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Impact of Patient-Specific Size Factors on Dosimetry Measurements: A Comparison of IndoseCT and Phantom-Based CT-Expo

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Abstract

Background: organ dose and effective dose (*E*) in computed tomography (CT) are of great concern due to the increasing number of CT examinations. Most organ dose and *E* estimation software assumes a standard patient size, while some use weight and length factors. IndoseCT, on the other hand, estimates organ dose and *E* by accounting for patient size, using the size-specific dose (SSDE).

Objectives: To date, no direct comparison has been made between software that accounts for patient size (IndoseCT) and software that assumes a standard patient (CT-Expo). Consequently, the accuracy of IndoseCT for organ dose and *E* remains unvalidated, as no published study has specifically compared IndoseCT with other software platforms.

Methods: 218 patients (124 males and 94 females) underwent Brain CT in 3 radiology units using 3 scanners: Philips, Siemens, and General Electric (GE). The patients were scanned using brain CT protocols. The organ dose and *E* were calculated using IndoseCT and compared with CT-Expo.

Results: The average male brain organ dose calculated using IndoseCT was 36.41 mGy, while the calculated brain organ dose using CT-Expo was 42 mGy, without a significant difference p-value > 0.001. For females, the average brain dose calculated using IndoseCT was 33.68 mGy, and the average calculated using CT-Expo was 40.83 mGy, with no significant difference (p-value > 0.001). IndoseCT and CT-Expo showed a significant difference (p-value < 0.001) for the other organs and *E*. However, the percentage difference between IndoseCT and CT-Expo falls within the range reported in the literature for studies comparing various software for assessing organ dose and *E*.

Conclusion: Size-specific factors are valuable for estimating organ dose and *E*. The observed differences between IndoseCT and CT-Expo arise primarily because CT-Expo assumes a standard patient with a constant body size, whereas IndoseCT accounts for patient size, yielding more accurate dose estimates.

Keywords*: IndoseCT, CT-Expo, Organ Dose, Computed tomography, Brain CT*

1. Introduction

Radiation dose in computed tomography (CT) has become highly important due to the high number of CT examinations performed worldwide. Various studies reported an increase in CT examinations over the years, resulting in a significant increase in population dose [1]. For the USA, Brenner et al. reported an increase in the number of CT examinations per year, rising from 2.8 million in 1981 to 20 million in 1995 and to 62 million in 2007 [1], and to 93 million in 2023 [2]. In Germany, from 1996 to 2012, the annual *E* for CT procedures doubled [3]. A retrospective analysis carried out in Italy between 2004 and 2014 [4] showed an increase by 39% in the number of CT examinations per 1,000 person [5].

Various software introduced for the calculation of organ dose, including CT-Expo [6], National Cancer Institute CT (NCICT) dosimetry system [7], National Cancer Institute dosimetry system for Computed Tomography extended (NCICTX) [8], virtual dose [9], and IndoseCT [10]. Different studies compared different software evaluating organ dose and *E* [9], [11–15]. Their results showed significant differences among software, as published by De Mattia et al. (2020). They reported that the difference between software exceeds 600%, while the work published by Ding et al. (2023) mentioned that the difference reaches 300% [16,17].

CT-Expo is an Excel-based software application developed using Visual Basic to estimate patient dose from CT examinations. CT-Expo relies on a set of mathematical phantoms (Adam, Eva, Child, Baby), in which body surfaces and organ geometries are defined by mathematical equations. The software can simulate tube current modulation during CT scanning and allows selection between axial and spiral acquisition modes. It operates within a spreadsheet environment and is built upon a well-established computational approach developed by Stamm and Nagel (2002) [5]. It is based on computational Monte Carlo simulation methods using the data collected in the German surveys on CT practice [18]. The calculation models consist of

anthropomorphic mathematical phantoms: ADAM, representing males; EVA, representing females. The doses are determined based on the scanner manufacturer, scanner type, scan region, and scanning protocol parameters [19].

IndoseCT is software developed to measure and manage the radiation dose of a patient who underwent a CT procedure, developed by C. Anam [20]. IndoseCT measures the radiation output of the CT scanner in terms of volume computed tomography dose index ($CTDI_{vol}$), *E*, and size-specific dose estimation (SSDE), either based on the water equivalent diameter (D_w) or effective diameter (D_{eff}) [21]. The software measurement accuracy has been approved as a replacement for the manual measurement of SSDE [22]. The organ dose measurement on IndoseCT, based on P. Sahbaee et al. where the work provided normalisation factors based on patient diameter [23].

Unlike several conventional dose estimation tools that rely on standard reference phantoms or apply length and weight-based correction factors to approximate patient habitus [5], IndoseCT directly incorporates patient-specific size parameters into its dose calculations [21]. While other software often assumes a fixed body geometry (e.g., mathematical or voxel phantoms representing an average adult) and subsequently adjusts organ dose using empirical scaling factors, IndoseCT integrates actual patient dimensions, such as the effective diameter, into the dosimetry model. This fundamental difference allows IndoseCT to account for individual variations in body habitus.

To date, no direct comparison has been made between software that accounts for patient size (IndoseCT) and software that assumes a standard patient phantom (CT-Expo). This study addresses this challenge by measuring individual patient organ dose and *E* using size-specific factors (IndoseCT) and comparing the results with those obtained using a standard phantom approach (CT-Expo).

2. Methods

2.1. Patients and scanners

This study was conducted in accordance with the Declaration of Helsinki International Ethical Guidelines for Health-related Research Involving Humans. Ethical approval was obtained from the Research Ethics Committee (REC) of Al-Quds University (Study Protocol code: 270/REC/2023) and the Human Research Ethics Committee of Universiti Sains Malaysia (HREC) (Study Protocol code: USM/JEPeM/PP/23020182) with waived consent form. Data were retrospectively collected from three radiology units: Allmed Radiology Centre (Siemens SOMATOM go.), Palestine Medical Complex Hospital (Philips Ingenuity Core), and Mohammad Alqasem Hospital (GE Revolution). The dataset comprised 218 patients (124 males and 94 females) who underwent brain CT examinations across these centres. The scanning protocols varied according to the scanner manufacturer (Philips, Siemens, and GE), as summarized in Table 1.

2.1.1. IndoseCT vs CT-Expo

Organ dose and SSDE were calculated using IndoseCT software (Version 20.b), which applies the size-specific correction factors proposed by Sahbaee et al. (2014) (the factors in Sahbaee 2014 paper Figure 2) [24]. The software automatically extracted $CTDI_{vol}$ and DLP values from the imported DICOM images. The effective diameter (D_{eff}) was used as the size metric, as body diameter was employed by Sahbaee et al. (2014) to derive their normalization factors. SSDE was computed automatically using the software's auto-measurement feature, which has been proved by Brade et al. (2024) [22]. For the organ dose measurements, the user is required to select the body region (brain in this study) and the appropriate phantom size (16 cm for head, 32 cm for body).

In CT-Expo software, the geometric properties of the CT scanner are influenced by the scanner vendor, model, and patient gender. These are critical factors that affect areas outside the detector array, such as over-beaming (K_{OB}), additional scan lengths in spiral mode, known as over-ranging (ΔL), reference tube voltage (U_{ref}), and head phantom (P_H) or body phantom (P_B). The user should manually determine kilovoltage (kV), milliampere (mA) and table feed (TF), detectors array size (h_{rec}) and rotation time in seconds (S). These parameters play a significant role in determining the calculated $CTDI_{vol}$, DLP, normalized weighted computed tomography dose index ($_nCTDI_w$) [25].

2.2. Organ dose measurements

The measurements of organ dose using IndoseCT , employ normalization factors obtained from Sahbaee et al., (2014) [23]. These factors, obtained by Sahbaee (2014) (Figure 2 in his paper), provide fractional conversion coefficients for each organ (e.g., brain, eyes, thyroid, lungs, etc.) under different scan protocols (Head, Neck, Chest). Specifically, for a given protocol, the organ dose was calculated as the product of SSDE and the corresponding normalization factor, while CT-Expo employs an anthropomorphic phantom (Figure 1 (A and B)), the CT-Expo phantom is based on the design characteristics of the MIRD-5 phantom; CT-Expo is based on the database of organ dose developed at the Research Centre for Environment and Health (GSF) in Germany. The measurements were arranged in Microsoft Excel, which was used for statistical analysis and data presentation, with a *p*-value < 0.001 considered significant.

2.3. Effective Dose (*E*) Measurements

2.3.1. Effective Dose calculation with IndoseCT Software

The $CTDI_{vol}$ and DLP were automatically extracted from the patient's DICOM image by the IndoseCT software to measure SSDE, corrected DLP (DLPc), and *E*. The IndoseCT

software calculated the patient's effective diameter (D_{eff}) using Equation 1. IndoseCT automatically selects the anterior-posterior dimension (AP), and lateral dimension (LAT) for each slice to measure SSDE [26,27].

$$D_{eff} = \sqrt{AP \times LAT} \quad (1)$$

The calculated D_{eff} is utilized to acquire the conversion factor (f_{size}) from AAPM report 293, this factor converts $CTDI_{vol}$ to SSDE according to Equation 2 [28].

$$SSDE = CTDI_{VOL} \times f_{size} \quad (2)$$

Where f_{size} is obtained from the AAPM 293 report [29]. The measured SSDE was utilized to calculate the total radiation output received by the patient, which is presented by corrected DLP (DLP_c) [30] and the DLPc was measured according to Equation 3 [21].

$$DLP_c = SSDE \times scan\ length \quad (3)$$

DLP is usually employed to calculate *E* [31], while the software IndoseCT uses DLPc to calculate *E* according to Equation 4 [21].

$$E_{IndoseCT} = DLPc \times k \quad (4)$$

Where k is a size-specific factor (DLP_c to *E*) based on Sahbaee et al (2014) [23]. However, the use of body-size-based conversion factors to estimate *E* raises a new concern for some researchers to include patient size in *E* calculation [32].

2. 2.3.2. Effective Dose calculation with CT-Expo software

CT-Expo uses Equation 5 for E calculation. In this equation, the CT factor in Tables 2 and 2 is included in the E calculation. Also, the employed DLP is weighted DLP (DLPw), which is calculated based on Equation 6.

$$E = \frac{DLP_W}{P_{H,B}} * K_{CT\ H,B} * \frac{1}{Z_+ - Z_-} * \sum_{Z_-}^{Z_+} f(z) \quad (5)$$

Where $f(z)$ is the E conversion factor across the scan range [33], modified based on start and end points (Z+,Z-) [25] as shown in Figure 1 (A and B), where the scan range is determined by the user on the selected phantom. Additionally, the conversion factor varies by sex. K_{CT} is the scanner factor determined by the selected vendor and model for the head (H) and body (B) phantoms. The CT-Expo includes the over-ranging (ΔL) in measurement of scan length based on Equation 6.

$$DLP_w = \left((Z_+ - Z_-) + h_{rec} + \Delta L\right) * CTDI_{Vol} \qquad 6$$

Where the h_{recon} is the total beam collimation. In Equation 5, the over-beaming is used in the measurement of scan length, while the over-ranging (K_{OB}) is used by the software to correct scan length [25]. So the measured E for the head using CT-Expo is higher than other software's [5].

2.4. Statistical test

Statistical analyses were performed using Microsoft Excel. A two-tailed paired t-test was applied to compare organ doses and effective dose between IndoseCT and CT-Expo, owing to the paired design of the study. For organs where the normality of paired differences was violated. Given the multiple comparisons performed (2 effective dose comparisons by sex, 8 organ comparisons in males, and 9 organ comparisons in females). Difference was considered statistically significant only when the two-tailed p-value < 0.001.

3. Results

3.1. Effective Dose (*E*)

The effective dose (E) differed significantly between IndoseCT and CT-Expo in both sexes (p-value < 0.001 for males and females, paired t-test) as presented in Figure 2. For males, CT-Expo yielded a mean E of 2.93 ± 1.59 mSv (95% CI: 2.65 – 3.21 mSv), compared to 1.37 ± 0.52 mSv (95% CI: 1.28 – 1.46 mSv) for IndoseCT, representing a relative increase of 113%. In females, CT-Expo produced a mean E of 2.51 ± 1.56 mSv (95% CI: 2.19 – 2.83 mSv), while

IndoseCT gave 1.30 ± 0.62 mSv (95% CI: 1.17 – 1.43 mSv), corresponding to a 93% difference. These findings demonstrate that CT-Expo systematically yields higher effective dose estimates compared to IndoseCT for both genders, with non-overlapping confidence intervals confirming the robustness of the observed differences.

3.2. Organs Dose

The comparison of organ dose estimates between IndoseCT and CT-Expo revealed systematic differences for the brain, skin, bone marrow, thyroid, and eye lens in both males and females as illustrated in Figure 3. For the brain, CT-Expo yielded higher mean doses (males: 42.00 ± 16.04 mGy, 95% CI: 39.15–44.85; females: 40.83 ± 18.77 mGy, 95% CI: 37.00–44.66) than IndoseCT (males: 36.41 ± 14.69 mGy, 95% CI: 33.80–39.02; females: 33.68 ± 13.10 mGy, 95% CI: 31.00–36.36), with relative increases of 15.35% and 21.25%, respectively. The overlapping confidence intervals between the two software estimates for both genders confirm that this difference was not statistically significant (p-value > 0.001), indicating that for the primary organ in the scan field, the size-specific approach of IndoseCT is comparable to the standard phantom approach of CT-Expo.

Unlike brain tissue, doses for other directly exposed organs showed highly significant differences (p-value < 0.001 for all comparisons). Skin dose estimates from CT-Expo (males: 4.55 ± 2.29 mGy, 95% CI: 4.15–4.95; females: 4.39 ± 2.95 mGy, 95% CI: 3.79 – 4.99) were substantially higher than IndoseCT values (males: 2.53 ± 1.26 mGy, 95% CI: 2.31 – 2.75; females: 2.32 ± 1.08 mGy, 95% CI: 2.10 – 2.54), representing increases of 80.05% in males and 88.99% in females. The non-overlapping confidence intervals between the two software estimates confirm the robustness of these differences. Similarly, bone marrow discrepancies

reached 134.73% in males and 149.62% in females, with CT-Expo reporting higher mean values (males: 6.58 ± 2.83 mGy, 95% CI: 6.08 – 7.08; females: 6.38 ± 3.60 mGy, 95% CI: 5.64 – 7.12) than IndoseCT (males: 2.80 ± 1.42 mGy, 95% CI: 2.55 – 3.05; females: 2.56 ± 1.22 mGy, 95% CI: 2.31 – 2.81).

The most pronounced difference was observed for the thyroid: CT-Expo doses (males: 18.97 ± 21.08 mGy, 95% CI: 15.22 – 22.72; females: 20.17 ± 26.23 mGy, 95% CI: 14.80 – 25.54) surpassed IndoseCT values (males: 3.13 ± 8.93 mGy, 95% CI: 1.54 – 4.72; females: 2.69 ± 7.21 mGy, 95% CI: 1.21 – 4.17) by 505.80% and 650.12%, respectively. The non-overlapping confidence intervals between the two software estimates for both genders confirm the statistical significance of these differences p-value < 0.001. For the eye lenses, CT-Expo estimates (males: 54.73 ± 20.91 mGy, 95% CI: 51.01 – 58.45; females: 51.09 ± 23.47 mGy, 95% CI: 46.28 – 55.90) were significantly higher than IndoseCT (males: 38.98 ± 15.76 mGy, 95% CI: 36.18 – 41.78; females: 35.81 ± 14.26 mGy, 95% CI: 32.89 – 38.73), with differences of 40.42% and 42.69%, respectively p-value < 0.001. However eye lenses exhibited overlapped 95% CI between the two software's highlighting the comparable organ dose value for organs exposed directly to exposure.

Except for the brain, all comparisons met the predefined significance level (p-value < 0.001), while Brain and eye lenses exhibited overlapped 95% CI indicating the comparable difference for organ dose exposed directly to exposure and significant difference for organs exposed to scattered radiation.

For radiosensitive organs exposed to scattered radiation, IndoseCT consistently measured higher doses than CT-Expo as clarified in Figure 4, often where CT-Expo reported zero or near-zero values. In males, IndoseCT estimated testicular doses at 0.10 ± 0.05 mGy (95% CI: 0.09 – 0.11), while CT-Expo yielded 0.00 mGy (100% difference); similarly, male

breast doses were 1.99 ± 4.25 mGy (95% CI: 1.23 – 2.75) versus 0.00 mGy (100%) in CT-Expo, and colon doses were 0.34 ± 0.32 mGy (95% CI: 0.28 – 0.40) versus 0.00 mGy (100%). The prostate also showed a 100% difference (0.06 ± 0.03 mGy, 95% CI: 0.055 – 0.065 vs. 0.00 mGy).

In females, ovarian doses were 0.05 ± 0.05 mGy with IndoseCT (95% CI: 0.04–0.06) compared to 0.00 mGy with CT-Expo (100%), and uterine doses showed an identical pattern (0.05 ± 0.03 mGy, 95% CI: 0.044–0.056 vs. 0.00 mGy, 100%). Female breast doses, while measurable by both software tools, were higher with IndoseCT (1.90 ± 4.14 mGy, 95% CI: 1.06 – 2.74) than with CT-Expo (0.07 ± 0.23 mGy, 95% CI: 0.023–0.117), representing a 96.19% difference. Female colon doses followed the same trend as males, with IndoseCT reporting 0.31 ± 0.27 mGy (95% CI: 0.255 – 0.365) and CT-Expo 0.00 mGy (100%). For all organs where CT-Expo reported zero, the confidence intervals of the two software estimates do not overlap, confirming the statistical significance of these differences. These findings demonstrate that IndoseCT identifies measurable scatter in distal organs where CT-Expo reports zero, confirming IndoseCT's higher sensitivity to low-level radiation.

4. Discussion

This work aims to assess the accuracy of IndoseCT software in estimating organ dose and *E* related to CT examinations. The results showed highly significant differences for all organ dose (p-value < 0.001), while the difference was not significant for brain tissue (p-value > 0.001). Meanwhile, the *E* exhibited highly significant difference (p-value < 0.001).

The percentage of difference between the two software within the difference reported in the work published by Cristina De Mattia et al (2020). The reported thyroid discrepancy (up to 650.12%) is consistent with De Mattia et al. (2020), who found differences exceeding 600%. In their work, they reported differences between software up to 640% [5]. In our work, the

highest percentage difference was 650.12% for female thyroid. However, De Mattia et al., (2020) concluded that the measurements of organ dose depended on the software employed due to a significant difference reported in the literatures [5]. This confirms that the software choice is often the largest variable in dose estimation, exceeding the variability of the scan parameters themselves.

The organs that were exposed to radiation directly or to the primary beam mainly exhibited a lower percentage of difference and overlapped 95% CI in organ dose between the two software. In contrast, the organs that were exposed to scattered photons or exposed indirectly to radiation exhibited a higher percentage of difference and non overlapped 95% CI in measured organ dose.

Bladder, colon, and male breast organ dose measured by CT-Expo was around 0.00. While the IndoseCT results show values match the work published by Wyk et al., (2024) in which the internal scatter was highest closest to the exposed area and lower to far area [34]. The Bronwin Van Wyk results can be observed in IndoseCT estimation of organ dose, where far organs have low organ dose, while the CT-Expo estimation for far organ dose, such as testicular dose, was zero.

A significant difference was observed in the effective dose (E) calculations between the two software (p-value < 0.001), with CT-Expo yielding consistently higher values [5]. This discrepancy is primarily attributed to CT-Expo's inclusion of the over-beaming (K_{OB}) and over-ranging (ΔL) factors, which are designed to account for radiation delivered outside the intended detector array and scan range. While IndoseCT uses a corrected DLP (DLPc) that may be lower than the standard based on patient size, the weighted DLP (DLPw) in CT-Expo is always higher due to the addition of K_{OB} and ΔL. Additionally, the workflow for each tool varies significantly. IndoseCT utilizes automated extraction of $CTDI_{vol}$ and DLP from DICOM

data, while CT-Expo relies on the manual selection of scanner and patient variables (scanner vendor, scanner model, phantom size, patient gender, scanning parameters, and scan range). In CT-Expo, the user-defined gender affects the ΔL calculation, while the scanner vendor and model define the specific and constants used in the dosimetry model.

CT-Expo *E* findings are consistent with the organ-specific dose estimates reported in organ dose, where CT-Expo systematically exceeded IndoseCT for several radiosensitive tissues, with a high percentage difference. The *E* differences, although substantial, were somewhat less pronounced than the most extreme organ discrepancies, reflecting the tissue weighting factors applied in *E* calculation. Notably, while the brain did not show a significant difference at the $p = 0.001$ level, the *E*, which incorporates contributions from highly significant organs such as the thyroid and bone marrow, remained highly significantly different between the two software tools for both genders.

A substantial discrepancy was observed in female breast organ dose (organ dose) results compared to other organs, which can be attributed to the divergent anatomical modelling used by each software. Although breast size is a critical factor in dose estimation [34], CT-Expo utilizes a fixed breast size within its standard 'EVA' phantom, whereas IndoseCT incorporates individual body size into its calculations [35]. This fundamental difference in accounting for patient habitus likely explains the large gap in organ dose results. Furthermore, the scan range played a significant role; for patients where the scan length was extended to include the mandible, the IndoseCT region was reclassified as 'Head and Neck'. As illustrated in Sahbaee (2014) work (Figure 2 in Sahbaee (2014)), this shift increased the normalization factor from 0 (for 'Head' only) to 8 for 'Head and Neck'. In contrast, CT-Expo manages these variations by employing a conversion factor, $f(z)$ based specifically on the longitudinal start and end points (Z+, Z-) shown in Figure 1.

For males' breast, the critical finding warrants more emphasis is that CT-Expo reports zero dose for male breasts. which is consistent with the findings reported by Mattia et al., (2020) [5]. This occurs because the ADAM male phantom in CT-Expo does not include breast tissue, highlighting a significant lack of anatomical representation in older phantom-based software, that IndoseCT successfully overcomes by using size-specific factors.

Different dosimetry software yields varying estimates of organ dose in CT due to differences in organ masses across software, normalization factors for organ dose calculations [31], [23], required input data, phantoms, and calculation algorithms [5]. In this work, we relate the higher organ dose obtained by CT-Expo for organs exposed directly to the primary beam, such as the brain, to the use of overbeaming (K_{OB}) and over-ranging (ΔL) which increase DLPw compared to DLPc. At the same time, we relate the higher organ dose obtained for organs exposed to scattered radiation, such as testis and breast, by IndoseCT due to more accurate calculation by IndoseCT software, where the scattered radiation is higher beside the primary beam and lower in far areas [34]. IndoseCT's approach aligns more closely with the previous literature on internal scatter (Van Wyk et al. 2024), which confirms that radiation is present even in tissues far from the primary beam [34]. The lower quantity of scattered photons was estimated by IndoseCT and set to zero by CT-Expo.

Patient size plays a critical role in organ dose and E calculation [23], While anthropomorphic phantoms have fixed size and weight [14], some software programs require patient weight and height to normalize organ dose accordingly [9], Alternatively, several researchers have attempted to estimate organ dose using patient-specific size factors [35], [36]. Organ doses derived from size-specific factors appear more logical and accurate than those obtained using standard techniques. Table 3 clarifies the primary difference related to varied measurements across the twos software's.

This study has several limitations. First, the analysis was restricted to brain CT examinations, limiting the generalizability of the findings to other CT. Although the observed differences are likely applicable to other protocols, further validation across a wider range of CT examinations is needed. Second, the retrospective design and the use of three different CT scanners introduced variability in scanning parameters that may have affected dose estimates. Third, the study did not include direct physical dose measurements using phantoms or TLDs, which would have provided a gold standard for validation.

5. Conclusion

This study successfully validated IndoseCT against the established CT-Expo software, demonstrating that while brain tissue organ dose estimates are comparable between the two platforms ($p > 0.001$), significant differences exist for other organs and effective dose (E). These discrepancies are primarily driven by the fundamental difference in anatomical modelling. CT-Expo relies on standard anthropomorphic phantoms with fixed geometries, whereas, IndoseCT incorporates patient-specific dimensions via the size-specific dose estimate (SSDE) concept. Furthermore, the inclusion of technical factors such as over-beaming and over-ranging in CT-Expo leads to higher primary beam dose estimates, while IndoseCT provides more sensitive quantification of internal scattered radiation to distal organs that standard phantoms often set to zero. Despite these variations, the percentage differences remain within ranges previously reported in medical literature. Consequently, IndoseCT is a reliable and more personalized tool for estimating radiation risk, offering a logical progression from standard phantom-based dosimetry to patient-specific dose management in clinical practice

6. Declarations

Ethics approval and consent to participate: This study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Research Ethics Committee of Al-Quds University (Study Protocol code: 270/REC/2023) and the Human

Research Ethics Committee of Universiti Sains Malaysia (Study Protocol code: USM/JEPeM/PP/23020182). Informed consent was waived by both ethics committees due to the retrospective nature of the study.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests: Dr. Choirul Anam is the developer of the IndoseCT software. The other authors declare no competing interests.

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Authors' contributions: H.A. and N.D.O. conceived and designed the study. N.D.O. supervised the project, contributed to data interpretation, and critically revised the manuscript. H.A. performed the image and statistical analyses, collected and processed the data, and drafted the manuscript. C.A. contributed to the development of the methodology, provided expertise on the IndoseCT software, and critically revised the manuscript. H.A.L. contributed to data collection and interpretation. All authors reviewed and approved the final manuscript.

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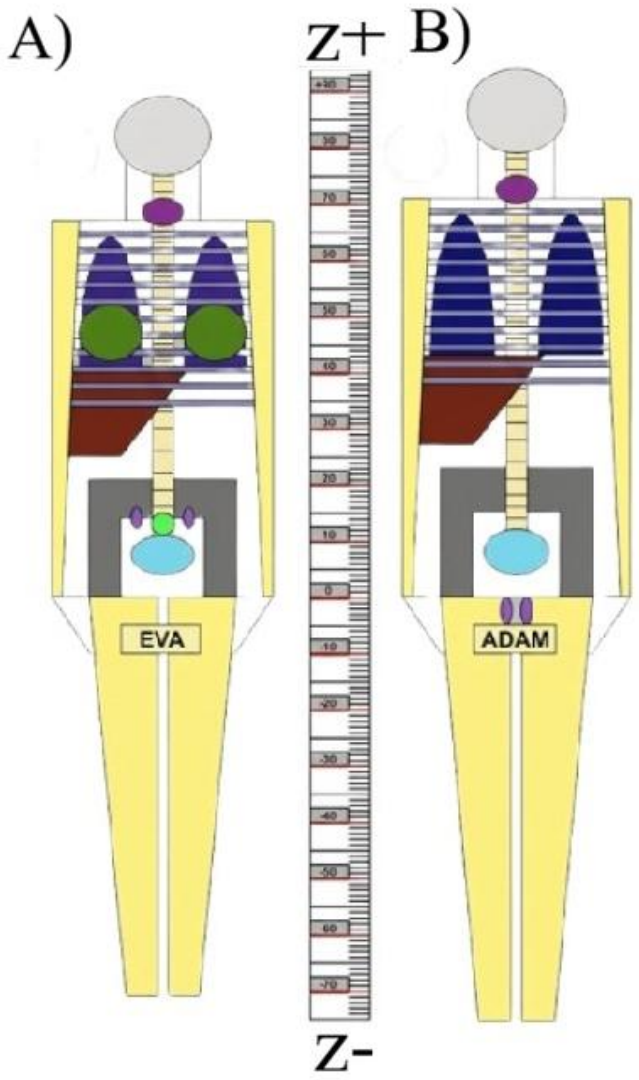
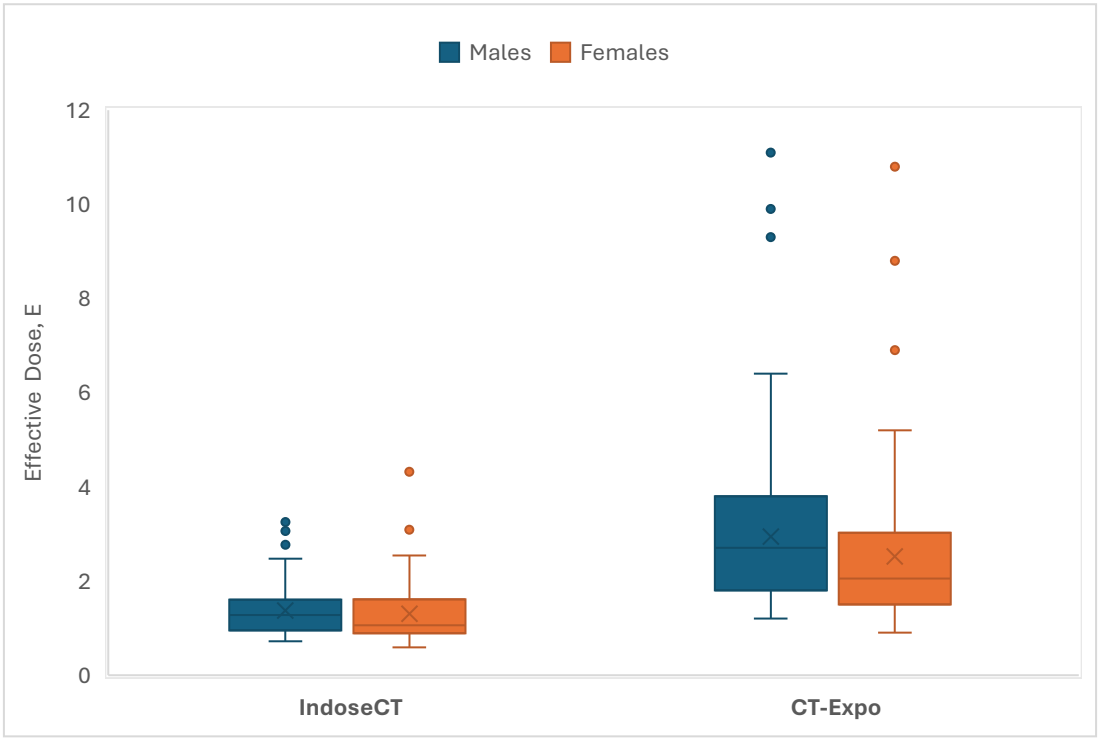
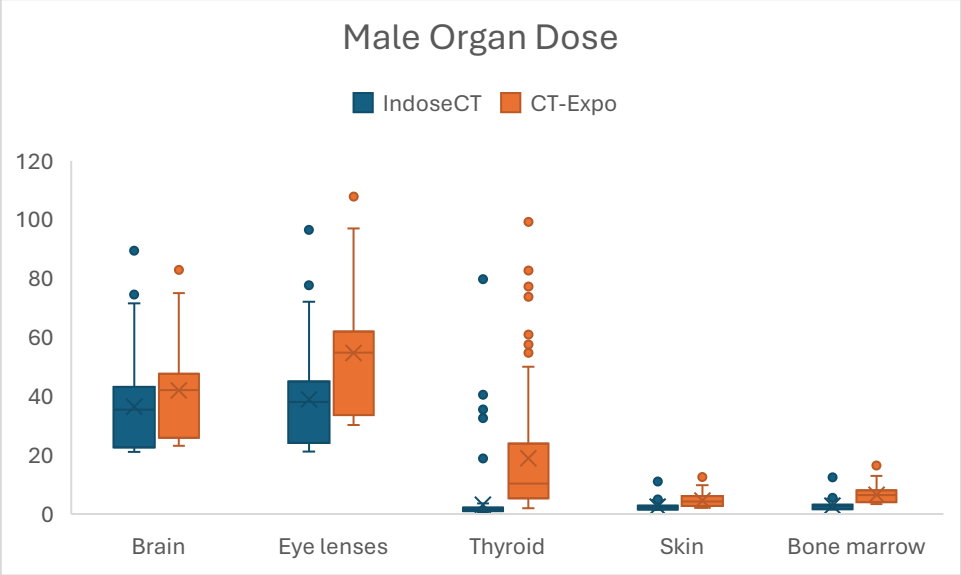
Scanner	Number of patients	kVp	mAs	AEC	$CTDI_{vol}$ (mGy)	Scan length	Number of patients
Philips	81	120	133 – 400	ON	32.00 – 124.00	16 - 21	81
Siemens	74	130	104 – 288	ON	26.84 – 64.00	16	74
GE	31	100	165	Off	35.96	16	31
	32	120	225	Off	82.35	16	32

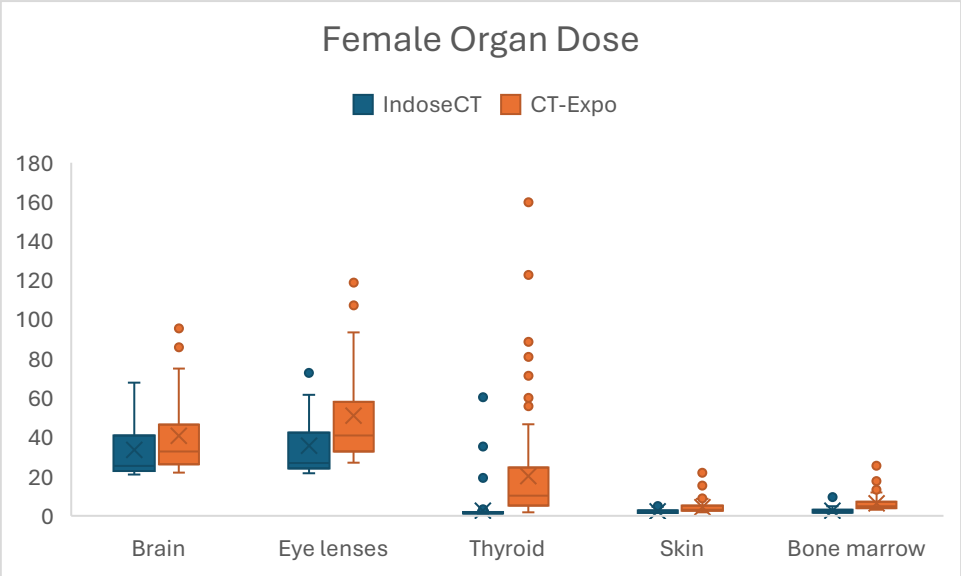
Scanner	Phantom	${}_{n}CTDI_{w}$ (mGy/mAs)	U_{ref} (kV)	$P_{B,H}$	K_{CT}	K_{OB}	ΔL (cm)
Siemens SOMATOM® Go now	ADAM	0.246	130	0.75	0.90	1.01	2.3
	EVA	0.246	130	0.75	0.90	1.01	1.1
Philips Ingenuity Core	ADAM	0.129	120	0.76	0.90	1.08	2.9
	EVA	0.129	120	0.76	0.90	1.08	1.5
GE Revolution™	ADAM	0.175	120	0.73	0.90	1.08	1.7
	EVA	0.175	120	0.73	0.90	1.08	0.8

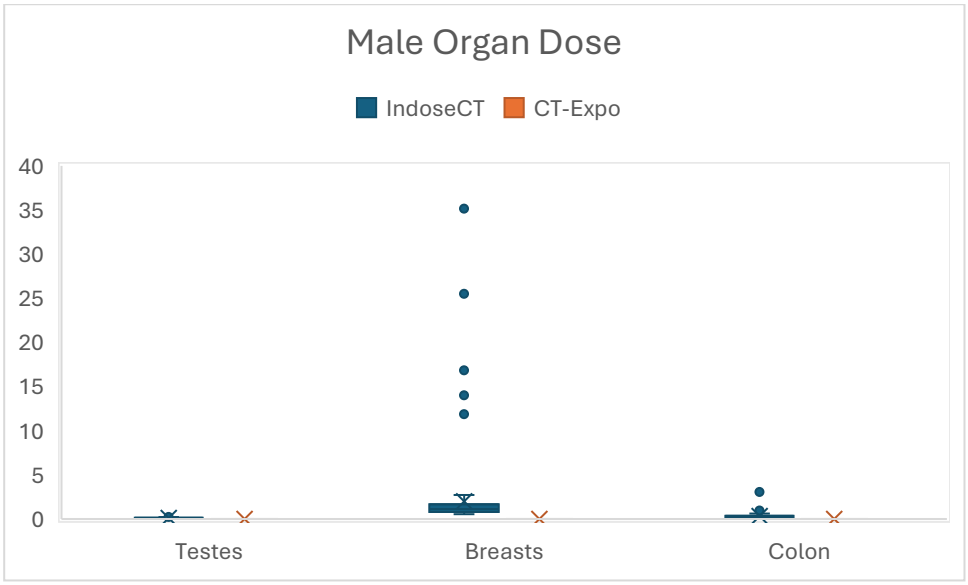
Feature	IndoseCT (Version 20.b)	CT-Expo (Version 2.8)
Data Entry	Automatic extraction from DICOM.	Manual entry (kV, mA, TF, rotation time).
Size Metric	Effective Diameter (D_{eff})	Mathematical Phantoms (ADAM/ EVA).
Source Database	Sahbaee et al. (2014) normalization factors.	GSF Monte Carlo database (1990s).
Dose Basis	SSDE based on D_{eff}.	Weighted CTDI simulation.
Geometric Factors	Corrected DLP (DLPc).	Over-beaming (K_{OB}), Over-ranging (ΔL) weighted DLP (DLPw).
Sensitivity	High sensitivity to low-level internal scatter.	Frequently reports zero dose for distant organs.

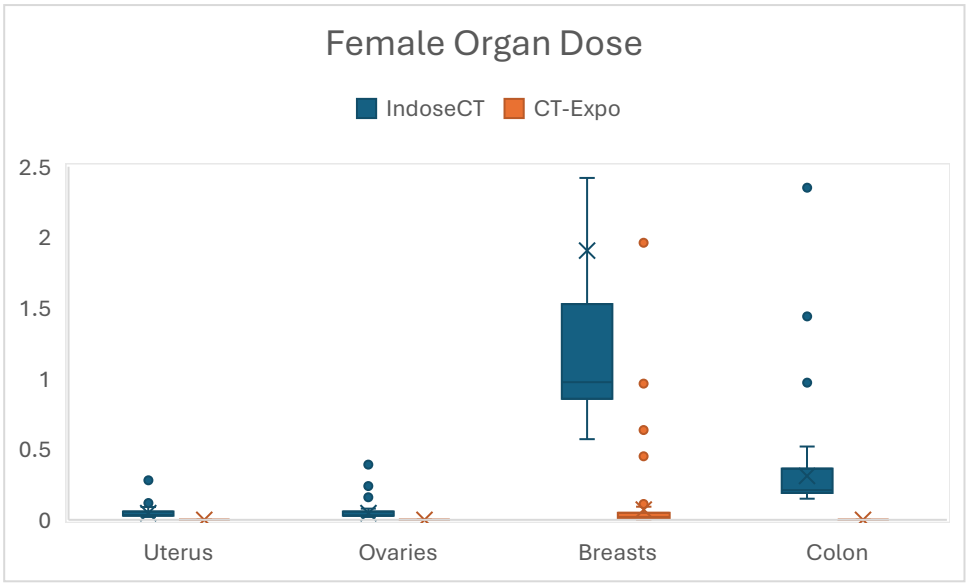

A)
Z+
B)
EVA
ADAM
Z-


Males
Females
12
10
8
6
4
2
0
Effective Dose, E
IndoseCT
CT-Expo


Male Organ Dose
IndoseCT
CT-Expo
120
100
80
60
40
20
0
Brain
Eye lenses
Thyroid
Skin
Bone marrow


Female Organ Dose
IndoseCT
CT-Expo
180
160
140
120
100
80
60
40
20
0
Brain
Eye lenses
Thyroid
Skin
Bone marrow


Male Organ Dose
IndoseCT
CT-Expo
40
35
30
25
20
15
10
5
0
Testes
Breasts
Colon


Female Organ Dose
IndoseCT
CT-Expo
2.5
2
1.5
1
0.5
0
Uterus
Ovaries
Breasts
Colon