Association of Radiation Doses and Cancer Risks from CT Pulmonary Angiography Examinations in Relation to Body Effective Diameter

H H Harun[a], M K A Karim[a,b] *, Z Abbas[a], A Sabarudin[c], S C Muniandy[d] and K H Ng[e]

[a]Department of Physics, Faculty of Science, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[b]Center for Diagnostic Nuclear Imaging, Faculty of Medicine, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[c]Department of Diagnostic & Applied Health Sciences, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, 56000, Kuala Lumpur, Malaysia
[d]Department of Radiology, Hospital Kuala Lumpur, Jalan Pahang, 50586 Kuala Lumpur, Malaysia
[e]Department of Biomedical Imaging, Faculty of Medicines, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

*Corresponding author: khalis.karim@gmail.com

ABSTRACT

This study aims to evaluate the patient's dose exposure from Computed Tomography Pulmonary Angiography (CTPA) examination and to estimates the cancer risk induced from the examinations based on the patient's size. One hundred patients were recruited, and data information was collected retrospectively. A multi-detector (MDCT) (Philips Brilliance 128, USA) scanner were utilized for the CTPA examination, and dose data were obtained from the system. The effective diameter of each subjects' image was measured for the Size-specific dose estimates (SSDEs). All subjects divided into Group 1 (19 – 25 cm), Group 2 (25-28 cm) and Group 3 (28-38 cm), where the association between gender were analysed. Effective dose (E), SSDE, organ dose and cancer risk of each group were evaluated and compared statistically using independent t-test and one-way ANOVA. The range of mean $CTDI_{vol}$, DLP and E values were (6.44 – 17.42 mGy), (239 – 631 mGy), (5.19 – 13.90 mSv), respectively. In respective with the patient's effective diameter, the mean SSDE value for Group 1, Group 2 and Group 3 were 9.93 ± 3.89 mGy, 13.70 ± 9.04 mGy and 22.29 ± 7.35 mGy. The organ dose and cancer risk attained for breast, lung and liver were 17.05 ± 10.40 mGy (194 per one million procedure), 17.55 ± 10.86 mGy (192 per one million procedure) and 15.04 ± 9.75 mGy (53 per one million procedure), respectively. Lung and breast with more massive patient's effective diameter received the highest dose exposure which increases the probability of the cancer risk. $CTDI_{vol}$ was found to be underestimated, and SSDE provides more accurate in describing the radiation dose and cancer risk. Body effective diameter found to be significant on the estimation except for gender. Therefore, it is essential to apply optimised protocols in order to reduce patient's exposure during CTPA examination.

Keywords: Computed Tomography; radiation dose; cancer risk; CTPA; effective diameter

1. Introduction

Computed tomography (CT) scan has become the most preferred imaging technique, and its utilization has been increasing significantly — as the numbers of the examination using this technique is consistently growing. Albeit its good diagnostic value, in the year 2001, the International Commission on Radiological Protection (ICRP) has expressed concern over the higher usage of CT in medicine and over its remarks that may induced cancer risk when compared to other imaging modalities (Foley et al., 2012).

CT Pulmonary Angiography (CTPA) is one of the imaging techniques that allow the visualization of pulmonary arteries to facilitate diagnosis and treatment of pulmonary embolism (PE). PE is considered as a severe medical condition associated with high mortality, which requires fast and accurate detection. Thanks to the advancement of CT technology, more than 90% of acceptable examinations can be achieved for detecting PE (Sauter et al., 2018). However, one single CTPA examination may contribute up to 10 mSv of effective dose which increases the possibility of radiation-induced cancer risk to the populations (Halid et al., 2018; Sauter et al., 2018).

Volumetric Computed Tomography Dose Index ($CTDI_{vol}$) usually represent radiation dose for CT scanner, which based on a dose estimation of a standardized phantom with consideration of pitch value (Daudelin et al., 2018). Mili-gray is the SI unit and visualizes the mean over the volume of the scan. DLP is the product of $CTDI_{vol}$ and the scan length that describes the total radiation dose delivered to the patient in mili-gray and centimetres. DLP becomes the gold standard as a set reference in the CT examination due to radiation risk-related and represents the full radiation dose per examination (Najafi et al., 2015). $CTDI_{vol}$ however, has many potential errors as they do not consider the size of the body, which varies between patients, especially children.

Hence, the size-specific dose estimates (SSDEs) was introduced by the American Physicians Association (AAPM) in 2011, which incorporates individual patient factors into the $CTDI_{vol}$ calculation (Burton and Szczykutowicz, 2018). Instead of basing dose calculation solely on a phantom, SSDE requires the input of individual patient size in the CT scanner (Pourjabbar et al., 2014). It was found that the ratio of SSDE with $CTDI_{vol}$ is inversely proportional to the size of the patient (Anam et al., 2017).

The k-factor is defined as the proportionality constant between the effective dose and the DLP. In the clinical setting, the DLP is understood to be the product of the CTDI$_{vol}$ and the scan length: where the k is k-factor (mSv mGy-1 cm-1), E is effective dose (mSv), DLP is dose-length product (mGy cm), CTDI$_{vol}$ is in mGy and l is the scan length (cm) for different scan types (Zhou et al., 2017). The k-factors used to date were initially developed by Shrimpton et al. using computational phantoms (Shrimpton, PC, Hillier MC, 2014). The k-factors for extended scan regions were published in the updated EG, which was adopted in the American Association of Physicists in Medicine (AAPM) Report 96 (Pourjabbar et al., 2014). Those k-factors were based on the tissue weighting factors published in the International Commission on Radiological Protection (ICRP) Publication 60 which form the internationally recognized basis of the effective dose since the ICRP updated their tissue weighting factors in the ICRP Publication 103 (van der Molen et al., 2013).

It has been acknowledged that radiation exposure has become crucial issues due to increasing the risk of inducing cancer, especially to young ages patients (O'Daniel et al., 2005). More than 2% of populations receive a significant amount of doses that have the potential to develop cancer risk where younger patients are the main contributor (Sauter et al., 2018). Hence, dose reduction strategies to achieve ''as low as reasonably achievable'' (ALARA) principle is a must while preserving good image quality of CT examination.

The most promising assessment is estimating the organ dose and cancer risk according to the patient's body habitus. Both assessments varied in different conditions, dependency on age, sex and population studied (Karim et al., 2017). The limitation of radiation dose estimation may overcome by these assessments tailored to an individual patient exposure rather than a general population. The 7th report on Biological Effects of Ionizing Radiation (BEIR VII Phase 2) by the United States National Academy of Sciences popularly cited in estimating the cancer risk-based in radiological scans.

The previous study reported that the detrimental effects of radiation exposure are higher in susceptible patient populations, especially young women and children (Brenner and Hall, 2007). As such, it is crucial to calculate an accurate organ-equivalent dose before obtaining an estimation of cancer risk. At the moment there is no research has been found that evaluated the organ dose and cancer risk meticulously in CTPA examination elsewhere (Laqmani et al., 2016, 2014; Sabel et al., 2016; Sauter et al., 2018). This study aims to evaluate the dose exposure and to estimate cancer risk attributes from CTPA examinations based on the size and habitus of the patients.

2. Materials and method

3

2.1. CT parameter measurements

The research protocol was approved by the ethics committee of the Ministry of Health (Malaysia), which waived patient consent form for the retrospective analysis with an approval ID: NMRR-18-3088-44138. The records of 100 adults who underwent CTPA were retrieved from a Hospital Kuala Lumpur, Malaysia. The subjects were above age 18, and they experienced the procedure between September 2018 to February 2019. All subjects were scanned using a Philips Brilliance 128 multi-detector CT (MDCT) scanner, and the images were reconstructed using the DICOM software.

CTPA was performed using 40 to 70 ml of iodinated contrast medium, followed by 50 ml saline chaser, which was intravenously injected into the subjects at a flow rate of 5 ml/s. The bolus tracker technique was performed by placing the region of interest (ROI) on the main pulmonary trunk. The scan was started after 3 to 14 seconds, with a threshold of 70 HU. The z-dom modulation was activated before each scan. The scan was carried out craniocaudally with either 100 kVp or 120 kVp, a pitch of 0.798 and a 0.625 x 40 mm detector configuration. Images were reconstructed with 1 mm slice thickness and 512 x 512 matrix size. The iDose^4 level 4 iterative reconstructive technique was used for post-processing of images. The radiographers performing the scan were well experienced in this protocol at least three years.

Scanning acquisition parameters and data such as subjects' gender, anteroposterior (AP) and lateral (LAT) body lengths, tube voltage (kV), tube current(mA), rotation time, pitch factor, CTDI$_{vol}$ and dose-length-product (DLP) were recorded from scanner console. The AP and LAT lengths of each subjects' image were measured using digital callipers on the scanner console, at the mid-slice location of the transverse CT images as illustrated in Figure 1. Only the scan data of pulmonary embolism scan were included, while cases with incomplete details and modified protocols were excluded.

2.2. Radiation dose

CTDI$_{vol}$, AP and LAT lengths obtained from the scanner console were used to calculate SSDE based on the American Association of Physicists in Medicine (AAPM) Report 204. For comparison purposes, the SSDE were also estimated using CT-EXPO Ver 2.3.1 (SASCRAD, Bucholz, der Norheide, Germany) and Monte Carlo simulation based on scanning parameter used in each examination. Derivation of SSDE, according to AAPM, report 204 began with the calculation of the effective diameter of the subjects' body, as the following equation:

$$Effective\ Diameter\ (cm) = \sqrt{AP\ x\ LAT} \qquad (1)$$

The effective diameters (body size) were normalized to the tabulated body size-dependent conversion factor (f-size) stated in the AAPM report 204. SSDE was calculated by multiplying the normalized f-size with the $CTDI_{vol}$ displayed on the scanner console as in equation below:

$$SSDE = normalised\ f_{size}\ \times\ CTDI_{vol} \qquad (2)$$

In this study, the E and organ dose was estimated only by CT-EXPO software. This software offers automatic output calculation of radiation exposure to the organs based on the detailed scanner model, manufacturer and scanning parameters. The software utilized a Monte Carlo simulation model and estimates the radiation dose based on radiation transport attributable organ dose on the adult phantom.

2.3. Risk assessments

The cancer risk for selected organs was determined using the following equation:

$$R = \sum r_T . H_T \qquad (4)$$

where r_T is the nominal risk factor attained from the International Commission on Radiological Protection (ICRP) Publication 103 (ICRP 2007), and the H_T is the organ-specific equivalent dose obtained by CT-EXPO in breast, lung and liver respectively. The cancer risk (R) per procedure was estimated by multiplying the organ dose with the risk factor (r_T).

2.4. Statistical analysis

All data were analysed by using SPSS V25.0 (SPSS, version 25.0 for Windows, Chicago, Illinois, USA) for statistical study. A p-value of <0.05 was considered to indicate statistically significant differences. Since the data were normally distributed, the independent t-test and one-way ANOVA were used in this study.

3. Results and Discussion

3.1. Patient characteristic and radiation dose

Table 1 shows the mean baseline characteristics of study subjects compromising 42 men and 58 women. The effective diameters were ranged from 20.14 to 37.48 cm in males and 19.71 – 32.25 in females. The calculation of $CTDI_{vol}$, DLP, E and organ dose were grouped according to effective diameters and in total, as indicated in Table 2. As a whole, the $CTDI_{vol}$ DLP, E values were 11.06 ± 7.1, 400.38 ± 259.10

and 8.68 ± 5.47 respectively. The mean values of organ dose for breast (females only), lung and liver were 17.05 ± 10.40 mSv, 17.55 ± 10.86 mSv and 15.04 ± 9.75 mSv, respectively. Surprisingly all SSDE values were higher than CTDI$_{vol}$ for each subjects' effective diameters group for both calculation methods. The details of the observation, as shown in Table 3 and Figure 2.

The subjects size varied along the Z-axis of the scan due to changes in the thickness and composition of the subjects' habitus. As expected, the variation of the subjects' effective diameter was contributed to the SSDE in line with a previous study (Sabel et al., 2016). Hence, the CTDI$_{vol}$ calculated from the console was observed to be undervalued compared to SSDE, especially in small-sized subjects. Overall, the reference phantom based CTDI$_{vol}$ values underestimated the radiation dose received by the subjects as comparison by SSDE approach. The small variations in SSDE to CTDI$_{vol}$ ratio generated by CT-EXPO in different subject sizes group was expected since the software's calculations were based on a constant mathematical phantom (Karim et al., 2017).

However, the ratio generated by the AAPM report method was wider in a small-sized group compare to bigger-sized as the *f*-size increased in decreasing subjects' body size. A previous study had observed that when the automated exposure control (AEC) system was deployed, both CTDI$_{vol}$ and SSDE values were higher in large-sized subjects than those who were standard-sized. When the AEC system was turned off, there seems to be no significant difference between the radiation doses in different subject sizes (Kim et al., 2018). This observation was aligned with this study, where the AEC was deployed.

Another study reported that reducing the tube voltage in CT examination involve contrast media could maximize the photoelectric effect, as the applied voltage was closer to the K-edge of iodine (33.2 keV) (Dane et al., 2018). It could enhance the performance of image quality as well as to reduce the radiation dose. Most studies applied the AEC system to modulate the tube current and reduce unnecessary radiation exposure to their subjects (Isa et al., 2019; Kalra et al., 2004; Karim et al., 2017; Smith-Bindman et al., 2009; Sookpeng et al., 2013). However, a different approach to select both pitch factor and beam collimation showed different radiation exposure-outcome with various institutions and CT-Scanner types.

3.2. Organ dose assessment

It is clearly shown that the breast and lungs received the highest radiation dose exposure as these organs cover all in the primary beam. Both also had an equally high risk of developing cancer. On the other hand, the liver attained the lowest values in organ dose and cancer risk. It was mainly because, in a CTPA procedure, the liver would only be partially scanned as it was not entirely within the region of interest. This

4. Conclusion

In conclusion, SSDE is more promising to evaluate sectional radiation dose compare to $CTDI_{vol}$ accurately. Other radiation dose descriptor such as DLP, E and organ dose found dramatically increase with increasing patient's effective diameter. It is observed that the cancer risk was significantly different between patients' effective diameters and slightly lower by a male instead by a female. Further study could focus on another group ages of subjects scan and additional dose descriptor software to compare by current CT dosimetry software.

Acknowledgement:

References

Anam, C., Haryanto, F., Widita, R., Arif, I., Dougherty, G., McLean, D., 2017. The impact of patient table on size-specific dose estimate (SSDE). Australas. Phys. Eng. Sci. Med. 40, 153–158. https://doi.org/10.1007/s13246-016-0497-z

Bashier, E.H., Suliman, I.I., 2018. Multi-slice CT examinations of adult patients at Sudanese hospitals: radiation exposure based on size-specific dose estimates (SSDE). Radiol. Medica 123, 424–431. https://doi.org/10.1007/s11547-018-0859-6

Brenner, D.J., Hall, E.J., 2007. Computed tomography--an increasing source of radiation exposure. N. Engl. J. Med. 357, 2277–2284. https://doi.org/10.1056/NEJMra072149

Burton, C.S., Szczykutowicz, T.P., 2018. Evaluation of AAPM Reports 204 and 220: Estimation of effective diameter, water-equivalent diameter, and ellipticity ratios for chest, abdomen, pelvis, and head CT scans. J. Appl. Clin. Med. Phys. 19, 228–238. https://doi.org/10.1002/acm2.12223

Dane, B., Patel, H., O'Donnell, T., Girvin, F., Brusca-Augello, G., Alpert, J.B., Niu, B., Attia, M., Babb, J., Ko, J.P., 2018. Image Quality on Dual-energy CTPA Virtual Monoenergetic Images: Quantitative and Qualitative Assessment. Acad. Radiol. 25, 1075–1086. https://doi.org/10.1016/j.acra.2017.12.012

Daudelin, A., Medich, D., Andrabi, S.Y., Martel, C., 2018. Comparison of methods to estimate water-equivalent diameter for calculation of patient dose. J. Appl. Clin. Med. Phys. 19, 718–723. https://doi.org/10.1002/acm2.12383

Foley, S.J., McEntee, M.F., Rainford, L.A., 2012. Establishment of CT diagnostic reference levels in Ireland. Br. J. Radiol. 85, 1390–7. https://doi.org/10.1259/bjr/15839549

Halid, B., Karim, M.K.A., Sabarudin, A., Bakar, K.A., Shariff, N.D., 2018. Assessment of lifetime attributable risk of stomach and colon cancer during abdominal CT examinations based on monte carlo simulation, in: IFMBE Proceedings. pp. 455–459. https://doi.org/10.1007/978-981-10-4361-1_77

Isa, I.N.., Rahmat, S.M.S., Dom, S.M., Kayun, Z., Karim, M.K.., 2019. The effects of mis-centering on radiation dose during CT head examination: A phantom study. J. Xray. Sci. Technol. 27, 631–639. https://doi.org/10.3233/XST-190491

Kalra, M.K.M., Maher, M.M., Toth, T.T.L., Schmidt, B., Westerman, B.L., Morgan, H.T., Saini, S., 2004. Techniques and applications of automatic tube current modulation for CT. Radiology 233, 649–57. https://doi.org/10.1148/radiol.2333031150

Karim, M.K.A., Hashim, S., Bakar, K.A., Bradley, D.A., Ang, W.C., Bahrudin, N.A., Mhareb, M.H.A., 2017. Estimation of radiation cancer risk in CT-KUB. Radiat. Phys. Chem. 137, 130–134. https://doi.org/10.1016/j.radphyschem.2016.10.024

Karim, M.K.A., Hashim, S., Sabarudin, A., Bradley, D.A., Bahruddin, N.A., 2016. Evaluating organ dose and radiation risk of routine CT examinations in Johor Malaysia. Sains Malaysiana 45, 567–573.

Karim, M.K.A., Rahim, N.A., Matsubara, K., Hashim, S., Mhareb, M.H.A., Musa, Y., 2019. The effectiveness of bismuth breast shielding with protocol optimization in CT Thorax examination. J. Xray. Sci. Technol. 27, 139–147. https://doi.org/10.3233/XST-180397

Kim, E.Y., Kim, T.J., Goo, J.M., Kim, H.Y., Lee, J.W., Lee, S., Lim, J.T., Kim, Y., 2018. Size-specific dose estimation in the Korean lung cancer screening project: Does a 32-cm diameter phantom represent a standard-sized patient in korean population? Korean J. Radiol. 19, 1179–1186. https://doi.org/10.3348/kjr.2018.19.6.1179

Lahham, A., ALMasri, H., Kameel, S., 2018. Estimation of female radiation doses and breast cancer risk from chest CT examinations. Radiat. Prot. Dosimetry 179, 303–309. https://doi.org/10.1093/rpd/ncx283

Laqmani, A., Kurfürst, M., Butscheidt, S., Sehner, S., Schmidt-Holtz, J., Behzadi, C., Nagel, H.D., Adam, G., Regier, M., 2016. CT pulmonary angiography at reduced radiation exposure and contrast material volume using iterative model reconstruction and iDose4 technique in comparison to FBP. PLoS One 11, 1–15. https://doi.org/10.1371/journal.pone.0162429

Laqmani, A., Regier, M., Veldhoen, S., Backhaus, A., Wassenberg, F., Sehner, S., Groth, M., Nagel, H.-D.D., Adam, G., Henes, F.O., 2014. Improved image quality and low radiation dose with hybrid

iterative reconstruction with 80 kV CT pulmonary angiography. Eur. J. Radiol. 83, 1962–9. https://doi.org/10.1016/j.ejrad.2014.06.016

Najafi, M., Deevband, M.R., Ahmadi, M., Kardan, M.R., 2015. Establishment of diagnostic reference levels for common multi-detector computed tomography examinations in Iran. Australas. Phys. Eng. Sci. Med. 38, 603–609. https://doi.org/10.1007/s13246-015-0388-8

O'Daniel, J.C., Stevens, D.M., Cody, D.D., 2005. Reducing radiation exposure from survey CT scans. AJR. Am. J. Roentgenol. 185, 509–515.

Pourjabbar, S., Singh, S., Padole, A., Saini, A., Blake, M.A., Kalra, M.K., 2014. Size-specific dose estimates: Localizer or transverse abdominal computed tomography images? World J. Radiol. 6, 210–7. https://doi.org/10.4329/wjr.v6.i5.210

Sabel, B.O., Buric, K., Karara, N., Thierfelder, K.M., Dinkel, J., Sommer, W.H., Meinel, F.G., 2016. High-pitch CT pulmonary angiography in third generation dual-source CT: Image quality in an unselected patient population. PLoS One 11, 1–11. https://doi.org/10.1371/journal.pone.0146949

Sauter, A., Koehler, T., Brendel, B., Aichele, J., Neumann, J., Noël, P.B., Rummeny, E.J., Muenzel, D., 2018. CT pulmonary angiography: dose reduction via a next generation iterative reconstruction algorithm. Acta radiol. 0, 1–10. https://doi.org/10.1177/0284185118784976

Shrimpton, PC, Hillier MC, M.S. and G.S., 2014. Public Health England - Doses from Computed Tomography (CT) Examinations in the UK – 2011 Review.

Smith-Bindman, R., Lipson, J., Marcus, R., Kim, K.-P., Mahesh, M., Gould, R., Berrington de González, A., Miglioretti, D.L., 2009. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch. Intern. Med. 169, 2078–86. https://doi.org/10.1001/archinternmed.2009.427

Sookpeng, S., Martin, C.J., Gentle, D.J., 2013. Comparison of different phantom designs for CT scanner automatic tube current modulation system tests. J. Radiol. Prot. 33, 735–61. https://doi.org/10.1088/0952-4746/33/4/735

van der Molen, A.J., Schilham, A., Stoop, P., Prokop, M., Geleijns, J., 2013. A national survey on radiation dose in CT in The Netherlands. Insights Imaging 4, 383–390. https://doi.org/10.1007/s13244-013-0253-9

Zhou, Y., Yang, C., Cao, X., Du, X., Yu, N., Zhou, X., Zhu, B., Wang, J., 2017. Survey of patients' CT radiation dose in Jiangsu Province. J. Public Heal. Emerg. 1, 9–9. https://doi.org/10.21037/jphe.2016.12.10

Table

Table 1
Data on baseline characteristic based on gender

Baseline Characteristic	Values		
	Male	Female	TOTAL
Age*	49.26 ± 14.57	48.60 ± 19.12	48.88 ± 17.28
AP (cm)*	21.68 ± 3.68	21.88 ± 2.71	21.80 ± 3.14
LAT (cm)*	33.46 ± 4.17	32.85 ± 3.53	33.10 ± 3.80
Effective Diameter (cm)*	26.89 ± 3.71	26.76 ± 2.64	26.82 ± 3.12

*(mean ±SD)

Table 2

Overview of the $CTDI_{vol}$, DLP, E and organ dose values from different group of patient's effective diameter

Effective Diameter (cm)	Dose descriptors			Organ equivalent dose (mSv)*		
	$CTDI_{vol}$ (mGy)*	DLP (mGy.cm)*	E (mSv)*	Breast	Lung	Liver
Group 1 (19 – 25)	6.44 ± 2.63	239.59 ± 97.36	5.19 ± 2.50	10.94 ± 4.62	10.62 ± 4.12	9.15 ± 4.23
Group 2 (25 – 28)	9.86 ± 6.46	351.85 ± 231.85	7.47 ± 4.11	15.48 ± 7.93	15.55 ± 8.39	13.48 ± 6.99
Group 3 (28 – 38)	17.42 ± 6.90	631.46 ± 274.43	13.90 ± 5.66	23.81 ± 12.17	27.39 ± 11.87	23.19 ± 11.76
p - value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
TOTAL	11.06 ± 7.17	400.38 ± 259.10	8.68 ± 5.47	17.05 ± 10.40	17.55 ± 10.86	15.04 ± 9.75

*(mean ±SD)

Table 3

A comparison of SSDE value obtained from AAPM and CT-Expo with its ratio to $CTDI_{vol}$

Effective diameter (cm)	Dose descriptors			
	[a]SSDE (mGy)	[b]SSDE (mGy)*	Ratio [a]SSDE/$CTDI_{vol}$	Ratio [b]SSDE/$CTDI_{vol}$
Group 1 (19 – 25)	9.93 ± 3.89	9.01 ± 3.78	1.54	1.30
Group 2 (25 – 28)	13.70 ± 9.04	13.41 ± 7.74	1.42	1.34
Group 3 (28 – 38)	22.29 ± 7.35	23.98 ± 9.63	1.28	1.31
TOTAL	14.62 ± 8.41	15.37 ± 9.67	1.41	1.32

[a]SSDE = the value obtained from AAPM 204 report
[b]SSDE = the value obtained from CT-Expo calculator
*(mean ±SD)

Table 4

Estimation of cancer risk according to the CTPA examination per million procedures

Effective Diameter (cm)	Nominal Risk Factor $(r_T)10^{-4}\text{Sv}^{-1}$	Cancer Risk (in million procedures) *		
		Breast	Lung	Liver
		112.10	114.20	30.30
Group 1 (19 – 25)		118.67 ± 54.45	114.14 ± 47.03	31.55 ± 12.88
Group 2 (25 – 28)		174.38 ± 94.26	167.06 ± 91.60	46.59 ± 25.63
Group 3 (28 – 38)		278.63 ± 118.27	305.67 ± 120.17	84.39 ± 33.77
p - value		0.0001	0.0001	0.0001
TOTAL		194.00 ± 113.84	191.91 ± 118.36	53.19 ± 32.90

*(mean ±SD)

Table 5

Comparison based on different gender according to the CTPA examination

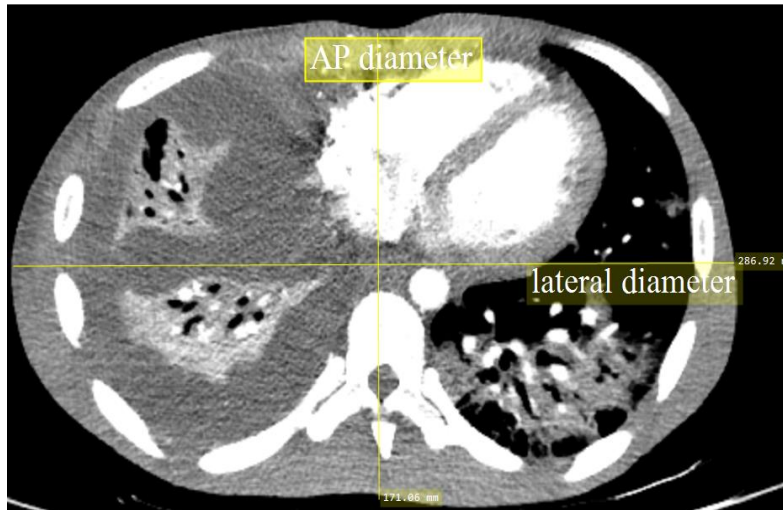| Variable		Gender		P - value
		Male	Female	
E (mSv)*		7.47 ± 4.11	9.53 ± 5.68	0.04
Organ Dose (mSv)*	Breast	n/a	17.05 ± 10.40	n/a
	Lung	15.55 ± 8.39	17.63 ± 10.41	NS
	Liver	13.48 ± 6.99	14.58 ± 9.28	NS
Cancer Risk (per million procedure) *	Brest	n/a	194.00 ± 113.84	n/a
	Lung	185.54 ± 124.36	196.53 ± 114.70	NS
	Liver	52.35 ± 35.31	53.79 ± 31.34	NS

*(mean ±SD)

* NS: not significant

Figure

Fig. 1. Patient's effective diameter measurement at the mid-slice location of the transverse CT images
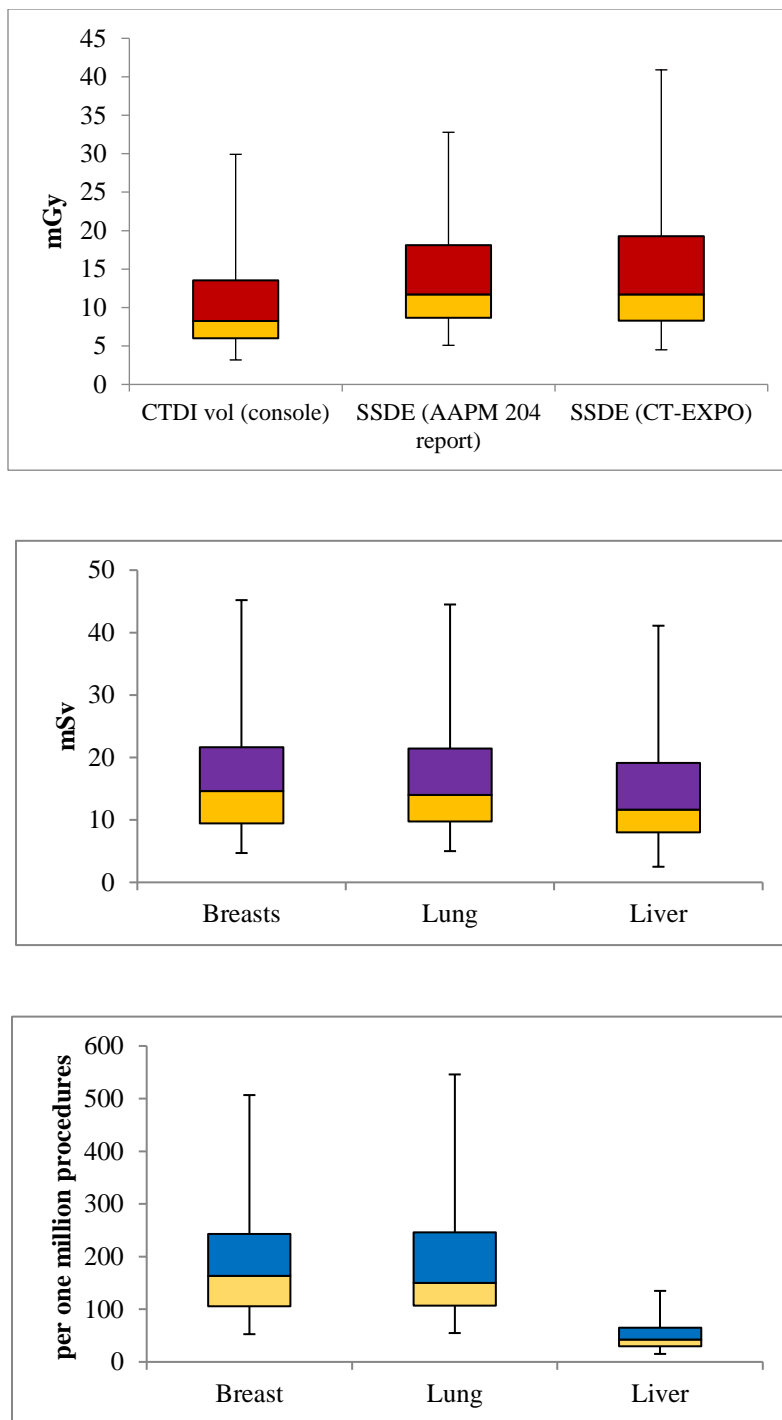
Fig. 2. The distribution of radiation dose and cancer probability risk value in CTPA examination: (a) CTDI$_{vol}$ vs SSDE (b) Organ Dose (c) Cancer Risk.