TA5 - RADIATION PROTECTION IN MEDICINE (POSTER PRESENTATION)

SCATTER RADIATION BREAST EXPOSURE DURING HEAD CT: IMPACT OF SCANNING CONDITIONS AND ANTHROPOMETRIC PARAMETERS ON SHIELDED AND UNSHIELDED BREAST DOSE

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ABSTRACT

Constantly increasing clinical requests for CT scanning of the head on our facility continue to raise concern regarding radiation exposure of patients, especially radiosensitive tissues positioned close to the scanning plane. The aim of our prospective study was to estimate scatter radiation doses to the breast from routine head CT scans, both with and without use of lead shielding, and to establish influence of various technical and anthropometric factors on doses using statistical data analysis. In 85 patient referred to head CT for objective medical reasons, one breast was covered with lead apron during CT scanning. Radiation doses were measured at skin of both breasts and over the apron simultaneously, by the use of thermo luminescent dosimeters. The doses showed a mean reduction by 37% due to lead shielding. After we statistically analyzed our data, we observed significant correlation between under-the-shield dose and values of technical parameters. We used multiple linear regression model to describe the relationships of doses to unshielded and shielded breast respectively, with anthropometric and technical factors. Our study proved lead shielding of the breast to be effective, easy to use and leading to a significant reduction in scatter dose.

INTRODUCTION

Computed tomography (CT) is an extremely valuable diagnostic tool. It has become a standard modality in assessing a variety of disorders, providing many clinical benefits. Advances in technology in last 3 decades have resulted in a number of distinct generations of scanners. Development of helical technology and, most recently, multidetector (or multislice) scanners, have provided new applications for CT and increased its use.
Medical radiation is the second largest source of exposure to the population, with greatest source being natural background radiation. Today CT accounts for the largest component of medical radiation: 40% to 67%, although it represents only 5% of all x-ray imaging. (1, 2). The number of CT examinations performed in the United States has increased 6 times in decade spanning the mid-1980s to mid-1990s. (3). Typical values

of patient dose in CT can be expected to change with developments in technology and clinical practice. Recent studies are suggesting broadly increasing levels of exposure per examination. For example, in a recent review of CT use and radiation dose, the effective dose (a measure of whole body dose based on individual organ doses and specific organ sensitivities) of a chest CT was 54 times that of a mammogram or 68 times the dose of a chest x-ray. Moreover, the cancer risk is cumulative over a lifetime, so each exposure (CT examination) contributes to the lifetime exposure. (5) Radiation for older adults and the elderly does not carry the same cancer risk as it does for the younger population, because many radiation induced cancers, particularly solid malignancies, will not be evident for decades.

Many health care providers, as well as the general public, have become aware of unnecessary CT radiation exposure, including potential cancer risks.

Despite the increase in CT use and ewer growing attention, there has not been appropriate increase in the use of techniques for reducing these risks. One reason for this lack of adjustments is likely that CT is a digital technology and there is no penalty for high dose of radiation in lower image quality. Quite contrary, higher doses improve image quality, unlike radiography, where higher doses result in overexposed, or dark, examinations. By an appropriate choice of technical parameters, attention to quality control and the application of diagnostic reference levels, more than a 50 percent reduction in patient dose is possible. (2)

Breast cancer is the most commonly occurring cancer among woman (22% of all cancers in 2000) and its estimated annual incidence worldwide is about one million cases. Over the last two decades, the annual incidence rate of breast cancer has been increasing steadily (4)

Based on epidemiological studies conducted in different populations,

The breast tissue is a structure with particular sensitivity to radiation. Therefore, its exposure to x-rays, when involved in scanning, represents a well-established risk factor for developing fatal cancer. If close but not directly in the area of scanning, scatter or internal deflection of the x-ray particles (photons) paths, may also affect that organ. The risk is dose-dependent and avoiding unnecessary exposure of mammary gland to radiation has a considerable benefit, since radiation doses from all sources accumulate over the life of an individual

Epidemiological studies on young women exposed to multiple thoracic fluoroscopes show us persuasive examples of excess cancer risk associated with diagnostic x-ray exposure. Excess (absolute) risk per unit of total dose (about 10 excess cases per 10,000 women per year per Gy at age 50, following exposure at age of 25) were comparable to those associated with acute doses among atomic bomb survivors (1).

Breast cancer in men is a rare disease, accounting for <1% of all breast cancer cases in the United States (6). Its incidence, once thought to be relatively stable, now seems to be substantially increasing, from 0.86 to

1.06 per 100,000 population over the last 25 years (6). Although the epidemiologic literature on female breast cancer (FBC) is extensive, little is known about the etiology of male breast cancer (MBC). Existing body of evidence on genetic and epidemiologic risk factors for breast cancer in men puts radiation exposure among those risk factors that seem to be consistently associated with MBC. The latent period for men exposed to radiation is ~20 to 30 years (6). In addition to case reports of breast cancer occurring in men exposed to radiation (6), several studies have shown that the risk of breast cancer is increased in men exposed to repeated and prolonged chest flouroscopies and for increased frequency of chest X-rays (6).

MATERIALS AND METHODS

Our study included 80 adult patients who underwent cranial CT examination for different indications. The study population consisted of 52 women (65%) and 28 men (35%). Their ages ranged from 78 to 22 (mean age, 46 years) 40 patients (50%) were <40 years old, and 12 patients (15 %) were <30 years old.

Body constitution

Body mass index (BMI) was calculated (BMI=body mass (kg)/height (m) ^{2}) and meatus acusticus externus -to-dosimeter distance (MAEDD) was measured for each patient.

Technical conditions

Scan parameters were recorded during examination: mA, kVp, number of slices, slice thickness and weighted computed tomography dose index (CTDI) values, which were automatically calculated by CT software and displayed on the screen.

During head CT examination one breast was covered with lead apron of 0.35-mm-equivalent lead density, and contra lateral breast was left unshielded, so that each patient served as her/his own control. The amount of scatter radiation measured at the skin of the shielded was compared with that of the unshielded breast. The left and right breasts were shielded in alternating order in each consecutive patient. It was intended that breast area be covered as tightly as possible, from midline to anterior axillary line, and from the clavicle to lower ribs.

CT equipment

In our study we used SCT-7800T (Shimadzu, Japan) helical CT unit. All head CT examination were performed using standard protocol that consisted of initial scout view, followed by 8 to 11 contiguous 10mm slices and 7 to 13 5mm slices for scull base. Exposure factors were kept at 120 kV and 200 mAs for 10mm and 250 mAs for 5mm slices. To reduce scanning *artifacts at scull base we used «stack» technique with 2mm overlapping slices.*

Dosimetry
Measurements were carried using $^{7}LiF:Mg,Ti$ (TLD-700) dosimeters (manufactured by Harshaw). Dimensions of dosimeters are 3x3 mm chips 0.9 mm thick, which were packed in pairs of two in rubber holders (7,8,9). The $^{7}LiF:Mg,Ti$ is nearly tissue-equivalent material that is very important in medical applications of radiation, especially diagnostic radiology.
In each cycle we had 10 calibration and 5 control dosimeters. For calibration, the irradiations with ^{137}Cs gamma rays were performed in the Secondary Standard Dosimetry Laboratory in the Rudjer Bošković Institute. Calibration doses were 5 mGy specified as "air kerma".

Annealing was performed in an automatic microprocessor controlled TLD oven (TLDO PTW). The procedure was: heating with automatically controlled speed to 400°; 60 min. at 400°C, cooling with controlled speed to 100°, 120 min. at 100°C and cooling to room temperature.

Before any irradiation TLDs were annealed. Just before every reading TLDs were preheated for 20 min. at 100°C in the TLD oven. The readings were carried out in a modified 'Toledo 654' (Pitman U. K.) reader that enables glow curve integration with variable integration limits for each dosimeter individually. Reading process includes preheating at 100°C for 6 seconds and heating for 35 seconds with constant heating rate (10,4°C per sec.) up to the temperature of 270 °C.

Statistical analysis
For statistical data analysis we used Statgraphics Plus 5.1 (StatPoint Inc. USA) statistical software. Its StatAdvisor option allowed us to calculate various statistics, including correlations, covariances, and partial correlations. Also included in the procedure were a number of multivariate analysis methods, which gave interesting views into the data.
Our study was approved by the hospital's Ethics Committee prior to initiation. The patients were informed that breast shielding was not a routine means of protection in head CT, and not addressed by laws in Croatia, but could not be harmful in any way and there would be no effect of shielding on examination efficacy. A written informed consent was obtained from all patients.

RESULTS

Results of our measurements are shown in Table 1.

Table 1. Results

	UTS	OTS	UB	BMI	mAs	MBD	N slices	CTDI	tilt

Min	0,04	0,03	0,09	15,82	2625,0	20,00	23,8	23,8	-18,0
Max	0,56	0,83	0,61	44,53	12200,0	30,00	90,1	47,6	25,0
R	0,52	0,80	0,52	28,71	9575,0	10,00	66,3	23,8	43,0
Stdev	0,10	0,14	0,12	4,26	1425,6	2,32	18,8	6,8	9,5
Average	0,17	0,20	0,31	26,48	5132,3	24,02	74,6	38,8	8,8
Xsr+3S	0,46	0,61	0,68	39,26	9409,0	30,99	131,1	59,1	37,2
Xsr-3S	-0,12	-0,21	-0,06	13,71	855,6	17,05	18,1	18,5	-19,7

(UTS) "Under-the-shield" scatter dose at skin of shielded breast in mGy, (OTS) "Over-the-shield" scatter dose on shielded breast in mGy, (UB) scatter dose at skin of unshielded breast in mGy, (BMI) Body mass index, mAs, (MBD) Meatus Acusticus Externus to Breast distance in cm, (Nslices) Total number of slices in one CT scanning, CTDI in mGy, (tilt) Gantry tilt in degrees, (Min) Minimal value, (Max) Maximal value, (R) Range, (Stdev) Standard deviation, (Average) Mean value, (Xsr+3S) Upper confidence level at 99,7%, (Xsr-3S) Lower confidence level at 99,7%

The difference between doses measured at the skin of the unshielded and the shielded breast was statistically significant ($p=1,3x10^{-18}$). The doses at the protected breast were by average factor of 2,03 (range 1,1 to 6,22) lower than those at the unshielded breast, i.e. surface breast exposure was reduced by 51% (range 9% to 84%) due to lead shielding. Exposure at skin under the shield and over the shield of shielded breast participated with 57% and 43% in total breast dose, respectively.
After we statistically analyzed our data, we observed significant correlation between under-the-shield dose and values of technical parameters. This relationship was statistically significant for CTDI, total mAs and number of slices in one head CT scan at the 90% or higher confidence level (P-value<0,10) with Pearson factors of 0,585 , 0,513 and 0,603 respectively.
Total breast dose correlated significantly more with over-the-shield (R-squared=0,632) then with under-the-shield (R-squared=0,366) values. Gantry tilt strongly correlated with over-the-shield dose, but for total breast and under-the-shield doses, correlation was not statistically important, with p=0,594 and p=0,824, respectively.
When we divided our population by sex, statistical analysis showed even stronger correlations for male, but weaker for female patients. In group with female patients correlation between over-the-shield dose and gantry tilt become statistically insignificant at the 90% or higher confidence level (p=0,17).
Results of fitting a multiple regression to describe relationships between scatter doses and independent variables (CTDI, mAs, gantry tilt, number of slices in one scan, BMI, meatus acusticus exernus-to-breast distance) indicated that those variables explain only 54,73% of the variability in breast doses. By removing terms that are not statistically significant at

the 90% or higher confidence level, the remaining factors (CTDI, gantry angle, mAs) are explaining 65,3% of the variability in dose to the unshielded breast. For shielded breast remaining factors (BMI, meatus-breast distance) are explaining 55% of variability. P-value in ANOVA table was lower than 0,10 , so there is a statistically significant relationship between the variable at the 90% or higher confidence level.

DISCUSSION

There is much that radiologist can do to keep radiation exposures low during head CT scanning without compromising image quality (2,10). First, the referring physician should evaluate the justification of examination. Then, the operator should adopt technical parameters to each patient individually, with special attention being paid to pediatric and young patients. The use of shielding for superficial structures in the examination field is controversial, since it can affect the display of deeper structures. When such organs are not in the field of interest, like breast during head CT scanning, radiation dose to the breast is due to scatter radiation from the interaction of the X-ray beam with patient tissue and tabletop. None of this incidental dose received by the breast contributes to useful image data and it may be reduced by the use of the breast shield without a detrimental effect on image quality.
The data from a number of studies suggest that the doses of scatter radiation to the breast in various diagnostic procedures range from almost immeasurable levels to those higher than in conventional mammography (11,12). There is debate regarding whether such low-level radiation provides a significantly increased risk of developing fatal cancer. For the purpose of this discussion, low-level radiation is ~100 milliSivert (mSv) (13) The dose from a single CT examination (which can include up to 4 different series, pre- and post contrast) can range from <1.0 mSv to >30.0 mSv (1,13) A recent study (14) of the radiation effects on the atomic bomb survivors seems to confirm a statistical finding of a risk of carcinogenesis in the dose range 0 to 0,1 Sv, and the validity of the linear no-threshold model for acute exposure to low doses, with an upper confidence limit for a possible threshold value of 0,06Sv. Prevalent view today is that there is a statistically significant increased risk of fatal cancer from low-dose radiation, possibly in the range of 10 to 50 mSv (13).
There is still a high level of uncertainty about low-dose risk, and we still have to come to terms with that uncertainty.
Beaconsfield et al studied the effect of shielding regions of the body that are not included in the direct path of the x-ray beam during CT. They reported that with lead protection breast doses were reduced by an average of 45% and 76% respectively, in 110 patients undergoing routine head CT. (10) Another study by Brnic et al studied the effect of breast shielding during CT scanning. They reported that with use of lead shields breast doses were reduced by 57% in 49 patients. The mean scatter

radiation dose to the breast in our series was 0,312+-0,12mGy, 10% higher than doses reported by Brnic and Beaconsfield. We believe that the difference in our results comes from usage of helical CT scanner in our study (16), while Beaconsfield and Brnic used conventional CT scanners. In comparison with the mammographic dose per film (17), scatter dose per one breast in head CT was more than four times lower. If head CT is performed repeatedly, the dose to the breasts might accumulate to significant level, possibly surpassing that of mammography.

Position of a tissue or organ within a body is important for its scatter exposure.(18) Those organs that lie along body axis are more exposed to internal scatter, and on the other hand, one can assume that in the case of the breast, which is a superficially located organ, external scatter would play a significant role (19). During head CT scanning external scatter originates from CT machine and from the periphery of the head. It reaches the breast from its convexity that lies above the coronal plane of the supine patient. Scatter radiation that comes from outside of the patient can, therefore, be considerably absorbed by protective lead shield. However, we can not eliminate the scatter radiating along the central axis of the neck, as well as scatter from the machine, which comes from below the level of patient support. In order to asses how much radiation was imparted to the breast from outside and how much was due to internal scatter, we measured separately the doses beneath (under -the-shield) and over (over-the-shield) the lead apron. Radiation dose for «Under the-shield» exposure was 0,178+-0,097 mGy and for «over the shield» exposure it was 0.135+-0,085 mGy, and they participated in total breast dose (dose measured at skin of contralateral unshielded breast) with 57% and 43% respectively.

For 360° scans, the ratio of scattered radiation to primary radiation is higher, on average, at the center of the patient than at the surface (18). Therefore, the correlation between total scatter dose to breast, a superficially located organ, was significantly greater with over-the-shield (R-squared=0,632) then with under-the-shield (R-squared=0,366) radiation doses.

An impact of body weight on radiation exposures in diagnostic radiology is well established (20). In our study we investigated the connection between patients' body constitution and scatter radiation to the breast. We have shown that patients with higher BMI are exposed to higher scatter breast doses, with higher percentage of internal scatter in total breast dose. Therefore, breast shielding is more effective in patients with lower BMI, due to higher percentage of external scatter in total breast dose. In our study, thinner patients with lower BMI were also generally younger (mean age for women with BMI<24 was 36 and for BMI>24 was 45 years), and therefore exposed to greater cancer risk.

After we statistically analyzed our data, we observed significant positive correlation between "under-the-shield" dose and values of technical scanning parameters (CTDI, total mAs and number of slices in one head CT *scan). All this parameters contribute to quantity of x-rays imparted to the tissue in scanning plane and are directly proportional to total scatter dose (tutorial) (unshielded breast dose). We can not influence internal scatter with shielding, and therefore an increase in total scatter dose proportionally increases "under-the-shield" dose. Technical parameters do not correlate with "over-the-shield" dose since it is the measure of external scatter, which is reduced by lead shielding. Radiation dose to unshielded breast can be influenced by changing technical conditions, while dose to the shielded breast depends mainly on anthropometric factors, which are specific for each patient and we can not influence them. Given that CTDI, as a main predictor of breast radiation load, is mainly dependent upon electrical conditions, low-dose protocols may be of value in dose reduction.*

The benefit of breast shielding during CT acquisition has been previously recognized and reported (20) In their paper Brnc e al demonstrated a reduction of breast scatter radiation dose from to by the use of a flat lead shield. They considered this reduction to be clinically significant and suggested it should not be omitted during scanning, especially in younger women with a higher sensitivity of breast tissue to radiation. Along with breast shielding some other radiosensitive tissues will also be protected against external scatter radiation, particularly bone marrow (42% of bone marrow in adults is found in the thorax) and skin (20).

Current legislation in Croatia does not address the question of breast shielding during CT scanning. The decision whether to use breast shielding for a particular patient should be made with an understanding of the expected low doses to the gland tissue and the cancer risk related to them. In younger women with glandular breast, significant radio sensitivity of breast tissue to radiation and other possible risk factors predisposing them for cancer, the effective dose resulting from particular absorbed dose would probably be higher. Although breasts have small contribution in total effective dose from head CT scanning (22) , the overall risk from head CT examination have to be perceived in the light of high radio sensitivity of the breast parenchyma and believed small sensitivity of brain tissue.

Breast protection with lead apron was in our circumstances easily carried out. In patients with favorable body geometry and clinical status it required not more than 1 minute of regular schedule time. The positioning of the lead apron proved to be simple because it's small and does not give rise to folds. We also noticed that such additional care made a positive impression on our patients, giving them more confidence in medical professionals and reducing fear and discomfort.

Scatter radiation to the breast can be measured in vivo or by usage of anthropomorphic phantom (23). Both methods have their advantages and disadvantages. Indirect phantom measurements are more fundamental, as they consider increasing tissue depth as well as breast composition, volume and shape as factors influencing radiation dose. On the other hand, *in vivo measurements, as one described in our study, are performed in real clinical circumstances f positioning of the patient and variations of body geometry, which influence shielding possibilities.*

CONCLUSION

CT radiation dose optimization is a crucial issue in patient radiation protection today. The benefit to the patient is our priority, and therefore we should strictly apply the policy of ALARA (as low as reasonably achievable). Our study proved lead shielding of the breast to be effective, leading to a significant reduction in scatter dose. The shield proved easy to use and did not increase the examination time. Thus it can be recommended to use shielding, especially on young patients and those who have to repeat the examination frequently.

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