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Analysis of repeated computed tomography scans and cumulative effective dose of patients in a hospital

Milani[a], A. L.; Alves[b], A. F. F.; Alvarez[c], M.; Souza[a], S. P.; Marques[a], T. G. S.; Silva[a], M. A. A.; Trindade Filho[d], J. C. S.; Pina[e*], D. R.

[a] *Botucatu Medical School, UNESP – Univ. Estadual Paulista Julio de Mesquita Filho, Botucatu, São Paulo, Brazil.*

[b] *Institute of Biosciences, UNESP – Univ. Estadual Paulista Julio de Mesquita Filho, Department of Biophysics and Pharmacology, Botucatu, São Paulo, Brazil.*

[c] *Botucatu Medical School, Clinics Hospital, Medical Physics and Radioprotection Nucleus, Botucatu, São Paulo, Brazil.*

[d] *Botucatu Medical School, UNESP – Univ Estadual Paulista Julio de Mesquita Filho, Department of Urology, Botucatu, São Paulo, Brazil.*

[e] *Botucatu Medical School, UNESP – Univ Estadual Paulista Julio de Mesquita Filho, Department of Infectology, Dermatology, Diagnostic Imaging and Radiotherapy, Botucatu, São Paulo, Brazil.*

[*] *corresponding author: diana.pina@unesp.br*

ABSTRACT

Computed tomography exams are considered diagnostic imaging exams that generate significant radiation dose to the patient. Justification, optimization, and dose limitation are radiological protection principles used to minimize patient and staff exposure, ensuring the quality of the service provided. The objective of this study was to analyze CT scan data, analyzing the number of exams, the patients' effective cumulated dose, and the repeatability of the exams. The study data covers the 2013 to 2022 period during which a progressive increase was observed in the number of exams performed over time, with exams doubling in this period. The most used Computed Tomography protocols were brain/skull (27.4%), pelvis (17.3%), and abdomen (13.7%) during the study period. Approximately 76.3% of patients have a cumulative dose of less than 25 mSv, while about 1% accumulated more than 100 mSv. The repeatability of CT scans for the same patient over a short period varies, reaching until 17 scans in 30 days for a single patient. The results indicated a necessity to develop strategies for individual dose management methods for the institution's internal practices. An intervention could be implemented by creating periodically updated handouts and guidelines based on professionals' knowledge.

Keywords: **Radiation Protection, Diagnostic Radiology, Cumulative Effective Dose, Radiation Risk, CT Radiation Dose.**

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1. INTRODUCTION

Among the various techniques for obtaining radiological images, Computed Tomography (CT) stands out due to its capabilities for acquiring sectional anatomical slices to diagnose multiple diseases [1]. Godfrey Hounsfield introduced the CT concept in 1972, and since then, generations of CT scanners have been designed to improve patients' diagnosis and treatment [2]. Hence, there was increased clinical applications since CT scans are an alternative to invasive or less accurate procedures in hospital environments [3].

The CT scan is considered the diagnostic imaging modality that generates the highest patient doses, so monitoring those values is essential. The radiation dose is directly associated with the acquisition protocol, the technology available, the patient's biometric characteristics, and the radiation protection culture employed in the hospital [4].

Thus, when acquiring ionizing radiation images in clinical practices, it is essential to evaluate the risk-benefit factor. The International Commission on Radiological Protection (ICRP) publishes guidelines to be followed, providing medical and physical instructions on radioprotection. As described in ICRP 103 of 2007 [5], the dose received by the patient can be estimated using the Effective Dose (E) measurement.

The basic principles described by ICRP to minimize patient exposure through radiation protection concepts are justification, optimization, and dose limitation. The principle of dose limitation does not apply to patients since the radiological exposure must offer less harm than the diagnosis' benefits [6]. Diagnostic procedures must have adequate justification to ensure each procedure cannot be replaced by another method without using ionizing radiation or even with fewer radiation doses [6]. Attention must be redoubled when justifying medical procedures and optimizing radiological protection, ensuring minimum possible exposure for the patient. Avoiding unnecessary and ineffective exposure is the responsibility of all clinical staff.

Masjedi et al. [7], compared the dose distribution in diagnostic procedures that use ionizing radiation. The study evaluated conventional radiography, fluoroscopy, interventional procedures, and CT. Although CT is considered the modality responsible for the highest radiation doses delivered to the patient, other modalities should not be disregarded [7]. Brown et al. [8], describe several complications caused by a lack of knowledge related to radiation exposure and report factors that can influence decision-making about doses in medical imaging. Professionals without adequate instruction can affect the number of requests for radiological exams, especially CT, increasing the patient's exposure to radiation and recurrent exams [9-11].

CT scans must be optimized so that the best clinical information possible is achieved, considering a balance between patients’ exposure and image quality. The optimization principle is effective when ionizing radiation exposures are As Low As Reasonably Achievable (ALARA) [5,6].

The amount of radiation to which a person has been exposed increases the risk of developing some types of cancer [12-14]. Pediatric patients have an increased risk due to their life expectancy and higher radiosensitivity tissues. Consequently, the probability of developing some comorbidity from radiation exposure also increases [14,15]. Therefore, it is essential to assess the level of knowledge and provide directed instructions to medical staff about the risks associated with ionizing radiation in hospital practices [8,16]. A skilled physician can assess and justify the need for a patient’s exposure to ionizing radiation through a CT scan, successfully practicing radiation protection principles.

To ensure the monitoring of the principle of justification and dosimetry of patients at the institution, the Nucleus of Medical Physics and Radioprotection (NFMRp) implemented a tool in the hospital system to record all examination requests and procedures performed in the CT department [17,18]. Implementing these parameters' monitoring goes beyond what is required by Brazilian legislation and corresponds to the provided service quality. This study aims to analyze CT scan data. More specifically, to analyze the number of exams, the patients’ cumulative effective dose levels, and the repeatability of the CT exams.

About the appropriate use of effective dose, it's important to emphasize that our work doesn't involve estimating individual risk, but rather the risk of a group of individuals who receive treatment at our institution. The effective dose is used at the population level to estimate the potential radiation risk for planning and optimizing [5].

It's crucial to recognize the limitations of the effective dose, as it's based on a reference population and its application may vary based on individual differences in radiosensitivity. However, by studying the repetition of computed tomography scans, we aim to gain a better understanding of the broader implications of radiation exposure in a population, making the effective dose an appropriate choice. In this study, the effective dose was used as a conservative estimate, and the results should be interpreted in conjunction with other specific patient factors, such as age, sex, and medical history.

2. MATERIALS AND METHODS

2.1. Electronic dose indicator

An electronic dose indicator (EDI) system has been designed and implemented for the automatic recording of CT scan information [17,18]. The effective doses are estimated by employing the Dose-Length Product (DLP) in conjunction with the conversion coefficient (k) derived from each protocol, as calculated by Pina et al. [17]. With each subsequent examination, this E value is integrated into the patient's EDI, enabling an estimation of the cumulative dose over time.

The EDI also comprises patient identification (ID), date of birth, date, and type of CT scan, justification, and requesting physician. The collected data granted a large patient scan information database, which will be described in detail in the next section.

2.2. Database

The study included all CT scans performed from May 31, 2012, to May 4, 2022. A total of 156,341 exams were considered, regardless of age group and clinical scenario. These exams correspond to 54,515 patients and 77 exam protocols. The research ethics committee approved the use of data provided by the institution in this study (CAAE48105121.6.0000.5411).

All exams were acquired in a regional reference hospital in the public health system. The hospital has two Toshiba Scanners (Canon), Activion 16, and a single GE scanner model Optima 660. Quality Control tests were periodically executed, accordingly to current Brazilian regulations Resolution of the Collegiate Board of Directors 611/2022 [19] and Normative Instruction 93/2021 [20].

Statistical analysis was employed to evaluate the significance of the results, those being reported using graphs and percentages.

3. RESULTS

Initially, a general evaluation of the number of CT scans performed per year was proposed. Figure 1 shows a 26.0% increase in exams between 2018 and 2019, 15.5% increase from 2019 to 2020, and a 13.4% increase from 2020 to 2021. From 2013 to 2021, the number of CT scans doubled.

Figure 1: *CT exam distribution during the years.*

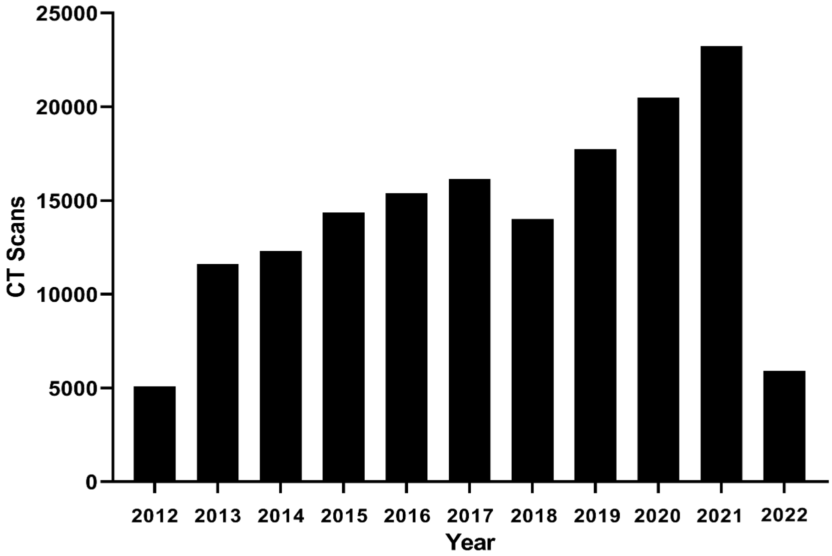
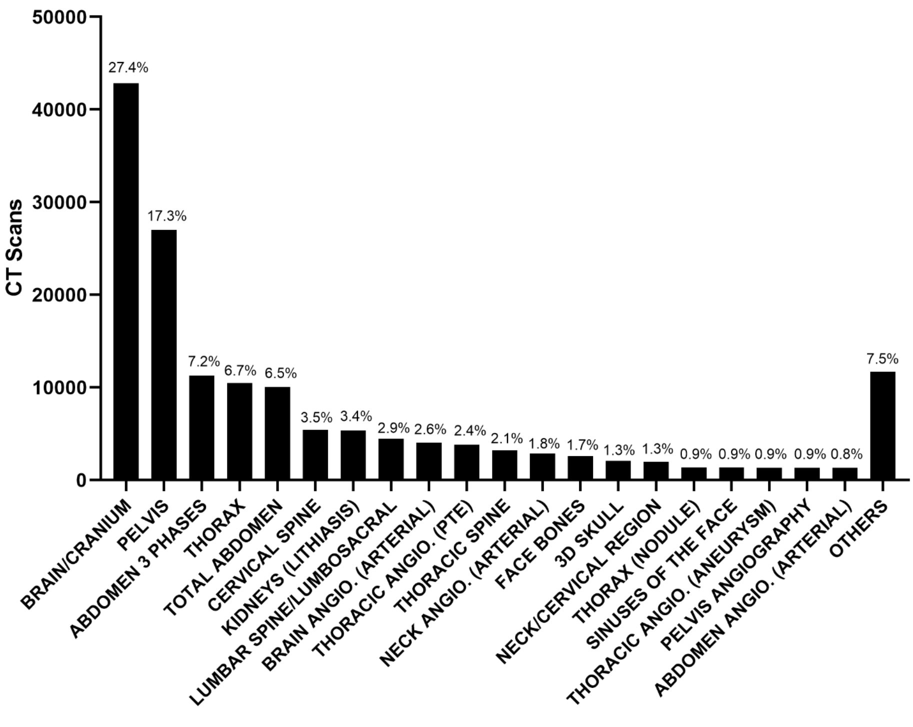


Figure 2 shows the main CT protocols used during the study period. The brain/skull protocol was the most performed exam (27.4%), followed by pelvis (17.3%) and abdomen (13.7%), considering 3-phase CT abdomen and complete abdomen.

Figure 2*: CT protocols most performed during the study period.*



The amount of effective cumulative dose is shown in Table 1. Approximately 76.3% of patients have a cumulative dose of less than 25 mSv, while about 1% cumulate more than 100 mSv.

Table 1: Number and percentage of patients who received cumulative E < 25 mSv, more than 25 mSv and less than 50 mSv, more than 50 mSv and less than 75 mSv, more than 75 mSv and less than 100 mSv and ≥100 mSv cumulative E over ten years.

Cumulative E (mSv)	**Number of patients**	**Percentage**
<25	41591	76,29%
≥25…<50	9039	16,58%
≥50…<75	2540	4,66%
≥75…<100	836	1,53%
≥100	508	0,93%

Table 2 compares the patients with a high cumulative dose to international studies. The country, the data period, and the number of participating patients were considered.

Table 2: Comparison with the literature of the number of patients with high radiation doses

Study	**Country**	**Period (years)**	**Total number of patients**	**Patients with high radiation dose (cumulative E ≥ 100 mSv)**	**Percentage (%)**
Present study	Brazil	10	54515	508	0,93%
Stopsack *et al.* (2019)	USA	10	54447	1034	1,90%
Jeukens *et al.* (2021)	Belgium	5	49978	482	1,00%
Rehani *et al.* (2020)	USA/Europe	1 - 5	~2,51 mi	33407	1,33%
Moghadam *et al.* (2021)	Canada	1	20750	-	0,67%

Ten patients with the highest E levels were individually evaluated. The studied parameters were related to the number of CT scans performed in 2018, 2019, 2020, and 2021 (Table 3). The number of exams with the same protocol for each patient is shown in Table 4.

Table 3: Patients who have performed alarming amounts of procedures with the same protocol in recent years - assessment of the number of CT scans per year.

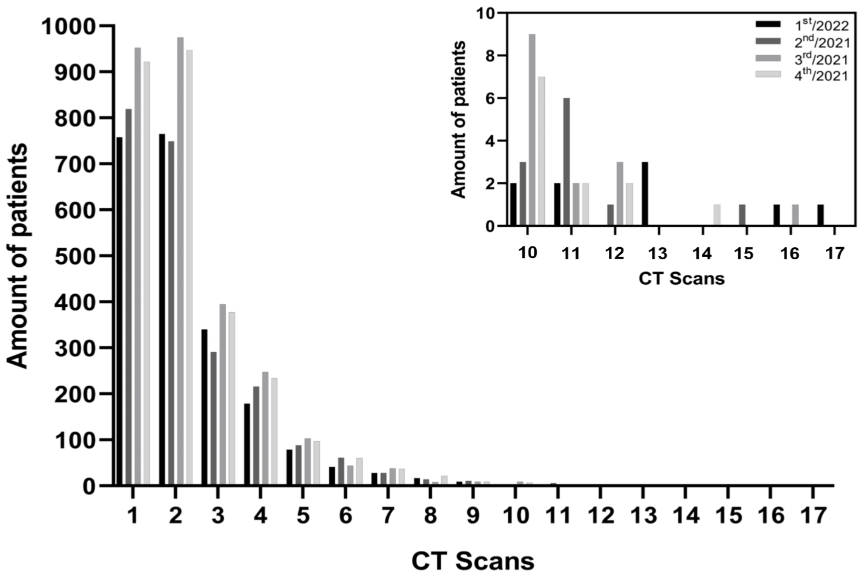
Patients ID	Total number of scans	Number of scans			
		2018	2019	2020	2021
1	29	8	9	6	6
2	40	16	24	0	0
3	30	0	3	6	21
4	28	0	3	25	0
5	33	0	33	0	0
6	20	0	0	0	20
7	62	10	5	42	4
8	25	2	3	16	4
9	21	19	0	2	0
10	26	20	6	0	0

Table 4: Patients who performed alarming amounts of procedures with the same protocol – number of exams by most performed protocols.

ID	Cumulated total dose (mSv)	Number of scans performed	The number of CT scans					
			Pelvis	Chest	Brain/ Skull	Abdomen	Abdomen 3 phases	Kidneys (lithiasis)
A	526	55	27	0	0	7	2	19
B	320	32	13	5	1	0	13	0
C	284	28	12	4	0	1	11	0
D	291	35	9	5	11	6	1	0
E	208	20	8	4	0	0	6	2
F	212	62	1	0	56	1	0	0
G	230	25	9	3	1	0	9	0
H	213	21	9	0	3	4	5	0
I	216	24	8	1	3	4	4	0
J	216	29	4	5	6	3	1	0

The following figure 3 evaluates the number of CT scans performed by the same patient during one month for the second, third, and fourth trimesters of 2021 and the first trimester of 2022.

Figure 3: *Number of patients and the respective number of exams in a month, referring to the 2nd, 3rd and 4th trimesters of 2021 and the 1st trimester of 2022.*



4. DISCUSSION

All CT exams performed over approximately ten years were evaluated in this study. The COVID-19 global pandemic did not significantly affect the number of exams. Medical care based on prescribing images by CT reflects a natural growth in the number of requests for tests performed over the years (Figure 1). Easier access to technology for patients, new image processing techniques, and new CT protocols were some of the factors that contributed to the results. In addition, the hospital in our study is a reference in a vast region of the country. It offers care to the regional health system, and associated companies, which increases the number of consultations performed and patients assisted over time. This increase was observable in all aspects of the hospital, including the number of CT scans.

The main anatomical regions imaged during the study were the brain/skull, pelvis, and abdomen. Thus, these protocols are responsible for 58.4% of all performed exams. In a study published by

Stopsack et al. [21], the most frequent regions were the pelvis, head, and thorax. From these CTs, the abdomen and pelvis were responsible for 87.1% of the radiation dosage in the study [21]. It is interesting to evaluate the cumulative effective dosage simultaneously with the CT exam numbers performed on the patient because there is a considerable ED variation according to the anatomical region. The individual analysis of recurring exam numbers alone does not allow for reasonable conclusions, and it is essential that the exam justification of the responsible physician is evaluated.

When analyzing each patient individually, the recurring exams are grouped into specific years (Table 3) and a few protocols (Table 4) that allow tracking individual parameters. The diagnostic hypothesis, the medical investigation protocols, and the patient's pattern of clinical evolution may justify these results. Patients with high numbers of exams or cumulative ED had CT exam justifications related to general abdominal area (e.g., pain) or specific (e.g., kidney, hepatic or intestinal involvement), oncology follow-up, human immunodeficiency virus, and hydrocephalus. These are the main cases where the same patient undergoes multiple CT scans in a row.

A cumulative effective dose superior to 100 mSv represents a greater probability of causing effects due to radiation exposure [4,5]. When comparing this group of patients with the literature, the result is similar, with approximately 1% of patients fitting into these conditions (Table 1) [21-24]. Frequent repetitive CT scans for the same patient in a short period indicate the need for a more specific and individualized analysis to characterize this behavior. It is not the responsibility of the Medical Physicist to contest a physician's request for a diagnostic exam with ionizing radiation. However, it is their role to verify if the CT exams are justified and adequate, as established by the radiation protection organizations [5,6]. The situation on this matter should be discussed by the institution's radiological protection committee in a multidisciplinary approach to guarantee the entire service quality.

Stopsak et al. [21] showed that an alternative exam that does not use ionizing radiation, such as ultrasonography, was adequate for evaluating nephrolithiasis. Smith-Bindman et al. [25] also compared radiological examinations with and without ionizing radiation for the initial evaluation of patients with suspected nephrolithiasis. The author concluded there was no considerable difference between the diagnosis of both modalities and that patients associated with initial ultrasonography exams had less accumulated exposure to radiation [25]. Accordingly, using alternative imaging exams can effectively reduce the number of patients with large amounts of CT scans.

The American College of Radiology's (ACR) Appropriateness Criteria are guidelines designed to help refer physicians to the most appropriate imaging or treatment decision for specific clinical conditions [26]. Hadley et al. [27], evaluated the impact of the application appropriateness criteria on CT for Trauma and observed significant results on patients' safety and on the hospital's finances, highlighting the importance of these criteria, which must be understood and followed by physicians.

Reports containing statistical information from CT scans should be posted on the hospital's internal communication channels to raise awareness. Interventions should be based on the reduction of unjustified exams to increase the quality of patient care. A request for a new CT exam should only occur after clinical staff communication and the patient's medical record verification, making unfeasible the request for sequential exams without plausible justification.

The collected data underscores the importance of evaluating the cumulative effective dosage in conjunction with the number of exams. It was shown that certain protocols and specific medical conditions contribute to a higher number of CT scans and cumulative effective doses. The results emphasize the critical role of ensuring the justification and adequacy of CT exams, as well as the need for a multidisciplinary approach within the institution's radiological protection committee to discuss alternative imaging modalities and optimize patient care.

5. CONCLUSION

This study evaluated the cumulated dose in patients undergoing CT scans and the repeatability of the exams. The results indicated urgency in developing strategies for individual dose management methods at the local level of the institution.

Thus, based on the results of this study, it is interesting to implement the policy of awareness, appropriateness, and auditing. After the awareness and appropriateness are implemented through training and guidelines elaboration, the audit must be performed, checking weekly exams, and ensuring that the justification principle was conducted in an effective and well-founded way.

The application of professional updating courses to disseminate the importance of exams justification for CT, along with the discussion of alternative imaging modalities when suited, must consider physicians' level of training and clinical field. The intervention must be performed by preparing periodically updated guidelines based on professionals' knowledge, already completed exams, and international protocols such as the ACR criterion [26]. All actions mentioned above serve as a decision-making support and continuous educational consultation tool while minimizing unjustified exams and mitigating patients' exposure.

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