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Evaluation of Organ Doses to Female Reproductive System During Abdominal CT Imaging: A Phantom Study

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ABSTRACT

Introduction: This study aimed to determine the absorbed radiation doses in radiosensitive female pelvic organs during abdominal computed tomography (CT) imaging using thermoluminescent dosimeters (TLD-100) and an anthropomorphic phantom.

Methods: A Computerized Imaging Reference Systems, Inc. female pelvic anthropomorphic phantom was used to simulate realistic human anatomy. TLD-100 dosimeters were positioned within organ-equivalent cavities corresponding to the ovaries, uterus, and urinary bladder. CT scans were performed using a Toshiba Aquilion 64-slice scanner with standard abdominal parameters (120 kVp, 300 mA, 5 mm slice thickness, pitch 1.0). After exposure, TLDs were read using a Harshaw 3500 reader, and organ doses were calculated based on calibration coefficients.

Results: The urinary bladder exhibited the highest mean absorbed dose (27.89 mGy), followed by the fundus uteri (26.34 mGy), left ovary (23.22 mGy), cervix uteri (21.88 mGy), and right ovary (20.91 mGy). Lower doses were measured in deeper or more peripheral regions, such as the recessus rectouterina (19.37 mGy) and the medulla spinalis (16.73 mGy).

Conclusion: The results indicate that even under standard clinical protocols, radiosensitive organs of the female reproductive system receive measurable radiation doses during abdominal CT. These findings emphasize the need for protocol optimization and shielding strategies to minimize exposure, especially in reproductive-age women.

Keywords: Experimental dosimetry, phantom study, female reproductive system

Introduction

One of the most popular imaging modalities in diagnostic radiology is computed tomography (CT), which produces high-resolution cross-sectional pictures that enable in-depth analysis of interior organs and anatomical structures (1). It is essential for the evaluation of abdominal and pelvic disorders, including neoplastic, inflammatory, and traumatic conditions, because of its speed, diagnostic precision, and accessibility. The evaluation of gynecologic tumors, staging of pelvic malignancies, identification of metastatic illness, monitoring of treatment response, and differential diagnosis of acute abdominal discomfort are among the various uses of CT of the female reproductive system in clinical practice (2,3). Additionally, CT can be used in emergency settings when magnetic resonance imaging (MRI) or ultrasound are unavailable or inconclusive (4). Nevertheless, CT produces comparatively larger radiation doses than other imaging methods despite its clinical benefits, making up between 60 and 70 percent of all medical radiation exposure globally (5). The rising frequency of CT scans, particularly in women of reproductive age, has raised concerns about unnecessary radiation exposure to radiosensitive organs such as the ovaries, uterus, and bladder. Optimizing imaging procedures and guaranteeing patient safety in such situations require an understanding of the radiation doses specific to each organ. Ionizing radiation is especially dangerous to the female reproductive system, which includes radiosensitive organs such as the uterus, ovaries, and bladder. Even though they are not the imaging objective, these organs are frequently found inside or close to the primary beam during abdominal and pelvic CT exams, resulting in quantifiable radiation exposure (6). Because the ovaries have a limited supply of germ cells, exposure to ionizing radiation can result in temporary or permanent

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infertility, depending on the patient's age and the radiation dose. The uterus is composed of proliferative, vascularized tissues. Reproductive outcomes may be affected by predictable effects, including fibrosis and endometrial shrinkage. Despite not being a reproductive organ, the bladder is physically close to the pelvic structures and receives a comparatively higher dose because of its central location and close proximity to the scan field (7,8).

Deterministic or stochastic biological consequences, such as decreased fertility, teratogenic results in women of reproductive age, and an elevated lifetime risk of radiation-induced cancers in radiosensitive pelvic tissues, can arise from even low to moderate radiation doses (9). Precise measurement of organ-specific absorbed doses in abdominal CT imaging is crucial to assess potential hazards and optimize radiation protection procedures for female patients.

Using anthropomorphic phantoms and a range of dosimetric devices, including thermoluminescent dosimeters (TLDs), optically stimulated luminescence dosimeters (OSLDs), and metal oxide semiconductor field-effect transistors (MOSFETs), a number of studies have recently examined organ-specific dose distributions during CT imaging (10,11). Regarding sensitivity, spatial resolution, and reusability, each system offers unique benefits. Because of its near-tissue equivalency, high sensitivity to low photon energies, linear dose-response characteristics, and capacity to measure cumulative absorbed dose over multiple exposures, TLD-100 (LiF:Mg,Ti) continues to be one of the most dependable and extensively used detectors in medical physics research. TLDs are especially well-suited for dose measurement in CT applications because they show no energy dependency within the diagnostic X-ray range (12).

The Computerized Imaging Reference Systems (CIRS), Inc. ATOM® female model and other anthropomorphic phantoms are essential for measuring radiation exposure in practical healthcare settings. Dosimeters may be precisely localized within organ-equivalent cavities or slices using these phantoms, which are constructed from tissue-equivalent materials that replicate the radiological characteristics of human organs. Anthropomorphic phantoms, in contrast to basic geometric or aqueous phantoms, mimic the intricate anatomical interactions among organs and account for variations in attenuation, dispersion, and absorption across different tissues. These setups preserve repeatability and control over imaging settings while enabling precise calculation of organ doses. Additionally, multiple dosimetric studies have demonstrated that the combination of anthropomorphic phantoms and TLD-100 dosimetry yields dose measurements that closely correlate with Monte Carlo simulation results and patient-derived dosimetric data, thereby validating their reliability for experimental radiation dose assessment in diagnostic radiology.

To measure the radiation doses absorbed by vital organs of the female reproductive system, this study used a CIRS female anthropomorphic phantom to simulate a realistic clinical scenario for abdominal CT imaging. We aimed to experimentally replicate the dose distribution that occurs during standard diagnostic CT procedures by positioning TLD-100 dosimeters in organ-equivalent regions of the phantom. This could provide information to help optimize dosing and protective measures for female patients.

Despite the increasing number of CT examinations, limited experimental dosimetric data that specifically quantify radiation doses to individual female pelvic organs using anthropomorphic phantoms with precisely placed detectors. Addressing this gap, the present study aims to experimentally evaluate organ-specific absorbed doses to radiosensitive female pelvic organs during abdominal CT imaging, using TLD-100 dosimeters positioned within a CIRS anthropomorphic female phantom. By replicating a realistic clinical imaging scenario, this study provides experimentally derived dose data that may contribute to improved radiation protection and dose optimization strategies for female patients undergoing CT examinations.

Based on this framework, we hypothesized that radiosensitive female pelvic organs receive measurable and clinically relevant radiation doses during routine abdominal CT examinations, and that these doses can be quantified experimentally using anthropomorphic phantom-based TLD-100 dosimetry.

Methods

Ethical approval for this study was obtained from a certified University of Health Sciences Türkiye, İstanbul Training and Research Hospital Clinical Research Ethics Committee (approval number: 281, date: 07.11.2025). As this study involved only phantom measurements and did not include human participants, informed consent was not required.

In this experimental dosimetric work, the human pelvic anatomy was simulated for dose quantification in abdominal CT using a CIRS anthropomorphic female pelvic phantom (Norfolk, Virginia, USA) (13).

As shown in Figure 1, the phantom represents the female lower abdomen and pelvic region and consists of axial slices that mimic the radiological features of the human body. Each slice is approximately 2.5 cm thick and is labeled numerically from superior to inferior (sections 1–16 anteriorly and 28–38 posteriorly), allowing reproducible alignment during assembly and consistent dosimeter placement across measurements.

The phantom enables realistic simulation of X-ray attenuation and scatter during CT imaging by replicating major pelvic structures such as the bladder, uterus, ovaries, rectum, and the surrounding soft tissues. Because of its modular architecture, dosimeters could be inserted at certain anatomical levels corresponding to clinical imaging planes and in organ-equivalent cavities. Exterior reference lines and numbering visible on the phantom's anterior and posterior surfaces facilitated precise slice identification and repositioning between scans.

TLDs (TLD-100, LiF:Mg,Ti), which are frequently used for diagnostic X-ray dosimetry due to near-tissue equivalency, high sensitivity, and repeatability, were utilized to assess radiation doses. To remove any residual signals, all TLD chips were annealed in a nitrogen atmosphere at 400 °C for one hour and at 100 °C for two hours prior to exposure. A reference X-ray beam (120 kVp, 10 mm Al filtration), traceable to a secondary standards dosimetry facility, was used to calibrate the dosimeters. Calibration procedures were performed at a national Secondary Standard Dosimetry Laboratory accredited for diagnostic X-ray dosimetry. The measured charge values were then converted into absorbed doses using the calibration coefficients (mGy/nC) obtained.

The overall measurement uncertainty associated with the TLD system, including calibration and reader-related factors, is typically reported to lie within 5–10% for diagnostic X-ray energy ranges.

TLD-100 dosimeters were positioned in organ-equivalent areas of the CIRS female pelvic anthropomorphic phantom to assess absorbed doses during abdominal CT imaging, as illustrated in Figure 2 and described in Table 1. The bladder, uterus, bilateral uterine tubes, right and left ovaries, rectum, and soft-tissue backdrop areas were all designated as cavities into which dosimeters were placed. To provide precise anatomical localization, each cavity was carefully chosen based on distinguishable bony features seen on the appropriate axial slices of the phantom.

For anatomical orientation, the uterine tubes extend laterally from the uterine cornua within the true pelvis, while the ovaries are located on the lateral pelvic wall within the ovarian fossa (14-17). The uterus is positioned centrally between the bladder anteriorly and the rectum posteriorly, reflecting its normal anatomical relationship (17,18). This anatomical framework facilitated accurate placement of TLD-100 detectors within organ-equivalent regions of the phantom.

Figure 1. Anterior (left) and posterior (right) views of the CIRS anthropomorphic female pelvic phantom used in this study. The numbered axial sections allow accurate localization and reproducible placement of TLD-100 dosimeters within organ-equivalent cavities for radiation dose measurements during abdominal CT imaging. CIRS: Computerized Imaging Reference System, CT: Computed tomography

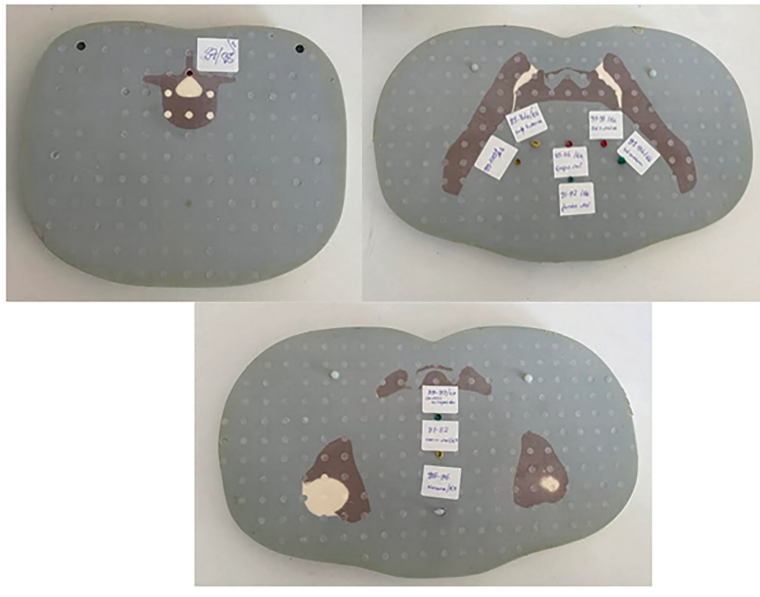

Figure 2. Dosimeters were inserted into cavities corresponding to the ovaries, uterus, and urinary bladder to measure absorbed doses during abdominal CT examinations. CT: Computed tomography

Table 1. Placement of TLD-100 dosimeters in organ-equivalent regions of the CIRS female pelvic phantom

Slice	Organ	TLD Number	TLD count per organ
1	Spinal cord	87–88	2
6	Right ovary	99–100	2
6	Left ovary	93–94	2
6	Uterine tube-right	83–84	2
6	Uterine tube-left	97–98	2
6	Corpus uteri	85–86	2
6	Fundus uteri	91–92	2
7	Bladder	95–96	2
7	Cervix uteri	81–82	2
7	Recessus rectouterina	89–90	2

A Toshiba Aquilion 64-slice CT scanner (Japan) was used to acquire CT images. To guarantee precise reproducibility, the CIRS female pelvic anthropomorphic phantom was placed supine on the scanner table and oriented at the isocenter using the integrated laser positioning system (see Figure 3). To replicate clinical imaging protocols commonly used in female patients, a standard abdominopelvic CT procedure was chosen.

The scanning parameters were: tube voltage of 120 kVp, tube current of 300 mA, rotation duration of 0.75 s, pitch of 1.0, and slice thickness of 2 mm. The entire pelvic region was covered by the scan length, which ran from the level of the iliac crest to the inferior boundary of the ischial tuberosities. Using the helical scan mode (GG-Hel), the field of view was adjusted to 552.3 mm (XL mode). The overall scan time was approximately 21 seconds, and the effective mAs was 240. To maintain consistent parameters during the process, automatic exposure control (AEC) was turned off. For optimal soft-tissue contrast visualization, the reconstruction matrix was set to 512 × 512 pixels, and the window level and window width were adjusted to 90 and 140, respectively. The total dose-length product for the acquisition was approximately 1143.7 mGy·cm, and the CT dose index volume was 26.9 mGy, as recorded on the scanner console.

Statistical Analysis

Because the study was limited to TLD placement on the CIRS anthropomorphic female pelvic phantom and direct dose readouts, no statistical analysis was required.

Results

The phantom image, which confirms correct positioning of the phantom within the CT scanner and full coverage of the targeted pelvic anatomy by the scanning area, provides crucial validation of the experimental setup (see Figure 4). The phantom's tissue-equivalent composition faithfully mimics human anatomy, as evidenced by the clear difference between bone and soft-tissue densities. An internal validation of the anatomical precision of TLD placement was achieved by visualizing specific pelvic organs on the obtained CT images. As a result, the radiation doses measured in organ-equivalent regions using TLD-100 dosimeters can be regarded as representative of those in actual clinical settings.

Following CT imaging, absorbed doses measured by TLD-100 dosimeters placed in the organ regions of interest of the CIRS female pelvic phantom were examined. Table 2 displays the measured mean organ doses (mGy) for each anatomical structure.

Discussion

The study objectively evaluated, using an anthropomorphic female phantom and a TLD-100 dosimeter, the radiation doses absorbed by radiosensitive female pelvic organs during abdominal CT scans. According to experimental results, the uterine fundus (26.34 mGy), the left ovary (23.22 mGy), and the bladder (27.89 mGy) received the highest

Figure 3. Positioning of the CIRS female pelvic anthropomorphic phantom on the Toshiba Aquilion 64-slice CT scanner. The phantom was placed in the supine position and aligned at the scanner isocenter using the built-in laser positioning system to ensure reproducible imaging geometry during abdominal–pelvic CT acquisitions. CIRS: Computerized Imaging Reference System, CT: Computed tomography

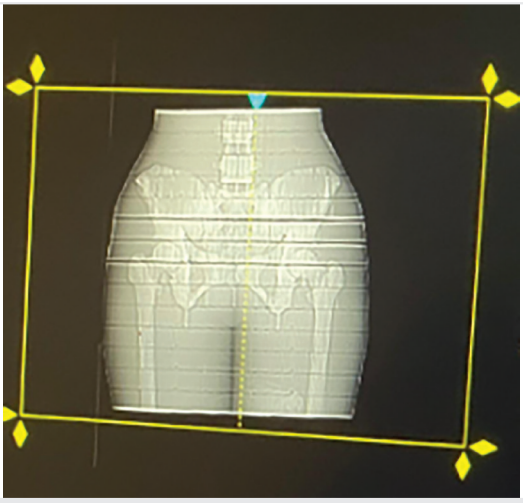

Figure 4. Computed tomography image of the CIRS female pelvic anthropomorphic phantom acquired with the Toshiba Aquilion 64-slice scanner. CIRS: Computerized Imaging Reference Systems

Table 2. Mean absorbed doses measured by TLD-100 dosimeters in female pelvic organs during abdominal CT imaging

Organ	Dose (mean mGy)
Spinal cord	16.73
Right ovary	20.91
Left ovary	23.22
Uterine tube-right	20.75
Uterine tube-left	21.57
Corpus uteri	21.35
Fundus uteri	26.34
Bladder	27.89
Cervix uteri	21.88
Recessus rectouterina	19.37

TLD: Thermoluminescent dosimeter, CT: Computed tomography

mean absorbed doses. These findings align with the anatomical position of the pelvic structures with respect to the CT beam path.

During abdominal CT scans, the bladder, located centrally in the pelvis, occupies the anterior region directly aligned with the primary X-ray beam. The bladder's higher absorbed dose, compared with surrounding organs, can be explained by its relatively large volume and proximity to the beam isocenter. Because the fundal area of the uterus is located above the bladder, it is particularly vulnerable to both primary and scattered radiation. The ovaries, situated laterally, close to the iliac fossae, were exposed to moderate doses (20.91-23.22 mGy), suggesting that the surrounding soft tissues were partially spared, but dispersed radiation exposure persisted.

The range of variability documented in earlier clinical research is consistent with our measured ovarian and uterine dose levels. Depending on scanner technology, Obed et al. (19) reported uterine doses of 12–43 mGy and ovarian doses of 11–33 mGy. Bladder and gonadal doses of 13.6±1.9 mGy and 13.0±1.9 mGy, respectively, were reported by Gao et al. (20). The relatively higher values observed in the present study may be related to differences between phantom-based experimental conditions and patient-based measurements, including variations in tissue composition and attenuation characteristics.

Furthermore, our study provides direct organ-specific dose measurements obtained by anatomically accurate placement of TLD-100 detectors within an anthropomorphic phantom, thereby addressing limitations highlighted in previous studies such as the lack of phantom-based validation reported by Obed et al. (19). In a recent large-scale patient-based investigation, Shubayr and Alashban (21) analyzed 665 abdomen–pelvis CT examinations and reported a mean uterine dose of 10.86±6.09 mGy (range: 2.13–24.06 mGy). These values are lower than the doses observed in our phantom measurements (21.35–26.34 mGy for the uterus), a difference that may reflect clinical variability in patient anatomy, scanning protocols, and physiological conditions. Phantom-based and patient-based studies together provide complementary information for understanding radiation exposure of female reproductive organs during pelvic CT imaging.

The rectouterine recessus (Douglas's pouch), a posterior pelvic anatomical landmark, was incorporated into the study to further assess the spatial dosage gradient. This region's significantly lower absorbed radiation (19.37 mGy) supports the intrinsic attenuation resulting from deeper soft tissue and sacral shielding. This measurement is crucial for radiation protection because it facilitates accurate scan length optimization and avoids needless exposure of posterior pelvic structures, such as bowel loops.

From a clinical standpoint, this study emphasizes the importance of optimization techniques, such as AEC, iterative reconstruction, and scan-interval minimization to reduce exposure while preserving diagnostic quality, because even standard abdominal CT protocols deliver specific doses to the reproductive organs.

Study Limitations

This study has several limitations. First, the measurements were performed using a single CT scanner and acquisition protocol, which may limit the generalizability to other CT systems or clinical protocols. Second, the study was conducted using an anthropomorphic phantom rather than on real patients. Although such phantoms are widely used in experimental dosimetry studies and provide controlled and reproducible measurement conditions, they cannot fully represent patient-specific anatomical variability and tissue heterogeneity.

Another limitation is that only TLD-100 dosimeters were used for dose measurements. Comparisons with other dosimetric techniques such as OSLDs, MOSFET detectors, or Monte Carlo–based dose simulations were not included. Future studies should incorporate multiple scanners, different CT protocols, advanced dosimetric techniques, and computational simulations to further validate and extend the present findings.

Conclusion

Using a realistic anthropomorphic female phantom and TLD-100 dosimetry, this study showed that radiosensitive female pelvic organs receive clinically relevant radiation doses during abdominal CT imaging, with a distinct dose gradient varying with anatomical position. The

following basic radiation protection principles corroborate the study's findings:

Justification: Ionizing radiation scans (such as CT) should only be performed when clinically indicated; whenever possible, alternatives such as ultrasonography or MRI should be considered.

Optimization (as low as reasonably achievable): Using dose-modulated technology, clinicians should adjust the scan parameters to the patient's anatomy and diagnostic requirements.

Dose awareness: Patient safety depends on ongoing dose index monitoring and adherence to DRLs.

These results emphasize the significance of protecting the reproductive organs in clinical female pelvic CT applications and offer insights into patient-centered dose optimization techniques.

Ethics

Ethics Committee Approval: Ethical approval for this study was obtained from a certified University of Health Sciences Türkiye, İstanbul Training and Research Hospital Clinical Research Ethics Committee (approval number: 281, date: 07.11.2025).

Informed Consent: As this study involved only phantom measurements and did not include human participants, informed consent was not required.

Footnotes

Authorship Contributions: Concept - D.T.K., B.Y., A.Ö.A., O.G., M.D., F.F.K.; Design - D.T.K., B.Y., M.D., F.F.K.; Data Collection or Processing - D.T.K., B.Y., Ö.C.S., F.F.K.; Analysis or Interpretation - B.Y., Ö.C.S., O.G., M.D., F.F.K.; Literature Search - D.T.K., A.Ö.A., Ö.C.S.; Writing - D.T.K., Ö.C.S., F.F.K.

Conflict of Interest: No conflict of interest was declared by the authors.

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