Signature: © Pol J Radiol, 2014; 79: 1-5
DOI: 10.12659/PJR.889952

Polish Journal of Radiology
www.PolRadiol.com
ORIGINAL ARTICLE

Received: 2013.10.26
Accepted: 2013.12.10

Evaluation of radiation doses delivered in different chest CT protocols

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Summary

Background: There are differences in the reference diagnostic levels for the computed tomography (CT) of the chest as cited in different literature sources. The doses are expressed either in weighted CT dose index ($CTDI_{VOL}$) used to express the dose per slice, dose-length product (DLP), and effective dose (E). The purpose of this study was to assess the radiation dose used in Low Dose Computer Tomography (LDCT) of the chest in comparison with routine chest CT examinations as well as to compare doses delivered in low dose chest CT with chest X-ray doses.

Material/Methods: $CTDI_{VOL}$ and DLP doses were taken to analysis from routine CT chest examinations (64 MDCT TK LIGHT SPEED GE Medical System) performed in 202 adult patients with FBP reconstruction: 51 low dose, 106 helical, 20 angio CT, and 25 high resolution CT protocols, as well as 19 helical protocols with iterative ASIR reconstruction. The analysis of chest X-ray doses was made on the basis of reports from 44 examinations.

Results: Mean values of $CTDI_{VOL}$ and DLP were, respectively: 2.1 mGy and 85.1 mGy·cm, for low dose, 9.7 mGy and 392.3 mGy·cm for helical, 18.2 mGy and 813.9 mGy·cm for angio CT, 2.3 mGy and 64.4 mGy·cm for high resolution CT, 8.9 mGy. and 317.6 mGy·cm for helical ASIR protocols. Significantly lower $CTDI_{VOL}$ and DLP values were observed for low dose and high resolution CT versus the remaining CT protocols; doses delivered in CT ASIR protocols were also lower (80–81%). The ratio between medial doses in low dose CT and chest X-ray was 11.56.

Conclusions: Radiation dose in extended chest LDCT with parameters allowing for identification of mediastinal structures and adrenal glands is still much lower than that in standard CT protocols. Effective doses predicted for LDCT may exceed those used in chest X-ray examinations by a factor of 4 to 12, depending on LDCT scan parameters. Our results, as well as results from other authors, suggest a possibility of reducing the dose by means of iterative reconstruction. Efforts towards further dose reduction which would permit replacing chest X-ray with low dose CT in certain research screening projects should be encouraged.

MeSH Keywords: radiation safety • radiation protection • computed tomography (CT) • chest CT • lung CT • low dose CT

PDF file: http://www.polradiol.com/download/index/idArt/889952

Background

The continuously growing interest in computed tomography (CT) examinations of the chest accompanies technical and methodological advances in multi-slice computed tomography, gradually replacing other imaging and functional examinations such as X-ray diagnostics with angiography or ventilation/perfusion scintigraphy. The increase in the absolute numbers of CT scans performed is also caused by the technique being used in screening examinations performed in healthy individuals from pre-defined high risk populations [1].

The exposure to radiation in computed tomography depends on exposure parameters used for the examination, technical parameters of the instrument and patient's body

Table 1. Scan parameters for computed tomography scanning protocols.

Scan parameters	Low dose	Helical (FBP)	High resolution	Angio	Helical (ASIR)
Number	51	106	25	20	19
kV	100	100	100	120	100
mAs	50	Autoselect	Autoselect	Autoselect	Autoselect
Slice thickness (mm)	1.5	5	1.25	1.25	5

composition [2,3]. Problems encountered when comparing doses from CT instruments from different manufacturers include the lack of uniform international guidelines and the use of different physical units to describe the doses delivered. These difficulties translate to the relatively rare use of the dose as a criterion in tender procedures. The most common indices describing the radiation doses in computed tomography include: $CTDI_{VOL}$ (volumetric computer tomography dose index), DLP (dose-length product) and E (effective dose absorbed) [4–7]. $CTDI_{VOL}$ is expressed in mGy. It is related to the local dose of radiation, describing the impact of exposure parameters, slice thickness, scanning pitch and filtration on the dose value. $CTDI_{VOL}$ is determined from phantom measurements of tomographic dose index at different exposure parameters with the majority of radiation dose being absorbed in the peripheral part of the phantom ($CTDI_P$) as compared to the central part ($CTDI_C$). $CTDI=(1/3\ CTDI_C)+(2/3\ CTDI_P)$. $CTDI_{VOL}$ is also dependent on pitch value, as $CTDI_{VOL}=CTDI/pitch$. This explains why higher $CTDI_{VOL}$ values are observed at low pitch values, e.g. in cardiological examinations compared to standard scans [1,8]. Such a rigid formula used to determine the volumetric computed tomography dose index from phantom measurements results in a trend to underestimate actual doses in children and lean individuals as well as to overestimate the dose in obese individuals. According to some authors, these differences may reach up to 20% [5,6]

DLP is expressed in w mGy·cm. It reflects the total radiation dose absorbed by the patient while considering the dose in relation to slice and scanning length (range). DLP is expressed by adding up doses expressed in CTDI over a certain scanning length: $DLP=CTDI\times T\times N$, where N is the number of slices of thickness T.

The effective dose E (mSv) is determined for male and female models (70 kg, 170 cm) on the basis of organ dose conversions along the Z-axis of the scan. A simplified method to determine the effective dose is commonly used, consisting in multiplication of DLP doses by appropriate coefficients depending on the body area being examined; for instance, the value of 0.014 is assumed for chest examinations. Similar as in the case of other indices, E underestimates actual values in children and lean individuals while overestimating these values in obese individuals [5,9,10].

The goal of this study was to estimate the ionizing dose load received in computed tomography scans of lungs while using an extended low dose protocol as compared to standard chest CT scans and chest X-ray examinations. To this end, the following hypotheses were successively verified: 1 – whether significant differences exist between the scanning ranges in individual groups of CT scans; 2 – whether significant differences exist between the $CTDI_{VOL}$values in individual groups of CT scans; and 3 – whether significant differences exist between the DLP values in individual groups of CT scans. Next, the difference between mean doses in the group of scans acquired using low dose CT protocols and the mean doses in chest radiograms acquired by indirect digital imaging was calculated using available conversion factors accounting for averaged organ weigh ratios as well as the size and age of subjects.

Material and Methods

Retrospective analysis was performed on $CTDI_{VOL}$ values expressed in mGy and DLP values expressed in mGy·cm, originating from dose reports describing radiation exposure in various protocols used in chest examinations with FBP reconstruction in 202 adult patients using a 64-slice TK LIGHT SPEED apparatus from GE Medical Systems, production year 2007. A similar method was used to analyze 19 chest CT scans acquired using an iterative image reconstruction method (ASIR).

Results used in the analysis were selected from examination protocols performed in our CT lab within the period of January 2010-August 2012 in patients with body mass indices within the normal range of 18.5–24.99.

All examinations used for dose analyses were standard, fully diagnostic examinations, and no scan was listed as rejected in periodic quality control analyses of CT scans. In addition, the scans were independently assessed by two authors with many years of experience in retrospective analysis of scans. Any doubts were decided by consensus and all analyzed scans were considered to be diagnostic scans.

Following protocols were used in CT scans with FBP image reconstruction: 1. low dose lung scan; 2. helical scan; 3. high resolution (HRCT) scan; 4. angio-CT scan. The fifth group consisted of helical reconstructed using the iterative ASIR protocol. The parameters of individual scanning protocols are presented in Table 1

Radiation exposures expressed in doses calculated initially in $\mu Gy\cdot m^2$ were analyzed for radiograms of 44 patients assessed within the same time period in 2 projections (antero-posterior and lateral) by means of indirect digital imaging using a QUEST 500 apparatus from Quantum Medical Imaging Corporation, production year 2005, exposure voltage 133 kV, zero opacity.

Table 2. Statistics for computed tomography chest examination protocols.

Protocol	DLP	$CTDI_{VOL}$
Low dose		
N (%)	51 (13.7%)	51 (13.7%)
Mean ±SD	85.1±7.0	2.1±0.0
Range	67.1–95.4	2.1–2.1
Median	85.5	2.1
95% CI	[83.1; 87.1]	[0.0; 0.0]
Helical (FBP)		
N (%)	106 (28.4%)	106 (28.4%)
Mean ±SD	392.3±83.1	9.7±1.9
Range	161.9–703.8	3.2–12.2
Median	404.6	10.3
95% CI	[376.3; 408.3]	[9.3; 10.0]
Angio		
N (%)	20 (5.4%)	20 (5.4%)
Mean ±SD	813.9±532.9	18.2±6.4
Range	200.5–2,284.9	6.9–28.7
Median	677.3	17.7
95% CI	[564.5; 1,063.3]	[15.2; 21.2]
HRCT		
N (%)	25 (6.7%)	25 (6.7%)
Mean ±SD	64.4±9.5	2.3±0.2
Range	44.6–80.3	1.7–2.4
Median	64.9	2.4
95% CI	[60.4; 68.3]	[2.2; 2.4]
Helical (ASIR)		
N (%)	19 (5.1%)	19 (5.1%)
Mean ±SD	317.6±196.1	8.9±5.9
Range	109.1–658.8	2.7–18.6
Median	189.5	5.4
95%CI	[223.1; 412.1]	[6.1; 11.8]

Descriptive statistics calculations were performed to characterize quantitative variables using means, standard deviations, medians, minimum and maximum values (ranges) and 95% confidence intervals (CI). Qualitative variables were presented as absolute numbers and percentage values.

In order to assess the difference between the mean dose delivered in the low dose CT protocol and the mean dose in the indirect digital imaging radiograms of the chest, the mean dose of the low dose lung CT scans was converted from the DLP value to the effective dose value by multiplying the DLP value by the conversion factor of 0.014. The mean dose value expressed in $\mu Gy \cdot m^2$ as recorded in two projections in chest X-rays was converted by multiplication of the dose value by 0.175 $mSv \cdot (Gy \cdot cm^2)^{-1}$.

Table 3. Statistics for doses delivered in chest X-rays.

Parameter	Dose ($\mu Gy \cdot m^2$)	Dose (mSv)
N (%)	44 (11.8%)	
Mean ±SD	58.8±35.9	0.103
Median	53.5	0.094

Shapiro-Wilk's W test was used to assess whether quantitative variables originated from sets of normal distribution, The significance of differences between two groups was assessed using the F-test (ANOVA) or Kruskal-Wallis test (in case of ANOVA applicability conditions not being met). Post-hoc tests were carried out in case statistically significant differences were detected (Tukey's test in case of F-tests, Dunn's test in case of Kruskal-Wallis tests).

The significance level $p=0.05$ was assumed in all calculations. The significance levels calculated using the STATISTICA software package are presented as p-values. All statistical calculations were performed using the StatSoft, Inc. (2011) STATISTICA data analysis software system, version 10.0. (*www.statsoft.com*) and MS Excel spreadsheets.

Results

Descriptive characteristics of individual CT scan groups are presented in Table 2.

Descriptive characteristics of chest X-rays acquired in 2 projections (antero-posterior and lateral) using an indirect digital imaging system are presented in Table 3.

No significant differences in scanning lengths were observed between CT scans acquired using low dose, helical FBP, helical ASIR and angio protocols (p: 0.2167–1.000). Slightly shorter scanning lengths were observed in high resolution CT scans as compared to other scans (significance border, p: 0.0755–0.0902).

Statistically significant differences in median $CTDI_{VOL}$ values were demonstrated in individual groups (Kruskal-Wallis statistic value $H=226.10$, $p=0.001$) between low dose protocols and the remaining CT scans ($p=0.0001$), between helical, HRCT and angio CT scans ($p=0.0001$) as well as between HRCT and helical ASIR scans. Means and median $CTDI_{VOL}$ doses were lower in helical scans as compared to angio CT scans at the borderline of significance ($p=0.0868$). Despite lower absolute $CTDI_{VOL}$ doses being recorded in helical scans with iterative reconstruction as compared to analogous scans based on FBP reconstruction, the difference was not found to be significant in the analyzed groups.

With regard to the DLP parameter, statistically significant differences in median values were observed in the study groups (Kruskal-Wallis statistic value H=290.29, p=0.001) between low dose protocols and the remaining CT scans (p=0.0001–0.0020), excluding HRCT and as well as between HRCT and helical scans, both with FBP and AIRT reconstruction (p=0.0001–0.0004). Despite lower absolute DLP doses being recorded in helical scans with iterative reconstruction as compared to analogous scans based on FBP reconstruction, the difference was not found to be significant in the analyzed groups.

The mean effective dose generated in low dose chest CT scans, after application of the conversion factor was 1.191 mSv (median 1.197 mSv) while the mean effective dose upon exposure to plain chest X-rays in 2 projections, taking into consideration the averaged organ weigh ratios, the size, age and sex of the patients and the projections used was 0.103 mSv (median 0.090 mSv). The ratio between mean low dose lung CT scan doses and lung X-ray doses was 11.56.

Discussion

Recommendations regarding doses applied in chest CT examinations were formulated during numerous conferences in the 1990s and up until 2001 at included the reference levels of $CTDI_{VOL}$ <30 mGy and DLP <650 mGy. According to data reported by many authors (Tsapaki, Shrimpton, Clarke, Poletti), these values were commonly exceeded [2,6]. The legal act defining the guidelines for individual computed tomography procedures and related dose limits within the European Union is directive EUR 16262, replacing directive 16260 from 1996. In relation to routine chest examinations, the limit dose per slice was defined as 30 mGy, and the DLP limit was defined as 650 mGy·cm. In case of high resolution computed tomography, the respective values are 35 mGy and 280 mGy·cm. The review of the bibliographic references cited in the aforementioned directive reveals a high number of papers published before 1999. Many CT systems installed to date develop the images using filtered back projection (FBP) technique. The first step proposed to reduce the DLP and E doses is narrowing down the scanning range. In case of patients with small body posture, reduction in mA values is also possible. Other factors contributing to the reduction of the exposure to ionizing radiation include modulation of radiation beams, reduction in kV value, increase in pitch and increase in noise filtration parameters [2,3,9,10]. When applying these settings in tomographs making use of FBP reconstruction, one has to balance out the reduction in exposure and the quality of the image. Several years ago, a come-back to alternative methods of image reconstruction was observed, where patient's exposure is reduced by radiation being turned off upon acquisition of slice data sufficient to reconstruct the image, was observed [11–13]. In practice, most common iterative image reconstruction methods include adaptive statistical iterative reconstruction (ASIR) and combinations of back projection with iterative methods (e.g. ASIR50 –50% FBP +50% ASIR) [3,11,12,13]. In the analyzed material, lower mean total doses were observed for ASIR-reconstructed images as compared to FBP-reconstructed images: ca. 19% for regular and ca. 11% for low dose examinations. The differences, however, were not statistically significant against the background of the collected data. Low dose CT scans are increasingly often used to replace plain X-ray images in screening for lung diseases in selected patient populations [11,14]. Therefore, an attempt was made to compare the doses recorded in LDCT scans to those in chest X-rays. To this end, the mean effective dose generated in low dose CT scans was compared to the mean effective dose generated in plain chest X-rays while using a conversion factor that accounted for averaged organ weigh ratios, the size, age and sex of the patients [15,16]. The mean effective dose recorded for chest X-rays was within the range referenced in the literature [17]. The ratio between mean low dose lung CT scan doses and lung X-ray doses was 11.56. The higher dose is the price being paid for the higher amount of information provided by the low dose CT scan of the lungs compared to plain chest X-rays. Exposure conditions, and particularly the current of 50 mA used in the LDCT scans included in this study permitted the assessment of mediastinal and epigastric structures in terms of large focal lesions. Pre-defined protocols proposed by the manufacturers usually employ currents of 20–30 mA. Detection of densities within pulmonary parenchyma is possible with currents in the range of 12–20 mA, allowing to reduce the dose more than twofold; since the dose is reduced along with mA, one might expect routine LDCT doses at the levels corresponding to 4–5 plain X-ray examinations. A similar effective dose level is also observed in mammographic examinations unrivaled in breast cancer screening [15–17].

The model-based iterative reconstruction (MBIR) is most recently introduced iterative technique providing a breakthrough in terms of dose reduction [3]. In this method, besides a significant dose reduction (up to 5 times compared to back projection), reduction in artifacts originating from bone mass is also possible; in case of chest examinations, this permits the assessment of pulmonary parenchyma in the shoulder girdle region and reduction of artifacts from upper extremities positioned along the chest in cases when lifting these extremities above patient's head for examination purposes is impossible If it is possible to reduce the LDCT dose to the level of PA + lateral X-rays, this technique could be proposed as suitable for screening examinations in groups at high risk of lung cancer. The efficacy of detecting early stages of lung carcinoma by LDCT is nearly 100%. Efficient screening is essential in programs to reduce lung cancer mortality, which currently amounts to more than 23,000 deaths a year in Poland.

Conclusions

The exposure to ionizing radiation in low dose computed tomography scans of the chest at parameters allowing for identification of mediastinal structures and adrenal glands is significantly lower than in standard computed tomography lung examination protocols.

The predicted effective doses in LDCT of lungs may be 4 to 12 times higher than doses used in plain lung X-rays, depending on scanning parameters.

The obtained results, as well as the literature data suggest a possibility to reduce the dose delivered in lung CT scans by using iterative image reconstruction protocols.

Further efforts are required to reduce the doses delivered in CT scans so as to encourage the replacement of plain chest X-rays by low dose computed tomography in selected screening programs.

Disclosure

The authors have no conflicts of interest to declare.

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