GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Check for updates

Study the variations in radiation doses in different multi-slice CT scan machines

Samia A. Fathelrahman [1,*], Albosairi T. Ahmed [1], Najla H. Khalid [1], Maha Esmaeal Ahmed [2] and Hamad A. Al-bishr [3]

[1] *Department of Radiological Sciences, Applied Medical Sciences College, Najran University, Najran KSA, P.O. Box 1989 KSA.*
[2] *National University, Radiological sciences and Medical imaging College, Khartoum, Sudan.*
[3] *Department of Radiology, King Khalid Hospital. MOH, KSA.*

GSC Advanced Research and Reviews, 2023, 17(02), 221–228

Publication history: Received on 18 October 2023; revised on 25 November 2023; accepted on 28 November 2023

Article DOI: https://doi.org/10.30574/gscarr.2023.17.2.0450

Abstract

Objectives: This study aimed to measure variations in dose output and patient's effective dose across the different computed tomography scanners during standard CT examinations of head, chest and abdomen, so as to determine patient, and machine settings that contribute to variations in radiation dose to optimize patient effective dose.

Methods: Retrospective, study performed in different hospitals, in Najran province (K.S.A) from October 2022 to June 2023. The study comprise 360 adults CT examinations. The mean values of CT dose index volume ($CTDI_{vol}$) and dose length product (DLP) were measured. The patient effective dose (ED) were calculated for each protocol and compared among different CT scanners.

Results: The mean values of $CTDI_{vol}$, DLP, and ED, varied across the different CT scanners, Regarding abdomen CT, the $CTDI_{vol}$ mean values were (5.56 mGy to 18.655 mGy) , the DLP (289.78 to 968.241 mGy/cm), and mean effective doses were (4.34 to 14.5 mSv), in chest CTs the mean values of $CTDI_{vol}$ were (5.05 to 14.39mGy), the DLP were (202.84 to 499.098mGy/cm), and median effective doses were (2.85 to 6.97 mSv), in head CTs the mean values of $CTDI_{vol}$ were (42.4to 68.278mGy), the DLP were (781 to 1209.18mGy/cm), and effective doses were (1.636 to 2.528mSv).

Conclusion: Regarding selected exams, CTDI, DLP and ED were found to be varied from low variations in head CT scan, to medium in chest CT scan and high variation in abdomen CTs among different CT scanners, The highest values of CTDI and DLP were noted in head CTs followed by abdomen, and the lowest were in chest CTs. The most factors affected the CT dose variations were the technical parameters settings, mainly the number of slices, however the scanner specifications reported some impact. Optimizing dose to a reliable standard for each anatomical part should be adjusting independently by each department according to the scanner characteristics, settings and patient factors.

Keywords: CT; CTDI; DLP; Effective dose; Ionizing radiation

1. Introduction

Medical imaging plays a vital role in accurate diagnosis and improved patient treatment [1]. The use of ionizing radiation in medical imaging is associated with a risk of cancer thus, efforts should be focus to standards of safety and optimization [2]. Computed Tomography (CT) is an x-ray imaging modality with a high radiation dose [3]. Since the risk of radiation induced malignancy attributable to CT is not totally zero, dose reductions policies are one of important consideration [4]. The optimization process requires a balance between patient dose and image quality, along with other clinical

* Corresponding author: Samia A. Fathelrahman

considerations [5]. With the rapid advanced of CT technology in clinical applications, CT should have obligation to teach, understand, and use CT dose reports in practical aspects [6].

The radiation output that a CT scanner provides during an examination can be calculated by using the volume CT dose index ($CTDI_{vol}$) and dose length product (DLP), which are an internationally standardized measurement that useful for comparing CT protocols between scanners [6]. $CTDI_{vol}$ (mili-gray (mGy)), can be considered the average radiation output per slice of the CT scanner and depends only on the type of scanner and acquisition parameters such as x-ray tube peak kilovoltage (kVp) and tube current–time product. However, it is not affected by patient size or scan length [7]. DLP indicates the total amount of radiation incident on the patient. A change in DLP is associated to changes in CT dose parameters and scan length [8].

Both $CTDI_{vol}$ and DLP parameters are displayed on the control console during and after CT planning, however, these only represent the radiation dose delivered by the CT device, whereas based on this, the patient dose is a variable consequential and dependent on the patient factors [9].

With effective dose the organ doses from a partial irradiation of the body are converted into an equivalent dose to the entire body, hence, the effective dose (Millisievert (mSv)), reveal the amount of radiation that received by a patient's tissue regarding its sensitivity [10]. It is used in protection planning, choosing imaging techniques, and evaluating differences in doses between procedures (ICRP 2021) [11]. Calculations of CT doses are required to chart scanner output to patient dose, considering the patient's size, scanned areas and composition, and scan range [12-13].

Many previous studies reported that the amount of CT doses fluctuated significantly across patients, hospitals, and machine factors or scanned area [14]. However, differences in patient populations and irregularities in data collection and analysis always affect both accurate evaluation of dose variations and determination the reason of variation [15]. Without determining specific factors behind variation in reported doses, it is undefined whether the setting of specific reference levels is needed [16]. Recently, the need for optimization of radiation doses to achieve the correct balance between diagnostic image quality and lower radiation dose in CT procedures has received much attention [17].

This study was aimed to evaluate the variation in CT output doses and patients' effective dose across the different computed tomography scanners to determine patient factors and machine setting that contribute to variations in order to optimize patient effective dose.

2. Materials and methods

This was a quantitative, descriptive, and cross-sectional study performed in different hospitals, in Najran province (K.S.A) using routine common CT examinations which performed in adults for clinical indications. During the study period, 360 adults male and female, their ages were ranged (18–90 years). All scan protocols were based on the manufacturer's routine for head, chest and abdomen protocols, and all used AEC system, which modulated tube current in the longitudinal and angular directions to adjust scanner output according to the attenuation for each patient at different tube positions [18]. The mean values of CTDI and DLP during the most frequent CT examinations were measured. The patient effective dose was calculated for each protocol by using of the dose length product and published conversion factors [19], and were compared among different CT scanners. Examinations were performed on 4 different CT scanners during single phase's standard routine CT examinations, in which each examination consisting of 30 patients to measure variation in dose output and patients effective dose across the different CT scanners. Data of examinations performed which stored in digital imaging and communications in medicine (DICOM) format were retrieved from PACS and used to review these examinations. Data were analyzed using Microsoft excel Statistics.

3. Results

Data were obtained from four different CT scanners including: Siemens, Canon, General Electric and Philips. The range and mean values of volumetric computed tomography dose index (CTDIvol), dose length product (DLP) and effective dose (ED) in relation to the patients characteristics, and technical scan parameters (kv, pitch, and number of the slices) were calculated as given below.

Table 1 Comparison of Standard CT Abdomen Protocols and doses in different CT machines

Scanner		Age	weight	Kv	No of slices	Pitch	CTDI mGy	DLP mGy/cm	ED mSv
1	Mean	34.33	63.75	120	159	0.813	18.66	968.24	14.50
	Max	53	89	120	175	0.813	18.84	1055	15.8
	Min	20	49	120	138	0.813	18.59	848	12.7
2	Mean	36.38	81.38	120	94	0.637	5.56	289.77	4.34
	Max	58	99	120	109	0.637	7.6	395.6	5.9
	Min	18	61	120	81	0.637	3.4	154.2	2.3
3	Mean	39.67	69.75	120	146	0.6	14.08	642.17	9.64
	Max	79	87	120	164	0.6	18.1	920	13.8
	Min	22	53	120	126	0.6	7.8	320	4.8
4	Mean	40.46	73	120	119	1.375	9.97	518.45	7.79
	Max	78	80	120	131	1.375	13.13	696	10.4
	Min	24	58	120	101	1.375	6.75	330	5

Table 2 Comparison of Standard CT chest Protocols and doses in different CT machines

Scanner		Age	Weight	Kv	No of slices	pitch	CTDI mGy	DLP mGy/cm	ED mSv
1	Mean	58.38	74.46	120	103	0.813	10.23	355.55	4.99
	Max	86	95	120	131	0.813	14.11	482.1	6.7
	Min	25	50	120	79	0.813	5.84	185.7	2.6
....2	Mean	31.83	70.41	120	65	0.637	5.05	202.84	2.85
	Max	52	81	120	85	0.637	9.2	429.4	6
	Min	18	50	120	50	0.637	2.3	81.9	1.1
3	Mean	56.38	72.75	120	54	1.2	12.42	336	4.68
	Max	81	82	140	63	1.2	18.1	373	5.2
	Min	32	61	120	38	1.2	8.4	267	3.7
4	Mean	56.11	74.66	100	111	0.984	14.38	499.08	6.98
	Max	90	87	100	125	0.984	19.3	686	9.6
	Min	24	60	100	85	0.984	7.7	267	3.7

Table 3 Comparison of Standard CT head Protocols and doses in different CT machines

Scanner		Age	Weight	Kv	slices	pitch	CTDI mGy	DLP mGy/cm	ED mSv
1	Mean	44.93	67.66	120	36	0.813	54.13	1050.13	2.19
	Max	76	93	120	40	0.813	54.13	1151.2	2.4

	Min	23	50	120	31	0.813	54.13	908.5	1.9
2	Mean	39.28	69.5	120	37	0.637	42.4	975.29	2.04
	Max	87	106	120	46	0.637	43	1057.7	2.2
	Min	18	51	120	32	0.637	34.6	864.1	1.8
3	Mean	47	67.36	120	52	0.55	47.081	781	1.63
	Max	74	79	120	62	0.55	58.8	1104	2.3
	Min	24	58	120	46	0.55	39	587	1.2
4	Mean	45.71	65.285	107.14	32	0.53	68.278	1209.18	2.53
	Max	85	80	120	37	0.531	87.2	1586	3.3
	Min	20	20	80	27	0.531	46	782	1.6

Table 4 Comparison of mean values of Standard Protocols and CT doses for selected exams in ach scanner

Protocols	**MeanAge**	**Mean weight**	**Mean Kv**	**Mean No of slices**	**MeanPitch**	**Mean CTDI mGy**	**Mean DLP mGy/cm**	**Mean ED mSv**
Scanner 1								
Abdomen	34.33	63.75	120	159	0.813	18.655	968.24	14.50
Chest	58.38	74.46	120	103	0.813	10.23	355.55	4.99
Head	44.93	67.66	120	36	0.813	54.13	1050.13	2.19
Scanner 2								
Abdomen	36.38	81.38	120	94	0.637	5.56	289.78	4.34
Chest	31.83	70.41	120	65	0.637	5.05	202.84	2.85
Head	39.28	69.5	120	37	0.637	42.4	975.29	2.043
Scanner 3								
Abdomen	39.67	69.75	120	146	0.6	14.08	642.166	9.64
Chest	56.38	72.75	120	54	1.2	12.418	336	4.69
Head	47	67.36	120	52	0.55	47.081	781	1.64
Scanner 4								
Abdomen	40.46	73	120	119	1.375	9.97	518.45	7.79
Chest	56.11	74.66	100	111	0.984	14.39	499.09	6.98
Head	45.71	65.28	107.14	32	0.53	68.28	1209.18	2.53

Table1, estimate the mean of the CT dose metric parameters ($CTDI_{vol}$, DLP, and ED) obtained for standard abdomen CT scan protocols among the four different scanners. Regarding scanner 1, the mean patients age and weight were 34.3 years, 63.74 kg respectively, the mean values of scan parameters were 120 kV, number of slices were 159, and pitch was 0.813, while the mean of the $CTDI_{vol}$, DLP and ED were 18.655mGy, 968.241mGy/cm, and 14.501mSv respectively.

Concerning scanner 2, the mean of patients age and weight were 36.38 years, 81.38 kg, the mean of scan parameters were 120 kv, 94 slices and pitch was 0.637, while the mean value of the $CTDI_{vol}$, DLP and effective dose were 5.56mGy, 289.775mGy/cm. and 4.337mSv respectively.

Also in scanner 3, the mean of patients age and weight were 39.7 years, 69.8 kg, the mean of scan parameters were 120 kv, 146 slices with pitch of 0.6, while the mean value of the $CTDI_{vol}$, DLP and ED were 14.08mGy, 642.16mGy/cm and 9.64mSv respectively.

In scanner 4, the mean of patients age and weight were 40.46 years, 73 kg, the mean values of scan parameters were 120 kv, 119 slices and pitch of 1.375, while the mean value of the $CTDI_{vol}$, DLP and ED were 9.9mGy, 518.45mGy/cm and 7.79mSv respectively.

Table 2, estimate the mean of the CT dose metric parameters for standard chest CT scan protocols among the four different scanners. Regarding scanner 1, the mean of patients age was 58.4 years, the mean patients weight was 74.5 kg, the means of scan parameters were 120 kv, 103 slices, and 0.813 pitch, while the mean of the CTDI vol, DLP and ED were 10.23 mGy, 355.553 mGy/cm and 4.99 mSv respectively.

For Scanner 2, the mean of patients age and weight were 31.83 years, 70.4 kg respectively, the mean values of scan parameters were 120 kv, 65 slices, and pitch of 0.637, while the mean value of the $CTDI_{vol}$, DLP and ED were 5.05 mGy, 202.881 mGy/cm and 2.85 mSv respectively.

In scanner 3, the mean of patients age and weight were 56.38 years, 72.75 kg respectively, the mean values of scan parameters were 120 kv, 54 slices, and pitch of 1.2, and the mean value of the $CTDI_{vol}$, DLP and ED were 12.42 mGy, 336 mGy/cm and 4.69 mSv.

Regarding scanner 4, the mean of patients age and weight were 56.1 years, 74.7 kg respectively, the mean values of scan parameters were 100 kv, 111 slices, and pitch of 0.984, while the mean value of the $CTDI_{vol}$, DLP and ED were 14.39mGy, 499.098 mGy/cm and 6.97mSv respectively.

Table 3, shows the mean of the CT dose parameters obtained for standard head CT scan protocols among the four different scanners. Where in scanner 1, the mean of patients age was 44.9 years, the mean of patients weight was 67.7 kg, the means of scan parameters were 120 kv, 36 slices and 0.813 pitch, while the mean of the $CTDI_{vol}$, DLP and ED were 54.13mGy, 1050.13mGy/cm, and 2.19mSv.

Regarding scanner 2, the mean of patients age and weight were 39.3 years, 69.5 kg respectively, the mean values of scan parameters were 120 kv, 38 slices and pitch of 0.637, while the mean value of the $CTDI_{vol}$, DLP and ED were 42.4mGy, 975.29mGy/cm, and the 2.04mSv.

Also in scanner 3, the mean of patients age and weight were 47 years, 67.36 kg respectively, the mean values of scan parameters were 120 kv, 52 slices, and pitch of 0.55, the mean value of the $CTDI_{vol}$, DLP and ED were 47.08mGy, 781mGy/cm, and 1.64mSv.

While in scanner 4, the mean of patients age and weight respectively were 45.7 years, 65.3 kg, the mean values of scan parameters were 100 kv, 33 slices, and pitch of 0.531, the mean value of the $CTDI_{vol}$, DLP and ED were 68.28mGy, 1209.19mGy/cm, 2.53mSv.

Table 4 compare the variations in patient dose in same CT scanner among the different scanned area, highest distribution of CTDI and DLP noted in head examination followed by abdomen and chest CTs, while lowest ED were calculated for head and the highest doses reported in the abdomen.

4. Discussion

Many previous studies reported that the amount of CT doses affected significantly across patients, hospitals, and scanned area, though reducing unnecessary variation in radiation dose across hospitals and imaging facilities is a complex but important practice for improving patient safety [9], this stud aim to assess the variation in CT output doses and patients' effective dose across the different computed tomography.

Table 1, displays a comparison of the abdomen protocols and doses in different CT machines, and reflects that the mean values of $CTDI_{vol}$ were ranged from 5.56mGy to 18.655mGy, the DLP were ranged from 289.78 to 968.241mGy/cm, and consequently mean effective doses ranged from 4.34 to 14.5mSv. The distribution demonstrate high variations in mean values of CT doses and patient ED for abdomen CT across different CT scanners, where scanner 1 gives the highest doses and scanner 2 the lowest, whatever the mean age and mean body weight, but when considered technical factors, mean doses for abdomen CT were noted to be increased with increasing the number of the slices. Table 2, displays a comparison of the chest protocols and doses in different CT machines, it demonstrates that the mean values of $CTDI_{vol}$ were ranged from 5.05 to 14.39, the DLP were ranged from 202.84 to 499.098, and median effective doses ranged from 2.85 to 6.97mSv. The distribution demonstrate also high variations in the mean values of DLP, $CTDI_{vol}$ and patient effective doses ED across different CT scanners. Where scanner 4 gives the highest doses and scanner 2 is the lowest, with different patient weight, pitch and number of the slices. Table 3, displays a comparison of head protocols and doses in different CT machines, and shows that the mean $CTDI_{vol}$ were ranged from 42.4to 68.278, the DLP were ranged from 781 to 1209.18, consequently median effective doses ranged from 1.636 to 2.528mSv. The distribution demonstrate average variation in the $CTDI_{vol}$ and DLP, where scanner 4 gives the highest doses and scanner 2 the lowest. However, low variation in patient effective doses was found across the four scanners. The results of this study reflect that, concerning same scanned area, with different values of pitch, number of slices, and patient weight, but same kV, variations in mean values of $CTDI_{vol}$, DLP, and ED, across the different CT scanners were documented and was ranged from low variations in head CT scan, to medium in chest CT scan and high variations in abdomen CT scan. While scanner 2 reported low level of CTDI, DLP and ED in all selected examinations whatever the mean age and mean body weight, we can note that the adaptation of scan parameters generally tend to decrease in the number of slices with applying average pitch in all protocols. We thought that CT machine manufacturers in their search to improve the performance of their devices in terms of image quality and patient radiation dose, they adjust their machines with advanced scanning protocols, software, and automatic exposure system, which directly affect variations between different scanners regardless of other parameters.

Furthermore, the study found variations in patient radiation dose in the same CT scanner among the different scanned areas with using AEC, same kV and pitch (scanner 1 &2) but with differ in the number of slices and patient weight (Table 4), while highest measurement values of $CTDI_{vol}$ and DLP were noted in head examinations, where the mean values of $CTDI_{vol}$ were (54.13, 42.4, 47.081, and 68.28mGy), mean of DLP were (1050.13, 975.29, 781, and 1209.18mGy/cm) in scanners 1, 2, 3, and 4, respectively, followed by abdomen, and chest CTs which reported lower output doses among all scanners except scanner 4, in which the high doses of the head CTs followed by the chest CTs and then the abdomen CTs. This finding indicates that head CTs in selected hospitals required to be well adapted, optimized, and compared with the national and international reference values. However, lowest ED were calculated for the head CTs where the mean values were (2.19, 2.043, 1.64, and 2.53mSv) in scanner 1, 2, 3 and 4, respectively ,and the highest ED doses were reported in the abdomen CTs (14.50, 434, 9.64, and.7.79) in scanner 1, 2, 3, and 4, respectively.

Concerning CT dosimetry, our study found considerable variations in CT dose across the different selected CT scanners, and different scanned areas, as a result of variances in selected technical parameters, machine manufacture, anatomical area under examination and patient dependent factors which affect dose levels and subsequently can increase CT dose variation. The most factors affected the CT dose variations were the set of the machine's technical parameters, mainly the number of slices and pitch which influence the $CTDI_{vol}$ and DLP, also the scanner specification reported some impact as in scanner 2. Conversely the dose variation is not largely related to the X-ray tube current or kilovoltage in this study, where the AEC and same KV were adjusted through almost exams among all scanners. Study done by Smith-Bindman et al. 2019, reported that variation in CT doses was mainly driven by how machines were used, rather than by patient or machine manufacturer or model [14].

These findings advise that radiology staff should be familiar with the concepts of choosing the correct settings for optimizing scanner output, and patient effective dose to a reliable standard between the different scanner models and scanned area.

The fundamental of dose optimization protocol is updating physician and radiology team knowledge and awareness about what establishes a diagnostic CT scan based on the association of CT protocol parameter adoptions with accurate diagnostic image quality. We recommended to adjustment the scanning parameters using lesser number of slices, appropriate pitch, using CT models that provided with advanced protocols, software and automatic exposure system whenever possible in order to reduce the patient's effective dose and maintain image quality that answers the clinical requires. Education and collaboration in setting standards could offer the largest effect on optimizing dose.

5. Conclusion

For the standard CT head, chest and abdomen protocols, CTDI, DLP and ED were found to be varied among different CT scanner models, this variation ranged from low variations in head CT scan, to medium in chest CT scan and high variations in abdomen CT scan. The highest values of ED were noted in abdomen examinations followed by chest, and the lowest values were found in the head examinations. The most important factor that affected the CT dose variations was the set of the machine's technical parameters, mainly the number of slices, however the scanner specification had reported some impact. Optimizing doses to a more constant standard for each anatomical part should be adjusting independently by each department according to the scanner specifications, setting and individually patient factors. Future studies should be focus on determining reference values for CT examinations in Najran province hospitals and comparing them with international references values. Also, the results of our study comparing the dose values in different protocols, thus, it can be presented to CT users in different hospitals so as to share the best practices on dose optimization used in different radiological centers.

Limitation of the study

Only four CT scanners were evaluated due to limited number of hospitals and CT machines in Najran region. Due to time limits, small study sample for each exam were used, also many variables like scan length, detectors number, slice thickness, that may affect dose output and patients effective dose were not included in the study.

Compliance with ethical standards

Acknowledgments

The author is grateful to all Najran hospital and radiology departments staff whom participated in this study.

Disclosure of conflict of interest

All authors have declared that there are no conflicts of interest.

Statement of ethical approval

'The present research work does not contain any studies performed on animals/humans subjects by any of the authors'.

Statement of informed consent

This study does not involve information about any individual e.g. case studies, survey, interview etc.,

Author contributions

Samia A Fathelrahman: conceptualization, writing reviewing and editing, Albosairi T Ahmed: methodology, Nagla H Mohamed: analysis, Hamad A. Al-bishr: data collection.

References

[1] Tsapaki, V., Radiation dose optimization in diagnostic and interventional radiology(Current issues and future perspectives. PhysicaMedica. 2020, 79:16-21. 10.1016/j.ejmp.2020.09.015

[2] Okyar, H.B, Ma, J., & Pinak, M. A, New IAEA Safety Report on Occupational Radiation Protection in the Uranium Mining and Processing Industry . (IAEA-CN--261). International Atomic Energy Agency (IAEA), 2018

https://media.superevent.com/documents/20180619/7f1e92530adbebe8859f74f54190f6ef/cn_261-uram2018-book-of-abstracts.pdf

[3] Toori, A. J., Shabestani-Monfared, A., Deevband, M. R., Abdi, R., &Nabahati, M., Dose assessment in computed tomography examination and establishment of local diagnostic reference levels in Mazandaran, Iran. Journal of biomedical physics & engineering. 2015, 5(4), 177

[4] Sarangi, P. K., Mohanty, J., Parida, S., & Swain, B. M.. Understanding Computed Tomography (CT) Dose Reduction Techniques and Principles in a Simplified Way, Current Trends in Clinical & Medical Imaging. 2017,1(2): 20-25,

[5] MALONE, Jim, et al. Justification of diagnostic medical exposures: some practical issues. Report of an International Atomic Energy Agency Consultation. The British journal of radiology, 2012, 85.1013: 523-538. https://doi.org/10.1259/bjr/42893576

[6] Maharjan S, Prajapati S, Panta B. Measurement of radiation dose in multi-slice computed tomography. Bangabandhu Sheikh Mujib Medical University Journal. 2016, 9(4): 196-200,

[7] Tamm EP, Rong XP, Cody DC, Ernst RD, Fitzgerald NE, Kundra V. Quality initiatives: CT radiation dose reduction—how to implement change without sacrificing diagnostic quality. RadioGraphics. 2011, 31:1823–1,

[8] Maldjian, Pierre D., and Alice R. Goldman. "Reducing radiation dose in body CT: a primer on dose metrics and key CT technical parameters." American journal of roentgenology. 2013, 200.4: 741-747,

[9] Zinsser, D., Marcus, R., Othman, A. E., Bamberg, F., Nikolaou, K., Flohr, T., &Notohamiprodjo, M. Dose Reduction and Dose Management in Computed Tomography–State of the Art FortschrRöntgenstr. 2018.; 190: 531–541,

[10] Gautam, S., Saurav, S. K., Adhikari, K., Singh, S., &Banstola, H. K.. Computed Tomography Dose Measurement in Three Hospitals of Pokhara. Int. J. Sci. Res. in Physics and Applied Sciences. 2021.Vol, 9(4).

[11] Harrison, J. D., Balonov, M., Bochud, F., Martin, C. J., Menzel, H. G., Smith-Bindman, R., & Wakeford, R. The use of dose quantities in radiological protection: ICRP publication 147 Ann ICRP 50 (1) 2021. Journal of Radiological Protection. 2021, 41(2), 410,

[12] Siegel J, Schmidt B, Bradley D, Suess C, Hildebolt C. Radiation dose and image quality in pediatric CT: effect of technical fac tors and phantom size and shape. Radiology. 2004. 233 (2): 515 – 522

[13] Amis S, Butler F, Applegate E, et al. American College of Radiology white paper on radiation dose in medicine. J Am CollRadiol., 2007; 4:272–284.

[14] Parakh A, Euler A, Szucs-Farkas Z, Schindera T. Transatlantic Comparison of CT Radiation Doses in the Era of Radiation Dose Tracking Software. AJR Am J Roentgenol. 2017; 209:1302-7. doi:10.2214/AJR.17.18087,

[15] EUROPEAN COMMISSION (EC). Diagnostic Reference Levels in Thirty-six European Countries Part 2/2. Radiation protection No. 180. 2014.

[16] Smith-Bindman, R., Wang, Y., Chu, P., Chung, R., Einstein, A. J., Balcombe, J., ... & Miglioretti, D. L. International variation in radiation dose for computed tomography examinations: prospective cohort study. Bmj. 2019., 364,

[17] Martin, C. J., Abuhaimed, A., & Lee, C. .Dose quantities for measurement and comparison of doses to individual patients in computed tomography (CT), Journal of Radiological Protection. 2021, 41(4), 792,

[18] Gies M, Kalender WA, Wolf H, Suess C, Madsen M. Dose reduction in CT by anatomically adapted tube current modulation. I. Simulation studies. Med Phys. 1999.;26(11):2235–2247,

[19] Christner, J. A. Kofler JM, McCollough CH. Estimating effective dose for CT using dose-length product compared with using organ doses: Consequences of adopting International Commission on Radiological Protection publication 103 or dual-energy scanning. AJR Am J Roentgenol. 2010., 194, 881-9.