Eur Radiol (2003) 13:2436–2440
DOI 10.1007/s00330-003-1945-1

Z. Brnić
B. Vekić
A. Hebrang
P. Anić

Efficacy of breast shielding during CT of the head

Received: 17 July 2002
Revised: 18 December 2002
Accepted: 17 March 2003
Published online: 25 June 2003

Z. Brnić (✉) · A. Hebrang · P. Anić
Department of Diagnostic
and Interventional Radiology,
University Hospital Merkur,
Zajčeva 19, 10000 Zagreb, Croatia
e-mail: zoran.brnic@zg.hinet.hr
Tel.: +38-51-2431414
Fax: +38-51-2431414

B. Vekić
"Ruđer Bošković" Research Institute,
10000 Zagreb, Croatia

Abstract In light of increasing frequency of CT examinations in the past decades, the aims of this prospective study were to investigate scatter radiation breast exposure in head CT and its dependence upon body constitution, and to assess the efficacy of lead shielding as a means of breast dose reduction. In 49 women referred to head CT for objective medical reasons one breast was covered with lead apron during CT scanning. Radiation doses were measured by use of thermoluminescent dosimeters, at skin of both breasts and over the apron. The doses were then compared as well as correlated to body mass index and meatus acusticus externus-to-dosimeter distance, respectively. Average exposure at the skin of the unshielded breast was 0.28 mGy (range 0.15–0.41 mGy), compared with 0.13 mGy (range 0.05–0.29 mGy) at the shielded breast. The doses showed a mean reduction by 57% due to lead shielding. At least half of breast exposure was imparted to the breast from outside, whereas the remainder results from internal scatter. The higher the body mass index, the higher the percentage of internal scatter in total breast dose. Although the level of scatter radiation to the breast is generally low during head CT examination, the use of lead cover enables recognizable further reduction of the exposure, and is recommended as a feasible and effective procedure of breast protection during CT of the head.

Keywords Radiation dose reduction · Head CT · Scatter radiation · Breast · Protective lead shielding

Introduction

The use of CT is rapidly increasing in the past two decades, and this method has become the major non-natural source of radiation exposure to the population. The CT examination delivers to the patients more radiation than all other imaging techniques, and contributes disproportionately to the collective dose. In Britain it has been estimated that 4% of diagnostic radiology procedures are CT examinations, being responsible for approximately 40% of the total annual collective dose [1].

Breast doses are high in CT examinations with breasts in scanning planes [2, 3], being not insignificant also when breasts are exposed only to scatter radiation [4, 5]. Breast doses received through scatter radiation during head CT may account for up to one-fifth of an average mammographic dose per one view [5, 6, 7].

While the possibilities of reduction of radiation load to organs lying in CT scanning planes are limited [2, 8, 9], the tissues outside the primary beam should be protected against scatter whenever it does not sacrifice image quality. Lead shielding results in significant reduction of external scatter to radiosensitive superficial organs in many diagnostic procedures [4, 5, 10, 11]. The published studies of breast shielding against scatter radiation in diagnostic radiology are scanty [4, 5], only the latter one dealing particularly with breast shielding during head CT examination.

The aims of this study were to investigate in vivo the levels of breast exposure to scatter radiation in head CT examination and the dependence of breast exposure upon body constitution. We tried to estimate the efficacy of external lead shielding as a mean of breast dose reduction, and to determine how much radiation reaches the organ from outside, in comparison with radiation load caused through internal scatter.

Materials and methods

The study included 49 consecutive adult women (age 53.67±16.42 years, age range 21–77 years) referred to head CT examination for objective medical reasons. Eleven patients (22.4%) were <40 years old, and 6 patients (12.3%) were <30 years old.

During head CT examination one breast was covered with lead apron of 0.35-mm-equivalent lead density, and contralateral breast was left unshielded, so that each patient served as her own control. The amount of scatter radiation measured at the skin of the shielded breast was compared with that of the unshielded breast. The left and right breast was 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.

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. A written informed consent was obtained from all patients.

Dosimetry

Thermoluminescent dosimeters (TLD) used for dose measurements were TLD-700 (^{7}LiF:Mg, Ti) lithium fluoride TLD (Harshaw Cristals and Electronics, Solon, Ohio), 3×3-mm chips 0.9 mm thick, which were packed in pairs of two in rubber holders. Prior to each irradiation, the dosimeters were annealed (TLDO oven) at 400°C for 1 h + 100°C for 2 h. Before readout, external (100°C for 20 min) and internal (100°C for 6 s) pre-heat treatment for all TLDs was used. Reading of the TLDs was performed using Toledo 654 (Pitman/Winten) system, which enables the integration of the glow curves with variable integration limits [12]. The properties of TLDs were investigated in advance. For calibration, the irradiations of TLDs with ^{137}Cs γ-rays were performed at a distance of 1 m from the source. The dose rate was 0.76 mGy/h (specified as "absorbed dose to water"). The individual sensitivity of each detector was previously determined by irradiations with the same ^{137}Cs γ-ray source. The dose at the lower detection limit, defined as three times the standard deviation of zero reading of unirradiated dosimeters, was also determined; for TLD-700 the lower detection limit was 0.009 mGy. At the same time, the reproducibility of calibration factors for TLD-700 was +3% and uniformity (the variations in sensitivities within the examined samples containing 50 detectors) was +4% [12].

After the informed consent was obtained, TLD holders were attached by adhesive tape to the skin of the left and the right breast, 2 cm craniolateraly from the nipple, over the area with the largest amount of glandular tissue. The third TLD was fixed *over* the apron at the position as close as possible to TLD *underneath* the shield. The three TLDs were thus at the same distance from patient's head in each measurement.

CT equipment

All head CT examinations were performed using SCT-4500TE (Shimadzu, Japan) CT unit. Standard non-contrast conventional head CT protocol consisted of initial scout view, followed by 13–15 contiguous 5-mm and 10-mm slices. Exposure factors were kept at 120 kV and 360 mAs per slice. Beam quality was defined with a half value layer of 3.5-mm aluminum filtration. During the scout view X-ray tube continuously moves linearly along the left side of the patient's head.

Body constitution

Body mass index was calculated (BMI=body mass/height^2) and meatus acusticus externus-to-dosimeter distance (MAIDD) was measured in each patient. Correlations were determined between the doses and BMI and MAIDD, respectively.

Statistical analysis

Student's *t*-test was used to determine statistical significance of the difference between the doses to the shielded and unshielded breast, with the level of the significance at $p<0.05$. Linear regression analysis was done and Pearson correlation coefficients were given to show the correlation between the doses and BMI and MAIDD, respectively.

Results

The doses measured at the skin of the unshielded and the shielded breasts, and over the apron at shielded side ("over-the-cover TLD"), are shown in Table 1. The difference between the two doses was significant ($p=1.4\times10^{-18}$). The doses at the protected breast were by average factor of 2.33 (range 1.06–8.00) lower than those at the unshielded breast, i.e. surface breast exposures were reduced by 57% (range 6–82%) due to lead shielding. "Under-the-cover exposure" and "over-the-cover exposure" participated with 46% (range 28–81%) and 54% (range 19–73%) in total breast exposure, respectively.

Meatus acusticus externus-to-dosimeter distance ranged in our series 22–33 cm (mean 28.53±2.60 cm). Mean patient weight was 74.41±16.57 kg and mean patient height was 170.45±8.38 cm. Mean BMI was 25.53±4.91 kg/m^2 (range 15.70–34.89 kg/m^2).

Correlations between breast doses and BMI and MAIDD, respectively, are shown in Table 2. There was

Table 1 Results of breast dose measurements in head CT examinations. *TLD* thermoluminescent dosimeters

	Mean±SD	Range
Unshielded breast dose (mGy)	0.28±0.07	0.15–0.41
Shielded breast dose ("under-the-cover TLD") (mGy)	0.13±0.05	0.05–0.29
"Over-the-cover TLD" dose at shielded side (mGy)	0.15±0.06	0.08–0.30

Table 2 Correlations between breast doses and body mass index (BMI) and meatus acusticus externus-to-dosimeter distance (MAIDD), respectively. *C* Pearson coefficient, *NS* nonsignificant

	BMI	MAIDD
Unshielded breast dose (mGy)	c=0.28[a], p>0.05 (NS)	c=–0.57, p<0.05
Shielded breast dose (“under-the-cover TLD”; mGy)	c=0.08, p>0.05 (NS)	c=–0.17, p>0.05 (NS)

[a] In subgroup of patients with BMI>30 c=0.31

practically no correlation found between BMI and “under-the-cover exposure”, whereas weak correlation was observed between BMI and unshielded breast dose. In the subgroup of very obese patients (BMI>30) the unshielded breast dose was by 11% higher than mean unshielded breast dose for the whole series. Significant inverse correlation was shown between MAIDD and unshielded breast dose patients with long neck had lower unshielded breast doses than patients with short neck. Weak positive correlation (c=0.25, p>0.05) was observed between BMI and the ratio “under-the-cover exposure”/total breast exposure (total breast exposure = “under-the-cover exposure” + “over-the-cover exposure”). Consecutively, in very obese patients participated in “under-the-cover exposure” with higher percentage in total breast exposure than in thin patients.

Discussion

Besides the radiosensitive structures that lie in primary beam and cannot easily be protected, the organs outside the CT scanning planes are exposed only to scatter radiation. During head CT examination scatter radiation propagates caudally through the patient’s neck, reaching breasts as well. This part of radiation cannot be reduced in any way, similarly as in the case of ovaries, which are inevitably exposed to significant doses of scatter in abdominal CT [11]; however, significant amount of scatter radiation, generated in patient’s head and in gantry, reaches superficial organs, particularly thyroid and breasts, from outside and can be reduced effectively by lead shielding.

A number of studies have dealt with scatter radiation to the thyroid and the breast in diagnostic radiological procedures [4, 5, 13, 14]. The data suggest that the doses of scatter radiation to the breasts in diagnostic procedures range from almost immeasurable levels to those higher than in conventional mammography [4, 5, 13, 14, 15, 16].

The mean dose of scatter radiation to the breasts found in our series (0.28±0.07 mGy) was about the same as shown by Beaconsfeld [5]. In comparison with the mammographic dose per film [15, 16], scatter dose per one breast in head CT was more than four times lower. If head CT examination were done in a patient several times in the lifetime, the dose to the breasts might accumulate to significant level, possibly surpassing that of mammography. It has become evident that breast cancer mortality (in contrast to, for example, lung cancer mortality) significantly increased also after frequent exposures to very low doses of radiation [17], which indicated that also low breast doses, as measured in our study, should not be neglected.

Radiation geometry is especially decisive for scatter exposure of an organ. Keeping in mind that internal scatter is responsible for the major part of thyroid dose in head CT [5, 11], one can assume that in the case of the breast, which is a superficially located organ, external scatter would play a substantial role; thus, we expected that the reduction of scatter to the breasts achieved through lead shielding would be greater than in the case of the thyroid [5, 11]. Our results showed that 57% of breast exposure in head CT has been eliminated with the use of 0.35-mm lead barrier, whereas Beaconsfeld et al. reported even higher reduction of scatter (by 70–90%) with the use of lead barrier with higher lead equivalent (0.50 mm) [5].

In order to assess how much radiation was imparted to the breast from outside and how much was due to internal scatter, we measured separately the doses *beneath* and *over* the lead apron. “Under-the-cover exposure”, as representative of the internal scatter, occurred in 46% of cases in total breast dose, whereas “over-the-cover exposure” occurred in 54%, being caused by the external scatter. Our results were not unexpected, since we know that internal scatter is the major source of radiation burden to many radiosensitive tissues, especially those deeply located [5, 11]; hence, the shielding is less effective when the source of scatter lies within patient’s body, then outside of that [11, 18]. The scatter originating from upper parts of CT machine and from the periphery of the head reaches the breast from outside, being considerably absorbed by protective shield. We could not, however, 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 other words, lead barrier is effective only against the radiation that reaches the breast from its convexity, from the sources that lie above the coronal plane of the supine patient.

Significant inverse correlation was shown between MAIDD and unshielded breast dose. The neck length is, hence, a factor that influences scatter radiation burden to the breast at least for two reasons: (a) the intensity of external scatter decreases proportionately to the square of the distance from its source (even a little increase in the distance causes significant decrease of breast doses); (b) the larger the volume of neck tissues, the larger attenuation of the internal scatter on its way to the breast.

An impact of body weight on radiation exposures in diagnostic radiology is well known [19]. We investigated the influence of patient's body constitution, particularly obesity and body geometry, upon scatter breast exposure. We have shown that obese patients are exposed to higher breast doses during head CT, with higher percentage of internal scatter in total breast dose than thinner patients; hence, shielding is more effective in thin patients due to higher percentage of external scatter in total breast dose.

It is questionable whether the degree of scatter reduction accomplished through the use of breast shielding may be biologically significant. In younger women with glandular breasts, significant radiosensitivity of breast tissue, and 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 [20], the overall risk from head CT examination have to be perceived in the light of high radiosensitivity of the breast parenchyma and believed small sensitivity of brain tissue. Every effort to reduce irradiation of the breast through the shielding is in accordance with the philosophy of radiation hygiene to keep exposure "as low as reasonably achievable" and with internationally adopted statements that "breast doses in head CT...are significant enough...to be a matter of concern" [21]. Along with breast shielding some other radiosensitive tissues will also be protected against external scatter radiation, particularly bone marrow (42% of bone marrow in adult is found in the thorax [22]) and skin.

Human body geometry makes it possible to shield breasts easier than many other radiosensitive organs, although even that may be the problem in some patients with unfavorable body build or clinical status. Breast protection with lead apron was in our circumstances easily carried out, requiring not more than 1 min of regular schedule time. We feel that such kind of care promoted confidence among our patients, without arousing fear from radiation or causing any discomfort.

We were not able to compare breast scatter doses in contiguous conventional CT scanning to those in spiral CT, the modality widely adopted at present, as we did not find any literature dealing with breast scatter doses in spiral CT; however, it is known that patient doses in spiral CT are either similar, as in conventional CT [23], or up to 50% lower [24, 25, 26]. Consecutively, it may be expected that spiral CT produces less scatter to the breasts compared with conventional CT, which needs to be further investigated.

Both direct and phantom dose measurements may have advantages and disadvantages in studies of scatter radiation doses to the breast. In vivo measurements in our study were performed in real clinical circumstances of positioning of the patient and variations of body geometry, which influence shielding possibilities. On the other hand, there were not doses within glandular breast tissue, but only entrance skin exposures assessed. Indirect phantom measurements would be therein more fundamental, as they consider increasing tissue depth as well as breast composition, volume, and shape as factors that may influence the effective radiation dose.

Conclusion

Although the level of breast radiation exposure during head CT examinations is generally low, shielding of the breasts with lead apron will further reduce the doses; however, if the effect of shielding limited only to reduction of external scatter, breast shielding must be set as our future imperative in patients' radiation protection as feasible and effective measure in routine daily practice.

Acknowledgements The authors thank Mr. Kruno and Mr. Jovica for their assistance.

References

1. Shrimpton PC, Edyvean S (1998) CT scanner dosimetry. Br J Radiol 71:1–3
2. Hopper KD, King SH, Lobel ME, TenHave TR, Weaver JS (1997) The breast: in-plane X-ray protection during diagnostic thoracic CT-shielding with bismuth radioprotective garments. Radiology 205:853–858
3. Cohnen M, Poll L, Puttmann C, Ewen K, Modder U (2001) Radiation exposure in multi-slice CT of the heart. Fortshr Röntgenstr 173:295–299
4. Fordham LA, Brown ED, Washburn D, Clark RL (1997) Efficacy and feasibility of breast shielding during abdominal fluoroscopic examinations. Acad Radiol 4:639–643
5. Beaconsfeld T, Nicholson R, Thornton A, Al-Kutoubi A (1998) Would thyroid and breast shielding be beneficial in CT of the head? Eur Radiol 8:664–667
6. Klein R, Aichinger H, Dierker J, Jansen JT, Joite-Barfuss S, Sabel M, Shultz-Wendtlant R, Zoetelief J (1997) Determination of average glandular dose with modern mammography units for two large groups of patients. Phys Med Biol 42:651–671
7. Burch A, Goodman DA (1998) A pilot survey of radiation doses received in the United Kingdom Breast Screening Program. Br J Radiol 71:517–527
8. Evans SH, Davis R, Cooke J, Anderson W (1989) A comparison of radiation doses to the breast in computed tomographic chest examinations for two scanning protocols. Clin Radiol 40:45–46

9. Hein E, Rogalla P, Klingebiel R, Hamm B (2002) Low-dose CT of the paranasal sinuses with eye-lens protection: effect on image quality and radiation dose. Eur Radiol 12:1693–1696
10. Price R, Halson P, Sampson M (1999) Dose reduction during CT scanning in an anthropomorphic phantom by the use of a male gonad shield. Br J Radiol 72:489–494
11. Hidajat N, Schröder RJ, Vogl T, Schedel H, Felix R (1996) Effektivität der bleiabdeckung zur dosisreduktion beim patienten in der computertomographie. Fortschr Rontgenstr 145:462–465
12. Miljanić S, Ranogajec-Komor M, Knežević Ž, Vekić B (2002) Main dosimetric characteristics of some tissue-equivalent TL detectors. Radiat Prot Dosim 100:437–442
13. Mustafa AA, Janeczek J (1989) Organ doses from cardiac and carotid digital subtraction angiography. Br J Radiol 62:838–842
14. Whelan C, McLean D, Poulos A (1999) Investigation of thyroid dose due to mammography. Australas Radiol 43:307–310
15. Gentry JR, DeWerd LA (1997) TLD measurements of in-vivo mammographic exposures and calculated mean glandular dose in the United States. Med Phys 24:309–311
16. International Atomic Energy Agency (1996) International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources. Vienna, p 280
17. Davis FG, Boice JD, Hrubec Z, Monson R (1989) Cancer mortality in a radiation-exposed cohort of Massachusetts tuberculosis patients. Cancer Res 49:6130–6136
18. Tse V, Lising J, Khadra M, Chiam Q, Nugent R, Yeaman L, Mulcahy M (1999) Radiation exposure during fluoroscopy: Should we be protecting our thyroids? Aust N Z J Surg 69:847–848
19. Rowley KA, Hill SJ, Watkins RA, Moores BM (1987) An investigation into the levels of radiation exposure in diagnostic examinations involving fluoroscopy. Br J Radiol 60:167–173
20. International Commission on Radiological Protection (1991) ICRP Publication 60. 1990 Recommendations of the Commission on Radiological Protection. Pergamon Press, Oxford, p 136
21. International Commission on Radiological Protection (2001) ICRP Publication 87. Managing patient dose in computed tomography. Pergamon Press, Oxford, p 31
22. Christy M (1981) Active bone marrow distribution as a function of age in humans. Phys Med Biol 26:389–400
23. Cohnen M, Cohnen B, Ewen K, Teubert G, Moder U (1998) Dossismessungen bei spiral-CT-Untersuchungen der Kopf-Hals-Region. Fortshr Rontgenstr 168:474–479
24. Lakits A, Prokesh R, Scholda C, Nowotny R, Kaider A, Bankier A (2000) Helical and conventional CT in imaging of metallic foreign bodies in the orbit. Acta Ophthalm Scand 78:79–83
25. Hidajat N, Maurer J, Schroder RJ, Wolf M, Vogl T, Felix R (1999) Radiation exposure in spiral computed tomography: dose distribution and dose reduction. Invest Radiol 34:51–57
26. Pitman AG, Budd RS, McKenzie AF (1991) Radiation dose in computed tomography of the pelvis: comparison of helical and axial scanning. Australas Radiol 413:29–35