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Radiation Organ Dose Measurement and Cancer Risk Estimation in CT Examination on Trauma Patients

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Abstract

Background: This study intended to measure radiation doses to various organs and calculate the risk of cancer incidence from neck computed tomography and head computed tomography scans of trauma patients by using a thermoluminescent dosimeter.

Methods: We assessed 93 patients who presented to the Emergency Department. Based on their health conditions, different computed tomography scans were performed. We used a fixed tube current of 200 mAs and tube voltage of 120 kVp for all patients. Next, we derived the effective radiation dose by multiplying the dose length product and conversion factor of each computed tomography scan based on the International Commission on Radiological Protection 103. Organ dose estimations were calculated from the dosimeter readout. We calculated the life attributable risk for cancer incidence based on the Committee on the Biological Effects of Ionizing Radiation VII preferred models.

Results: Neck computed tomography scans had a mean effective dose of 2.18 mSv. The mean effective dose for head computed tomography scans was 1.53 mSv. The highest mean equivalent organ dose was for the thyroid with the neck computed tomography scan and the lenses of the eyes with the head computed tomography scan. There was no significant difference between scan lengths in each computed tomography acquisition. There was a noticeable correlation observed between effective radiation dose and tube current. As anticipated, young people had a higher life attributable risk of cancer compared to the elderly. This amount was less than 0.011 per 100 persons for both computed tomography studies.

Conclusion: Our data showed a significant organ radiation dose in both neck and head computed tomography scans, not only for the thyroid and the lenses of the eyes, but also for the chest.

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Introduction

Computed tomography (CT) scanning is one of the main diagnostic procedures for trauma patients. It is undeniable that while emergency departments use CT scan exams to improve diagnostic accuracy, the concern regarding biological effects of ionizing radiation on patients remains a crucial matter. There are a number of clinical guidelines and regulations such as the Canadian C-spine rules and the NEXUS Criteria for Cervical Spine (c-spine) Imaging that assist emergency physicians in determining which patients should undergo CT scans. However, we could not find any specific guidelines that consider the amount of radiation exposure and estimate the probability of cancer incidence in trauma patients, which would cause limitations to the CT studies. The average annual radiation dose from natural sources (environmental sources) varies from 2.2 to 3.6 mSv per person, whereas CT exposure is 1-2 mSv for a head CT scan and 5-7 mSv for a chest CT scan.[1, 2] Increased low dose radiation to patients corresponds to an increased risk for cancer and genetic disorders. Extensive studies have evaluated the radiation doses to patients during CT scanning. Numerous dose reduction techniques have been applied to limit the radiation dose such as decreasing tube current and tube voltage, use of an appropriate shield, adjustments to collimation, use of an automatic tube voltage, and tube current.[3-9] According to recent studies, the use of lower tube voltage and protected shield can reduce the radiation dose more than 30% in comparison with routine CT methods.[10-12]

In order to evaluate the radiation dose from CT scans to radiosensitive organs like the thyroid gland, breasts, and lungs, many studies have used in vivo dosimeters such as metal oxide semiconductor field effect transistor (MOSFET) detectors or thermoluminescent dosimeters on an anthropomorphic phantom.[13-15] Currently, few studies have investigated the dose to radiosensitive organs during CT scans in patients who present to the emergency room.[16,17] The aim of this study is to evaluate the radiation dose by using a thermoluminescent dosimeter (TLD-100) for the three radiosensitive organs, namely lenses of the eyes, thyroid, and breast, during neck CT and head CT scans on trauma patients. We also have calculated the life attributable risk (LAR) of cancer incidence based on the Committee on the Biological Effects of Ionizing Radiation (BEIR) VII preferred models.

Materials and Methods

Study population

We assessed 48 head CT scans and 45 neck CT scans from 93 trauma patients who presented to the Emergency Department of Loghman Hakim Hospital from February 2017 to August 2017. Male patients had a mean age of 55 and female patients of 49. There were 54 males and 39 females. All patients provided their informed consent. The local Institutional Review Board approved this study.

CT scan technique

All patients underwent head and neck CT scans on a 16 multi-slice CT scanner (Activion Toshiba, Japan) according to the following scanning parameters. Each patient first underwent a lateral and coronal scanogram, followed by a neck CT scan from the base of the skull to the boundary between the thoracic and cervical spine. For the head CT, the scan ranged from the skull base to the vertex (routine head CT). We did not use any contrast agent for the scans. The scan parameters consisted of a tube voltage of 120 kVp, pitch factor of 1, and rotation time of 0.75 sec. The slice thickness was set at 5 mm for the head CT scan and 1.5 mm for the neck CT scan. The tube current was fixed at 200 mAs for the head CT scan and 120 mAs for the neck CT scan. Our indications for head CT and neck CT scans in trauma patients was based on the Canadian CT head rules and NEXUS Criteria for Cervical (C-spine) Imaging.

Radiation dose measurement method

We calculated the effective dose (ED) from the dose report page obtained from the CT console. We multiplied the dose length product (DLP) to the conversion factor by using the International

Table 1. The ED, CTDIvol, and DLP for head and neck CT scans.

	Head CT (Average ± SDe)	Neck CT (Average ± SD)
EDa (mSv)	1.7 ± 0.4	2.2 ± 1.4
CTDIvol b (mGy)	36.87 ± 9.6	22 ± 9.8
DLPc (mGy.cm)	807.67 ± 91.5	427.9 ± 87.8

a Effective dose; b Volumetric CT dose index; c Dose length product; e Standard deviation; CT: Computed tomography

Commission on Radiological Protection (ICRP) Publication 103 (head=0.0019 and neck=0.0051).[10,14,18-20] For measuring organ dose, we used a thermoluminescent dosimeter (TLD-100) that had been calibrated in a Secondary Standard Dosimeters Laboratory (SSDL, Karaj, Iran). We placed four TLDs on each patient, two on nipples of the breasts, one TLD on the thyroid, and the last one on the glabella (between both eyes). The conversion coefficient factor was derived from ICRP Publication 103 in order to calculate the ED of the mentioned organs.[18]

Cancer risk estimation

The BEIR VII report provides a method to estimate lifetime attributable risk of cancer based on the radiation dose and patient's age and gender. For all patients, the LAR of the cancer incidence for thyroid and breast was calculated from the BEIR VII report tabulation (Table 12D-1 page 311).[2]

The LAR is expressed by the formula:

$$LAR\ (D, e) = \sum M\ (D, e, a)\ S\ (a)/S\ (e)$$

Where:

D is the absorbed dose; 'e' is the exposed age of the patient; 'a' is the attained age; S (a) is the probability of survival until age 'a'; and S (e) is the probability of survival until age 'e'.

For example:

A 20-year-old male received a dose of 0.01 Gy to the thyroid from a CT scan. Table 12D-1 in the BEIR VII report shows the estimate lifetime risk of a thyroid cancer diagnosis for a male exposed to 0.1 Gy at age 20 would be 21 per 100,000. Thus, the estimate for a male exposed at 0.01Gy is determined as follows: (0.01/0.1)×21=2.1 per 100000 person.

Statistical analysis

All analyses were performed with SPSS software (version 16). We used regression analysis to assess the correlation between radiation dose and scan parameters that affected the radiation dose (scan time, scan length, and tube current). All results were assessed descriptively.

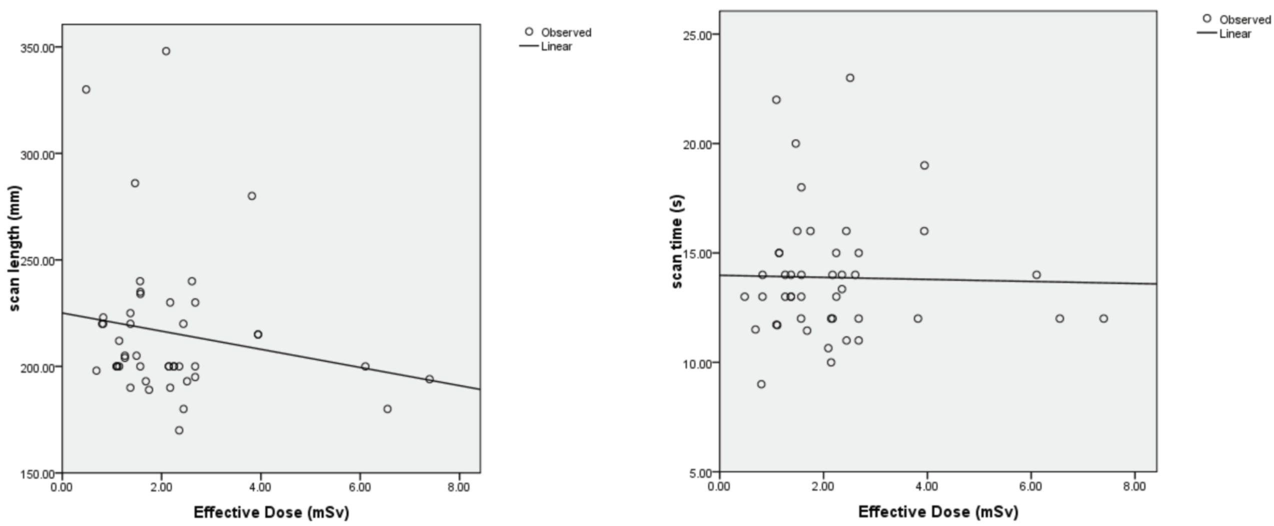

Figure 1. Correlation between effective dose (ED) and scan parameters for neck computed tomography (CT) scan. A) Correlation between scan length and ED. B) Correlation between scan time and ED.

Table 2. Organ radiation dose.

	Head CT (Average ± SDe)	Neck CT (Average ± SD)
Lenses of the eyes (mSv)	20.9 ± 9.6	9.8 ± 3.8
Thyroid (mSv)	3.8 ± 2.6	19.5 ± 6.5
Breast-right (mSv)	2.4 ± 0.8	2.7 ± 1.4
Breast-left (mSv)	3.2 ± 4.9	2.9 ± 1.5

CT: Computed tomography

Results

The mean body mass index (BMI) was 25.3±3.2 kg/m^2 for the head CT scan and 25.5±2.6 kg/m2 for the neck CT scan. The mean scan lengths were 18.01 cm for the head CT scan and 21.5 cm for the neck CT scan. Table 1 lists the radiation dose results. Table 2 lists the dose results for the specific CT scans. For head CT scans, the results indicated a significant correlation between radiation dose and scan time (P= 0.015), while this trend was not remarkable for scan length and ED (P=0.35). In the neck CT scans, we did not observe any correlation between the ED and scan length (P=0.243). Figures 1 and 2 show these for the neck and head CT scans.

Table 3 shows the LAR calculation for radiosensitive organs for the head and neck CT scans. As observed, thyroid LAR and breast LAR for young females is noticeable. For patients above 60 years of age, this amount was negligible. The use of a 16 detector CT scanner resulted in a cancer incidence of less than 0.0077/100 persons for breast and for 0.0023/100 persons for thyroid in women, and a thyroid cancer incidence of 0.00017/100 persons for the head CT in men. This result for the neck CT was 0.011/100 persons for thyroid and 0.00767/100 persons for breast in women.

Among the 48 head CT scans, we observed 4 abnormalities (2 hemorrhage, 1 skull fracture, and 1 skull base fracture). Among the 45 neck CT scans, 2 patients had vertebral fractures and the others were normal.

Discussion

A fundamental goal for medical imaging techniques is to provide maximum information content with minimum radiation exposure to the patient. Radiation exposure is an important topic in CT technology because of the vulnerable impact of ionizing radiation on the organs. Although many studies have reported that changes to imaging parameters could reduce the radiation dose, some concerns regarding diagnostic image

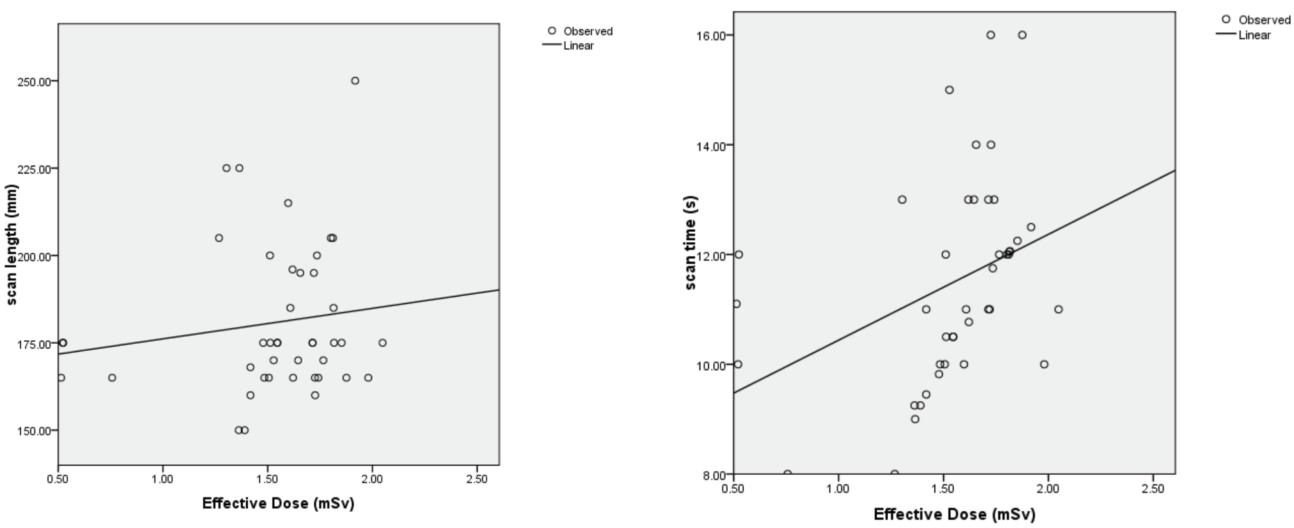

Figure 2. Correlation between effective dose (ED) and scan parameters for head computed tomography (CT) scan. A) Correlation between scan length and ED. B) Correlation between scan time and ED.

Table 3. The average life attributed risk (LAR) cancer incidence per 100,000 persons.

	Head CT			Neck CT		
	Female		Male	Female		Male
Age (y)	Thyroid LAR	Breast LAR	Thyroid LAR	Thyroid LAR	Breast LAR	Thyroid LAR
11-20	N/A	N/A	0.525	N/A	N/A	3.4425
21-30	2.3516	7.70694	0.00225	11.165	7.6725	3.775
31-40	0.928125	5.6625	0.17892	7.75125	4.05229	0.8325
41-50	0.645	2.27083	0.125	2.314	3.3913	0.33312
51-60	0.0375	1.09416	0.020821	0.4633	1.9177	0.09606
61-70	0.0325	0.5283	0.007	0.145083	0.6566	0.0395
71-80	0.0051083	0.221	0.0070875	0.012	0.27	0.0075
>80	0.0002583	0.0783	0.00033	N/A	N/A	N/A

CT: Computed tomography; LAR: Life attributable risk

quality remain. A number of manufacturers have developed various schemes to diminish radiation exposure and maintain image quality. For instance, new reconstruction algorithms, particularly the iterative reconstruction technique, can reduce radiation dose up to 15% in comparison with the filter back projection technique.[21,22]

Radiosensitive organs such as the thyroid and the lenses of the eyes receive high radiation doses during the scanning time, especially in head and neck CT scans. Many studies have suggested to decrease peripheral dose values by placing a shield on the patient and reduce the tube current.[21,23]

Adjusting the lower scan length is another radiation dose reduction method reported by some studies.[10,24] Liebmann et al. have been reported that the radiation dose to the thyroid in head CT scans with a standard protocol was 2.65 mSv, whereas in the current study the dose was much lower.[23] This difference could be attributed to the different scan length which was nearly 7 cm shorter in our study. Parikh and Shah reported that reducing z-coverage could reduce radiation dose without any effect on diagnostic ability. In comparison with the study by Parikh and Shah, we had a higher ED in the current study.[24] Different scan lengths and CT scanners might be the cause for this difference.

Among different radiation dose reduction techniques, decreasing the tube current is the one of the most routine of radiation dose reductions.[12,14,25,26] In the head CT scans, our results showed that the organ dose (thyroid) was fairly similar to that reported by Gunn et al. who used a different CT scanner and automatic tube current instead of a fixed tube current.[12] When compared with a study by Nikupaavo et al. of head CT scans, the radiation dose to the lenses of the eyes was slightly more in the current study due to the higher tube current.[13] Our results showed substantially lower CTDIvol and DLP compared to the results from a study by Rivers-Bowerman and Shankar. This difference might be the consequence of the impact of tube current on radiation dose. The tube current in our study was 200 mAs in comparison with 300 mAs in the Rivers-Bowerman and Shankar study.[21]

Another ED reduction technique is to decrease the scan length. The impact of reducing the z-axis scan range on reducing radiation dose in neck CT scans has been reported by Weiss et al.[10] The current study results for the neck CT scans had much higher DLP and CTDIvol compared to the Weiss et al. study. Although the scan length was much lower in the current study, the use of a fixed tube current would cause an increase in CTDIvol and DLP. In comparison with neck CT studies that used fixed tube currents, our results showed a significantly lower effective thyroid dose; again, a lower scan range would be the cause.[14, 15] The other dose reduction technique used for neck CT scans is the bismuth shield. Although many studies have suggested that a neck shield could reduce the radiation dose up to 42% (range: 33% to 42%), the diagnostic image quality would decline as a consequence of increased image noise.[14, 15, 23] Of note, it is not possible to use a shield on some trauma patients; hence, in the current study we have not used any shield.

The thyroid and lenses of the eyes, and other radiosensitive organs like the chest and abdomen, are considered during a CT scan, whether or not they located in the exposure range. Our results have shown that the radiation dose to the breasts in a routine neck CT was lower than reported by Weiss et al. with an approximately 2 mSv difference.[10] The current study results showed a higher breast dose when compared with the Gunn et al. study who used automatic tube current modulation for their head CT scans.[12]

We measured the amount of radiation absorbed dose and the estimated cancer risk for the thyroid and breast when using a 16 multi-slice CT scanner. Presumably, there were few neck and head CT studies published that estimated the cancer risk, especially in emergency departments.[27,28] Of note, our results might have underestimated the LAR of cancer because we did not consider smoking, family, genetics, and other causes of cancer incidence. Our data showed a significantly higher mean LAR of thyroid cancer for young females compared to young males in each CT scan study. However, the LAR of breast for head and neck CT scans were approximately the same (Table 3). Possibly, patients who need both neck and head CT scans due to their health conditions would probably have an increased risk of cancer.

This study has some limitations. We limited the number of TLDs to four because of each patient's condition. In addition, we used a 16 multi-slice CT scanner. However, the focus-detector, focus-isocenter distances, and bowtie filters differ among CT scanners. Thus, the impact of different dose reduction methods may vary among different CT scanners.

Conclusion

According to this study, the mean ED values of trauma patients was 2.18 mSv for neck CT scans and 1.53 mSv for head CT scans. Trauma patients need urgent medical procedures and sometimes they must undergo more than one CT scan. The increased radiation exposure from the CT scans would probably affect not only the exposed organ, but also increase the likelihood of cancer in the other radiosensitive organs, particularly for young people. The LAR result in the current study has clarified that the risk of cancer incidence for young people is more than two-fold higher than in elderly people. Our study showed that, in addition to the radiation dose to the thyroid and lenses of the eyes, the chest is another organ that received a notable radiation dose (approximately 3 mSv) in each CT scan. As a result, we suggest that decreasing each of the CT scan parameters and the use of a new reconstruction algorithm would probably be more effective than the routine CT technique used in the current tudy.

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Conflict of Interest

None declared.

References

1. Sharma OP, Oswanski MF, Sidhu R, Krugh K, Culler AS, Spangler M, et al. Analysis of radiation exposure in trauma patients at a level I trauma center. *J Emerg Med.* 2011;41(6):640-8. doi: 10.1016/j.jemermed.2011.03.004.
2. National Research Council (US) committee on health effects of exposure to low levels of ionizing radiations (BEIR VII). Health effects of exposure to low levels of ionizing radiations: Time for reassessment? Washington (DC): National Academies Press (US); 1998.
3. Geleijns J, Salvadó Artells M, Veldkamp WJ, López Tortosa M, Calzado Cantera A. Quantitative assessment of selective in-plane shielding of tissues in computed tomography through evaluation of absorbed dose and image quality. *Eur Radiol.* 2006;16(10):2334-40.
4. Deak PD, Langner O, Lell M, Kalender WA. Effects of adaptive section collimation on patient radiation dose in multisection spiral CT. *Radiology.* 2009;252(1):140-7. doi: 10.1148/radiol.2522081845.

5. Nazli SB, Aghamiri SMR, Gholizadeh Sendani N, Shams Akhtari A. Evaluation of radiation absorbed dose and image quality in different retrospective-ecg gating acquisition methods of cardiac ct angiography. *Radiat Prot Dosimetry.* 2018;178(3):304-9. doi: 10.1093/rpd/ncx111.
6. Tack D, De Maertelaer V, Gevenois PA. Dose reduction in multidetector CT using attenuation-based online tube current modulation. *AJR Am J Roentgenol.* 2003;181(2):331-4.
7. Mulkens TH, Bellinck P, Baeyaert M, Ghysen D, Van Dijck X, Mussen E, et al. Use of an automatic exposure control mechanism for dose optimization in multi-detector row CT examinations: clinical evaluation. *Radiology*. 2005;237(1):213-23
8. Hundt W, Rust F, Stäbler A, Wolff H, Suess C, Reiser M. Dose reduction in multislice computed tomography. *J Comput Assist Tomogr.* 2005;29(1):140-7.
9. Angel E, Yaghmai N, Jude CM, DeMarco JJ, Cagnon CH, Goldin JG, et al. Dose to radiosensitive organs during routine chest CT: effects of tube current modulation. *AJR Am J Roentgenol*. 2009;193(5):1340-5. doi: 10.2214/AJR.09.2886.
10. Weiss J, Maurer M, Ketelsen D, Notohamiprodjo M, Zinsser D, Wichmann JL, et al. Effect of reduced z-axis scan coverage on diagnostic performance and radiation dose of neck computed tomography in patients with suspected cervical abscess. *PLoS One.* 2017;12(7):e0180671. doi: 10.1371/journal.pone.0180671.
11. Wang J, Duan X, Christner JA, Leng S, Grant KL, McCollough CH. Bismuth shielding, organ-based tube current modulation, and global reduction of tube current for dose reduction to the eye at head CT. *Radiology*. 2012;262(1):191-8. doi: 10.1148/radiol.11110470.
12. Gunn ML, Kanal KM, Kolokythas O, Anzai Y. Radiation dose to the thyroid gland and breast from multidetector computed tomography of the cervical spine: does bismuth shielding with and without a cervical collar reduce dose? *J Comput Assist Tomogr.* 2009;33(6):987-90. doi: 10.1097/RCT.0b013e3181a776ff.
13. Nikupaavo U, Kaasalainen T, Reijonen V, Ahonen SM, Kortesniemi M. Lens dose in routine head CT: comparison of different optimization methods with anthropomorphic phantoms. *AJR Am J Roentgenol.* 2015;204(1):117-23. doi: 10.2214/AJR.14.12763.
14. Hoang JK, Yoshizumi TT, Choudhury KR, Nguyen GB, Toncheva G, Gafton AR, et al. Organ-based dose current modulation and thyroid shields: techniques of radiation dose reduction for neck CT. *AJR Am J Roentgenol*. 2012;198(5):1132-8. doi: 10.2214/AJR.11.7445.
15. Leswick DA, Hunt MM, Webster ST, Fladeland DA. Thyroid shields versus z-axis automatic tube current modulation for dose reduction at neck CT. *Radiology.* 2008;249(2):572-80. doi: 10.1148/radiol.2492071430.
16. Griffey RT, Sodickson A. Cumulative radiation exposure and cancer risk estimates in emergency department patients undergoing repeat or multiple CT. *AJR Am J Roentgenol.* 2009;192(4):887-92. doi: 10.2214/AJR.08.1351.
17. Linder F, Mani K, Juhlin C, Eklöf H. Routine whole body CT of high energy trauma patients leads to excessive radiation exposure. *Scand J Trauma Resusc Emerg Med.* 2016;24:7. doi: 10.1186/s13049-016-0199-2.
18. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP*. 2007;37(2-4):1-332.
19. Kilic K, Erbas G, Guryildirim M, Arac M, Ilgit E, Coskun B. Lowering the dose in head CT using adaptive statistical iterative reconstruction. *AJNR Am J Neuroradiol.* 2011;32(9):1578-82. doi: 10.3174/ajnr.A2585.
20. Deak PD, Smal Y, Kalender WA. Multisection CT protocols: sex- and age-specific conversion factors used to determine effective dose from dose-length product. *Radiology.* 2010;257(1):158-66. doi: 10.1148/radiol.10100047
21. Rivers-Bowerman MD, Shankar JJ. Iterative reconstruction for head CT: Effects on radiation dose and image quality. *Can J Neurol Sci.* 2014;41(5):620-5. doi: 10.1017/cjn.2014.11.
22. Fareed A, Vavere AL, Zimmermann E, Tanami Y, Steveson C, Matheson M, et al. Impact of iterative reconstruction vs. filtered back projection on image quality in 320-slice CT coronary angiography: Insights from the CORE320 multicenter study. *Medicine (Baltimore).* 2017;96(48):e8452. doi: 10.1097/MD.0000000000008452.
23. Liebmann M, Lüllau T, Kluge A, Poppe B, von Boetticher H. Patient radiation protection covers for head CT scans - a clinical evaluation of their effectiveness. *Rofo.* 2014;186(11):1022-7. doi: 10.1055/s-0034-1366279.
24. Parikh AK, Shah CC. Radiation dose reduction by indication-directed focused z-direction coverage for neck CT. *AJNR Am J Neuroradiol.* 2016;37(6):985-9. doi: 10.3174/ajnr.A4672.
25. Ryska P, Kvasnicka T, Jandura J, Klzo L, Grepl J, Zizka J. Reduction of effective dose and organ dose to the eye lens in head MDCT using iterative image reconstruction and automatic tube current modulation. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub.* 2014;158(2):265-72. doi: 10.5507/bp.2013.071.
26. Weidemann J, Stamm G, Galanski M, Keberle M. Comparison of the image quality of various fixed and dose modulated protocols for soft tissue neck CT on a GE Lightspeed scanner. *Eur J Radiol.* 2009;69(3):473-7. doi: 10.1016/j.ejrad.2007.11.027.

27. Lambert JW, Gould RG. Evaluation of a net dose-reducing organ-based tube current modulation technique: comparison with standard dose and bismuth-shielded acquisitions. *AJR Am J Roentgenol.* 2016;206(6):1233-40. doi: 10.2214/AJR.15.15778.
28. Sodickson A, Baeyens PF, Andriole KP, Prevedello LM, Nawfel RD, Hanson R, et al. Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. *Radiology.* 2009;251(1):175-84. doi: 10.1148/radiol.2511081296.