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Estimation of radiation doses and lifetime attributable risk of radiation-induced cancer in the uterus and prostate from abdomen pelvis CT examinations

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Computed tomography (CT) scans are one of the most common radiation imaging modalities, and CT scans are rising steadily worldwide. CT has the potential to enhance radiography practice, but it also has the risk of drastically increasing patient doses. One CT procedure for the abdomen pelvis (AP) area can expose a patient's prostate or uterus to a substantial radiation dose, leading to concerns about radiation-induced cancer. This study aimed to estimate organ doses of the uterus and prostate and evaluate the lifetime attributable risk (LAR) of cancer incidence and mortality resulting from AP CT examinations. This retrospective study included 665 patients, of which 380 (57%) were female, and 285 (43%) were male. Data were collected from the picture archiving and communication system for AP CT procedures and exposure parameter data. Organ doses for the uterus and prostate were calculated using National Cancer Institute CT (NCICT) software. Based on the risk models proposed by the BEIR VII report, the calculated organ doses were used to estimate the LAR of prostate and uterus cancer incidence and mortality due to radiation exposure from AP CT procedures. 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). The LAR of uterus and prostate cancer incidence was 1.75 ± 1.19 cases and 2.24 ± 1.06 cases per 100,000 persons, respectively. The LAR of cancer mortality rates from uterus and prostate cancers were 0.36 ± 0.22 and 0.48 ± 0.18 cases per 100,000 persons, respectively. The LAR of prostate and uterus cancer occurrence and mortality from radiation doses with AP CT procedures was low but not trivial. Therefore, efforts should be made to lower patient doses while retaining image

quality. Although the minimization of the patient's radiation dose must guide clinical practice, the estimated slight increase in risk could aid in easing fears regarding well-justified AP CT procedures.

1. Introduction

Computed tomography (CT) is a cross-sectional radiation imaging modality that significantly impacts medical diagnosis (1). This modality uses multiple energies and intensities to generate detailed two-dimensional and three-dimensional images and volumetric images of different body parts (2, 3). In recent years, the use of CT has increased considerably, with roughly 70 million CT procedures conducted annually in the USA (4, 5). In other countries, such as the Netherlands, the number of CT procedures doubled from around 580 thousand in 2002 to about 1.16 million in 2010 (1). Organ doses from conventional X-ray procedures are considerably smaller than those associated with CT procedures (6). Accordingly, CT procedures are the main contributors to the collective dose from all medical radiation procedures (7, 8). Although CT procedures make up only 5% of all X-ray exams, they contribute 40–67% of the overall medical dose [9] and are predicted to increase by around 10–15% yearly (9). Epidemiological studies have linked low levels of exposure to ionizing radiation in medical imaging procedures to the development of cancer and radiation-related diseases (10, 11).

Low-dose radiation risk is controversial, with claims that low-dose risks are overestimated (12) or underestimated (13, 14) using linear extrapolation from moderate-dose exposed groups. The linear no-threshold (LNT) model of ionizing radiation–induced cancer assumes that every increment of radiation dose, no matter how small, constitutes an increased cancer risk for humans. The assumption underlying the LNT model, frequently adopted by expert advisory bodies (15), that the risk at low doses is nearly linear with dose is a question of whether a low-dose risk exists. Although there is some radiobiological support for LNT based on DNA damage considerations, it is acknowledged to be an estimate made for practicality in the context of radiological protection. In fact, a substantial body of evidence suggests that there is considerable evidence of cancer risk at low doses (16, 17).

The survivors of the atomic bombings in Hiroshima and Nagasaki are one of the most important sources of information on radiation risks. Long-term survivors of the Hiroshima and Nagasaki atomic bombs, who were exposed to radiation doses, have been shown to have an increased risk of cancer (18–21). In a follow-up from 1958 to 2009, recent studies investigated the incidence of prostate and uterine cancer in a cohort of atomic bomb survivors from the Life Span Study, which included 62,534 women and 41,544 men. A study demonstrated a substantial linear dose response for prostate cancer, with an estimated excess relative risk (ERR) per Gy of 0.57 (22). The study concluded that "the observed dose response strengthens the evidence of a radiation effect on the risk of prostate cancer incidence in the atomic bomb survivors" (22). In addition, an increased risk of prostate cancer has been found after X-ray treatment for ankylosing spondylitis (23) and in a subset of nuclear workers who were internally exposed to various radionuclides (24). The study of female atomic bomb survivors found a significant association between radiation dose and risk of uterine cancer (ERR/Gy of 0.73), especially for exposure occurring in mid-puberty, but not for either early childhood or adult exposures (25). Increased corpus cancer risk has been reported in several studies of high-dose radiotherapy patients (26–28) and in one study of radiation workers (29).

In abdominal pelvic (AP) CT, the prostate and uterus are exposed to direct radiation, which can pose health risks to patients. Even though the radiation risk to any given patient may be low, the growing number of persons exposed and the rising radiation dose per procedure could lead to a significant number of cancer incidents directly related to radiation exposure from CT. It is crucial to understand how much radiation is supplied to patients during CT procedures to properly balance the probability of harm and the potential benefits. This is especially important because the threshold for using CT has been lowered and is now being used more frequently on healthy individuals in whom the risk of potential CT-induced carcinogenesis may outweigh its diagnostic usefulness. Therefore, this study aimed to estimate organ doses of the uterus and prostate and evaluate the lifetime attributable risk (LAR) of cancer incidence and mortality resulting from AP CT examinations.

2. Materials and methods

2.1. Study design

This retrospective study was conducted over 1 year at two general hospitals in Jazan, Saudi Arabia. The radiology departments included in this study were equipped with Siemens Somatom 64 CT scanners and GE Lightspeed 16 CT scanners. This study was approved by the ethics

TABLE 1 Mean values ± SD of CTDIvol, DLP, and scan length for AP CT examinations.

Gender	Age groups	N (%)	CTDIvol (mGy)	DLP (mGy.cm)	Scan length (cm)
Female	18–35	125	13.37 ± 7.2	611.32 ± 368.38	44.64 ± 13.17
	36–55	140	13.61 ± 8.12	537.07 ± 359.49	39.08 ± 11.73
	>55	115	17.67 ± 8.93	799.3 ± 497.16	41.92 ± 10.38
	Overall	380 (57)	14.76 ± 8.21	640.86 ± 417.69	41.77 ± 11.92
Male	17–35	80	10.93 ± 5.57	531.13 ± 310.31	47.52 ± 14.93
	36–55	120	13.72 ± 4.51	669 ± 246.84	50.04 ± 12.96
	>55	85	12.17 ± 3.28	657.64 ± 336.27	52.35 ± 19.28
	Overall	285 (43)	12.51 ± 4.73	623.29 ± 288.98	49.75 ± 14.89

TABLE 2 Mean values ± SD of effective dose and organ dose to the uterus and prostate from AP CT examinations.

Age groups	17–35	36–55	>55	Overall
Female				
Uterus dose (mGy)	9.79 ± 5.21	9.99 ± 6.05	13.07 ± 6.68	10.86 ± 6.09 (2.13–24.06)
Effective dose (mSv)	5.19 ± 2.75	5.31 ± 3.21	6.93 ± 3.53	5.76 ± 3.22 (1.13–12.71)
Male				
Prostate dose (mGy)	6.11 ± 3.11	7.65 ± 2.55	6.83 ± 1.89	7.00 ± 2.66 (2.18–12.94)
Effective dose (mSv)	3.82 ± 1.94	4.78 ± 1.59	4.26 ± 1.18	4.37 ± 1.66 (1.36–8.07)

FIGURE 1
Distribution of organ doses to the uterus and prostate from AP CT examinations.

committee of Jazan University in Jazan, Saudi Arabia (approval number: REC/44/788).

2.2. Study population and data collection

The study population was comprised of adult patients. Patient demographic data, including age and gender, were collected. Data were collected from the picture archiving and communication system (PACS). The collected data included the AP CT and exposure parameter data [CT dose index (CTDIvol) and dose-length product (DLP), and scan length]. Incomplete examinations, such as those missing one or more acquisitions, were excluded from the analysis.
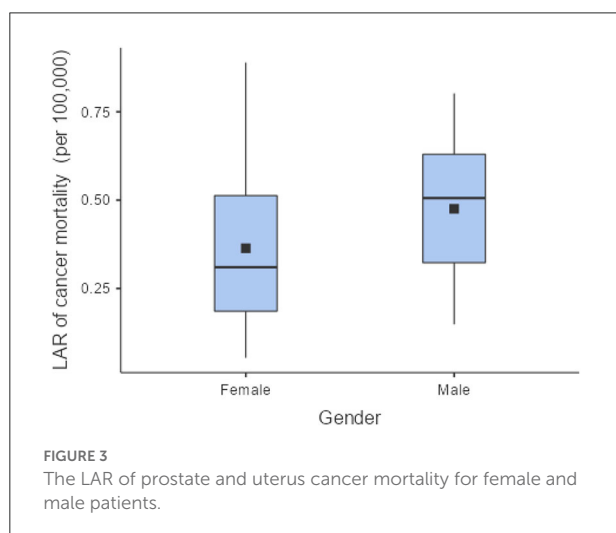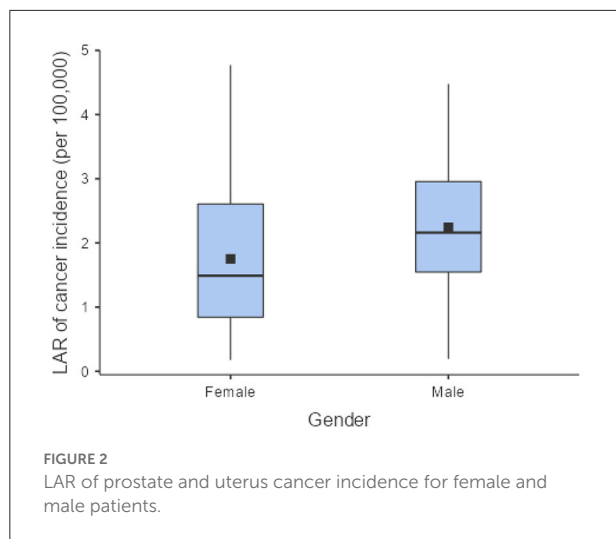
2.3. CT dosimetry

The National Cancer Institute CT (NCICT) dosimetry tool was used to calculate the organ doses of the prostate and uterus. The NCICT dosimetry tool is a massive library of precomputed
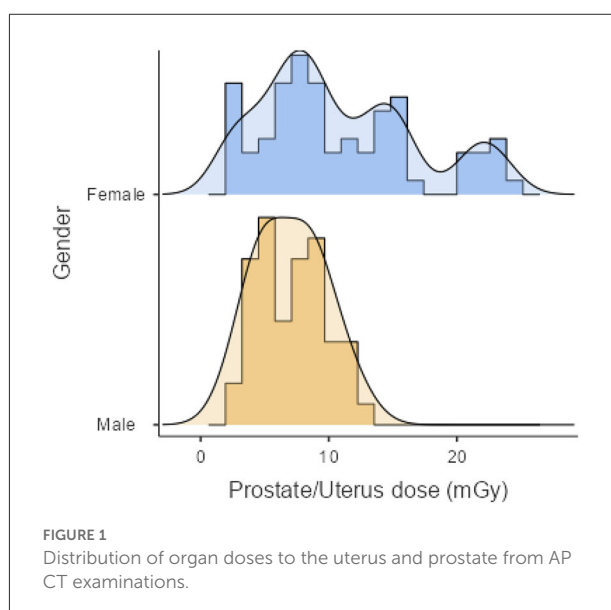
dose factors for various computational phantoms linked with Monte Carlo radiation transport methodologies (30). The dose factors (milligray/milligray) were calculated while considering various phantom sizes, which are the organ-absorbed dose (millgrays) normalized to the CTDIvol (millgrays) of the reference scanner. The absolute organ doses were estimated by multiplying the dose factors by the reported CTDIvol (milligrays) for each CT scanner of interest (milligrays). Lee et al. (30) reported on the intricate methods employed in organ dose calculations. The effective dose resulting from AP CT scans was also obtained using the NCICT.

2.4. Radiation risk assessment

By extrapolating from the risk estimated at high doses, LNT model has been the standard risk assessment utilized by

FIGURE 2
LAR of prostate and uterus cancer incidence for female and male patients.

FIGURE 3
The LAR of prostate and uterus cancer mortality for female and male patients.

the radiation protection community to determine the health effects associated with low doses (15, 31, 32). The risk models proposed by the BEIR VII (2006) report describe a technique to approximate the LAR of cancer based on the amount of a single radiation dose and a patient's age (32). LAR is defined as an additional cancer risk above and beyond baseline cancer risk. The age- and sex-specific LAR of the uterus and prostate cancer incidence and mortality for organ doses were calculated using BEIR VII risk estimates.

2.5. Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS version 20, IBM, Somers, NY, USA). Descriptive statistics of the continuous data were presented as mean ± SD. Inferential statistical tests, independent

samples t-tests and one-way analysis of variance (ANOVA), were performed to determine if gender and age groups are significantly different from each other on CTDIvol, DLP, scan length, effective and organ doses, with $p < 0.05$ considered statistically significant.

3. Results

### 3.1. Demographic and CT acquisition parameters

As illustrated in Table 1, the study included 665 CT procedures for adult patients with 380 (57%) females [mean age, 43.58 ± 17.74 years; range, 18–82 years], and 285 (43%) males [mean age, 42.79 ± 15.69 years; range, 18–80 years]). The AP CT were distributed among age groups as 31% for 18–35 years, 39% for 36–55 years, and 30% for >55 years. The mean DLP and CTDIvol values were higher for females compared to male patients, with no statistically significant differences. The mean scan length for male patients (49.75 ± 14.89 cm) was higher than for females (41.77 ± 11.92 cm), with statistically significant differences ($p = 0.001$).

3.2. Effective and organ dose estimations

As shown in Table 2, the mean effective doses resulting from AP CT for females and males were 5.76 ± 3.22 (range: 1.13–12.71 mSv) and 4.37 ± 1.66 mSv (range: 1.36–8.07 mSv), respectively. Mean organ doses for older age groups were higher than younger age groups, with statistically significant differences ($p < 0.001$). 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). The effective and organ doses were higher for female patients than for male patients, with statistically significant differences ($p = 0.005$). The distribution of organ doses for female and male patients is illustrated in Figure 1.

3.3. Individual radiation risk assessment

The LAR of uterus and prostate cancer incidence was 1.75 ± 1.19 cases and 2.24 ± 1.06 cases per 100,000 persons, respectively (Figure 2). The LAR of cancer mortality from uterus and prostate cancers were 0.36 ± 0.22 and 0.48 ± 0.18 cases per 100,000 persons, respectively (Figure 3). The values of LAR of prostate and uterus cancer occurrence from AP CT as a function of age and gender were higher in male patients than in females, with a consistent decline with age at exposure (Figure 4). When examining the values of LAR

FIGURE 4
LAR values of prostate and uterus cancer incidence from AP CT as a function of age and gender.

FIGURE 5
LAR values of prostate and uterus cancer mortality from AP CT as a function of age and gender.
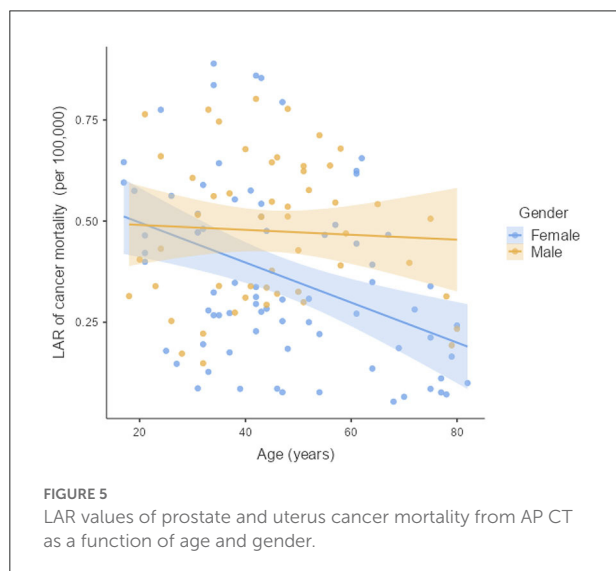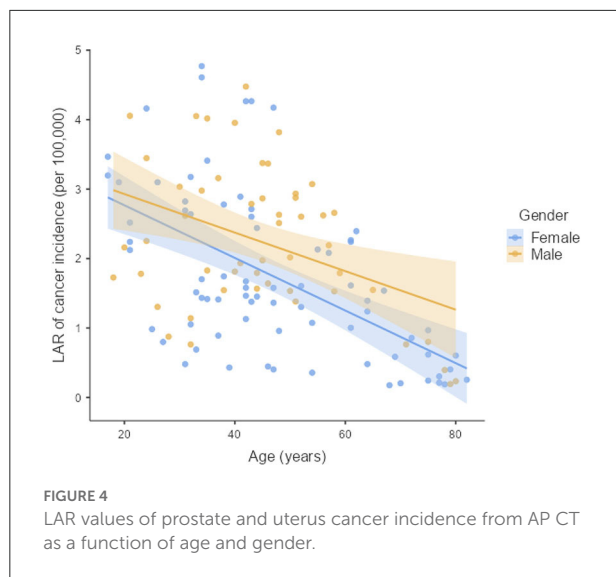
of prostate and uterine cancer mortality as a function of age and gender, it was shown that male and female patients both had a minor decline in LAR with increasing age at exposure (Figure 5).

4. Discussion

CT scans are one of the most common radiation imaging modalities, and CT scans are rising steadily worldwide. CT scans are constantly increasing worldwide with the potential to improve the practice of radiography, but they also have the potential to increase the patient dose. A single CT scan of the abdomen pelvis (AP) can expose a patient's prostate or uterus to a substantial radiation dose, leading to rising concerns about radiation-induced cancer. However, medical staff may not have

adequate knowledge of the risks of ionizing radiation used in these procedures. The risk of cancer incidence and mortality from ionizing radiation is appropriately expressed in terms of LAR values. Generally, radiation doses as low as reasonably achievable and consistent with acceptable image quality remain the most significant strategies for diminishing this potential risk. This study evaluated organ doses of the uterus and prostate and the LAR of cancer incidence and mortality resulting from AP CT.

The mean scan length for male patients was higher than for females, with statistically significant differences ($p < 0.001$). These results are consistent with the statistical studies showing that Saudi males' body height is relatively higher than that of Saudi females (33, 34). The results show that the mean value of effective dose (female: 5.76 ± 3.22 mSv vs. male: 4.37 ± 1.66 mSv) and organ dose (female: 10.86 ± 6.09 mGy vs. male: 7.00 ± 2.66 mGy) and DLP (female: 640.86 ± 417.69 mGy.cm vs. male: 623.29 ± 288.98 mGy.cm) were higher for females than for males. This is primarily because the DLP values were higher for females than for male patients. Patrick et al. investigated multiple body composition parameters to determine the strongest predictor of effective doses among patients. Their study found that total adipose tissue volume was significantly higher in females compared to male patients, and adipose tissue volume was the strongest predictor of DLP (35). Studies among the Saudi population have reported that Saudi females have higher body weight and cross-sectional area than males (36, 37). In comparison with other studies, the effective dose and organ doses to the prostate and uterus from AP CT in our study were lower than previously reported in other studies: 13 mSv (38) and 13.6 (39) for effective doses, and organ doses to the uterus of 10.4 mGy and the prostate of 10 mGy (40).

The LAR values of cancer incidence and mortality from AP CT were obtained for the prostate (2.24 and 0.48 cases per 100,000 persons) and the uterus (1.75 ± 1.19 cases and 0.36 ± 0.22 cases per 100,000 persons), indicating that males are at higher risk than females. The LAR of uterus cancer incidence and mortality as a function of age showed a steadily declining risk with age at exposure (Figures 4, 5). The LAR of prostate cancer incidence decreased with age at exposure. However, unlike for females in this study, the LAR of cancer mortality for prostate cancer showed a slightly decreasing trend with age at exposure for male patients (Figure 5). This is because the LAR of cancer mortality for the prostate remains within 7 ($\pm$2) cases from age 30 to 80 years, and the organ doses of the prostate dose were higher for older age groups in this study. Prostate cancer is among the most common cancers in males, with high morbidity and mortality in Saudi Arabia, with more prevalence in the age group of 50–70 years (41). The increased prostate organ doses and the natural prevalence of prostate cancer for older groups require special attention for male patients in Saudi Arabia.

Radiation has a stochastic effect that can cause cancer; no threshold value or dose can cause it (42). Calculating risk

does not mean identifying a risk unique to each patient (43). Nonetheless, the LAR estimate offers a standard for patients, radiation oncologists, and other medical personnel. As a result, this study's findings may help develop a database for calculating LARs related to CT scans of the pelvis.

Specific dose reduction strategies for reducing patient radiation dose from CT examination, such as tube current (mA) modulation, iterative reconstruction techniques, staff awareness, and the use of advanced imaging technologies, are found in the literature. Consequently, radiation protection during CT examination is essential, regardless of the radiation dose received (44–47).

This study has some limitations. First, there are differences between the Saudi population's baseline cancer incidence levels and mortality rates and those listed in the BEIR VII study (32). Second, the LAR of cancer occurrence from X-ray ranged from 80–140 kVp, possibly distinct from that of high-energy gamma rays that the BEIR VII database represents a majority based on these high-energy rays (48).

5. Conclusions

Using the risk models proposed by the BEIR VII report, the LAR of prostate and uterus cancer incidence and mortality due to radiation exposure from AP CT procedures were low, but not trivial. Moreover, risk associated with prostate cancer from radiation exposure along with the high natural prevalence of prostate cancer among older people necessitate special attention. Therefore, efforts should be made to reduce patient doses while maintaining image quality. Although the minimization of the patient's radiation dose must guide clinical practice, the estimated small increase in risk could aid in easing fears regarding well-justified AP CT procedures. To reduce the patients' LARs, different treatment planning CT protocols should be optimized to reduce the radiation dose.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Jazan University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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