Importance of Patient Dose Evaluation and Optimization in Thorax Computed Tomography

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Abstract. Computed tomography (CT) is one of the most important imaging modalities in modern medicine. Using CT, one can obtain useful information about a patient's health status, or condition. As this modality delivers some amount of radiation to the patient's body that can be harmful, special attention must be paid to choosing appropriate parameters that can reduce the dose but maintain helpful diagnostic information from the CT image. Radiation doses for CT examinations vary considerably among patients, institutions, and countries. This variation is mostly attributable to the technical parameters of the CT scanning protocols. An optimization process is a team effort of the CT radiologist, the lead CT technologist, and the clinically qualified medical physicist. The purpose of this study is to analyze patient doses in thorax CT in two public hospitals in Sarajevo, the capital of Bosnia and Herzegovina. Data were collected from five different CT devices from these hospitals, using the OpenREM system. The optimization process in both hospitals was surveyed as well, investigating their benefits and shortcomings. Finally, we propose possible ways for future optimization and harmonization of existing protocols in two hospitals, by adjusting different technical parameters such as the tube voltage, tube current, and pitch.

Keywords: Computed tomography · Patient dose · Optimization

A. Badnjević and L. Gurbeta Pokvić (Eds.): MEDICON 2023/CMBEBIH 2023, IFMBE Proceedings 93, pp. 242–251, 2024.
https://doi.org/10.1007/978-3-031-49062-0_26

1 Introduction

Thorax computed tomography (CT) is a commonly used imaging technique for the diagnosis and follow-up of various diseases affecting the lungs, mediastinum, and chest wall [1, 2]. It plays a key role in the management of trauma patients [3, 4]. CT is recognized as a method of choice in early lung cancer screening [5–9]. Like many other imaging techniques that rely on x-rays, it is associated with exposure to ionizing radiation. As technology has advanced and the cost of equipment has decreased, the use of CT has become more widespread. This should be regarded as a positive development, as CT is a valuable tool in modern medicine that provides information necessary for accurate diagnosis and treatment planning. However, the increasing use of CT scans has raised concerns about the potential risks associated with ionizing radiation, including an increased risk of cancer [10].

Patient dose evaluation and optimization is an important aspect of CT imaging that aims to minimize patient exposure to ionizing radiation while maintaining diagnostic image quality [11, 12]. Several factors, including patient size, CT scanner settings, and imaging protocols, can impact the radiation dose delivered to the patient during thorax CT scans. Therefore, it is crucial to assess the dose delivered to each patient and optimize the imaging protocol accordingly [1].

Optimization, however, is a challenging process. In general, increasing image quality and lowering the patient dose are two goals that sometimes conflict, and finding a balance that achieves both can be challenging. Furthermore, patients vary in size and anatomy characteristics. Larger patients may require higher radiation doses to produce adequate image quality. The desired imaging parameters, sometimes, may not be achieved due to the technical limitations of CT scanners. Moreover, the lack of standardization in imaging protocols, as well as lack of awareness and understanding of radiation risks, could lead to unnecessary exposures and affect the overall patient doses [13].

An increasing number of countries are implementing lung cancer screening programs that involve the use of CT [5–9]. By detecting lung cancer early, these screening programs can help to reduce the burden of disease and improve patient outcomes. However, there are also concerns about the potential harms of CT based screening, such as the risk of false positives, overdiagnosis, and radiation exposure. In such cases, the reduction of patient doses becomes an imperative, and the optimization process a necessity [9].

This study aims to explore patient doses and optimization practices in thorax CT in two public hospitals in Sarajevo, Bosnia and Herzegovina.

2 Materials and Methods

2.1 Data Collection

The study evaluated the dose data of 3008 CT chest procedures performed on patients who were admitted to one of the public hospitals in Sarajevo – Clinical Centre of the University of Sarajevo (KCUS), or General Hospital "Prim. dr. Abdulah Nakăs" Sarajevo (OBS), in a 12-month period. Dose descriptors and accompanying procedure information were collected by the OpenREM dose monitoring system (The Royal Marsden NHS Foundation Trust, London, United Kingdom) which interprets radiation-structured dose reports (RDSR) stored on the picture archiving and communication system (PACS).

OpenREM ensured that the patients' identities remained anonymous. This limited our ability to access additional information about the patients, such as pregnancy status, immunodeficiency, comorbidities, number of CT scans received, disease outcome, and other relevant factors. As a result, no corresponding approval from the local ethical committee was required.

The patients had RDSR files available, which provided detailed information about their CT examination, including the type of examination, date and time of the procedure, patient age and sex, exposure time (t), scan length (L), slice thickness (T), collimation width (nT), pitch (p), tube voltage (U), maximum and mean tube current (I), rotation time, as well as the values of dose indices, specifically air kerma length product (DLP) and pitch-corrected volume CT air kerma index ($CTDI_{vol}$). It needs to be emphasized that OpenREM cannot process data that are not provided by the RDSR file itself. The study excluded patients with incomplete data.

IBM's Statistical Package for Social Sciences (SPSS) version 26.0 (International Business Machines Corporation, Armonk, New York, USA) was employed to analyze the data, using a significance level of $\alpha = 0.05$ in statistical calculations. To test the normality of the distribution, the Kolmogorov-Smirnov test was utilized. Typically, the dose data are not normally distributed, so the non parametric Mann-Whitney U test was used to evaluate differences between data distributions.

Patients were scanned on one of the scanners listed in Table 1.

Table 1. CT scanners used in the study.

ID	Manufacturer	Model	Number of slices
CT1	Toshiba	Aquilion Prime SP	160
CT2	Siemens	SOMATOM Definition AS	16
CT3	Toshiba	Aquilion Prime SP	160
CT4	Toshiba	Astelion	16
CT5	GE	Optima660	128

2.2 Evaluation of Optimization Practices

Regulations in Bosnia and Herzegovina require clinically qualified medical physicist (CQMP) to be involved in practical aspects of medical exposure, such as calibration of equipment, calculation of the patient dose, development of com plex techniques, creation of quality assurance program and implementation of quality control. According to the regulations, justification and optimization aspects for examinations in diagnostic radiology are elements of a quality assurance program, whose implementation is required [14]. Another important aspect of the regulations is a requirement for full-time employment of medical physicists in hospitals that have nuclear medicine or radiotherapy departments, while departments of medical physics are required for institutions that provide all three fields that use ionizing radiation, namely, diagnostic radiology, nuclear medicine, and radiotherapy.

However, the optimization process is a team effort; this team has to consist of at least the lead CT radiologist, the lead CT technologist, and CQMP. It is recommended for a senior member of the facility administration team to be involved [13]. The role of vendor application specialists should not be neglected. In cases when a new CT scanner is installed, the application specialists are the first to set up imaging protocols, which are in some cases never reviewed or examined.

In this paper we surveyed the optimization process in both above-mentioned hospitals, investigating their strengths and weaknesses.

3 Results and Discussion

Data collected from OpenREM dose management system allows the evaluation of various parameters related to the scanning protocol. The most important ones are summarized in Table 2 which contains information on rotation time t, pitch p, tube voltage U, average tube current I_{ave} and maximum tube current I_{max} for CT scanners included in the study. Unfortunately, the RDSR file does not provide all information relevant to protocol design. However, a lot can be inferred from available data.

Table 2. Overview of the most important protocol parameters (rotation time t, pitch p, tube voltage U, average tube current I_{ave} and maximum tube current I_{max}) for computed tomography scanners included in the study.

	N_s	Series 1					Series 2				
		t	p	U	I_{ave}	I_{max}	t	p	U	I_{ave}	I_{max}
CT1	2	0.35	0.813	120	137	195	0.38	0.726	120	450	500
CT2	2	0.50	1.200	120	345	650	0.50	1.200	100	334	650
CT3	1	0.50	0.813	120	127	180					
CT4	1	0.75	0.980	120	71	110					
CT5	1	0.70	0.980	120	400	400					

The study includes patient dose and protocol data from 1549 male and 1459 female patients. Two sexes are equally distributed (binomial test, $p = 0.105$).

Figure 1 is a histogram that shows the age and sex distribution of patients. The average age of patients is 61.9 y with interquartile range (ΔQ) of 17.7 y. The distribution is negatively skewed ($s = -0.692$) and not normal (Kolmogorov Smirnov test, $p < 0.001$). The age distribution is the same between the two sexes (Mann-Whitney U test, $p = 0.963$).

Figures 2 and 3 show the relevant patient dose quantities, DLP and C_{VOL}, respectively, while Table 3 shows median and interquartile range values of these quantities.

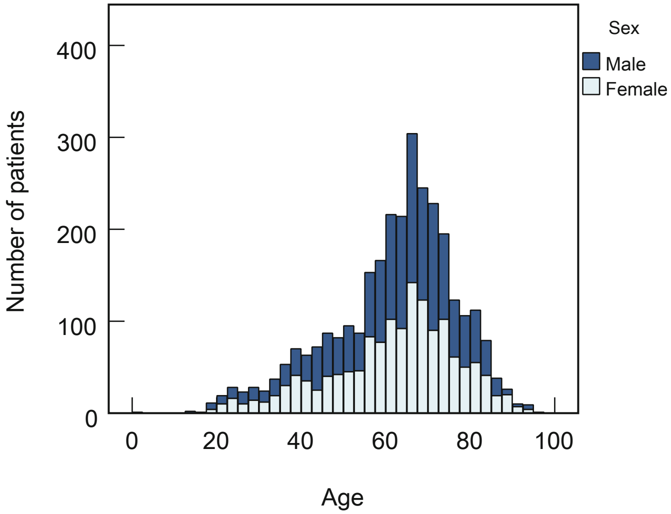

Fig. 1. Number of patients relative to age/sex.

Table 3. Median ($\tilde{x}$) and interquartile range (ΔQ) of air kerma-length product ($P_{\mathrm{KL,CT}}$ or DLP) and volume computed tomography air kerma index (C_{VOL} or $\mathrm{CTDI_{VOL}}$) for patients examined on CT scanners included in the study.

		$P_{KL,CT}(Gycm)$		$C_{VOL}(mGy)$	
		$\tilde{x}$	ΔQ	$\tilde{x}$	ΔQ
CT scanner	CT1	640	212	7.8	9.0
	CT2	413	381	6.5	3.4
	CT3	335	209	7.2	4.6
	CT4	316	240	7.1	5.7
	CT5	1039	157	24.8	1.6

Two hospitals were surveyed on their practices in the optimization process. The positive outcome of the regulations in medical exposure is the availability of medical physicists specialized in medical imaging – 4 in KCUS and 1 in OBS. However, no teams are officially committed to reviewing and management of imaging protocols. In KCUS, a provisional team was established to follow up results of national technical cooperation projects with International Atomic Energy Agency (IAEA). This team was involved in practical aspects of optimization in CT imaging. In OBS, however, no such team exists, and its protocol management is exclusively done by application specialists from corresponding equipment vendors.

Data collected by the OpenREM dose management system provides valuable data which allows analysis of scanning protocols (Table 2). It should be noted, however, that some relevant information regarding the CT scanning protocol, primarily a user-defined

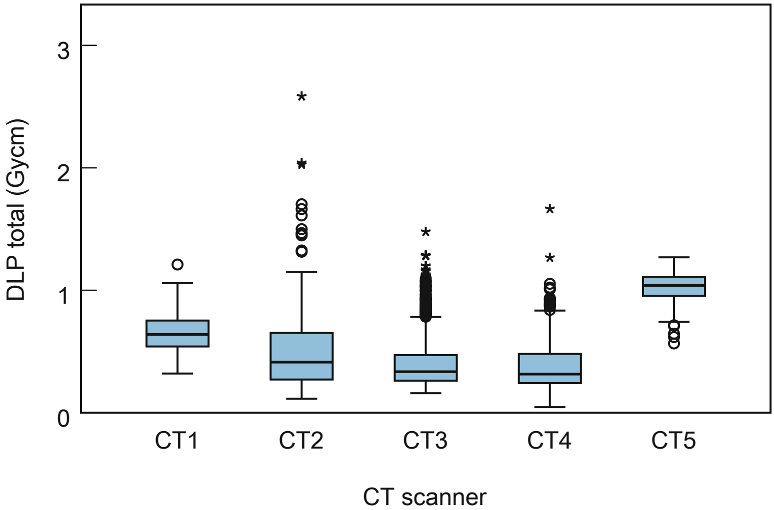

Fig. 2. Boxplot of total air kerma-length product ($P_{KL,CT}$ or DLP) for patients examined on CT scanners included in the study. Outliers and extreme values are represented with circles and asterisks, respectively.

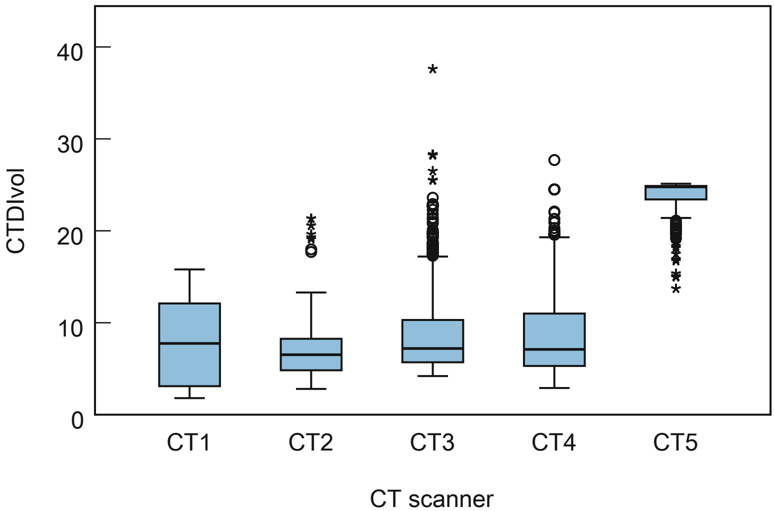

Fig. 3. Boxplot of volume computed tomography air kerma index (C_{VOL} or $CTDI_{VOL}$) for patients examined on CT scanners included in the study. Outliers and extreme values are represented with circles and asterisks, respectively.

parameter that controls the level of image noise in CT images, is not available. This parameter is known as "noise index", "standard deviation", or "reference mAs." By adjusting this parameter, the operator can increase or decrease the level of image noise, which can impact the image quality and radiation dose [13]. The noise level is set to a specific slice thickness (T). In practice, the noise level is the main input parameter for the tube current modulation (TCM), whose role is to change I in order to adjust the amount of radiation emitted by the X-ray tube during the scanning process based on the patient's anatomy [15]. Although the information on the "noise index" was not available, information on maximum and mean I allowed some insight into noise level settings.

It is not beyond reason to expect for the mean I to be somewhere in middle between minimum and maximum I, on average for all patients [16]. Although data provides no information on minimum I, the available protocols recommended by the American Association of Physicists in Medicine (AAPM) indicate the recommended minimum of 80 mA for Canon/Toshiba, and 100 mA for General Electric CT scanners [17]. The obvious problem that can be seen from median values presented in Table 2 is that I_{ave} and I_{max} in CT5 are the same, indicating the inappropriate settings of either noise index, or minimum I. Values for other examined CT scanners could be considered satisfactory.

Another value that stands out in Table 2 is U for CT2. The use of lower tube voltage is a recognized method for dose reduction and image quality optimization, especially in CT pulmonary angiography [18, 19]. The visualisation of iodine contrast is more prominent when lower U is used. This method of dose reduction requires use higher values of I, which is sometimes not possible. Hence, I_{max} for CT2 is 650 mA.

When compared to the recommended AAPM protocols, the reported values of pitch, p, are low for all scanners, except for CT2 [17]. In general, p should be above 1.

It is noticeable that CT1 and CT2 use two phases for standard chest CT – non-contrast (NC) phase and contrast-enhanced (CE) phase. Use of both, NC and CE series, in the same procedure is not recommended in routine practice [20].

Effectively, patient doses are increased by factor 2 when such imaging procedure is used.

Boxplots in Figs. 2 and 3 indicate distribution of patient doses in evaluated CT scanners. Table 3 indicates median ($\tilde{x}$) and interquartile range (ΔQ) of air kerma-length product ($P_{KL,CT}$ or DLP) and volume computed tomography air kerma index (C_{VOL} or $CTDI_{VOL}$). Total DLP refers to dose during the whole examination. This includes one or two scan projection radiographs (SPR), stationary acquisitions for contrast media tracking, as well as NC and CE phases which account for the most of radiation exposure. Values of $CTDI_{VOL}$ refer to a single helical acquisition, either NC or CE.

The highest doses are reported for CT5. Median DLP is 1039 mGy cm with interquartile range of $\Delta Q = 157$ mGy cm, while median $CTDI_{VOL}$ is 24.8 mGy ($\Delta Q = 1.6$ mGy). While value of $CTDI_{VOL}$ is below the national diagnostic reference level (DRL) which is set to 30 mGy, DLP is well above the recommended value (650 mGy cm), which indicates that optimization is necessary [14]. Values achieved on other CT scanners are within national and international recommendations. Median DLPs for CT1, CT2, CT3 and CT4 are (640, 413, 335 and 316) mGy cm. It should be noted that CT1 and CT2 include 2 series – NC and CE. DLPs could be considerably lower if the examination was reduced to the CE phase only. DLPs for CT3 and CT4 are not significantly different (Mann Whitney U test, $p = 0.055$). $CTDI_{VOL}$ values for CT1, CT2, CT3 and CT4 are between 6.5 mGy and 7.8 mGy. These values are very close to those recommended in international publications, and well below the national DRL.

Overall, optimization is necessary for CT1 and CT2, mainly due to use of both NC and CE phase in general chest CT examination. This is a problem related to the information flow and use of indication-based protocols. Unfortunately, it is not uncommon for CT technologists not to be aware of indication for chest CT. Hence, they do not know whether NC is required, or even if the delayed acquisition of chest and abdomen, which is commonly requested for base line staging and follow-up of lung cancer, is necessary. In this case, a major role should be given to the leading radiologist who should provide means for this information to be provided to technologists.

In the case of CT5, high values of $\mathrm{CTDI_{VOL}}$ and the same values of I_{ave} and I_{max}, indicate incorrect use of noise index and/or minimum I in the scanning protocol. Indeed, this has been proven to be true after the protocol was reviewed by the CQMP. The noise index (NI) was set to value of 12.5 at slice thickness of 0.625 mm. The NI wouldn't be considered high, but the reference slice thickness was too low. As a consequence, the TCM system increased I to values close to the chosen I_{max}. The CQMP should review the protocol and make necessary adjustments together with radiologists, as radiologists should be aware of protocol changes that would affect the image quality. Thus, the reduction of dose from 24.8 mGy to something more appropriate must be done in steps (i.e. by raising NI to 15, it is expected to achieve a 31% reduction in dose, and subsequently increasing it to 20 and continuing in the same manner until the desired result is reached). The sudden reduction of image quality may cause problems, and the new protocol could be immediately rejected by the radiologists in charge. In other words, this would lead to a decreased visibility of different tissue structures of interest and thus decreased sensitivity for observation of specific pathologies. Optimization of the protocol must be related to the tissue structure we want to sample by CT. One of the possible directions of the optimization is to use an anthropomorphic chest phantom [21]. In this sense, our next step could be the production of a homemade anthropomorphic thorax phantom to improve existing protocols for an immunocompromised patient. Recently, we used a similar approach, a 3D-printed infant head phantom, to optimize paediatric scanning protocol [22].

4 Conclusion

This study provided valuable insight into how dose management software can be used in the optimization process. Although the software provides limited data on protocol and image quality, its value is immense, as it makes possible frequent check-ups of protocols used in everyday practice in diagnostic radiology. The collected data from two hospitals in Sarajevo can be used to compare patient doses to the national DRLs, and also give valuable insight into how the examinations are performed. The existence of unoptimized protocols indicates that some changes need to be made in the decision process. Teams committed to CT protocol optimization should be established, utilizing all positive aspects of national regulations and international recommendations.

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