This risk is assessed by estimating the effective dose in mSv. We estimated the effective dose with a computer software from the National Cancer Institute (NCI) dosimetry system for CT (NCICT)[33]. This software estimates the effective dose based on input of the patients age group, gender and exact scan protocol parameters retrieved from the PACS digital imaging and communications in medicine (DICOM) scan log archive. We adjusted the scan length to match the patient CT scan length by interpreting the actual scan length in PACS. For each scan, NCICT estimates the organ doses for all different organs in mGy and the effective dose to the patient in mSv. The risk weighting factors in the software consider age group and gender based on the factors published in the International commission on radiological protection's Publication 103. Effective doses from all scans in one examination were added to find the total effective dose of that examination.

For comparison of the SWBCT protocol in the three CT machines (Siemens Somatom Definition Flash) at the trauma centre, the delivered dose and effective dose estimates were compared by scanning a whole body CT phantom PBU-60 Kyoto Kagaku[34] and estimating with NCICT. The phantom was scanned according to protocol, with arms fixed on a pillow on the abdomen, as in patients incapable of lifting their arms above the head. The same scan positions and scan lengths were used in the three similar machines. The total DLPs for the SWBCT protocol were 1646, 1630 and 1647 mGycm, respectively. We estimated the total effective dose to the phantom to 11.21, 11.04 and 11.70 mSv, respectively (Appendix 1).

X-ray examination registrations

We registered the number of X-ray images per anatomical part of the body per patient and the corresponding DAP per image as filed in the PACS DICOM archive. Before every exposure, a specific X-ray protocol adjusted to the patient's age, size and diagnostic purpose was chosen by the radiographer. We registered the DAP calculated by the X-ray machine for each specific image. The total DAP during trauma admissions and total hospitalization was calculated as continuous variables for each patient. The total DAP during the total hospitalization was also calculated per body part (the upper extremity including the clavicle, the chest/abdomen including the vertebral column, and the lower extremity including the pelvis). A retake

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

was defined as an anatomical body part examined more than one time.

CT examination registrations

We registered the number of CT scans per body part (caput, neck, chest, abdomen, pelvis and extremities) scanned per patient, with corresponding DLP per scan (abdomen and pelvis reported as one category) as filed in the PACS DICOM archive. Before every CT scan, a specific CT protocol adjusted to the patient's age, size and diagnostic purpose was chosen by the radiographer. We registered the DLP calculated by the CT machine for each specific scan. Effective dose was estimated for each scan using NCICT as described above. We calculated delivered DLP per patient into four continuous variables: SWBCT DLP dose in trauma admissions, total CT DLP in trauma admissions, DLP for the total hospitalization and DLP per body part for the total hospitalization (SWBCT examination split into body part scans). A complement CT scan was defined as a CT scan during the subsequent hospital stay for a body part not examined during trauma admissions and a duplicated CT scan as a body part scanned more than one time.

The SWBCT protocol includes caput scan without intravenous contrast, neck scan without intravenous contrast, chest scan with intravenous contrast in the arterial phase (including the spleen) and abdomen/pelvis scan with intravenous contrast in the portal venous phase. Shoulders and hips are often included in the chest and pelvis scan. All other scans of extremities were registered as separate body part scans. A selective CT was defined to exclude one or more of the four SWBCT body scans. On the trauma surgeon's discretion, duplicate CT scans of one or more body parts during one examination could be ordered. For example, an examination of a complicated neck fracture justified an extra arterial contrast phase of the neck during the chest scan.

Non-ionizing diagnostic exams: Ultrasound and MRI

Focused assessment with sonography for trauma (FAST)[35] is included in the ATLS manual as a method for identification of free fluid in the pericardial and peritoneal cavities. The extended FAST (EFAST) also includes examination of the pleural cavities[36]. Pre-hospital FAST/EFAST was gradually introduced in the trauma centre helicopter emergency medical service during 2015. We registered the number of FAST and EFAST examinations per patient performed pre-hospital and during trauma admissions. We also registered the sum of all ultrasound examinations for each patient (excluding FAST/EFAST) during the subsequent hospital stay. Use of intravenous ultrasound contrast examinations, pleural ultrasound and thoracentesis (ultrasound guided) were registered separately.

At the trauma centre, magnetic resonance imaging (MRI) examination is not in routine use during trauma admissions. We registered the number of MRI examinations per patient during the subsequent hospital stay, in total and categorized by body parts.

Statistics

We used IBM SPSS 24 for data analysis. Normality was tested with Kolmogorov-Smirnov and Shapiro-Wilk tests and distributions assessed with histograms and Q–Q plots. We tested differences in category data between children and adults with chi-square statistics or Fisher's exact test (when $n < 5$). Values of $p < 0.05$ were considered statistically significant. We report medians with lower and upper quartiles (Q1, Q3) for non-normally distributed data. We report the number of X-ray images and CT scans with missing DAP and DLP values. We calculated DAP, DLP and effective dose values after exclusion of missing values.

RESULTS

Demographics

Table 1 displays characteristics for the 144 patients admitted with TTA in 2015. The patients were 26 children ≤16 years and 118 adults.

X-ray examinations

Table 2 displays the number of patients stratified by the number of X-ray images per body part and the number of images per anatomical body part for all 144 patients during the total hospitalization. In total, 134 (93.1%) underwent one or more X-ray examinations during the total hospitalization. X-ray of the chest and pelvis was most frequent. During trauma admission 1, 114 (79.2%) underwent chest and 95 (66.0%) pelvis X-ray. For the 36 patients in trauma admission 2, the corresponding numbers were 28 (77.8%) and 18 (50.0%). Thirteen (36.1%) underwent chest and seven (19.4%) pelvis X-ray in both trauma admissions. Other X-ray examinations were used in 31 (21.5%) during trauma admission 1, 7 (19.4%) during trauma admission 2 and 1 (2.8%) during both trauma admissions 1 and 2.

CT examinations

In total, 122 (84.7%) of the 144 patients underwent one or more CT examinations during the total hospitalization. The majority (116 (80.5%)) underwent these examinations during the trauma admissions. Table 3 displays the number of patients stratified by the number of CT scans per body part and the

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Table 1. Characteristics of the trauma population (*n* = 144).

Characteristics	
Male sex, *n* (%)	114 (79.2)
Tourist, *n* (%)	28 (19.4)
Age, years in median (Q1, Q3)	31 (19, 49)
Age groups, *n* (%)	
<5	9 (6.3)
5–16	17 (11.8)
>16	118 (81.9)
Transport to first hospital by	
Ambulance helicopter, *n* (%)	80 (55.6)
Fixed wing air ambulance, *n* (%)	9 (6.2)
Road ambulance, *n* (%)	53 (36.8)
Private transportation, *n* (%)	2 (1.4)
Trauma mechanism	
Penetrating traumas, *n* (%)	5 (3.5)
Blunt, *n* (%)	139 (96.5)
Road traffic, *n* (%)	63 (45.3)
Snowmobile, *n* (%)	11 (7.9)
Falls, *n* (%)	31 (22.3)
Hit by blunt object, *n* (%)	13 (9.4)
Explosion/fire, *n* (%)	8 (5.7)
Avalanches and/or hypothermia, *n* (%)	8 (5.8)
Other causes, *n* (%)	5 (3.6)
Transferred from other hospitals, *n* (%)	36 (25.0)
ISS, (Q1, Q3, range)	9 (2, 22, 0–59)
ISS > 15, *n* (%)	52 (36.1)
NISS, (Q1, Q3, range)	12 (3, 27, 0–66)
NISS > 15, *n* (%)	64 (44.4)
Length of stay, median days (Q1, Q3)	4 (1.2, 11.5)
30-day mortality, *n* (%)	10 (6.9)

Q1: lower quartile; Q3: upper quartile; NISS: new injury severity score.

number of CT scans per body part for all 144 patients during the total hospitalization. Scans obtained during SWBCT examinations are split into body part scans and distributed accordingly in the table. Scans of the same body part in both the arterial and venous phases are counted as two scans. The patient with six abdomen and pelvis scans had an ISS of 43 and 34 full days of hospitalization.

In total during trauma admissions, 73 (50.7%) patients underwent SWBCT, 43 (29.9%) a selective CT, and 28 (19.4%) no CT examination. Eleven different selective CT combinations were registered. CT caput/neck was most frequent, followed by CT chest/abdomen/pelvis. Eleven (7.6%) patients underwent CT in both trauma admissions. In trauma admission 1, 11 underwent 10 SWBCT and one CT caput. In trauma admission 2, two underwent a duplicated SWBCT, and the other eight with previous SWBCT underwent selective CT. The patient with CT caput in trauma admission 1 underwent CT caput/neck and abdomen in trauma admission 2. Only six (21.4%) of 28 without CT during the trauma admissions received a complementary CT during the subsequent hospital stay.

Non-ionizing radiation examinations

Table 4 displays the non-ionizing radiation examinations used pre-hospital and during hospitalization. Among the 36 patients with two trauma admissions, nine (25.0%) underwent a FAST and one (2.8%) an EFAST re-examination in trauma admission 2.

There was no significant difference in use of MRI and ultrasound during the subsequent hospital stay between children and adults. Four (15.4%) children versus 28 (23.7%) adults ($p = 0.442$) underwent MRI, and 1 (3.8%) child versus 8 (6.8%) adults ($p = 1.0$) underwent ultrasound.

Ionizing radiation exposure

During trauma admission 1, 118 (81.9%) of 144 patients underwent X-ray examination. DAP values were missing for 10 images. Three patients had no DAP registered (five missing values). They were excluded in calculation of the median DAP value. One patient had a DAP registered for one of six images and was included despite five missing DAP values (Table 5).

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Table 2. The number of patients stratified by the number of X-ray images per body part and the number of images per body part for 144 patients during the total hospitalization.

	Number of patients stratified by the number of images (0–28 images)																								Number of images per body part
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	…	20	21	…	28	Total	
Clavicle	139	1	3		1																			144	11
Shoulder	137		4	1		1	1																	144	22
Humerus	139		4	1																				144	11
Elbow/lower arm	130		5	4	2	1	1	1																144	48
Wrist	133	1	3	2	2	2							1											144	31
Hand	130		3	7		1	1			1			1											144	50
Chest	12	75	21	9	4	8	2	1	4	1	1	1	1		1	1		1		1				144	359
Neck	139	2	2		1																			144	10
Thoracic vertebral column	139	2	3																					144	8
Lumbar vertebral column	139		3	2																				144	12
Abdomen	139		3		1			1																144	17
Pelvis	39	86	14	2	2	1																		144	133
Hip	134	3	4		3																			144	23
Femur	130	2	3	2			1	1		1	3													144	66
Knee	128		8	1	2	2	1		1				1											144	63
Fibula/tibia	131		4	2	3	1	1	1															1	144	44
Ankle	134		2	2		2				1	1	1									1			144	71
Foot	136		1	5		1											1							144	38

X-ray: conventional radiographic examination.

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Table 3. The number of patients stratified by the number of CT scans per body part and the number of scans per body part in 144 patients during the total hospitalization.

	Number of patients stratified by the number of scans[a] (0–6 scans)								Number of scans per body part
	0	1	2	3	4	5	6	Total	
CT caput	38	77	18	8	2	1		144	150
CT neck	34	93	13	3	1			144	132
CT chest	51	73	17		2	1		144	120
CT abdomen	53	70	15	3	1	1	1	144	124
CT pelvis	56	69	14	3	1		1	144	116
CT extremities	124	15	3	2				144	27

[a]SWBCT examination split into body part scans, examinations with scans in both the arterial and the venous phases of the same body part registered as two scans.

Table 4. Non ionizing diagnostic examinations per patient admitted with TTA.

Type of examination	At accident site (n = 144)	In trauma admission1 (n = 144)	In trauma admission 2 (n = 36)	During subsequent hospital stay (n = 144)
FAST, n (%)	3 (2.1)	88 (61.1)	13 (36.1)	0
EFAST, n (%)	12 (8.3)[a]	18 (12.5)	8 (22.2)[a]	0
Ultrasound (excluding FAST/EFAST), n (%)	0	0	0	14 (9.7)
With intravenous contrast, n (%)	0	0	0	0
Pleural, n (%)	0	0	0	7 (4.9)
Thoracentesis, n (%)	0	0	0	2 (1.4)
MRI (all types of examinations), n (%)		0	0	32 (22.2)
MR caput, n (%)		0	0	21 (14.6)
MR neck, n (%)		0	0	10 (6.9)
MR spine, n (%)		0	0	10 (6.9)
MR chest, n (%)		0	0	2 (1.4)
MR upper extremity, n (%)		0	0	1 (0.7)
MR upper extremity, n (%)		0	0	1 (0.7)

[a]One patient had only pleural scan excluding FAST.

Table 5. DAP in trauma patients admitted with TTA.[a]

	Patients with X-ray (n)	Median DAP (Gycm^2 (Q1, Q3))	DAP range (Gycm^2)
During trauma admissions			
Trauma admission 1	118	1.67 (0.97, 1.91)	0.01–5.01
Trauma admission 2	28	0.81 (0.12, 1.83)	0.02–3.37
Trauma admissions 1 + 2	130	1.67 (0.95, 2.07)	0.01–5.01
During total hospitalization			
X-ray including all types of images	134	1.86 (1.12, 2.87)	0.02–34.00
X-ray images of chest/column	132	0.13 (0.11, 0.43)	0.01–13.78
X-ray images of pelvis/lower extremities[b]	113	1.68 (1.36, 2.45)	0.05–32.28
X-ray images of upper extremities	35	0.32 (0.10, 1.05)	0.03–3.26

X-ray Conventional radiographic examination, *Gycm2* Gray-centimetres squared
[a]DAP values for 16 (1.6%) of 1018 images from 134 patients were missing, 10 from trauma admission 1 (in 4 patients) and 6 during the subsequent hospitalization (in two other patients).
[b]All DAP values for pelvis/lower extremities were missing in one patient, data from 112 patients included in calculations.

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

During trauma admission 2, DAP values for all 28 patients exposed to X-ray were available. All patients with missing values in trauma admission 1 had DAP values registered in trauma admission 2, so no patients were excluded from calculations of central tendency in trauma admission 2 or trauma admissions 1 + 2 (Table 5).

During the total hospitalization, all 134 patients examined with X-ray had DAP values registered. In addition to the 10 missing DAP values from trauma admission 1, six more from mobile C-arm X-ray imaging in the operating room in two more patients were missing. Calculations of the median DAP value for the total hospitalization therefore include data from all patients, but 16 (1.6%) of 1018 DAP values from six (4.5%) of 134 patients are missing. They were for images of the chest/column region ($n = 3$) and the pelvis/lower extremities ($n = 13$) (Table 5).

There was no significant difference in use of X-ray imaging during the total hospitalization between children and adults. The number examined with X-ray was 23 (88.5%) children versus 111 (94.1%) adults ($p = 0.387$). The number examined with more than five X-ray images was 10 (38.5%) children versus 44 (37.3%) adults ($p = 0.911$).

In addition, seven (4.9%) patients underwent angiographic examination and/or intervention. DAP values were registered in four. Median DAP was 43.49 (Q1 = 7.58, Q3 = 379.87, range 6.12–481.48) Gycm^2.

Table 6 displays DLP values and estimated effective doses from CT scans during trauma admissions and the total hospitalization. In trauma admission 1, one CT neck DLP and effective dose value was missing. All other values were available. Accordingly, during the total hospitalization DLP and effective dose value were missing for one (0.1%) of 669 scans.

There was a significant difference in the proportion of patients undergoing CT examination during hospitalization between children and adults. Sixteen (61.5%) children versus 106 (89.8%) adults were examined with CT ($p < 0.001$). The number examined with more than five CT scans was 4 (15.4%) children versus 48 (40.7%) adults ($p = 0.023$).

DISCUSSION

The main findings in this study are that most (97.2%) of the patients met with TTA underwent at least one ionizing radiation examination. CT was used in 84.7%, and 50.7% underwent a SWBCT. Median DLP and effective dose for all CT examinations during the total hospitalization were 2396 mGycm and 20.42 mSv, respectively. Most of this dose was delivered during trauma admissions, as the median DLP increased with only 300 mGycm during the subsequent hospital stay. The use of MRI and ultrasound was low during this phase. Patients were young, and most were not severely injured.

Radiation protecting authorities publish national diagnostic reference levels for X-ray and CT in DAP and DLP, respectively, and hospitals are encourage to adhere to this quality and safety standard[2, 37]. The Norwegian radiation protection authority (NRPA) has published DAP reference levels for a range of X-ray examinations[2]. Our median DAP values for the total hospitalization were well below reference levels.

NRPA published its first diagnostic reference level for a whole body trauma CT in 2018[2]. It is based on representative doses for adult sized patients examined in 2017 from 28 different CT laboratories in Norway using independent whole body trauma CT protocols. Median DLP was 1838 (upper quartile 2357) mGycm, and the reference level was set at 2400 mGycm.

The median DLP (2461 mGycm) for trauma patients examined with a SWBCT at the trauma centre in the present study was slightly above the national diagnostic reference level. Five (8.8%) of the 57 examinations included medically justified duplicated scans (DLP range of 2883–3118). This probably contributed to the relatively high median DLP. Further, our protocol uses overlapping body area scanning. The overlap can be avoided by using multiphase intravenous contrast injections in a combined chest, abdomen and pelvis scan[20]. Finally, DLP increases with body weight. Accordingly, mean weight above the national average could influence DLP. Such data were not available. We find it unlikely that our study population, which included children, was heavier than the population the national reference level is based on. However, it is known that mean body mass index in the population in this Norwegian region is slightly above the national average[27].

Direct comparison with and between previous studies of trauma populations is difficult because they do not report DAP or DLP. Instead, most report estimated mean effective dose using different estimation methods. Tien *et al.*[9] reported a total mean hospitalization effective dose of 22.7 mSv for 171 Level 1 trauma patients. Their population only included adults admitted directly and excluded patients who died. Surface doses were measured with optically stimulated luminescence dosemeter, and effective doses estimated with impact CT patient dosimetry calculator (version 0.99v)[38]. They made the assumption that all radiations measured were from CT scanning. In addition, they estimated effective doses by multiplying the number of X-ray images and CT scans with standard effective dose conversion factors published by the National radiological protection board (NRPB). For CT, they used the NRPB-SR250 (1993) factors, and for X-ray, the NRPB-SR262 (1998). Interestingly, the use of conversion factors (17.8 mSv) underestimated the dose to the patients compared to dosimeter data.

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Table 6. DLP and effective dose in patients admitted with TTA. [a]

	Patients with CT (*n*)	Median DLP (Q1, Q3) mGycm	DLP range mGycm	Median effective dos (Q1, Q3) mSv	Effective dose range (mSv)
During trauma admission					
CT trauma admission 1	108	2048 (1263, 2637)	156–4365	19.21, (8.45, 25.2)	1.23–46.81
CT trauma admission 2[b]	19	1793 (1030, 2627)	329–3118	15.90 (6.73, 27.16)	1.12–46.26
CT trauma admissions 1 + 2	116	2096 (1294, 2715)	156–6444	19.48 (11.15, 16.16)	1.23–73.17
SWBCT trauma admission 1[b,c]	68	2553 (2116, 2782)	1516–4041	22.72 (17.72, 27.81)	11.36–45.15
SWBCT trauma admission 2[b,c]	7	2376 (1793, 2918)	801–3118	19.99 (15.52, 27.16)	11.91–27.84
SWBCT at trauma centre[b,c]	57	2461 (2048, 2695)	801–3871	22.29 (17.80, 27.28)	11.41–40.81
SWBCT at referring hospitals[b,c]	18	2673 (2454, 3279)	1659–4041	22.06 (16.55, 29.71)	11.36–45.15
During total hospitalisation[d]					
CT including all types of scans	122	2396 (1396, 3510)	36–10604	20.42 (11.29, 29.75)	0.12–158.79
CT caput scan	106	1098 (939, 1676)	36–4060	1.51 (1.26, 2.41)	0.21–6.90
CT neck scan[e]	109	268 (213, 349)	27–1843	2.28 (1.92, 3.45)	0.24–27.40
CT chest scan	92	306 (237, 434)	100–2636	6.27 (4.55, 9.22)	2.70–54.98
CT abdomen/pelvis scan	91	843 (595, 1104)	254–6179	13.93 (9.90, 17.59)	2.64–95.76
CT extremities scan	20	210 (130, 496)	64–2639	0.08 (0.03, 1.11)	0.01–25.08

mGycm milligraycentimeter, *mSv* milliSivert,
[a]The DLP value was missing for one (0.1%) of 669 CT scans from 122 patients.
[b]Effective dose normally distributed.
[c]DLP normally distributed.
[d]SWBCT examination split into body part scans.
[e]All DLP values for CT neck missing for one patient, data from 108 patients included in calculations.

Winslow *et al.*[18] reported a total mean effective dose of 40.2 mSv for 86 adult Level 1 trauma centre patients. Most (92%) underwent SWBCT. Doses were for the first 24 h only, and the most severely injured patients and those lacking dose information were excluded. Dose estimates for CT were calculated by multiplying machine DLP values with standard conversions factors[39, 40] (corrected for age), and for X-ray by using the radiation dose assessment resource calculator[41]. Sharma *et al.*[11] estimated mean cumulative effective doses for both the first 24 h (11.76 mSv) and the total hospitalization (14.56 mSv) for 177 Level 1 trauma patients. They included transferred patients but not the examinations at referring hospitals. Dose estimates were from the literature reported conversion factors for each X-ray image and DLP for each CT scan[39, 42]. The majority of examinations were done during the first 24 h. A total of 1505 X-ray images and 400 CT scans were undertaken during the total hospitalization. CT accounted for 21% of the examinations and 93% of the total cumulative effective dose. The use of SWBCT was low (13%), with a mean effective dose of 31.5 mSv. Sierink *et al.*[14] randomized patients to SWBCT or individualized imaging, and estimated doses were 20.9 and 20.6 mSv, respectively. Doses were estimated from calculated representative doses for single-pass CT body scans of various body regions on the basis of optimised trauma CT protocols at one of the study sites multiplied with the number of scans per patient. They estimated effective dose using impact CT dosimetry calculator[38]. Salottolo *et al.*[19] reported median hospitalization DLP (1700.22 mGycm) for 57 of 165 trauma patients admitted to intensive care. They estimated the median total effective dose (9.38 mSv) by multiplying conversion factors with DLP per scan[43, 44].

For comparison, we used NCICT and estimated effective dose for all CT scans. Our values correspond with the doses reported in the studies mentioned above.

In our opinion, reporting DAP and DLP instead of effective doses would support a better understanding of ionizing radiation exposure and facilitate comparison of results between future studies. DAP and DLP are the measures routinely used for monitoring dose delivered to patients. The effective dose unit is not intended to be used for populations or individual risk estimates, especially not in populations composed of different sexes and ages[45]. The effective dose estimate is useful for comparison of ionizing radiation risk from different modalities, such as X-ray, CT and angiography for individuals. When effective dose estimates are reported, the definitions and use of conversion factors should be reported in detail for all estimates, as the conversion factors change with time[46].

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Dose to patients from ionizing radiation may be reduced in three ways. First, quality audits like the present study or implementation of dose-tracking software can contribute to dose reduction through protocol optimization[47–49]. These methods support an active use of national reference levels. The CT machines and SWBCT protocol at our trauma centre were unchanged between 2015 and 2018. The DLP to the anthropomorphic phantom (50 kg heavy and 165 cm tall) as measured in 2018 was below the national median in all three machines. Presentation of SWBCT protocol parameters, including DLP for a standardized whole body phantom, would facilitate comparisons across laboratories. Such data have not been published from NRPA or others.

Next, replacing ionizing radiation examinations with other methods, such as MRI or ultrasound, will reduce dose. Especially, increased use of MRI and ultrasound instead of duplicated CT scans during the hospital stay subsequent to trauma admissions is advocated[21, 22]. The present study identified a low use of non-ionizing radiation examinations during this phase, which represent a potential for future improvements.

Finally, the probably most potent way for reducing delivered dose to patients is to reduce unjustified ionizing radiation examinations[3, 4, 21, 22]. In a follow-up of the present study population, we will associate CT use and identified injuries. We believe such data can contribute to guide trauma surgeons' decision making.

STRENGTHS AND LIMITATIONS

In the present study, we report delivered dose data for all patients in detail. We included patients at all ages, both transferred patients and those who died during the hospitalization. Patients who die are severely injured and typically receive high doses. DAP and DLP were collected from PACS for every single image and scan, and the estimated effective doses came from NCICT calculations. The audit approach ensured that only values not documented in the electronic health records were missing in the analyses.

The study population was small but comparable with previous studies. The inclusion of children reduces the median DAP and DLP values. This must be taken into consideration when results from our study are compared with national diagnostic reference levels. We chose not to calculate effective dose for X-ray examinations because they would be insignificant compared to the doses from CT.

CONCLUSION

The majority of trauma patients were examined with an ionizing radiation method, and most of the radiation dose from CT examinations was delivered during the trauma admissions as SWBCT examinations. The use of non-ionizing radiation methods was low. DLP for a SWBCT was above the Norwegian diagnostic reference level, but the effective dose was comparable to previous studies. We suggest measures to optimize our protocol, and advocate reporting of DAP and DLP in future studies for comparison of doses delivered to trauma populations.

ACKNOWLEDGEMENTS

We would like to thank Arne Erikson, former radiation protection officer at UNN, for all his support during the process. We would also like to thank Ina Lundberg for participating in the injury consensus coding. We gratefully acknowledge the UNN, Division of Diagnostic services for supporting quality work in trauma care.

FUNDING

This work was supported by the University Hospital of North Norway (UNN). The funding source had no influence on the study.

REFERENCES

1. United Nations Environment Program. Radiation Effects and Sources. United Nations Sales Publication, Ed. (Vienna: UNSCEAR Secretariat) pp. 1–68 (2016). Doi: 10.18356/b1749f17-en.
2. Widmark/Norwegian Radiation Protection Authority. Diagnostic reference level (DRL) in Norway 2017. Results, revision and establishment of new DRL. NRPA report 2018:3 Langage: Norwegian. pp. 1–54 (2018). Available at: www.nrpa.no (accessed: 18 May 2018).
3. International Commission on Radiological Protection (ICRP). *The 2007 recommendations of the international commission on radiological protection. ICRP publication 103*. Ann. IRCP **37**(2–4), 1–332 (2007).
4. International Atomic Energy Agency. Radiation Protection and Safety in Medical Uses of Ionizing Radiation, SSG-46. (Vienna: International Atomic Energy Agency) pp. 1–320 (2018).
5. Shore, R. E. *et al. Implications of recent epidemiologic studies for the linear nonthreshold model and radiation protection*. J. Radiol. Prot. **38**, 1217–1233 (2018).
6. Huber-Wagner, S., Lefering, R., Qvick, L.-M., Körner, M., Kay, M. V., Pfeifer, K.-J., Reiser, M., Mutschler, W. and Kanz, K.-G. *Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study*. Lancet **373**, 1455–1461 (2009).
7. Kimura, A. and Tanaka, N. *Whole-body computed tomography is associated with decreased mortality in blunt trauma patients with moderate-to-severe consciousness disturbance: a multicenter, retrospective study*. J. Trauma Acute Care Surg. **75**, 202–206 (2013).
8. Caputo, N. D., Stahmer, C., Lim, G. and Shah, K. *Whole-body computed tomographic scanning leads*

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

to better survival as opposed to selective scanning in trauma patients: a systematic review and meta-analysis. J. Trauma Acute Care Surg. **77**, 534–539 (2014).
9. Tien, H. C., Tremblay, L. N., Rizoli, S. B., Gelberg, J., Spencer, F., Caldwell, C. and Brenneman, F. D. *Radiation exposure from diagnostic imaging in severely injured trauma patients*. J. Trauma **62**, 151–156 (2007).
10. You, J. S., Lee, H.-J., Chung, Y. E., Lee, H. S., Kim, M. J., Chung, S. P., Kim, M.-J., Park, I. and Kim, K. W. *Diagnostic radiation exposure of injury patients in the emergency department: a cross-sectional large scaled study*. PLoS One **8**, 1–8 (2013).
11. Sharma, O. P., Oswanski, M. F., Sidhu, R., Krugh, K., Krugh, K., Culler, A. S., Spangler, M., Ethington, M., Stombaugh, H. A. and Lauer, S. K. *Analysis of radiation exposure in trauma patients at a level i trauma center*. J. Emerg. Med. **41**, 640–648 (2011).
12. Huber-Wagner, S., Kanz, K.-G., Hanschen, M., van Griensven, M., Biberthaler, P. and Lefering, R. *Whole-body computed tomography in severely injured patients*. Curr. Opin. Crit. Care **24**, 55–61 (2018).
13. Huber-Wagner, S., Biberthaler, P., Häberle, S., Wierer, M., Dobritz, M., Rummeny, E., van Griesven, M., Kanz, K.-G., Lefering, R. and The Traumaregister DGU. *Whole-body CT in haemodynamically unstable severely injured patients—a retrospective, multicentre study*. PLoS One **8**, 1–10 (2013).
14. Sierink, J. C. *et al. Immediate total-body CT scanning versus conventional imaging and selective CT scanning in patients with severe trauma (REACT-2): a randomised controlled trial*. Lancet **388**, 673–683 (2016).
15. Surendran, A., Mori, A., Varma, D. K. and Gruen, R. L. *Systematic review of the benefits and harms of whole-body computed tomography in the early management of multitrauma patients: are we getting the whole picture?* J. Trauma Acute Care Surg. **76**, 1122–1130 (2014).
16. Healy, D. A., Hegarty, A., Feeley, I., Clarke-Moloney, M., Grace, P. A. and Walsh, S. R. *Systematic review and meta-analysis of routine total body CT compared with selective CT in trauma patients*. Emerg. Med. J. **31**, 101–108 (2014).
17. Long, B., April, M. D., Summers, S. and Koyfman, A. *Whole body CT versus selective radiological imaging strategy in trauma: an evidence-based clinical review*. Am. J. Emerg. Med. **35**, 1356–1362 (2017).
18. Winslow, J. E., Hinshaw, J. W., Hughes, M. J., Williams, R. C. and Bozeman, W. P. *Quantitative assessment of diagnostic radiation doses in adult blunt trauma patients*. Ann. Emerg. Med. **52**, 93–97 (2008).
19. Salottolo, K., Bar-Or, R., Fleishman, M., Maruyama, G., Slone, D. S., Mains, C. W. and Bar-Or, D. *Current utilization and radiation dose from computed tomography in patients with trauma*. Crit. Care Med. **37**, 1336–1340 (2009).
20. Jeavons, C., Hacking, C., Beenen, L. F. and Gunn, M. L. *A review of split-bolus single-pass CT in the assessment of trauma patients*. Emerg. Radiol. **25**, 367–374 (2018).
21. Tonolini, M., Valconi, E., Vanzulli, A. and Bianco, R. *Radiation overexposure from repeated CT scans in young adults with acute abdominal pain*. Emerg. Radiol. **25**, 21–27 (2018).
22. Oikarinen, H., Meriläinen, S., Pääkkö, E., Karttunen, A., Nieminen, M. T. and Tervonen, O. *Unjustified CT examinations in young patients*. Eur. Radiol. **19**, 1161–1165 (2009).
23. Kim, S. H., Jung, S. E., Oh, S. H., Park, K. N. and Youn, C. S. *Effects of a radiation dose reduction strategy for computed tomography in severely injured trauma patients in the emergency department: an observational study*. Scand. J. Trauma Resusc. Emerg. Med. **19**(67), 1–7 (2011).
24. Davies, R. M., Scrimshire, A. B., Sweetman, L., Anderton, M. J. and Holt, E. M. *A decision tool for whole-body CT in major trauma that safely reduces unnecessary scanning and associated radiation risks: an initial exploratory analysis*. Injury **47**, 43–49 (2016).
25. Smith, R. *Audit and research*. BMJ **305**, 905 (1992).
26. Wilson, A., Grimshaw, G., Baker, R. and Thompson, J. *Differentiating between audit and research: postal survey of health authorities' views*. BMJ **319**, 1235 (1999).
27. Statistics Norway. Statistics Norway (2017). Available at: https://www.ssb.no (accessed: 27 November 2017).
28. Dehli, T., Monsen, S. A., Fredriksen, K. and Bartnes, K. *Evaluation of a trauma team activation protocol revision: a prospective cohort study*. Scand. J. Trauma Resusc. Emerg. Med. **24**(/105), 1–7 (2016).
29. American College of Surgeons. Advanced Trauma Life Support® (ATLS®) (1980). Available at: https://www.facs.org/quality-programs/trauma/atls/about (accessed :31 October 2018).
30. Baker, S. P., O'Neill, B., Haddon, W. and Long, W. B. *The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care*. J. Trauma **14**, 187–196 (1974).
31. Osler, T., Baker, S. and Long, W. A. *Modification of the injury severity score that both improves accuracy and simplifies scoring*. J. Trauma Inj. Infect. Crit. Care **43**, 922–925 (1997).
32. Association for the Advancement of Automotive Medicine. The Abbreviated Injury Scale 2005 Update 2008 (2016). Available at: http://www.aaam.org/abbreviated-injury-scale-ais/ (accessed: 18 February 2019).
33. Lee, C., Kim, K. P., Bolch, W. E., Moroz, B. E. and Folio, L. *NCICT: a computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans*. J. Radiol. Prot. **35**, 891–909 (2015).
34. Kyoto Kagaku Co., L. CT Whole Body Phantom PBU-60 pp. 1–11 (2009). Available at: http://www.kyotokagaku.com (accessed: 2 January 2019).
35. Scalea, T. M., Rodriguez, A., Chiu, W. C., Brenneman, F. D., Fallon, W. F., Kazuyoshi, K., Mckenney, M. G., Nerlich, M. L., Ochsner, M. G. and Yoshii, H. *Focused assessment with sonography for trauma (FAST): results from an international consensus conference*. J. Trauma **46**, 466–472 (1999).
36. Nandipati, K. C., Allamaneni, S., Kakarla, R., Wong, A., Richards, N., Satterfield, J., Turner, J. W. and Sung, K.-J. *Extended focused assessment with sonography for trauma (EFAST) in the diagnosis of pneumothorax: experience at a community based level I trauma center*. Injury **42**, 511–514 (2011).
37. Public Health England. Doses from Computed Tomography (CT) Examinations in the UK—2011 Review, PHE-CRCE-013. pp. 1–123 (2014). Available at: www.gov.uk (accessed: 2 February 2019).

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

38. ImPACT CT Scanner Evaluation Group. ImPACT CT Dosimetry Tool. Avaiable at: http://www.impactscan.org/ctdosimetry (accessed: 2 January 2020).
39. Jessen, K. A., Shrimpton, P. C., Geleijns, J., Panzer, W. and Tosi, G. *Dosimetry for optimisation of patient protection in computed tomography*. Appl. Radiat. Isot. **50**, 165–172 (1999).
40. McCollough, C. H. and Schueler, B. A. *Calculation of effective dose*. Med. Phys. **27**, 828–837 (2000).
41. RADAR Members. RADAR-RAdiation Dose Assessment Resource. Available at: https://www.impactscan.org/ctdosimetry (accessed: 2 January 2020).
42. Huda, W. and Gkanatsios, N. A. *Effective dose and energy imparted in diagnostic radiology*. Med. Phys. **24**, 1311–1316 (1997).
43. European Commission. European Guidelines on Quality Criteria for Computed Tomogrphy. (Luxembourg: Office for Official Publications of the European Communities, EUR16262EN) (2004).
44. Conferance of Radiation Control Program Directors INC. Nationwide evaluation of X-ray trends (NEXT). Tabulation and graphical summary of 2000 survey of Computed Tomography. Publication E-70-2 (2007).
45. Shrimpton, P. C., Jansen, J. T. M. and Harrison, J. D. *Updated estimates of typical effective doses for common CT examinations in the UK following the 2011 national review*. Br. J. Radiol. **89**(20150346), 1–15 (2016).
46. Martin, C. J. *Effective dose: how should it be applied to medical exposures?* Br. J. Radiol. **80**, 639–647 (2007).
47. Higashigaito, K., Becker, A. S., Sprengel, K., Simmen, H. P., Wanner, G. and Alkadhi, H. *Automatic radiation dose monitoring for CT of trauma patients with different protocols: feasibility and accuracy*. Clin. Radiol. **71**, 905–911 (2016).
48. Hui, C. M., MacGregor, J. H., Tien, H. C. and Kortbeek, J. B. *Radiation dose from initial trauma assessment and resuscitation: Review of the literature*. Can. J. Surg. **52**, 147–152 (2009).
49. Pyfferoen, L., Mulkens, T. H., Zanca, F., De Bondt, T., Parizel, P. M. and Casselman, J. W. *Benchmarking adult CT-dose levels to regional and national references using a dose-tracking software: A multicentre experience*. Insights Imaging **8**, 513–521 (2017).

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

APPENDIX 1: CT whole body phantom scanning using the multi-trauma protocol 09.05.18.

CT whole body phantom: Kyoto Kagaku co. LTD PBU-60(E), length 165 cm, weight 50 kg.

Effective dose estimates by National cancer institute's software for dosimetry the NCICT. Reference: Lee *et al.* NCICT: a computational solution to estimate organ doses for paediatrics and adult patients undergoing CT scans. J. Radiol. Prot. 35(4), 891–901 (2015).

Protocol: University Hospital of North Norway's multi-trauma whole body CT protocol. Head first, supine, Spiral (tube A), Slice/collimation 128 × 0.6 (total collimation 38.4). CT head/face and neck scan without intravenous contrast. CT thorax including spleen and liver in arterial contrast phase, abdomen/pelvis scan with intravenous portal contrast phase. The arms fixed on a pillow on the abdomen, as in patients incapable on lifting their arms above the head. The scan length and scan position were the same in the three machines.

Machine name	Siemens Somatom definition flash		
CT in room	7	8	12
Installation year	2013	2012	2012
Caput scan			
Care kV	Off	Off	Off
Reference kV—70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs—70 kg	390	390	390
Mean mAs used	343	345	336
Reference $CTDI_{vol}$	59.76	59.76	59.76
$CTDI_{vol}$ used	52.53	52.81	51.42
Dose slider	—	—	—
Rotation time (s)	1	1	1
Pitch	0.55	0.55	0.55
DLP (mGycm)	978.7	979.1	959.8
Effective dose (mSv)	1.437	1.437	1.409
Neck scan			
Care kV	On	On	On
Reference kV—70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs—70 kg	195	195	195
Mean mAs used	87	92	91
Reference $CTDI_{vol}$	13.24	13.24	13.24
$CTDI_{vol}$ used	5.9	6.28	6.19
Dose slider	2	2	2
Rotation time (s)	1	1	1
Pitch	0.7	0.7	0.7
DLP (mGycm)	114.9	117.9	121.2
Effective dose (mSv)	0.831	1.057	0.98
Chest scan			
Care kV	On	On	On
Reference kV	120	120	120
kV used	100	120	120
Care dose	On	On	On
Protocol mAs—70 kg	107	65	65
Mean mAs used	81	53	54
Reference $CTDI_{vol}$	4.39	4.39	4.39
$CTDI_{vol}$ used	3.36	3.63	3.66
Dose slider	3	3	3
Rotation time (s)	0.5	0.5	0.5
Pitch	1.2	1.2	1.2
DLP (mGycm)	138.8	146.9	149.2
Effective dose (mSv)	2.68	2.774	2.753

(Continued)

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020

Appendix 1: Continued

Abdomen/pelvic scan			
Care kV	On	On	On
Reference kV—70 kg	120	120	120
kV used	120	120	120
Care dose	On	On	On
Reference mAs—70 kg	160	160	160
Mean mAs used	126	117	128
Reference $CTDI_{vol}$	10.79	10.79	10.79
$CTDI_{vol}$ used	8.53	7.93	8.64
Dose slider	7	7	7
Rotation time (s)	0.5	0.5	0.5
Pitch	1	1	1
DLP (mGycm)	382.6	356.1	387
Effective dose (mSv)	6.173	5.773	6.56
Total examination			
DLP (mGycm, without scout DLP)	1615	1617	1600
Effective dose total (mSv)	11.121	11.041	11.072

CT: computer tomography, kV: kilo volt, mAs: milliampere seconds, $CTDI_{vol}$: volume CT dose index, DLP: dose length product.

Downloaded from https://academic.oup.com/rpd/article/189/1/35/5736345 by University Library of Tromsø user on 12 August 2020