

ORIGINAL ARTICLE

Evaluation of Patient's Received Dose in Abdomen/Pelvis CT Examinations: A Case Study in Lahijan Hospital, Iran

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Abstract

Purpose: Computed Tomography (CT) is a widely used medical imaging technique that employs continuous X-ray radiation. However, compared to other imaging modalities, CT scanning delivers relatively high radiation doses, potentially causing tissue damage and increasing cancer risk. This study aims to assess the radiation dose received by patients during abdominal-pelvic CT examinations, compare it with existing studies, and propose methods to minimize patient dose, thereby reducing associated cancer risks.

Materials and Methods: This study evaluated radiation doses to the liver, stomach, bladder, left kidney, and right kidney in six patients scanned with a Siemens CT scanner. Dosimetry was performed using TLD-GR200 thermoluminescent dosimeters.

Results: Results show that the bladder received the highest average dose, followed by the stomach, liver, left kidney, and right kidney, in that order. Notably, the mean dose to the stomach exceeded that of the bladder, indicating a heightened risk to the stomach. The organ doses measured in this study were consistent with values reported in prior studies and within the Diagnostic Reference Levels (DRLs) recommended by the International Commission on Radiological Protection (ICRP). However, given the stochastic nature of radiation risks, which lack a threshold and can manifest even at doses below 10 mSv, continued efforts to optimize patient dose are imperative.

Conclusion: This study highlights that the bladder receives the highest radiation dose, while the kidneys receive the lowest. The observed organ doses align with ICRP recommendations and prior research. Nonetheless, minimizing radiation exposure remains critical to enhance patient safety without compromising diagnostic efficacy.

Keywords: Dosimetry; Thermoluminescent Dosimeter; Computed Tomography Scan; Abdomen/Pelvis Examinations; Received Dose.

1. Introduction

Humans are continuously exposed to natural radiation sources, including cosmic rays and natural radioisotopes present in soil, water, and air [1]. In addition, industrial and medical sources can expose humans to radiation, either intentionally or unintentionally [2-4]. Medical imaging systems based on X-rays (e.g., CT scans) and γ -rays (e.g., PET scans) are among such medical sources [5]. CT scanning, as one of the x-ray imaging modalities, is increasingly used in disease diagnosis due to its ability to produce detailed tomographic images of the human body, rapid advancements in technology, and improvements in imaging techniques [6-8]. For instance, the number of CT scans performed in the UK increased from 250,000 in 1980 to 5 million in 2013, indicating a nearly 20-fold growth [9]. However, CT scans use continuous x-ray exposure to obtain tomographic images, exposing patients to radiation for durations ranging from a few seconds to tens of seconds, depending on the type of scan. Globally, CT scans constitute only about 6% of all X-ray imaging procedures, yet they account for approximately 43% of the total effective dose patients receive [10]. One of the widely used clinical dosimetry techniques is scintillation dosimetry with Thermoluminescent Dosimeters (TLDs), which are available in forms such as chips, rods, or powders. These detectors are compact, user-friendly, and provide a dependable response, making them well-suited for clinical applications. Lithium Fluoride (LiF), commonly employed in TLDs, is particularly advantageous due to its near-equivalence to human soft tissue in terms of density, which makes it highly suitable for internal dosimetry. Furthermore, experimental studies have confirmed its reliable performance not only in low-dose measurements but also in higher dose ranges, with proven application in clinical radiography and radiotherapy from low μ Gy up to Gy levels, though with somewhat reduced precision compared to the low-dose region [8, 11, 12]. According to ICRP Report 87, the absorbed dose from CT procedures typically ranges from 10 mGy to 100 mGy [13]. Furthermore, as outlined in the National Academy of Sciences' BEIR VII report on the biological effects of ionizing radiation, a dose of 100 mSv in a population of 100,000 could result in cancer in roughly 800 men and 1,300 women. In specific cases, uterine cancer has even been observed with

doses as low as 10 mSv [14]. CT scan procedures generally include three main types: head, chest, and abdomen-pelvis scans. Among these, the abdomen-pelvis scan is one of the most common procedures worldwide. Its imaging protocols are often multiphasic (3 to 4 phases), which imposes a higher effective dose on the patient. Additionally, the abdomen and pelvis contain a larger number of radiation-sensitive organs than other regions, thus increasing the potential for radiation-induced cancer in this area [15, 16]. Since cancer is a stochastic effect of radiation exposure with no dose threshold, CT scanning can elevate a patient's risk of developing cancer [5]. Therefore, limiting the patient's radiation dose in CT scans is crucial according to the ALARA principle (As Low As Reasonably Achievable), and knowing the dose patients receive is essential for this purpose [17]. Accordingly, in most countries, the radiation dose for radiation workers and the general public is monitored continuously or periodically [18-20]. In a study by Nasser Shubayr *et al.*, radiation doses and lifetime attributable risk of radiation-induced cancer in the uterus and prostate from abdomen pelvis CT examinations have been estimated. The mean effective dose resulting from AP CT for females and males was 5.76 ± 3.22 (range: 1.13–12.71 mSv) and 4.37 ± 1.66 mSv (range: 1.36–8.07 mSv), respectively. The mean organ dose to the uterus was 10.86 ± 6.09 mGy (range: 2.13–24.06 mGy). The mean organ dose to the prostate was 7.00 ± 2.66 mGy (range: 2.18–12.94 mGy) [21]. In another study by Ameneh Peiro *et al.*, the total dose received by the pelvis during multi-field radiological examinations to illustrate the importance of observing the patient protection rules for these kinds of examinations has been measured. For the mGy. In the studied multi-field X-ray examinations studied, the measured scattered doses to the pelvis ranged from 2.65 to 15.45 mGy, depending on the number of scanned organs and their distances from the pelvis [22]. In Iran, such measurements have been conducted or are underway in certain provinces [23-25]. Moreover, the International Commission on Radiological Protection (ICRP) periodically reviews both stochastic and deterministic effects of radiation on the human body and publishes permissible radiation dose limits for the public and radiation workers. These guidelines help radiation workers manage their dose levels and protect the public [26,

27]. Knowledge of the radiation dose patients receive in CT scan procedures can lead to strategies for reducing patient dose while maintaining image quality. The objective of this study is to determine the radiation dose received by radiation-sensitive organs in the abdomen-pelvis region during CT abdomen-pelvis scans through experimental methods.

2. Materials and Methods

In this study, the surface dose resulting from abdominal-pelvic CT scans was examined in 6 patients scanned with a Siemens 16-slice CT scanner. Inclusion criteria for patients included complete scanning of the abdominal-pelvic region and informed consent regarding the purpose and procedure of this study. For implementing this protocol, 30 TLD dosimeters of type GR-200 (LiF: Mg, Cu, P with a diameter of 4.5 mm and thickness of 0.9 mm, manufactured in China) were prepared and used for patient dose assessment after calibration. In general, the dosimetry process using TLD involves two main steps: dosimeter calibration and patient dosimetry. Initially, the dosimeters were calibrated in two stages, yielding the Element Correction Coefficient (ECC) and Calibration Factor (CF) for each dosimeter. After calibration and annealing of the TLDs, given that five organs (liver, stomach, bladder, right and left kidneys) were assessed for each patient, a total of 30 calibrated and annealed TLDs were required. To initiate patient dosimetry, the patient's entire body was first scanned to locate the target organs. Then, each TLD was securely placed perpendicular to the organ on the skin and labeled. In cases where contrast material was used, two scans—one with and one without contrast—were performed, with the TLDs remaining in place to record the dose for both stages. In this study, 4 out of 6 patients scanned by the Siemens 16-slice CT scanner underwent dual-phase scans with and without contrast, while the remaining scans were non-contrast. After completion of the scan, the TLDs were removed from the patient's body and read using a TLD reader (model 5500 Harshaw, USA). The CT scanner used in this study was the Siemens 16-slice, with its technical specifications provided in Table 1. Also, the patient information and scan information are shown in Table 2.

In order to extrapolate experimentally measured skin doses to corresponding organ doses, a dedicated Monte Carlo simulation framework was established using the GEANT4 toolkit. The computational phantom was generated from patient-specific imaging protocols (Table 3) by reconstructing a full human body model based on CT scan datasets of the Rando anthropomorphic phantom.

To facilitate dosimetric evaluation, GR200 TLDs were virtually positioned at two distinct levels: (i) on the skin surface corresponding to the anatomical location of each organ, and (ii) within the volumetric region of interest of the target organs. For each organ, a set of 10 TLDs was assigned on the skin, and 10 TLDs were embedded within the organ volume, enabling spatially representative dose sampling.

The absorbed dose for each organ was calculated as the mean value of the TLD readings within the respective region. Subsequently, organ doses were estimated by applying the Correction Ratio (CR) (ratio of organ-to-skin dose), thereby enabling the conversion of experimental skin dose measurements into organ-specific dose equivalents. The helical acquisition was modeled by simultaneous rotation and translation of the X-ray source with a pitch of 1.2083. The dose was scored in 3D voxels, ensuring proper representation of overlapping slices.

3. Results

Since the TLD readings are in nC, dose values (in mGy) can be obtained from the calibration curve using

Table 1. Technical Specifications of the CT Scanners Used

Technical specification	Siemens Scanner
Device Generation	7
Slice	16
Slice Thickness	5
Collimation	16 × 0.7
Tilt	0
Pitch	1.5
Rotation Time	0.8
Rounding time	0.8 s
X-Ray tube	3.5 MHU
Power	32 KW
Voltage	110 V
Current	123 mA

Table 2. The patient information and scan information for Siemens CT scans

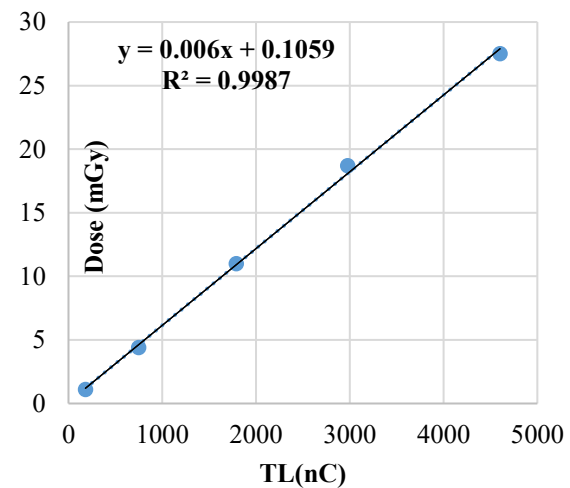
Patient number	Patient information		Scan information	
1	Weight (kg)	42	CTDI _{vol} (mGy)	3.14
	Hight (cm)	160	DLP (mGy.cm)	133.5
	Age (year)	41	H.V (kV)	110
	BMI	16.4	Scan Time (s)	20.26
	----	----	Number of Scans	2
2	Weight (kg)	85	CTDI _{vol} (mGy)	8.80
	Hight (cm)	177	DLP (mGy.cm)	416.5
	Age (year)	60	H.V (kV)	110
	BMI	27.1	Scan Time (s)	22.52
	----	----	Number of Scans	2
3	Weight (kg)	84	CTDI _{vol} (mGy)	7.56
	Hight (cm)	168	DLP (mGy.cm)	479.1
	Age (year)	44	H.V (kV)	110
	BMI	29.8	Scan Time (s)	30.19
	----	----	Number of Scans	2
4	Weight (kg)	72	CTDI _{vol} (mGy)	6.54
	Hight (cm)	170	DLP (mGy.cm)	418.9
	Age (year)	50	H.V (kV)	110
	BMI	24.9	Scan Time (s)	30.47
	----	----	Number of Scans	2
5	Weight (kg)	62	CTDI _{vol} (mGy)	6.11
	Hight (cm)	164	DLP (mGy.cm)	314
	Age (year)	30	H.V (kV)	110
	BMI	23.1	Scan Time (s)	4.60
	----	----	Number of Scans	1
6	Weight (kg)	70	CTDI _{vol} (mGy)	6.3
	Hight (cm)	180	DLP (mGy.cm)	327
	Age (year)	44	H.V (kV)	110
	BMI	21.6	Scan Time (s)	4.60
	----	----	Number of Scans	1

the formula. The calibration curves for the TLDs used are shown in [Figure 1](#).

[Table 4](#) present the dosimetry results for the abdominal and pelvic organs obtained from the Siemens 16-slice CT scanner and converted results, respectively. The data are displayed by patient number, correction ratio, and dose distribution for individual organs, including the liver, stomach, right and left kidneys, and bladder.

Table 3. The patient-specific imaging protocols

Patient Number	Voltage (kV)	Current (mA.s)	Contrast
1	110	39	with and without
2	110	108	
3	110	93	
4	110	81	
5	110	75	without
6	110	76	

**Figure 1.** Calibration curve

4. Discussion

This section interprets the organ dose estimates derived from skin TLD measurements using GEANT4 based skin to organ conversion factors. [Table 4](#) data were available for six patients and five abdominal/pelvic organs (liver, stomach, right kidney, left kidney, bladder). Across the cohort, the bladder received the highest dose, with a mean of 25.20 mGy, followed by the stomach (16.65 mGy), left kidney (13.34 mGy), liver (12.90 mGy), and right kidney (13.00 mGy). The bladder was the maximum dose organ in 5 of 6 patients; in one patient, the left kidney marginally exceeded the bladder. These patterns are consistent with the higher skin doses measured over

the pelvic region and with relatively large conversion factors for deep pelvic anatomy.

Mean CRs exhibited a systematic organ dependence: bladder 0.825, left kidney 0.806, right kidney 0.802, stomach 0.755, and liver 0.722. Thus, for a given skin reading over the organ projection, the expected organ dose is ~72% (liver) to ~83% (bladder) of the local skin dose. The spread of CRs across patients was modest for liver and stomach ($CV \approx 2\text{--}3\%$) and larger for the bladder ($CV \approx 2.9\%$), reflecting both anatomical variability and differences in scan geometry/beam distribution. Because organ dose is computed as $CR \times \text{skin dose}$, inter patient organ dose differences reflect both the local exposure field (skin dose) and organ specific CRs.

Substantial between patient variability was observed. Patients 5–6 consistently showed lower organ doses than Patients 1–4 across all organs (e.g., liver 4.45–10.24 mGy vs. 14.10–17.36 mGy; bladder

13.90–15.22 mGy vs. 31.64–37.14 mGy in patients 2–4). This likely reflects protocol level differences (e.g., mAs, kVp, scan length, and pitch), patient habitus/centering, or z axis coverage. While formal protocol metadata were not part of the dataset, the magnitude of these differences underscores the importance of normalizing organ dose reporting to scanner output metrics ($CTDI_{vol}$, DLP) and scan length in future work. Left–right kidney asymmetry varied by patient, consistent with small differences in lateral positioning or local beam modulation.

In 2015, Hossein Sadra *et al.* estimated the received dose during CT examinations in five hospitals affiliated with Shahid Beheshti University using real data and the ImPACT CT Patient Dosimetry software. According to their study results, the absorbed doses for the bladder and stomach in a single scan were 16.441 mSv and 15.331 mSv, respectively [28]. In 2020, Fuji *et al.* investigated the dose received by 80

Table 4. Dosimetry results

Patient number	Organ	Skin Surface dose (mGy)	Correction ratio	Organ Dose (mGy)
1	liver	19.969	0.706	14.098
	stomach	21.972	0.751	16.500
	right kidney	18.187	0.801	14.56
	left kidney	22.376	0.803	17.967
	bladder	21.254	0.796	16.918
2	liver	22.394	0.731	16.370
	stomach	33.208	0.773	25.669
	right kidney	21.615	0.819	17.702
	left kidney	15.439	0.828	12.783
	bladder	38.443	0.823	31.638
3	liver	23.156	0.732	16.950
	stomach	29.943	0.768	22.996
	right kidney	18.600	0.818	15.214
	left kidney	19.111	0.825	15.766
	bladder	43.644	0.851	37.141
4	liver	23.906	0.726	17.355
	stomach	27.202	0.759	20.646
	right kidney	22.458	0.809	18.168
	left kidney	22.736	0.809	18.393
	bladder	42.929	0.847	36.360
5	liver	6.200	0.717	4.445
	stomach	7.633	0.738	5.633
	right kidney	3.973	0.783	3.110
	left kidney	6.256	0.786	4.917
	bladder	18.654	0.816	15.221
6	liver	11.450	0.717	8.209
	stomach	11.496	0.738	8.484
	right kidney	11.846	0.783	9.275
	left kidney	13.023	0.786	10.236
	bladder	17.035	0.816	13.900

adult patients undergoing chest-abdomen-pelvis CT scans using Monte Carlo simulations and a human-like phantom, examining the effect of Tube Current Modulation (TCM) on reducing both the absorbed and effective doses for patients. Without TCM, the absorbed doses for the liver, stomach, and bladder in both simulation and actual measurements were nearly identical; however, with TCM, the real measurements for liver, stomach, and bladder doses were 2-3 mGy higher than the simulation results. Notably, TCM reduced the organ doses by up to 7 mGy. The absorbed doses for the liver, stomach, and bladder in Fuji's study were nearly twice as high as those found in the current study with the Siemens 16-slice CT scanner, potentially due to higher CTDI_{vol} and DLP values, which were approximately three times greater than those in the present study [19].

In addition, the CT Dose Index CTDI_{vol}) (and Dose-Length Product (DLP) values used for abdomen-pelvis scans with the Siemens 16-slice CT scanner ranged from 3.14-8.8 mGy and 133.5-479.1 mGy.cm, respectively. National reference values for CTDI_{vol} and DLP in abdomen-pelvis CT exams are 14 mGy and 650 mGy.cm, respectively [29], both of which are higher than those observed in the current study. Findings from the 2017 study by Alkhoraief *et al.* indicated significant variations in dose levels across different CT scan types and from one machine to another. Therefore, differences between reported doses in various abdomen-pelvis CT studies and those found in this study are not unexpected. Since most studies do not report the doses received by all organs in the abdomen and pelvis region, direct comparison of this study's results with previous studies is challenging [30].

Overall, the CT dose values obtained in this study do not exceed the doses reported in prior studies or the diagnostic reference doses recommended by the ICRP. However, based on data from BEIR VII [31] and the potential for malignancies at doses of 10 mSv and even lower (following a linear no-threshold dose-response model), it is recommended, in line with the ALARA principle, to use alternative imaging methods such as MRI or ultrasound whenever possible to minimize malignancy risk in patients. If CT imaging is necessary, scan settings should be optimized to reduce absorbed doses in sensitive organs without compromising image quality. Timely quality control

of the scanner, the use of tube current modulation, selecting a higher pitch factor in helical mode, reducing scan length, and employing protective shielding can effectively reduce patient dose.

5. Conclusion

Today, CT scanning is one of the most widely used imaging modalities for evaluating internal organs. Given the relatively high radiation exposure associated with this technique, accurate assessment of organ-absorbed dose is essential, particularly for radiosensitive structures. In the present study, the absorbed doses to abdominal-pelvic organs of actual patients were measured using GR-200 TLD dosimeters, with skin-to-organ dose conversion performed via GEANT4-based correction ratios. The results demonstrated that the bladder consistently received the highest radiation dose, ranging from approximately 13.9 to 37.1 mGy across patients, reflecting both its anatomical location within the primary beam and variations in scan parameters. The liver and stomach absorbed intermediate doses (liver: ~4.4–17.3 mGy; stomach: ~5.6–25.7 mGy), whereas the right and left kidneys showed the lowest doses overall (right kidney: ~3.1–18.2 mGy; left kidney: ~4.9–18.4 mGy). These organ-specific dose distributions are consistent with anatomical positioning relative to the x-ray beam path and with prior literature. Importantly, all measured values remained within the ranges reported in previous studies and below the diagnostic reference levels recommended by the ICRP, supporting the safety of the applied protocols while underscoring the need for continued optimization to further minimize unnecessary exposure.

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