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Dose estimation in abdominal CT scans using CT-EXPO software

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ABSTRACT

The application of ionizing radiation in diagnostic medicine has increased worldwide in the last decades. Computed Tomography (CT) is the main radiological procedure that contributes to the increase of the collective dose in the population. The aim of this study was to estimate the doses received by patients undergoing CT scans in a public hospital in Santa Catarina - Brazil, employing data from the DICOM header and utilizing the CT-Expo V. 2.7 software. The data were selected from 45 abdominal CT scans consisting of two series: pre-contrast and one post-contrast intravenous, of adult patients performed in December 2020. The spreadsheets with the data extracted from the DICOM headers were provided by the Santa Catarina Telemedicine System (STT). The effective dose and organ doses were calculated by CTDIvol and DLP values using the software. Overall, the organs that showed the higher equivalent doses were the kidneys (19.5 mSv), spleen (18.5 mSv), stomach (18.9 mSv), and liver (18.1 mSv). The estimated effective doses were 7.31 and 8.41 mSv, for non-contrast and contrast-enhanced examinations. The use of software such as CT-Expo can support the estimation of effective doses received by patients through the information extracted from the DICOM header. The presented methodology can be a useful tool to retrospectively estimate the doses in CT services in Brazil.

Keywords: **Tomography, Radiation Dosage, Radiation Exposure; CT Expo; DICOM header.**

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1. INTRODUCTION

The application of ionizing radiation in diagnostic medicine has dramatically increased worldwide in the last decades, increasing more than 100% of the average dose in the world population [1, 2]. In this period, radiological examinations have become the primary source of exposure to anthropogenic nature. In many countries, the collective dose from medical procedures has already exceeded other artificial radiation sources. For example, in the United States, the effective dose per caput is 2.16 mSv for medical exposures. Besides, half of the effective doses (1.37 mSv) in the U.S. originated from Computed Tomography (CT) examinations, with CT scans accounting for 63% of the collective dose [3]. A similar situation has been occurring in other countries, indicating that CT is the main radiological procedure that contributes to the increase of the collective dose in the population [2].

CT scans have become an essential examination in diagnostic radiology. The clinical value and benefits of CT scans are unquestionable. However, exposure to ionizing radiation at high doses can result in potentially harmful effects on patients, associated with an increase in cancer incidence and morbidity [1-4]. Therefore, several studies and organizations have been initiated worldwide to estimate and monitor doses and evaluate means to optimize the doses from these examinations [5-9].

Studies of dose estimation in CT procedures have obtained values through technical parameters such as Computed Tomography Dose Index (CTDI) and Dose Length Product (DLP) [7-9]. Both CTDI and DLP are necessary indicators for estimating the doses received by patients. In 2002, a normative was issued by the International Electrotechnical Commission (IEC) defining that these parameters should be informed by the CT scanners manufacturers [10]. Therefore, CTDI and DLP should be provided in the equipment console. Moreover, in 2007, these dose indices started to be informed in the Radiation Dose Structured Report (RDSR) issued by CT systems, facilitating its use to estimate the radiation dose received by patients [11].

However, not all CT scanners provide the RDSR; in these cases, tools such as the CT-Expo software, a Monte-Carlo-based modeling, and computational phantoms have been used to estimate the effective doses, and the information needed for obtaining them is collected directly from the DICOM header [8, 9].

Based on this information, the objective of this study was to use the CT-Expo V-2.7 software, employing DICOM header data, to determine the CT dose-volume index (CTDIvol), dose length product (DLP), organ dose, and effective dose in patients undergoing CT examinations in a public hospital in Santa Catarina – Brazil.

2. MATERIALS AND METHODS

This work consisted of a cross-sectional, retrospective, descriptive study. Data were selected from 45 abdominal CT scans of adult patients performed in December 2020 in a CT scanner from General Electric Healthcare (GE) Revolution EVO 16-channel from a public hospital located in Santa Catarina - Brazil.

To calculate the organ dose and effective dose, the scan parameters of the Digital Imaging and Communications in Medicine (DICOM) headers of each exam were provided by the Santa Catarina Telemedicine System (STT) to the researchers, under the approval of the Research Ethics Committee (CAAE: 36650720.6.0000.5365).

The scan parameters used were: kVp, mAs, pitch, scan date, age, gender, rotation time, table feed and the number of series. These parameters were provided in spreadsheets. The scan length from regions simulated in the CT-Expo was checked directly from the CT scanner console since they were not reported in the DICOM header of the scans.

The software used was CT-Expo version-2.7 which is Monte-Carlo-based and uses mathematical phantoms (Adam, Eva, Child, Baby) that are expressed by equations of the internal organs and body surface [12, 13]. In addition to space to enter the exposure parameters, the software allows the selection of the scanner vendor and model, helical or axial acquisition mode, age, and gender.

The software was run using the following settings: scanner model Revolution EVO 16 (large body), male Phantom (1.70 m tall, 70 kg), female Phantom (1.60 m tall, 60 kg), spiral mode, scan ranger, and the exposure parameters extracted from the DICOM header for each exam. The abdominal regions were delineated at phantom Adam and EVA starting at the level of the liver and ending after symphysis pubis. The tissue weighting factors that were used were those provided by the ICRP publication number 103 [14]. (Fig. 1).

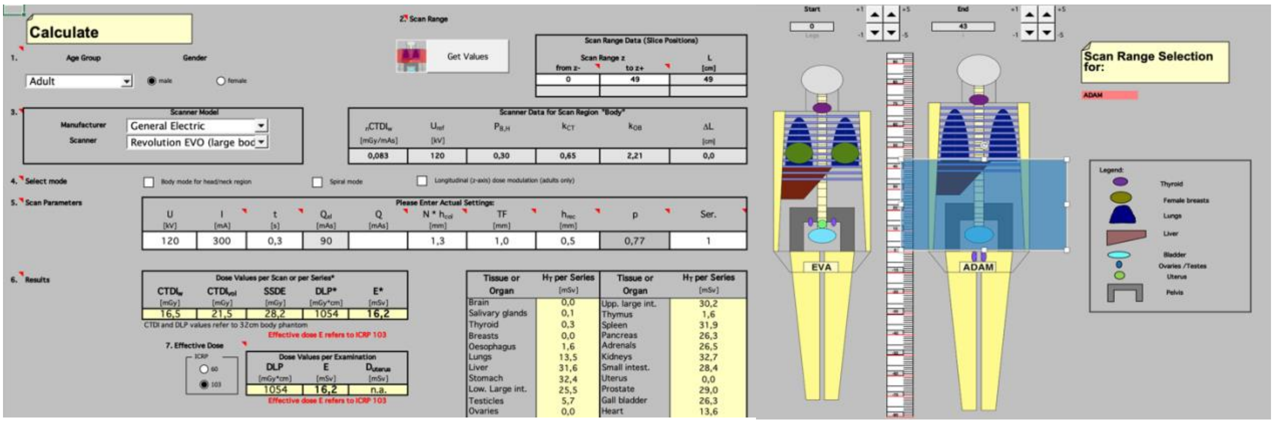

Figure 1: *CT-Expo→ Interface Calculate and Scan ranger.*
Source: SASCRAD, 2020 [12].

The abdominal CT protocol applied to the scans used in this study consisted of 120 kVp, 400 mA reference, 0.40 mm total collimation, 1.35 pitch and time per rotation of 0.8 s. In addition to abdominal CT scans, some patients were undergone to thorax and pelvic CT scans. The parameters of the latter exams were also used to complement this study. Most of the exams performed consisted of two series: pre-contrast and one post-contrast intravenous, since the service did not have an injection pump.

The CTDIvol, DLP, effective dose, and organ dose values were obtained after data from each patient's abdominal and pelvic CT scans were run through the software. The data obtained was organized using Microsoft Excel with each body procedure treated on a separate worksheet. The CTDIvol, DLP and E data were analyzed concerning mean, minimum, maximum and 75th percentile.

3. RESULTS AND DISCUSSION

The patients' samples had aged with a mean value of 52 (SD 18, Age_{max} 87, Age_{min} 22) years and the median was 44 years. Furthermore, 14 patients were female, and 31 were male. Other anthropometric characteristics of patients, such as weight, height, and Body Mass Index (BMI), could not be extracted from the DICOM header since they are not mandatory information for the exam, and are not usually entered by the professionals. Table 1 shows the technical parameters extracted from the DICOM header.

Table 1: Technical parameters used to calculate the dose from DICOM Header and CT-Expo.

DICOM TAG	DICOM Name	Name in CT-Expo
[0018,1160]	Filter Type	Body Mode
[0018,0060]	kVp	kV
[0008,0070]	Manufacturer	Manufacturer
[0008,1090]	Manufacturer's Model Name	Scanner
[0010,1010]	Patient’s age	Age Group
[0010,0040]	Patient’s sex	Gender
[0040,0254]	Performed Procedure Step	Scan ranger
[0018,9305]	Revolution Time	Acquisition Time
[0020,0011]	Series Number	Number of Scan Series
[0020,1041]	Slice Location	Scan Range
[0018,0050]	Slice Thickness	Reconstructed Slice Thickness
[0018,9311]	Spiral Pitch Factor	Pitch
[0018,9310]	Table Feed Per Rotation	Table Feed Per Rotation
[0018,9307]	Total Collimation Width	Total Collimation
[0018,1151]	X-Ray Tube Current	mA

Several authors have used DICOM header data extraction combined with computational tools for dose estimation in radiological examinations. Ekpo et al. [9] performed a retrospective study of CT scans of 171 adult patients in Nigeria. The data used were collected from the DICOM header of the hospital.

Out of the 45 patients in this study, 29 had CT exams without intravenous contrast, and 16 with intravenous contrast, all being total abdominal CT scans (upper abdomen and pelvis). The mean value of series performed for the contrast-enhanced exams was four, and two exams reached nine series, encompassing the pre- and contrast-enhanced phases and biopsy. A high number of series or exam phases is one of the main causes of high doses in CT patients. The data were collected from the helical scans or "spital scan" only, which are used as the routine protocol in the Hospital.

Table 2 shows a statistical analysis of the radiation dose index in CTDIvol per sequence and DLP per examination and includes the minimum–maximum, mean, median, and first and third quartile values of CTDIvol, DLP and effective dose (E) in relation to the radiation dose received by patients during abdominal CT scans (with and without contrast).

Table 2: Values of CTDIvol, DLP e Effective Dose (ED) of abdominal CT scans.

Procedure (Phases)	**$CTDI_{Vol}$ (mGy)**			**DLP (mGy.cm)**			**ED (mSv)**		
	Mean	**Min-Max**	**75th**	**Mean**	**Min-Max**	**75th**	**Mean**	**Min-Max**	**75th**
Abdomen all scans	11.8	2.9-19.9	16.3	487.1	124.9-840	676.8	8.0	1.9-15.3	10.7
Abdomen without contrast	12.2	3.7-19.3	16.3	510.2	160.4-830,9	699.74	8.4	2.5-15.3	11.6
Abdomen with contrast	11.2	2.9-19.9	16.1	445.1	124.9-840	572.25	7.3	1.9-13.2	9.9

The CTDIvol at the 75th percentile for CT abdomen with and without contrast were 16.1 and 16.3 mGy, respectively. The DLP at the 75th percentile were 572.25 and 699.74 for CT scans with and without contrast, respectively. The values for the 75th percentile obtained were lower than those published in the study by Kanal et al.: CTDIvol 19 mGy with contrast, and CTDIvol 18 mGy. The DLP values differed significantly: DLP 995 mGy and DLP 877 mGy with and without contrast, respectively. This difference could be a result of the kVp and pitch used, as well as the type of scanner [17].

The values of CTDIvol and DLP in this study were approximately lower than and comparable with those reported in other studies [7, 17]. In the exams with contrast, the mean effective dose was lower than in exams without contrast. That probably occurs in the second examination, and there is naturally an optimization of the scanned area as also reported by other authors [7,8, 14]. In addition, the protocols may change according to the specifics of each patient, affecting the radiation dose [7, 14].

Based on the dose results obtained in these examinations, it was found that patients undergoing total abdominal CT examination in the evaluated service can receive an average effective dose of 8 mSv. This value is similar to that reported in the study by De Mattia et al. [8]. They tested four commercial CT protocol software, including CT-Expo. The effective dose to the abdomen-pelvis was 8-9 mSv.

In a study conducted by Rodrigues et al. [14] on dose in abdominal CT scans, CT-Expo was also used. The values of effective dose obtained were lower (4 mSv) than those obtained in the present study. This difference is possible because the equipment and acquisition parameters of the protocol are different and the version (V 1.5) of the software is different from that used in this study (v. 2.7).

The mean organ doses (equivalent doses) from abdominal CT scans were also calculated. The values obtained are shown in Figure 2.

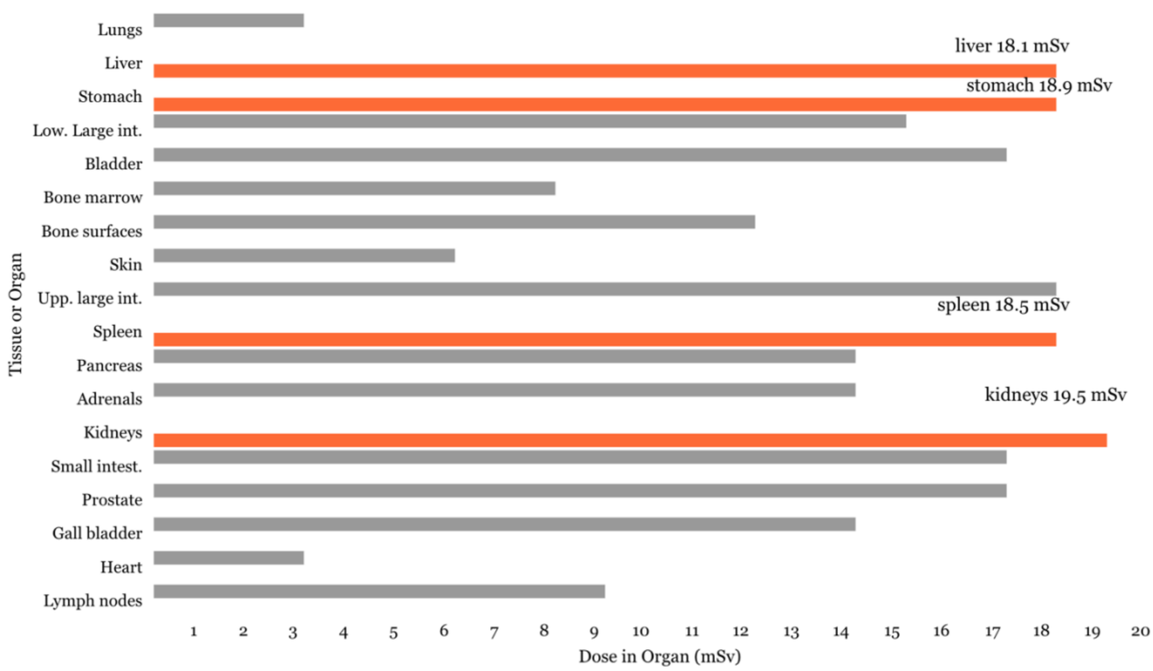

Figure 2: Average equivalent organ dose for abdominal CT scans calculated with CT-Expo V 2.7 software.

Overall, the organs that showed the higher equivalent doses were the kidneys (19.5 mSv), spleen (18.5 mSv), stomach (18.9 mSv), and liver (18.1 mSv). The results of this study showed a small difference when compared with other studies. In the study of Ekpo et al., the CT-Expo was also used. The organ dose was 4.6% higher than that reported for the Stomach, 4.4% higher for the liver, and 0.4% higher than that for the skin. A difference of a few millimeters in scan length can change the dose result in the organ and explain the small differences found [9].

The number of CT scans is growing worldwide, as are the doses from these procedures, despite advances in CT technology. These examinations can involve relatively high doses to patients, approaching or exceeding the currently proposed DRLs, and that could be related to an increased risk of developing cancer arising from medical exposures. Based on this, patient dose estimation studies are essential [6, 15-17].

The DRLs established in international guidelines are routinely established based on the 75th percentile [9, 16,17]. This study exclusively presented the mean values for effective doses and organ doses per scan series, with respective minimum - maximum and 75th percentile. Larger sample size and inclusion of clinical indications are identified as the future improvement in this study. Despite the initially limited number of samples, this study is part of a larger ongoing project to investigate the doses (absorbed and effective) for CT procedures in different services in Santa Catarina, Brazil.

Furthermore, the adequate justification of the exams, the use of appropriate technical parameters, constant training of the team, adequate quality control, and the application of DRLs are actions that can contribute to the optimization of the doses [6, 7, 16].

4. CONCLUSION

The CT equipment with RDSR shows dose and dose index values at the end of each exam, allowing a faster and more practical evaluation of the patient doses, besides being an excellent dosage optimization tool. However, not all CT scanners contain the RDSR settings, and the use of software such as CT-Expo can support the estimation of effective doses received by patients through the information extracted from the DICOM header.

We suggest the application of our method or a similar one to services where CT scanners do not yet provide RDSR. The presented methodology can be a useful tool to retrospectively estimate the doses in CT services in Brazil.

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