# ORGAN DOSES AND ASSOCIATED CANCER RISKS FOR COMPUTED TOMOGRAPHY EXAMINATIONS OF THE THORACIC REGION

by

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**The use of computed tomography is increasing rapidly and doses are not negligible especially when medical procedures require more than one scan. The purpose of the present study was to measure doses in an anthropomorphic Rando phantom during a standard and low dose computed tomography protocol of the thorax and to estimate risks of radiation induced cancer for adult patients that undergo multiple computed tomography scans of the thorax. Thermoluminescent and radiophotoluminescent dosimeters were used for dose measurements. Radiation risks of cancer incidence, in the form of lifetime attributable risk, were estimated using the BEIR VII model. For five exposures with the standard protocol mean organ doses were 94 mGy (breast), 85 mGy (stomach), 85 mGy (thyroid), 78 mGy (lung), 52 mGy (liver), and 16 mGy (colon). Associated lifetime attributable risk were found to be up to 0.401 % (401 breast cancers per 100 000 exposed patients) and 0.116 % (116 lung cancers per 100 000 exposed patients) for female and male, respectively. A low dose protocol reduces doses (and risks) by the average factor of 5 and therefore the use of a low dose protocol is recommended whenever it is medicaly justified.**

*Key words: organ dose, radiation cancer risk, computed tomography, thorax, low dose protocol*

## INTRODUCTION

Computed tomography (CT) is established as an essential tool, not only for diagnosis, but also for follow-up of the diseases, as an aid in intervention, for screening and also for imaging in radiotherapy. Constant increase in the use of CT together with associated doses for organs within a scan volume, considerably larger in comparison to corresponding conventional radiographs, have focused attention also on the potential risk of radiation induced cancer. According to present epidemiological data the lowest dose of photon radiation for which reasonably reliable evidence of increased cancer risk exists is about 10-50 mGy for single and 50-100 mGy for protracted exposure [1]. The typical dose to an organ within a scan volume during the CT scan is about 10-20 mGy and often can be even higher [2, 3], but when medical procedures require more than one CT scan, cumulative organ doses for a short period can be higher than 50 mGy.

Radiation protection principles, as justification and optimisation of protection, in CT are topics of scientific and public concern. The most important principles which have to be followed are appropriate justification of every CT scan and optimization of all technical parameters in such a way that the image quality is secured keeping the dose and potential risk as low as possible [4, 5]. It was shown in a previous study [6], which was carried out on 60 patients with lymphoproliferative disorders, that a low dose CT technique can be equally capable of demonstrating mediastinal pathology for follow-up of patients with malignant lymphomas compared to the standard dose CT technique. The cohort involved a large number of younger and middle- aged patients who were selected for the study as repeated CT scans during their lifetime are very important. Due to effective treatment these patients have a life expectancy similar to the healthy population and therefore the risk of long term effects of ionizing radiation associated with multiple CT scans has to be considered and minimized.

The purpose of the present study was to measure organ doses in an anthropomorphic Rando phantom

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during the standard and low dose CT protocol of the thorax and, taking into consideration an average number of multiple CT scans required for the selected population, to estimate the lifetime attributable risk (LAR) of cancer incidence. In addition, doses on the surface of the phantom during both protocols were measured and compared to the surface doses measured on 60 patients from the previous study [6] using the same CT device.

## MATERIALS AND METHODS

### CT protocols

The phantom study was performed on a spiral SCT 7800TX (Shimatzu, Japan) CT unit at the Clinical Hospital Merkur. The doses were measured with two different scanning CT protocols of the thorax. The standard protocol was carried out with exposure settings of 120 kV, 160 mA, 7 mm slices, 0.8 s/slice and pitch 1. The parameters for the low dose protocol were chosen based on the previous measurements on a male Rando Alderson phantom which resulted in the largest dose reduction without compromising the image quality influenced by only one parameter; the tube current [6]. The settings for the low dose protocol in this study were 120 kV, 30 mA, 7 mm slices 0.8 s/slice and pitch 1. The number of slices for both protocols was 47. Scanning volume was from the lung apices to the base. Before each exposure, a topogram was made in AP projection with standard exposure conditions of 120 kV and 100 mAs.

### Phantom

The phantom used for this study was an anthropomorphic male Rando Alderson Phantom (175 cm height, 73.5 kg weight) which consists of 35 axial segments with a width of 2.5 cm containing a human skeleton and tissue equivalent material. It represents an average adult patient. Inside the phantom dosimeters are placed into the holes located on in the positions of different organs/tissues.

### Dosimetry systems

The doses in/on the phantom were measured with thermoluminescent dosimeters (TLD), based on LiF:Mg,Ti (TLD-100, Thermo Scientific) and radiophotoluminescent (RPL) glass dosimeters (type GD-352M, Asahi Techno Glass Corporation). TLD were made in the form of pellets ( 4.5 mm × 0.9 mm). RPL dosimeters were silver activated phosphate glass rods ( 1.5 mm × 12 mm) packed in a plastic holder (outer dimensions: 4.3 mm × 14.5 mm) containing a tin energy compensation filter which enables their use for medium and low energy X-rays that are usually used in diagnostic radiology. Relative standard uncertainty of the determined dose for RPL and TLD was reported as 2.1 % and 2.9 %, respectively [7]. For RPL, uncertainties include repeatability, calibration and angular correction, while for TLD angular correction is not included because angular dependence is reported only for RPL [8, 9]. Detailed characterisation of RPL and TLD are given in previously published papers [7, 10, 11].

Prior to the measurements for improved accuracy for all TLD, individual sensitivity correction factors were calculated by irradiating all TLD to a uniform dose of 5 mGy (kerma „free in air") using the $^{137}$Cs source in the Secondary Standard Dosimetry Laboratory (SSDL) at the Rudjer Bošković Institute [12]. In case of RPL dosimeters there was no need for individual sensitivity corrections [7, 10]. Calibrations of RPL and TL detectors for in/on phantom measurements were also done using the same $^{137}$Cs radiation source and previously determined correction factors for dosimeters obtained for X-ray spectra typically used in CT imaging were applied. Measured doses in the phantom were expressed as "absorbed dose to water" using the conversion factor from kerma "free in air" ($K_{air}$) to "absorbed dose to water" ($D_w$): $D_w/K_{air}$ = = 1.112 [13]. The final results of organ/tissue doses, $D_T$, presented with standard deviations in tables and figures and used for risk estimates, are calculated as a mean value of RPL and TLD values.

### Measurements

A total of 58 dosimeters were placed inside the phantom on the selected organ positions (thyroid, lung, breast, liver, and colon) which are determined by consulting an atlas of sectional anatomy. The entrance surface dose (ESD) was measured during both protocols on the surface of the phantom on the positions of the eye lens, thyroid, breasts and gonads bilaterally. For measurements of doses on the surface two TLD (packed in thin dark polyethylene bags) and two RPL were packed together. The final ESD value is calculated as a mean value of 4 dosimeters. In order to obtain better accuracy of dose measurements and taking into consideration an average number of required CT scans for patients with lymphoproliferative disorders during therapy, five expositions together with five topograms were made in order to simulate the conditions the same as it had been done previously on patients [6].

### Cancer risk estimate

Cancer risks, in the form of LAR of cancer incidence, were estimated by applying the methods introduced in the biological effects of ionizing radiation

(BEIR) report VII [14]. LAR is defined as the probability that an irradiated person could develop a radiation-induced cancer during their lifetime. For leukaemia and cancer LAR data are tabulated for each gender and eleven discrete ages at of exposure in table 12D-1 of the BEIR VII report as the number of cancer cases per $10^5$ persons exposed to a single dose of 100 mGy [14]. Assuming a „linear no-threshold" (LNT) dose-risk relationship, the LAR for measured organ doses ($D_T$) in this study were calculated with linear extrapolation of LAR data from BEIR VII table 12D-1. When necessary, linear interpolation for age at exposure was applied. To estimate the radiation risk for multiple CT scans assumption of risk additivity was applied as suggested in [14]. As patients with lymphoproliferative disorders undergo multiple thorax CT scans in a short time (usually in an interval of 3-12 months during 1-2 years), LAR for a single irradiation was multiplied by the average number of CT scans to obtain a LAR for multiple irradiation.

## RESULTS AND DISCUSSION

### Dose measurements in the phantom

For each protocol doses in the phantom were measured with two types of dosimeters (TLD and RPL). With the exception of dosimeters in the thyroid and colon, the agreement between two dosimetry systems was satisfactory and it was on average within 7 %. Uncertainties of both types of dosimeters are below 3 % [8], but in this study they might be higher (especially for RPL) as the angular dependence uncertainty factor used in [8] was estimated for a 6 MV photon beam [7] and not for CT conditions. A possible explanation for larger under/overestimation by RPL compared to TLD in the thyroid and colon, might be larger dimensions of RPL dosimeters in comparison to TLD which results that for the same hole, close to the border of the scan volume, the RPL was possible partly in the scan volume, while TLD was completely in/out.

For further calculations mean values of TLD and RPL values were calculated and used.

Comparison of doses for the standard and low dose CT protocol measured in the phantom for 5 consecutive expositions is given in fig. 1. For the standard protocol, as well as for the low dose protocol, the highest doses were measured on the position of the breast and were 94 4 mGy and 17.2 0.2 mGy, respectively.

The mean doses measured during the standard protocol in different organs were on average 5 times (range 4.3-6.1) higher in comparison to the low dose protocol.

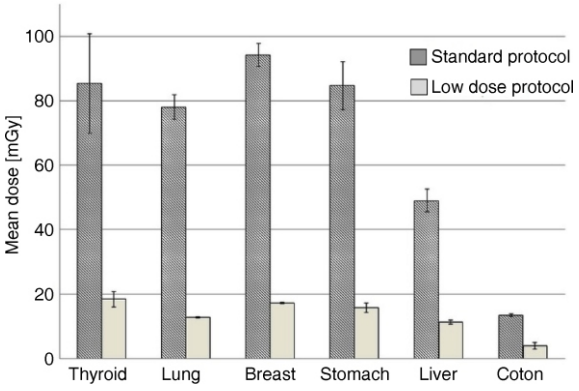


**Figure 1. Comparison of mean organ doses with standard deviations for 5 exposures measured in the Rando phantom during the standard and low dose CT protocol; error bars in the figure show the standard deviation of measured dose values within each organ**

### Dose measurements on the phantom and comparison with entrance surface doses measured in the previous study on the patients

Results for entrance surface doses (ESD) measured on the phantom in comparison with ESD measured in the previous study [6] on 60 patients with lymphoproliferative disorders for both protocols are shown in tab. 1. All results are related with only one CT exposition. Due to large dissipations of the measured patient doses (due to large differences in size of patients, number of slices and imaged volume) not only mean values of ESD, but minimum and maximum values are also shown. The anthropomorphic phantom used in this study represents an average adult person and, as expected, phantom dose values shown in tab. 1 are between the min and max patient dose values.

Dose variations for different patients are small for breasts (relative standard deviation for both protocols is 9 %), but for the thyroid they are very prominent (relative standard deviation is 48 % and 28 % for the standard and low dose protocol respectively). The reason for those differences in dose variations is that dur-

**Table 1. Comparison of ESD measured on the phantom and on the 60 patients for the standard (A) and low dose (B) CT protocol; both ESD were related with a single exposition**

| Organ | Protocol | Patients[A] ESD [mGy] | | | | Phantom[B] ESD [mGy] | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Min | Max | Mean | SD |
| Lens | A | 0.60 | 0.42 | 0.12 | 3.08 | 0.31 | 0.07 |
| | B | 0.11 | 0.04 | 0.03 | 0.21 | 0.07 | 0.02 |
| Thyroid | A | 16.40 | 7.92 | 2.95 | 30.81 | 25.1 | 2.2 |
| | B | 4.68 | 1.31 | 2.81 | 7.12 | 4.6 | 0.8 |
| Breast | A | 22.78 | 2.10 | 17.44 | 28.09 | 20.4 | 1.9 |
| | B | 6.31 | 0.59 | 3.51 | 8.80 | 3.9 | 0.6 |
| Gonads | A | 0.22 | 0.19 | 0.05 | 1.07 | 0.15 | 0.01 |
| | B | 0.10 | 0.05 | 0.02 | 0.35 | 0.03 | 0.01 |

(A) from study [6], (B) this study

ing the CT of the thorax breasts are completely included in the scan volume while the thyroid is on the border of the scanned region and depending on the patient's anatomy, it can be partly or completely excluded from the scan volume. For phantom measurements the maximum scan area was chosen. For both protocols ESD for the breast measured on the phantom was 10 % higher than $D_T$ for the breast. ESD to $D_T$ ratio for the breast was 1.1 0.1 and 1.1 0.2 for the standard and low dose protocol, respectively.

In this study ESD was measured for the anthropomorphic phantom and compared with ESD values measured for the patients [6] using the same methodology and two types of RPL and TL dosimeters. In literature, Alzimami *et al*. [15] used TL dosimeters type GR-200A to measure a patient's ESD during conventional and CT urography but justification and uncertainty was not discussed. ESD for CT examinations on an antropomorphic phantom was measured by Tsalafoutas *et al*. [16] but using different instruments (active solid state detectors) in order to estimate the skin dose. Tagekami *et al*. [17] recently tested a small optically stimulated luminescence (OSL) dosimeter to measure the ESD when performing a CT examination and concluded that the OSL dosimeter can be considered suitable for measuring the ESD with an uncertainty of 30 % during CT examinations in which pitch factors below 1.000 are applied.

## Cancer risk estimate

LAR of developing radiation-induced cancer associated with five exposures to the standard CT protocol for 20 and 56 year old persons are shown in tab. 2. The age of 56 was chosen because the average patient's age in the previous study [6] was 56 years. The average age of the youngest group of patients was 20. The average number of required CT examinations was assumed to be five. In tab. 2 only the results for the standard CT protocol are presented. Low dose protocol reduces doses and associated LAR by the average factor of 5. The reverse order for breast and lung for a 56 year old female patient compared to a 20 year old female patient is due to the fact that lung cancer risk does not decrease with increasing age at exposure. Moreover, excess relative risk (ERR) for lung cancer has a maximum when age at exposure is around 55 years [18].

**Table 2. LAR of developing radiation-induced cancer associated with five exposures using the standard CT protocol for 20 and 56 year old persons; $D_T$ is the organ dose measured in the phantom**

| Cancer site | $D_T$ [mGy] | LAR[(a)] | | | |
|---|---|---|---|---|---|
| | | 20 years | | 56 years | |
| | | Male | Female | Male | Female |
| Thyroid | 85 | 18 | 96 | 1 | 2 |
| Lung | 78 | 116 | 270 | 73 | 166 |
| Breast | 94 | – | 401 | – | 44 |
| Liver | 52 | 12 | 5 | 6 | 3 |
| Stomach | 85 | 34 | 46 | 19 | 25 |
| Colon | 16 | 28 | 18 | 16 | 11 |

[(a)] Number of cancer cases per $10^5$ exposed persons

In literature there are many studies dealing with cancer risk associated with CT examinations. In the majority of the studies the radiation induced risk is calculated by means of an estimate of organ and effective doses using the computed tomography dose index (CTDI) values and/or on the basis of Monte Carlo calculations and mathematical phantoms [19-23]. The advantage of dose measurements in the phantom is the direct measurement of doses in the positions of sensitive organs or tissues which are indispensable to estimate risk for particular cancers. Also some studies reported that compared with direct TLD measurements, computer simulated techniques are likely to underestimate the dose [24, 25].

Cancer risk estimates in this study have been made using BEIR VII methods assuming a linear dose-risk relationship and definition of LAR. Limitations and uncertainties [20, 26] of cancer risk models is an important issue; controversy concerning the use of the LNT model for low doses and low dose rates [27, 28] should be also mentioned, but this discussion is beyond the scope of this paper. However, most of the doses in this study are above the very delicate region below 10 mGy (where the radiation-cancer relationship is not clear) and it was assumed as reasonable to consider the LNT model (as suggested by standard bodies) [4, 14, 29, 30]. Nevertheless, the measured doses are valuable information and it is always reasonable to consider dose reduction if it is medically justified especially in patients that require multiple irradiations which consequently lead to a higher cumulative dose.

## CONCLUSION

The highest organ doses during the single standard CT protocol of the thorax were measured for the breast (18.8 mGy), stomach (17 mGy), thyroid (17 mGy) and lung (15.6 mGy). Assuming that the average number of CT scans for patients with lymphoproliferative disorders is five (during 1-2 years), associated LAR for the standard dose CT protocol were found to be up to 0.401 % for female and 0.116 % for male. Comparison of the results for the standard and low dose protocol showed that the low dose protocol yielded with the reduction of organ doses (and risks) by the average factor of 5 (5.1 0.7). As the low dose CT technique can be equally capable of demonstrating mediastinal pathology for follow-up of this group of patients as previously shown in [6], the use of the low dose protocol is highly recommended as an alternative in routine clinical practice.

## AUTHORS' CONTRIBUTIONS

The manuscript was written by M. Majer, Ž. Knežević, and S. Miljanić. J. Popić and H. Hršak were responsible for CT irradiations and the relationship between the dosimeter's positions in the phantom and the particular organ. M. Majer and Ž. Knežević were responsible for dosimetry and data analysis. The cancer risk estimate was prepared by M. Majer. Results were discussed by all authors. The figures and tables were prepared by M. Majer.

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## ДОЗЕ У ОРГАНИМА И ПРИДРУЖЕНИ РИЗИК КАРЦИНОМА ПРИ ИСПИТИВАЊУ ГРУДНОГ КОША КОМПЈУТЕРСКОМ ТОМОГРАФИЈОМ

Употреба компјутерске томографије је у великом порасту, а дозе нису занемариве поготово ако медицинска процедура захтева више од једног снимања. Циљ овог рада био је да се измере дозе у антропоморфном фантому Рандо током снимања грудног коша компјутерском томографијом применом стандардног и нискодозног протокола, као и процена ризика за обољевање од карцинома након зрачења за одрасле болеснике који пролазе неколико снимања грудног коша. Дозе су мерене термолуминесцентним и радиофотолуминисцентним дозиметрима. Ризици за појаву карцинома, у облику животног ризика за оболевање од карцинома, процењени су коришћењем модела BEIR VII. За пет снимања стандарним протоколом, средње дозе у органима износиле су 94 mGy (груди), 85 mGy (трбух), 85 mGy (штитњача), 78 mGy (плућа), 52 mGy (јетра), и 16 mGy (дебело црево). Одговарајући животни ризици за оболевање од карцинома износили су највише 0.401 % (401 карцином груди на 100 000 озрачених болесника) и 0.116 % (116 карцинома плућа на 100 000 озрачених болесника) за жене, односно мушкарце. Употреба нискодозног протокола смањила је дозе (и ризике) у просеку за пет пута и стога се употреба нискодозног протокола препоручује кад год је медицински оправдана.

*Кључне речи: доза органа, ризик радијационог канцера, компјутерска томографија, грудни кош, протокол ниских доза*