Original

Reducing Radiation Doses in Female Breast and Lung during CT Examinations of Thorax: A new Technique in two Scanners

Mehnati P.[1]*, Ghavami M.[2], Heidari H.[1]

[1]Department of Medical Physics, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran
[2]Department of Radiology, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran

ABSTRACT

Background: Chest CT is a commonly used examination for the diagnosis of lung diseases, but a breast within the scanned field is nearly never the organ of interest.

Objective: The purpose of this study is to compare the female breast and lung doses using split and standard protocols in chest CT scanning.

Materials and Methods: The sliced chest and breast female phantoms were used. CT exams were performed using a single-slice (SS)- and a 16 multi-slice (MS)-CT scanner at 100 kVp and 120 kVp. Two different protocols, including standard and split protocols, were selected for scanning. The breast and lung doses were measured using thermo-luminescence dosimeters which were inserted into different layers of the chest and breast phantoms. The differences in breast and lung radiation doses in two protocols were studied in two scanners, analyzed by SPSS software and compared by t-test.

Results: Breast dose by split scanning technique reduced 11% and 31% in SS- and MS- CT. Also, the radiation dose of lung tissue in this method decreased 18% and 54% in SS- and MS- CT, respectively. Moreover, there was a significant difference ($p < 0.0001$) in the breast and lung radiation doses between standard and split scanning protocols.

Conclusion: The application of a split scan technique instead of standard protocol has a considerable potential to reduce breast and lung doses in SS- and MS- CT scanners. If split scanning protocol is associated with an optimum kV and MSCT, the maximum dose decline will be provided.

Keywords

Breast Dose, Lung Dose, Split Protocol, Chest CT

Introduction

Computed tomography (CT) technology offers high-quality images and valuable diagnostic results, especially for the management of lung and heart diseases. Application of CT exams is increasing in hospitals as they provide more accurate diagnoses and screening of lung and heart diseases, but radiation doses are increased in organs in the scanning field during CT imagings [1, 2].

In the US the number of CT scans increases almost 10% each year, and in South Korea it is much faster, between 11-31% each year [3]. The amount of acumulative doses from CT tests was about 35% and 46% in Germany and the UK, respectively, compared with all medical radiation

*Corresponding author: Parinaz Mehnati, Department of Medical Physics, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran
E-mail: pari-nazmehnati8@gmail.com

doses the patients obtained [4]. Presently, it seems an increase in the CT scan numbers has an important effect on the public health.

Sensitive organs to ionizing radiation during thorax CT are breast, lung and heart. Breast is superficial and more sensitive than lung or heart to radiation doses in women. This issue demands a re-evaluation of female CT imaging processes and techniques.

Most articles studied the possibility of breast and lung doses reduction in chest CT by changing on the tube current, potential or tube current modulation and bismuth shield [5-8].

There is a large variety of parameters in CT scans and radiation doses in chest CT. The standard tube voltage and current in the range of 100-140 KVp and 100-533 mAs, respectivily was used for conventional protocols of chest CT. In deed, there are significant differences between scanning parameters and doses that patients received in their chest CTs [9] but common limitation at the replacement of exposure factors is their effect on the quality of CT images. Therefore, finding a method unaffected by the exposure factors without image quality deterioration especially for sensitive organs at risk, is of immense interest.

This research introduced a new technique to lower radiation dose deliverey to breast and lung during thorax CT exams without changing exposure factors.

In other words, this new technique would alter the protocol of scanning field selection for reduction of breast and lung doses. This idea starts by understanding the nature of radiation distribution and the shape of radiation beam in z-direction. Goldman et al. presented a study measuring tube current intensity during chest CT. They showed an example of doses measured by TLD inside phantom for a 10-mm slice thickness, plotted as function of TLD position along z-axis because ionizing chambers are typically larger than widths of the beams and thus difficult to measure [10]. The peak of the measured dose is almost in the center of scanning field; they showed this in the first figure in their article.

Another study showed dose distribution during chest CT in CTDI phantom by optically stimulated luminescence (OSL) dosimeter. The scanning measuring result was typically higher at the surface by a factor of two doses in comparison to the center depth of body phantom [11].

The standard protocol of a routine chest CT scanning starts from apex of lung and continues to lung base only through a single scan. In a chest CT, the female breast is almost in the center of the scanning field even closer than other organs skin to the x-ray tube induced to its anatomical and superficial positions in the body. Therefore, breast will receive a higher dose in standard protocol.

The field of scanning is usually selected by the operator from topogram view which did not usually notice its role in possible dose reduction. Changes in scannig field and its function on the breast dose decline were studied in this research. In this new technique, after taking the topogram scan, the area is divided into two phases called the split-scan technique. In split protocol, breast is placed in the end or first of scanning field during chest CT and the change in location of the breast from center of field was studied for dose reduction possibility. This subject is more important in younger women and children who are often scanned for benign indications but breast almost receives high doses of radiation.

Many researchers have shown various methods to be used for radiation dosage measurement in x-ray CT exams [12]. The European Guidelines (Report EUR 16262) describe two dose indicators for CT exams, weighted computed tomography dose index (CTDIW) and DLP [13].

The CTDIw and DLP are two general factors recording dose in CT used for the measurment of each specific CT test with 32cm phantom. Using CTDI has some limitations and its representation of the dose for objects of substantially different size, shape or attenu-

ation like the human body is questionable [2]. Further, CTDI is expressed as dose to air, not dose to tissue, thus leaving CTDI a step away from tissue dosimetry. Therefore, CTDI value will be lower for larger and higher in slim patients. In this study, CTDI and DLP of the chest phantom were recorded, but the main dosimetery method for the measurement of breast and lung radiation dosage was Thermo-Luminescent Dosimetry (TLD) that presents point for calculation of equivalent dose.

There are some studies on the optimization of x-ray spectra via tube potential selection, whose variation affects the organ dose and what makes an effective dose [14]. Kim et al. have shown that a declining kV-value offers a significant reduction in breast radiation dose [15].

This study introduced a new technique for breast and lung radiation dose reduction in chest CT by changing scanning protocol from standard to split without variation on exposure factors. The main purpose was to reduce the radiation dosages for female breast, as it is the most sensitive organ during a chest CT. Also, the possibility of more dose reduction in lung and breast was studied by selecting two tube potentials at SS- and MS- CT with split protocols in thorax CT.

Material and Methods

Chest and breast phantoms were designed and built based on the recommendation of ICRP 23, ICRU 48, and available anatomical reference data in the department of Medical Physics, Tabriz University of Medical Sciences. The initial plan of the chest phantom was drawn using Autocad software 2012 and then cut out using a waterjet cutter (KMT, Radox) according to plan. The structures of lung and breast phantoms were divided into multiple layers; lung into ten layers, 2.5 cm thick and breast into four layers, 1 cm thick. These sliced plan selections especially in the breast provides a fasility to measure each layer radiation dose and organ depth dose. Polyethylene

was used as the material for chest and breast phantoms, and the lung phantom was made of cork because they have similar soft tissues and air attenuation coefficient in CT exams [16].

In the scanning process, the anatomic field of chest CT was imaged as a topogram. The two scanning protocols, standard and split, were selected from topogram view manually. Standard protocol is a countinuous scanning that starts from 1 cm above the apex to 1 cm below the base of the lung (slice one to thirty) but in split protocol, the scanning field of standard protocol was divided into two phases. It means instead of having a contiguous scan process, scanning was done in two parts, starting from the lung apex to the initial border of the breast named split one (slice one to six) and the second part continues until the base of the lung named split two (slice seven to thirty). Details of selection of scaning field of view are shown in Figure 1. This process was performed with and without lead shielding of the next phase phantom, a part of phantom out of the scanning area. Photographic demonstration of the split protocol and process of CT scanning are shown in Figure 2.

In this study single slice (SS), (GE, Hi Speed) and 16 multi slice (MS), (GE, Bright Speed) CT scanners at spiral mode were used. The mAs (100), slice thickness (10 mm) and pitch (1.3) for all examinations in two protocols were constant. The tube potentials of 100 and 120 kVp were used in standard protocol for both SS and MS scanners.

A complete set of quality control procedures was performed on SS and MS scanners by CT quality set of PTW Germany. The study began after approving the accuracy of kVp, mA, and CTDIw of CT units (less than 5% difference).

DLP is dependent on CTDI, slice number and thickness, tube current and total acquisition time. The displayed DLP is calculated from the product of scan length and the weighted average dose to a 32cm plastic phantom. DLP was recorded for all experiments from two scanners reported in this research.
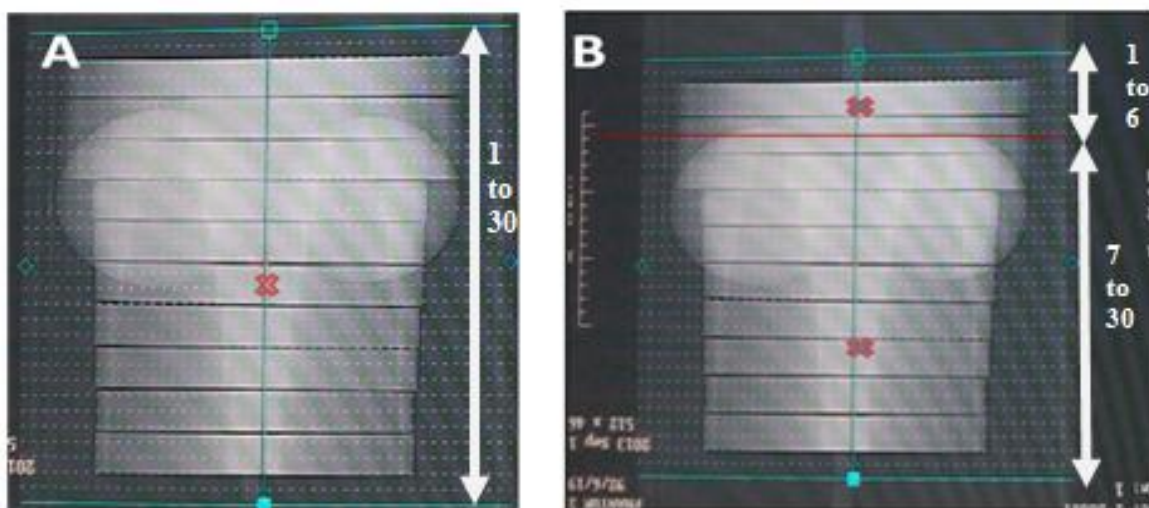
Figure 1: Topogram of Chest in Single- and Multi-slice Scanner
A) Standard Protocol, B) Split Protocol. The Celtic cross is the center of the scanning field. Arrows show slice length of scan.
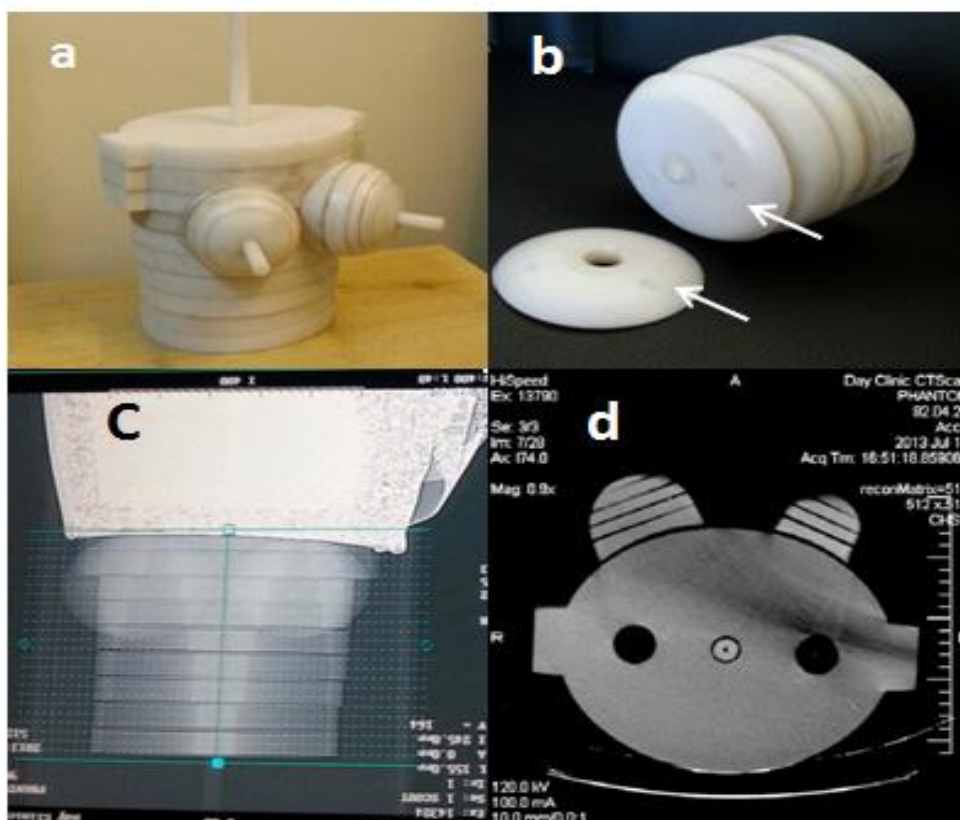
Figure 2: Photographs of phantom and split process of chest CT. a) Chest phantom with breast, b) breast sliced phantom, arrows show caved place of TLD, c) split protocol for scanning slice 7 to 30 by lead covering of slice 1 to 6 of phantom. d) An example of CT image of phantom scanning from slice 7 to 30 by split protocol.

However, for point radiation dose measurement in each organ, a smaller dosimeter was preferable, and TLD 100 (Horshaw/Bicorn) in 0.9 x 3.1 x 3.1 mm3 was used for dosimetry in the present study. In each experiment, a couple of TLD in the six and twelve o`clock direction were stuck in each layer of the lung and breast phantoms (Figure 2). The TLDs calibrated used energy level of CT because they have strong energy dependence.

In the current study, data are represented in mean ±SD (standard deviation from the mean) analyzed by SPSS software (version 16) and compared by T-test for statistical analysis. A p-value of <0.05 was considered significant.

Results

The results of using 100 and 120 kVp and subsequently calculated CTDI and DLP in the thorax CT of the phantoms are shown in Table 1 for standard protocol. An increase in kilovoltage from 100 to 120 kVp showed 28% and 40% increasing dose in SS- and MS- CT,

Table 1: CTDI and DLP during Chest CT by Standard Protocol in Chest CT

CT	Tube potential (mGy.cm)	CTDI (Kvp)	DLP (mGy)
*SS	100	4.4	140.8
	120	6.1	195.2
**MS	100	2.86	97.73
	120	4.76	162.3

*SS: Single Scanner, **MS: Multi Scanner

respectively. When scanning protocol changed to split protocol CTDI was constant, but the DLP value changed at 100 kVp (Table 2).

The selected scanning field of the chest CT from topogram and the center of scanning are shown in Figure 1 for two techniques, including standard- and split-protocols in SS- and MS- CT scanners.

Breast Doses

The effects of tube potential on three layers of breast doses by standard protocol have been studied by TLDs on each layer. The mean breast dose for 100 and 120 kVp were 9.22± 0.28 mSv and 11.31 ± 0.48 mSv in SSCT, respectively. The mean breast layer doses measured by TLD for 100 and 120 kVp were 5.05 ± 0.25 mSv and 6.25 ± 0.35 mSv in MSCT, respectively. A comparison between the selections of 100 kVp instead of 120 kVp on the breast doses showed a reduction of 18% and 19% for SS- and MS- CT, respectively.

When this experiment was repeated for split protocol at 100 kVp, all three breast layer doses decreased and mean dose of breast changed to 8.25 ± 0.35 mSv for SS- and 3.45 ± 0.35 mSv for MS- CT.

A comparison between selections of split protocol instead of standard protocol on the breast dose showed a decrease of 10% and 31% for SS and MS, respectively.

Lung Dose

The mean lung four layers' TLD recorded dose at 100 and 120 kVp were 8.72 ± 0.17 mSv and 10.02 ± 0.37 mSv in SSCT, respec-

Table 2: CTDI (mGy) and DLP (mGy.cm) by Split Protocol in Chest CT

CT	Tube potential (kVp)	CTDI 1 to 6 (slice)	CTDI 7 to 30 (slice)	DLP 1 to 6 (slice)	DLP 7 to 30 (slice)
*SS	100	4.4	4.4	88.0	114.40
**MS	100	2.86	2.86	28.63	124.25

*SS: Single Scanner, **MS: Multi Scanner

tively. But mean doses in MSCT were 4.42 ± 0.27 mSv and 5.72 ± 0.21 mSv, respectively.

A comparison between using 100 kVp instead of 120 kVp on the lung dose showed a decrease of 13% and 23% in SS and MS, respectively.

When the split protocol was applied in chest CT with the same format, the mean lung dose converted to 7.1 ± 0.32 mSv for SS and 2.02 ± 0.13 mSv for MS, respectively.

A comparison between selections of split protocol instead of standard protocol on the lung dose showed a decrease of 18% and 54 % for SS and MS, respectively.

The mean doses of breast and lung in standard and split protocols by different kilovoltages were compared together, as shown in Figure 3.

All experiments of split protocol were performed by lead shield in opposite sides of main scanning field because initial experiment results without shield showed dose reduction of breast and lung were not practicable due to
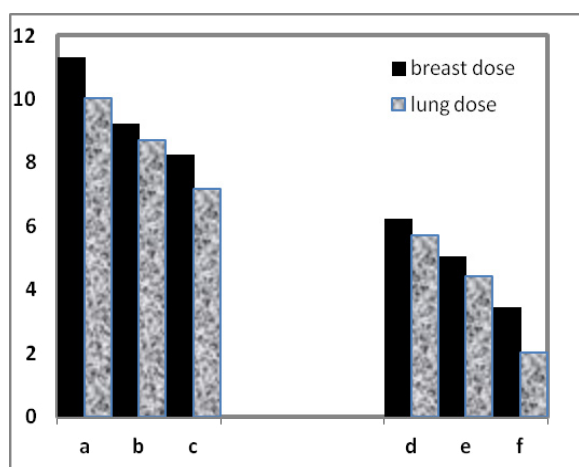
Figure 3: Comparison of breast and lung doses in standard and split scanning protocols in single slice (SS)- and multi slice (MS) - CT scanner by different kilovolts. The letters of a) is 120 kVp and b) is 100 kVp by standard protocol in SS and c) split protocol 100 kVp. The letters of d) is 120 kVp and e) is 100 kVp by standard protocol in MS and f) split protocol 100 kVp.

scatter-ray (data not shown).

Altogether, a comparison of standard and split data in the doses from the breast and lung was significant (p<0.001) for SS and MS in thorax CT study.

Three radiologists with more than 10 years of experience considered CT images performed by two protocols. They did not recognize contrast difference between images performed in two protocols for diagnosis purposes and signal to noise ratio (SNR) for two protocols was less than five percent.

Discussion

In this study, changes on the scan protocols have been applied in order to optimize breast and lung doses during chest CT.

There is a small but real increased risk of breast cancer associated with chest CT scans and cardiac CT imaging because of anatomical location of the breast in main field of thorax CT scanning [1, 17]. The risk is higher for young women and those who receive multiple CT scans while the breast is not the organ of interest for CT imaging. Therefore, breast radiation dose reduction without decline of image diagnostic value is necessary and it will be possible if exposure factors do not change during chest CT.

About twenty methods are included in dose reduction in Chest CT for example tube current and potential, type of scanner and mode of scanning, image receptor and processor etc. but almost all of them are related to exposure factors affecting imaging quality more or less [18, 19].

This study introduces a new technique by changing the standard protocol to split protocol in order to reduce breast and lung doses during thorax CT without affecting exposure factors. We did not find this technique in published articles. The study of two simultaneous scanners provides an opportunity to compare both devices results practically.

The diagnosis properties of CT imaging by two protocols were similar, as observed and

confirmed by three expert radiologists.

The theory of experiment with split technique was the fact that the breast was always located in the center of the scanning field, which means it is possible to receive higher radiation dose. In the split protocol, central location of breast in scanning field changed to end in split one and first in split two during chest-CT scanning.

The reduction of breast radiation dose was 10% and 31% for SS- and MS- CT, respectively by split protocol. In split protocol, a maximum breast radiation dosage saving is possible in MS- CT (31%) at 100 kVp.

Although reducing scanning parameters such as X-ray tube current, scan time and using bismuth shield reduces radiation exposure as mentioned in above studies, they also affect the image volubility or SNR for diagnostic purposes, especially if the scanning parameters are not adjusted carefully [20].

In interventional radiology such as CT angiography (CTA), a retrospective cohort study of 100 patients found that the main hazard of cardiac CTA is lung cancer, and that the risk of radiation damage for women is 2.6 times more than that of men. The second report specifically analyzes the potential damage from coronary CTA to breast tissue [21].

The two-phase scanning causes a decrease of lung doses to 7.10 mSv and 2.02 mSv in SS- and MS- CT scanners, respectively. This means using split protocol instead of standard protocol reduces lung dose 18% and 53 % in SS- and MS- CT, respectively. Thus, next study is supposed to be performed in CT angiography for investigation possibility of reducing breast and lung doses by split protocol scanning.

Bismuth shielding is used to reduce the radiation doses from CT to anterior radiosensitive organs such as breast and thyroid [22]. Bismuth shielding appears to be easy to use, and studies confirm a reduction in anterior surface dose and 38% and 40.53% breast dose reduction in helical scan mode [21, 23]. There are several disadvantages in using bismuth shield such as increasing patient's radiation dose and/or adverse effect on image quality presented; perhaps it is not available in all radiation centers. For example in our city, there is no CT center which has this shield. However, changes in the scanning process without tube current alteration is a new assay that does not depend on equipment, and it is a practicable assay in both single- and multi-detector CTs.

Comparison between two scanners determined that a higher dose was delivered to breast (33%) and lung (45%) layer in SS- versus MS- CT.

Conclusion

The application of a split scan provided technique instead of standard protocol has considerable potentials to reduce breast and lung doses in SS- and MS- CT scanners. If split scanning protocol is associated with an optimum kV and MSCT, maximum dose decline will be provided.

Acknowledgment

Conflict of Interest

None declared.

References

1. Janbabanezhad-Toori A, Shabestani-Monfared A, Deevband M, Abdi R, Nabahati M. Dose Assessment in Computed Tomography Examination and Establishment of Local Diagnostic Reference Levels in Mazandaran, Iran. *Journal of Biomedical Physics and Engineering*. 2015.

2. 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**:1340-5. doi.org/10.2214/AJR.09.2886. PubMed PMID: 19843751. PubMed PMCID: 2954276.

3. Goo HW. CT radiation dose optimization and estimation: an update for radiologists. *Korean J Radiol.* 2012;**13**:1-11. doi.org/10.3348/kjr.2012.13.1.1.

PubMed PMID: 22247630. PubMed PMCID: 3253393.

4. Pantos I, Thalassinou S, Argentos S, Kelekis NL, Panayiotakis G, Efstathopoulos EP. Adult patient radiation doses from non-cardiac CT examinations: a review of published results. *Br J Radiol.* 2011;**84**:293-303. doi.org/10.1259/bjr/69070614. PubMed PMID: 21266399. PubMed PMCID: 3473464.

5. Kim YK, Sung YM, Choi JH, Kim EY, Kim HS. Reduced radiation exposure of the female breast during low-dose chest CT using organ-based tube current modulation and a bismuth shield: comparison of image quality and radiation dose. *AJR Am J Roentgenol.* 2013;**200**:537-44. doi.org/10.2214/AJR.12.9237. PubMed PMID: 23436842.

6. Zhu X, Yu J, Huang Z. Low-dose chest CT: optimizing radiation protection for patients. *AJR Am J Roentgenol.* 2004;**183**:809-16. doi.org/10.2214/ajr.183.3.1830809. PubMed PMID: 15333374.

7. Tappouni R, Mathers B. Scan Quality and Entrance Skin Dose in Thoracic CT: A Comparison between Bismuth Breast Shield and Posteriorly Centered Partial CT Scans. *ISRN Radiol.* 2013;**2013**:457396. doi.org/10.5402/2013/457396. PubMed PMID: 24967274. PubMed PMCID: 4045517.

8. 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**:1340-5. doi.org/10.2214/AJR.09.2886. PubMed PMID: 19843751. PubMed PMCID: 2954276.

9. Linet MS, Slovis TL, Miller DL, Kleinerman R, Lee C, Rajaraman P, et al. Cancer risks associated with external radiation from diagnostic imaging procedures. *CA Cancer J Clin.* 2012;**62**:75-100. doi.org/10.3322/caac.21132. PubMed PMID: 22307864. PubMed PMCID: 3548988.

10. Goldman LW. Principles of CT: radiation dose and image quality. *J Nucl Med Technol.* 2007;**35**:213-25; quiz 26-8. doi.org/10.2967/jnmt.106.037846. PubMed PMID: 18006597.

11. Bauhs JA, Vrieze TJ, Primak AN, Bruesewitz MR, McCollough CH. CT dosimetry: comparison of measurement techniques and devices. *Radiographics.* 2008;**28**:245-53. doi.org/10.1148/rg.281075024. PubMed PMID: 18203941.

12. Shrimpton P, Wall B. Assessment of patient dose from computed tomography. *Radiation Protection Dosimetry.* 1992;**43**:205-8.

13. Bongartz G, Golding S, Jurik A, Leonardi M, Van Meerten E, Geleijns J, et al. European guidelines on quality criteria for computed tomography. EUR(Luxembourg). 1999.

14. Kubo T, Lin PJ, Stiller W, Takahashi M, Kauc- zor HU, Ohno Y, et al. Radiation dose reduction in chest CT: a review. *AJR Am J Roentgenol.* 2008;**190**:335-43. doi.org/10.2214/AJR.07.2556. PubMed PMID: 18212218.

15. Kim MJ, Park CH, Choi SJ, Hwang KH, Kim HS. Multidetector computed tomography chest examinations with low-kilovoltage protocols in adults: effect on image quality and radiation dose. *J Comput Assist Tomogr.* 2009;**33**:416-21. doi.org/10.1097/RCT.0b013e318181fab5. PubMed PMID: 19478637.

16. McCollough CH, Bruesewitz MR, McNitt-Gray MF, Bush K, Ruckdeschel T, Payne JT, et al. The phantom portion of the American College of Radiology (ACR) computed tomography (CT) accreditation program: practical tips, artifact examples, and pitfalls to avoid. *Med Phys.* 2004;**31**:2423-42. doi.org/10.1118/1.1769632. PubMed PMID: 15487722.

17. Hurwitz LM, Reiman RE, Yoshizumi TT, Goodman PC, Toncheva G, Nguyen G, et al. Radiation dose from contemporary cardiothoracic multidetector CT protocols with an anthropomorphic female phantom: implications for cancer induction. *Radiology.* 2007;**245**:742-50. doi.org/10.1148/radiol.2453062046. PubMed PMID: 17923509.

18. Sargazi V, Mehnati P. Strategies for breast dose reduction in chest CT scan. *International Journal of Analytical, Pharmaceutical, & Biomedical Sciences.* 2014;**3**:66-72.

19. Hidajat N, Wolf M, Nunnemann A, Liersch P, Gebauer B, Teichgraber U, et al. Survey of conventional and spiral ct doses. *Radiology.* 2001;**218**:395-401. doi.org/10.1148/radiology.218.2.r01ja12395. PubMed PMID: 11161152.

20. Slovis TL. CT and computed radiography: the pictures are great, but is the radiation dose greater than required? *AJR Am J Roentgenol.* 2002;**179**:39-41. doi.org/10.2214/ajr.179.1.1790039. PubMed PMID: 12076901.

21. Abadi S, Mehrez H, Ursani A, Parker M, Paul N. Direct quantification of breast dose during coronary CT angiography and evaluation of dose reduction strategies. *AJR Am J Roentgenol.* 2011;**196**:W152-8. doi.org/10.2214/AJR.10.4626. PubMed PMID: 21257856.

22. McCollough CH, Wang J, Berland LL. Bismuth shields for CT dose reduction: do they help or hurt? *J Am Coll Radiol.* 2011;**8**:878-9. doi.org/10.1016/j.jacr.2011.09.001. PubMed PMID: 22137008.

23. Hohl C, Wildberger JE, Suss C, Thomas C, Muhlenbruch G, Schmidt T, et al. Radiation dose reduction to breast and thyroid during MDCT: effectiveness of an in-plane bismuth shield. *Acta Radiol.* 2006;**47**:562-7. doi.org/10.1080/02841850600702150. PubMed PMID: 16875333.