



Research article

The effective and collective dose to patients undergoing abdominopelvic and trunk computed tomography examinations: A Belgian multicentre study



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ARTICLE INFO

Keywords:

Computed tomography
Effective dose
Collective dose
Imaging referral guidelines

ABSTRACT

Objectives: This study aims to evaluate the radiation exposure to patients undergoing an abdominopelvic or a chest and abdominopelvic (trunk) CT examination and to assess compliance to imaging referral guidelines.

Methods: To this end, 357 standard abdominopelvic and trunk CT scans were collected from 8 Belgian institutions in 2011 and 2015. Effective dose (E) and collective dose were calculated using CT dose descriptors (CTDI_{vol} and DLP), which were obtained from dose reports generated by the CT scanner. Subsequently, these CT requests were compared against the national referral guidelines to assess compliance. Population estimates for dose and compliance were obtained using multilevel linear regression and generalized estimating equation models.

Results: Between 2011 and 2015, a significant decrease of 28% in CTDI_{vol} and DLP was found for abdominopelvic CT. The corresponding E decreased by 27%, and the collective dose by 23%. For trunk CT, a non-significant decrease of 6% was found in CTDI_{vol} and a significant decrease of 14% in both DLP and E. However, the collective dose of trunk examinations increased by 39%. In 2011, 24% of the abdominopelvic examinations were not compliant with the guidelines, whereas this percentage dropped to 17% in 2015. Non-justified examinations accounted for 8% and 12% of all trunk CT scans in 2011 and 2015, respectively.

Conclusion: Between 2011 and 2015, there was a decrease in dose for patients undergoing abdominopelvic or trunk CT in Belgium. However, a fraction of the estimated doses are linked to unnecessary CT examinations, which should be avoided.

1. Introduction

Recently, the Dose Datamed 2 (DDM2) study revealed that Belgium has the highest mean medical effective dose per caput in the European Union, predominantly due to the use of computed tomography (CT) [1]. Although there are uncertainties in quantifying radiation risks from exposure during radiological examinations, most scholars currently use the linear no-threshold (LNT) risk model to do so, stating that the risk of radiation-induced cancer or hereditary effects increases linearly with an increasing radiation dose [2]. Therefore, lowering the population dose is essential to reduce potential health risks.

Moreover, several studies have suggested that some of the CT examinations might not be justified [3,4]. In many European countries, imaging referral guidelines are available to support the referring

practitioner in selecting the correct imaging procedure [5]. In addition, radiation doses should be kept as low as reasonably achievable (the ALARA principle). Dose reduction tools, such as tube current modulation (TCM) and iterative reconstruction (IR), can help to achieve lower doses while maintaining an adequate image quality [6].

Generally, effective dose (E) is used as a quantity to assess the risk of exposure to ionizing radiation and to compare radiation exposure for different types of examinations. According to the International Commission on Radiological Protection (ICRP) 103 guidelines, E is calculated as a weighted sum of equivalent organ doses [7]. A simplified approach is to multiply the dose-length product (DLP) value, which represents the radiation output of a given scan protocol, with a conversion factor [8]. In current study, these two approaches are compared.

Abbreviations: ALARA, as low as reasonably achievable; CI, confidence interval; CT, computed tomography; CTDI_{vol}, volume computed tomography dose index; DDM2, dose datamed 2; DLP, dose-length product; E, effective dose; GEE, generalized estimating equation; ICC, intraclass correlation coefficient; ICRP, International Commission on Radiological Protection; IR, iterative reconstruction; kVp, peak kilovoltage; LNT, linear no-threshold; mAs, milliamperere-second; PACS, Picture Archiving and Communication System; SPSS, Statistical Package for Social Sciences; TCM, tube current modulation

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<https://doi.org/10.1016/j.ejrad.2018.12.019>

Received 12 April 2018; Received in revised form 18 December 2018; Accepted 23 December 2018

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Table 1

Overview of the type and region of the participating institutions and the percentage of the examinations which use tube current modulation (TCM) and iterative reconstruction (IR).

Institution	Type of institution	Region	CT scanner (manufacturer)	Included in study		Use of IR (%)		Use of TCM (%)	
				2011	2015	2011	2015	2011	2015
1	University	Flanders	Somatom definition AS (Siemens)	yes	yes	0%	0%	92%	100%
			Somatom definition flash (Siemens)	yes	yes	0%	0%	100%	100%
			Aquilion 32 (Toshiba)	yes	yes	not available	not available	100%	100%
2	University	Flanders	Sensation 64 (Siemens)	yes	yes	not available	93%	100%	93%
			Sensation 16 (Siemens)	yes	out of service	not available	–	92%	–
			Somatom definition flash (Siemens)	yes	yes	0%	50%	100%	100%
			Brilliance 64 (Philips)	yes	out of service	not available	–	100%	–
			Aquilion one (Toshiba)	no	new device	–	100%	–	100%
3	University	Brussels	Brilliance 64 (Philips)	no ^a	yes	–	100%	–	100%
			Brilliance 40 (Philips)	no ^a	yes	–	not available	–	67%
4	General	Flanders	Lightspeed VCT (GE)	yes	yes	not available	50%	82%	75%
			Discovery CT750HD (GE)	no	new device	–	100%	–	86%
5	General	Flanders	Discovery CT750HD (GE)	yes	yes	100%	100%	88%	92%
			Lightspeed16 (GE)	yes	out of service	not available	–	60%	–
			Revolution (GE)	no	new device	–	100%	–	100%
6	General	Wallonia	Somatom definition AS+ (Siemens)	yes	yes	not available	100%	100%	100%
			Sensation 64 (Siemens)	yes	out of service	not available	–	67%	–
			Sensation 16 (Siemens)	yes	out of service	not available	–	100%	–
7	General	Wallonia	Discovery CT750HD (GE)	yes	yes	100%	100%	N/A	93%
			Lightspeed VCT (GE)	yes	yes	100%	100%	50%	100%
8	General	Flanders	Discovery CT750HD (GE)	no ^a	yes	–	100%	–	N/A
			Brightspeed 16 (GE)	no ^a	yes	–	not available	–	N/A
Total						22% (47/217)	69% (97/140)	76% (164/217)	84% (117/140)

TCM tube current modulation, IR iterative reconstruction.

^a Institution was not included in 2011.

This study focuses on the radiation exposure to the Belgian population undergoing two frequently requested CT examinations, namely abdominopelvic CT and chest and abdominopelvic (trunk) CT [1,9]. Data were collected in 2011 and 2015 to evaluate if there is a change in dose over time. In addition to assessing the dose per examination, this study checked the CT imaging requests against the national imaging referral guidelines to verify compliance [10].

2. Materials and methods

2.1. Patient population

In order to assess the radiation exposure to patients undergoing abdominal and trunk CT scans, a retrospective analysis was conducted based on secondary data from two prospective, multicentre, observational studies. The original studies addressed the application of imaging referral guidelines for the efficient use of medical imaging in Belgium [11,12]. To this end, data were collected in 8 Belgian hospitals during a period of 2 weeks per institution in 2011 and, due to budgetary restrictions, only 1 week per institution in 2015. The type and region of the participating institutions are listed in Table 1. From the original database, adult patients who received a standard abdominopelvic or trunk CT scan were selected for the present study and the corresponding images were obtained from the radiology department's Picture Archiving and Communication System (PACS).

Information about the height and weight of the patients was only available for the study population in 2015. Therefore, to make a valid estimate of patient size, the patients' effective diameter was used as a surrogate. The effective diameter is calculated by taking the square root of the anterior-posterior (AP) dimension of the patient multiplied by the lateral (LAT) dimension [13]. The AP and LAT dimensions were measured at the level of the umbilicus for each individual patient. A good correlation was found between effective diameter and patient weight for the study population in 2015 (Pearson correlation coefficient = 0.82, $p < 0.001$). These results indicate that effective diameter is an acceptable surrogate for patient size.

Informed consent was collected from the participating patients in the original study and study approval was obtained from the institutional ethical committee of each participating centre.

2.2. Calculation of effective dose with CT-EXPO

Volume computed tomography dose index ($CTDI_{vol}$) and dose-length product (DLP) were obtained from the CT dose reports. CT-EXPO software (Version 2.4; Medizinische Hochschule, Hannover, Germany) was used to estimate organ doses and mean E for the CT examinations, which apply for standard patients that are represented by the mathematical phantoms ADAM (170 cm and 70 kg) and EVA (160 cm and 60 kg) [14]. Scan-specific exposure factors (peak kilovoltage (kVp), milliampere-second (mAs), slice thickness) were extracted from the DICOM headers of the CT images, and were used as input data for the software. Scan length was calculated by dividing the DLP value by the $CTDI_{vol}$ value from the dose report. Scanner model and manufacturer were selected in CT-EXPO, together with mode of scanning (axial or helical) and use of TCM. E was calculated using ICRP 103 tissue weighting factors [7]. The use of TCM and IR was also retrieved from the DICOM header of the CT images. These data were then pooled together to estimate an E that applies for the entire population, regardless of age and gender of the patient, CT device, scan protocol and use of dose reduction tools.

2.3. Calculation of effective dose from DLP using conversion factors

For the abdominopelvic CT examinations, E was also calculated by means of two sets of DLP-to-E conversion factors: one published by Deak et al. and one by Huda et al. (Table 2) [15,16]. Since no conversion factors have been defined so far for a combined acquisition of the abdomen and pelvis, the mean of the corresponding conversion factors was used to calculate E for the abdominopelvic CT examinations. For multiphase examinations, the obtained E values of each acquisition were summed to establish an E value per examination.

Table 2

The DLP-to-E conversion factors (mSv. mGy-1.cm-1) as published by Deak et al. and Huda et al. [15,16].

Region	Deak et al.	Huda et al.
Abdomen	0.0153	0.0163
Pelvis	0.0129	0.0143
Abdomen - pelvis	0.0141 ^a	0.0153 ^a

^a Conversion factors are calculated as the mean of the factors for abdomen and pelvis.

2.4. Collective dose calculation

The collective dose for 2011 and 2015 was estimated by multiplying the mean E of the examination by the number of CT examinations (abdominopelvic CT: 427 012 (2011) and 465 829 (2015); trunk CT: 95 442 (2011) and 153 631 (2015)). The CT-EXPO derived mean E was used to estimate collective dose.

2.5. Compliance with the imaging referral guidelines

To assess the compliance with imaging referral guidelines, a new anamnesis and a physical examination were performed on every patient by a radiology resident in 2011 and a medical graduate in 2015 [11,12]. Both medical professionals were trained by a senior radiologist with more than 25 years of experience. The request for each CT examination was considered against the national imaging referral guidelines to confirm whether or not the examination was justified [10]. A procedure was not justified if imaging was deemed not necessary or if another imaging modality was preferred.

2.6. Statistical analysis

Traditional regression techniques assume that individual observations are uncorrelated. However, the individual dose values from the present study are not independent of each other. Dose values derived from the same CT device (= cluster) are more similar than those from other CT devices due to similarities in scanning protocols or dose reduction tools. Dose values from the same institution also share a common environment. As the clustered structure of the data required a multilevel approach, multilevel linear regression analysis with random intercept was conducted to assess difference of dose between 2011 and 2015. This statistical analysis technique allowed us to obtain proper parameter estimates, despite the unbalanced design of the study (unequal sample size for 2011 and 2015) [17,18]. Separate models were fit for each dose metric and each model estimated a mean for the Belgian population as well as its 95% confidence interval (CI). To account for

the clustered structure, institution and CT device were included as random factors. Year was entered as a fixed factor, together with patient gender, age, effective diameter, type of examination and number of acquisitions. In addition, logistic regression was used in a generalized estimating equation (GEE) model that accounted for clustering in order to determine the proportion of justified and non-justified CT examinations in 2011 and 2015. In this model, institution was included as a random factor and year as a fixed factor. A two-tailed Mann-Whitney test was applied to evaluate if there is a statistically significant difference in effective diameter between the 2011 and 2015 cohorts. Furthermore, correlations between E calculated with CT-EXPO or with conversion factors were visualised by means of scatterplots, and an intraclass correlation coefficient (ICC) was calculated to determine the degree of agreement between the two methods. For all tests, a significance level of 0.05 was adopted, and, in case of multiple testing, a Bonferroni correction was applied.

All statistical analyses were performed using IBM Statistical Package for Social Sciences (IBM SPSS) Statistics, version 23 (IBM Corporation, Armonk, N.Y., USA)

3. Results

3.1. Patient population and CT examinations

A total of 357 CT examinations were analysed. A hundred and twenty-three patients (60 female, 63 male) undergoing an abdominopelvic CT scan were included for 2011 and 71 (34 female, 37 male) for 2015. The mean age of these patients was 57 years (range: 20–86 years) in 2011 and 58 years in 2015 (range: 26–88 years). For trunk CT, 94 patients (42 female, 52 male) with a mean age of 59 years (range: 18–85 years) were included in 2011 and 69 (24 female, 45 male) with a mean age of 68 years (range: 21–92 years) in 2015. Moreover, 23% of the abdominopelvic and 88% of the trunk examinations were performed in the context of oncological staging or follow-up.

In both 2011 and 2015, the median number of acquisitions was one for the abdominopelvic examinations and two for the trunk CT scans. Furthermore, the median scan length for a typical abdominopelvic CT acquisition was 51 cm in 2011 and 49 cm in 2015; for a typical trunk CT examination, the median scan length was 68 cm in 2011 and 70 cm in 2015.

The Mann-Whitney test showed no significant difference in the distribution of effective diameter between 2011 and 2015 for both abdominopelvic and trunk CT (p = 0.147 and p = 0.149, respectively).

3.2. CT dosimetry

Fig. 1 displays boxplots of the CTDI_{vol} and DLP values of the

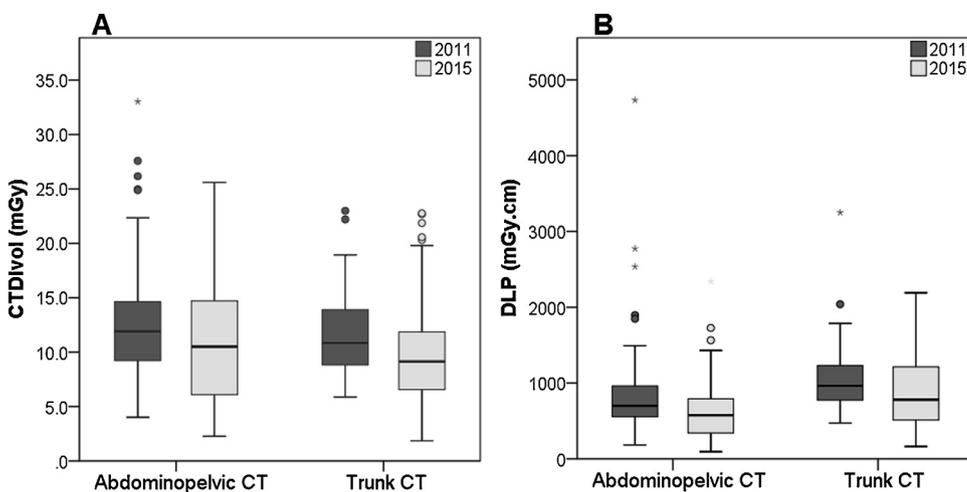


Fig. 1. Boxplots showing the distribution of CTDI_{vol} (A) and DLP values (B) for the abdominopelvic and chest and abdominopelvic (trunk) CT examinations from 2011 and 2015. The CTDI_{vol} values were taken from single-phase examinations only (abdominopelvic: 91 in 2011, 56 in 2015; trunk: 12 in 2011, 25 in 2015) while the DLP values are shown for both single-phase and multi-phase procedures (abdominopelvic: 123 in 2011, 71 in 2015; trunk: 94 in 2011, 69 in 2015).

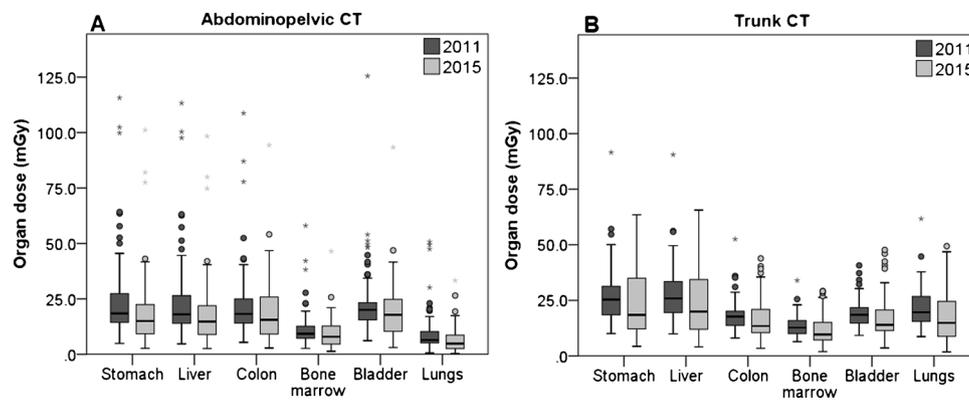


Fig. 2. Boxplots of the distribution of the organ doses (mGy) contributing the most to effective dose of abdominopelvic (A) and trunk CT (B) in 2011 and 2015.

abdominopelvic and the trunk CT examinations, grouped per year. CTDI_{vol} values were obtained from the single-phase examinations only (abdominopelvic: 91 in 2011, 56 in 2015; trunk: 12 in 2011, 25 in 2015), while DLP values are shown for all examinations. A wide dose variation is observed in the boxplots. This variability in spread is also reflected in the calculated organ doses (Fig. 2).

The results from the multilevel linear regression models apply to a population with a mean age of 60 years, a 50/50 sex ratio, a mean effective diameter of 29 cm and for CT examinations consisting of an average of 1.65 acquisitions. For abdominopelvic examinations, the analysis showed a significant decrease of 28% in CTDI_{vol} ($p < 0.001$; 95% CI: -34% to -21%) and 28% in DLP ($p < 0.001$; 95% CI: -34% to -22%) between 2011 and 2015. For trunk CT, a non-significant decrease of 6% was found in the mean CTDI_{vol} value ($p = 0.457$; 95% CI: -21% to +11%), and a significant decrease of 14% in the mean DLP value ($p = 0.002$; 95% CI: -21% to -5%) for the same period. The mean E values are presented in Table 3, revealing a significant decline of 27% for abdominopelvic CT ($p < 0.001$; 95% CI: -34% to -20%) and a significant drop of 14% for trunk CT ($p = 0.004$; 95% CI: -22% to -5%) between 2011 and 2015.

3.3. Use of TCM and IR

TCM was used in 76% (164/217) of the CT examinations in 2011 and in 84% (117/140) of the scans in 2015 (Table 1). Nine out of the 15 CT devices (60%) used in 2011 were not equipped with IR. In 2015, in only 3 out of the 17 devices (18%) used, IR was not available. This increased availability led to an increase in the use of IR from 22% (47/217) in 2011 to 69% (97/140) in 2015.

3.4. Collective dose and justification

The collective dose for the Belgian population from the two types of CT under study is shown in Fig. 3. A decrease of 23% was accomplished between 2011 and 2015 for abdominopelvic CT. However, the collective dose from trunk CT increased by 39% in 2015. Fig. 3 also illustrates the proportion of the collective dose that was not justified according to the national referral guidelines. In 2011, 24% (95% CI: 13% to 39%) of the abdominopelvic examinations did not comply with the guidelines. This percentage decreased to 17% (95% CI: 12% to 24%) in 2015 (not

significant: $p = 0.238$). The proportion of non-justified trunk CT was 8% (95% CI: 4% to 18%) in 2011 and 12% (95% CI: 6% to 22%) in 2015. Again, the difference between 2011 and 2015 is not significant ($p = 0.578$).

3.5. Comparison E calculated with CT-EXPO and with conversion factors

The scatterplots (Fig. 4) reveal a high correlation between E calculated with CT-EXPO (E_{expo}) and E calculated by means of the conversion factors published by Deak et al. and Huda et al. (E_{deak} and E_{huda}). This high correlation is confirmed by the ICC values: the ICC equals 0.916 (95% CI: 0.725 to 0.962) for comparison between E_{expo} and E_{deak} and 0.951 (95% CI: 0.901 to 0.972) for the comparison between E_{expo} with E_{huda} . A difference of 15% is found between mean E_{expo} and mean E_{deak} and a difference of 7% between mean E_{expo} and mean E_{huda} .

4. Discussion

For abdominopelvic CT, the present study shows a significant decrease of 28% in CTDI_{vol}, 28% in DLP and 27% in E between 2011 and 2015 for the Belgian population. For trunk CT, a non-significant decrease of 6% was found in CTDI_{vol} and a significant decrease of 14% in both DLP and E. Unfortunately, the design of this study did not allow us to determine the causes of this dose reduction with certainty. The median number of acquisitions and the median scan length were comparable in 2011 and 2015, and can therefore not account for to the reduction. However, compared to 2011, an increased availability of IR software was observed in 2015 (Table 1). Several studies have demonstrated the reducing effect of IR on radiation dose [19–21]. In addition, dose reduction can be achieved through the use of TCM [22]. A slight increase in TCM use was observed in our study when comparing the 2011 and 2015 data. The degree of TCM dose reduction is strongly dependent on the CT device used [23–25]; and, even with the same CT device, differences in use can significantly affect patient dose [26]. The present study also observed some older CT devices being taken out of service and replaced by newer-generation CT systems.

The wide spread of doses demonstrated in the boxplots (Figs. 1 and 2) has also been reported by several other studies [27–29]. Some variation in doses is to be expected because of differences in patient size,

Table 3

A comparison of the effective doses (mSv) calculated in the present study and those reported by the Dose Datamed 2 (DDM2) study [1].

	Present study (2011)	Present study (2015)	DDM2 (2014)
CT abdomen (- pelvis)	14.4 (11.1 – 18.6) ^a	10.4 (8.0 – 13.6) ^a	11.3 (2.61 – 28.7) ^b
CT chest - abdomen (- pelvis)	14.8 (11.4 – 19.3) ^a	12.8 (9.9 – 16.7) ^a	14.8 (2.35 – 50.5) ^b

^a Values are mean (95% confidence interval).

^b Values are mean (range).

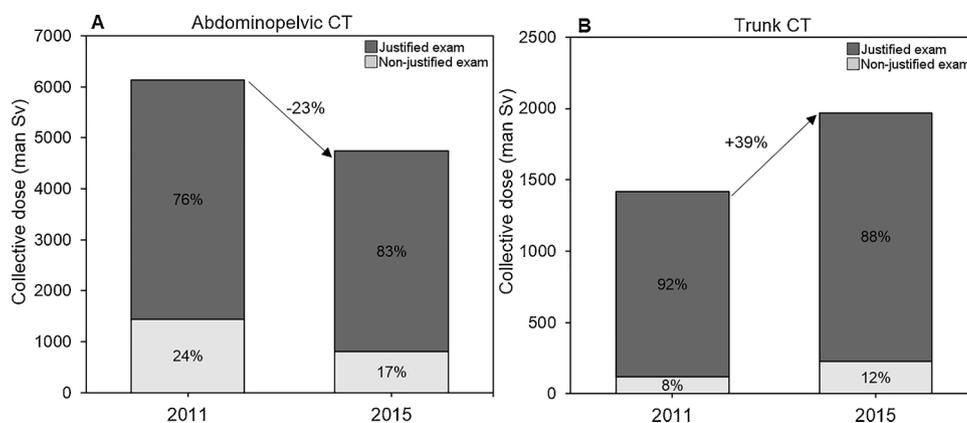


Fig. 3. The collective dose (man Sv) for abdominopelvic (A) and trunk (B) CT examinations in Belgium. The labels on the bars show the proportions of justified and non-justified CT examinations.

image quality requirements and use of CT devices, but the extent of the variability leaves room for improvement [27,30]. As previous studies have demonstrated, an institutional-level dose audit can help to achieve more consistent doses and have a positive impact on the dose of a CT examination [31–33].

Although the observed doses per examination are average in comparison with other European countries (Table 3), the DDM2 study revealed that Belgium has the highest mean E per caput. With a mean E of 2 mSv per caput, Belgium has a radiation exposure to the population that is almost twice as high as the mean E per caput for the European population (1.1 mSv per caput) [1]. It appears that the high radiation exposure to the Belgian population is not caused by the dose per examination, but is rather the result of the number of examinations performed. Although the number of abdominopelvic CT examinations increased slightly between 2011 (427 012) and 2015 (465 829), a significant decrease in dose per examination led to a reduction of the collective dose. Despite a decrease in dose for trunk CT, a considerable increase in number of trunk examinations (2011: 95 445; 2015: 153 631) caused an increase in collective dose for this type of examination, which can be related to its extensive use in oncology.

The present study shows a trend towards a radiation dose reduction, which could have been triggered by several technological developments (TCM and IR) and their application in daily practice. These factors contribute to the implementation of the ALARA principle: keeping the dose as low as reasonably achievable. However, Fig. 3 demonstrates that part of the collective dose results from non-justified CT examinations. Inappropriate imaging leads to a violation of the justification process, which is also a fundamental concept in the protection of the population against the risks of ionizing radiation. The procedure is not

in accordance with the justification principle if the expected risk from a procedure exceeds the clinical benefit of the CT procedure [34]. Non-compliance with the referral guidelines results in radiation exposure without benefit and must be avoided. Imaging referral guidelines are an aiding tool for physicians in selecting the appropriate imaging procedure [35–37]. A study conducted in Finland estimated a higher percentage of non-justified abdominal CT examinations than the present study (Finland: 37%, Belgium: 24% in 2011 and 17% in 2015) [38], whereas a Polish study estimated that 8% of the abdominal CT examinations were not indicated [39]. However, assessing justification is a complicated matter. For example, in the Finnish and the Polish study, assessment of justification was only based on imaging referrals, while the present Belgian study performed a new physical examination and anamnesis and used this information, together with the details of the referral, to check compliance with the guidelines.

To save time, large-scale dose surveys often use conversion factors to convert DLP to E [29,31]. The ICC values show a good correlation between E calculated with CT-EXPO and E estimated with conversion factors. However, a good correlation can be accompanied by a systematic error. A review of the scatterplots revealed that the dose values retrieved from CT-EXPO are on average 15% higher than E_{deak} and 7% higher than E_{huda} . Therefore, these results should be interpreted with caution. Other studies also found an average difference of 10–15% between these two methods [40,41]. Although conversion factors estimate E in a consistent way, some deviation from the actual value of E is to be expected. The higher E values seen in Fig. 4 are often linked to larger patients. In current study, CT exposure values of these patients are applied on the standard-sized patient models of CT-EXPO. As a result, this will lead to an overestimation of E for larger patients

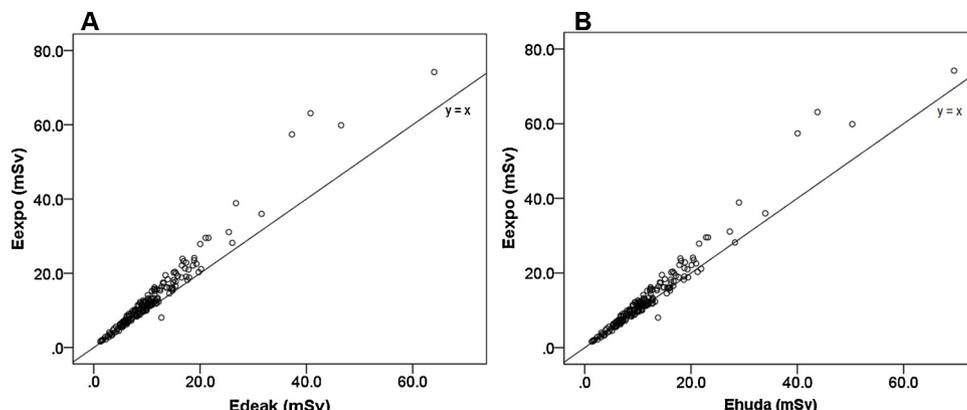


Fig. 4. The correlation between E (mSv) of the abdominopelvic CT procedures calculated with CT-EXPO (E_{expo}) and E calculated with the DLP-to-E conversion factors from Deak et al. (E_{deak}) [15] (A) and the conversion factors from Huda et al. (E_{huda}) [16] (B). The solid line represents perfect correlation ($y = x$).

compared to the reference patient considered in the software.

Even though this study yielded some interesting results, it is not without its limitations. First of all, change of dose over time was only assessed for two types of CT examinations. These specific examinations were selected because they deliver high doses to radiation-sensitive organs, such as the lungs, stomach and colon. Secondly, one of the methods used to calculate E was by means of CT-EXPO, which uses a mathematical phantom to estimate organ doses. However, the latest ICRP guidelines propose the use of voxel models which provide a more realistic representation of the human body [7]. Another factor which was not accounted for in the dose calculation with CT-EXPO is the use of contrast media during the CT examinations. Recently, the use of iodinated contrast medium has been reported to increase considerably the dose to iodinated tissues for the same CT exposure [42–44]. For the contrast enhanced CT procedures, there would be an additional uncertainty in the estimation of effective dose. As numerous papers have emphasized, E is frequently misused as a quantity to assess the dose and risk for an individual patient [6,7,30,45,46]. Calculating E per patient is in essence incorrect, but our methodology allowed us to incorporate examination- and patient-specific features into the dose calculation. Moreover, the aim is to eventually estimate a mean E that applies to the population, not to individual patients. In the present study, only one reference male and female phantom was used together with the exposure settings retrieved from the DICOM header of the CT examination. However, the size of the individual patient will differ from the size of the reference phantom. As the majority of the patients are typically larger than the reference phantom models, this will result in an over-estimation of the calculated organ doses and E values. This is a limitation of using CT-EXPO for dose calculation.

5. Conclusion

The findings of this study reveal an evolution towards a reduction in radiation exposure to patients undergoing abdominopelvic and trunk CT examinations in Belgium, specifically between 2011 and 2015. However, a fraction of the estimated doses are linked to unnecessary CT examinations, which should be avoided.

Role of the funding source

This study was supported by the Belgian College of Radiology. The funding source was not involved in the design and conduct of this particular study, in the analysis and interpretation of the data, or in the preparation, review, and approval of the manuscript.

Conflict of interest

We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work.

- This study has received funding by the Belgian College of Radiology.
- The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

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