JOURNAL CLUB:

Scatter Radiation Dose From Digital Screening Mammography Measured in a Representative Patient Population

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OBJECTIVE. The purpose of this study was to quantify the amount of scatter radiation received at the skin surface overlying the thyroid gland, salivary gland, lens of the eye, sternum, and uterus during a routine screening digital mammographic examination measured in a representative patient population.

SUBJECTS AND METHODS. The subjects were 207 women without symptoms with varied body mass indexes who underwent annual screening mammography while wearing six optically stimulated luminescence dosimeters placed at the bridge of the nose, right submandibular gland, right and left thyroid lobes, mid sternum, and 2 cm caudal to the umbilicus to assess scatter radiation dose to the skin.

RESULTS. The average scatter radiation doses at the skin surface during digital screening mammography in the representative population of women were as follows: overlying the right lobe of the thyroid, 0.24 mGy; left lobe of the thyroid, 0.25 mGy; salivary gland, 0.2 mGy; bridge of the nose, 0.025 mGy; sternum, 0.87 mGy; and umbilicus, 0.011 mGy. The scatter radiation doses at the umbilicus and the bridge of the nose were too low to measure with statistical confidence. Scatter radiation dose increased with increasing body mass index and increasing breast compression thickness.

CONCLUSION. Scatter radiation dose at the skin overlying organs of interest is a small fraction of the entrance skin dose to the breast. The low levels of scatter radiation measured do not support delaying clinically indicated mammography during early pregnancy.

Keywords: mammography, radiation risk, scatter radiation

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Mammography continues to be the primary imaging tool in the detection of early breast cancer. Because of the overall increase in the use of medical ionizing radiation, many patients and their physicians are appropriately concerned about individual radiation dose and specifically concerned about the risks of radiation from mammography. Although the dose absorbed by the breast and adjacent organs during mammography is a small component of the lifetime accumulated dose from medical imaging and other sources, the popular press tends to emphasize the radiation risk of mammography, particularly screening mammography [1, 2]. There is also a lack of knowledge and awareness of radiation doses and safety. Referring physicians, regardless of their area field of practice, underestimate both dose and potential effects [3–7].

Physicians are obligated to balance the risks and benefits of various medical procedures while keeping the patient informed of risk-to-benefit ratios. This is particularly important for women of child-bearing age and pregnant women. Knowledge of the scatter radiation dose from screening mammography is important because it enables health care providers to better educate women regarding the radiation risks associated with mammography.

Although direct radiation dose measurements to the breast and predicted radiation-induced breast cancers from mammography have been well documented [1, 8, 9], doses to other organs from scatter radiation have not been directly measured but have been estimated through computer simulations and the use of phantom models [10, 11]. Such measurements may not reflect the effects of variation in habitus and body mass index (BMI), which can considerably deviate from the assumed shape of the phantom. Furthermore, phantom measurements may be underestimates of radiation doses in overweight and obese women.

We used optically stimulated luminescence (OSL) dosimetry to measure the scatter radiation dose received at the skin surface overlying the thyroid gland, submandibular

gland, lens of the eye, sternum, and umbilicus (uterus) during screening mammography in a representative patient population. We also evaluated the effects of BMI and breast compression thickness. Our goal was to use the information as a framework for discussions with patients regarding scatter radiation during routine screening mammography.

Subjects and Methods

The subjects in this study were 207 women (age range, 36–90 years) without symptoms arriving for annual screening mammography who were invited to participate in the study. The study was HIPAA compliant and institutional review board approved. Informed written consent was sought and documented. Men, pregnant women, women younger than 35 years or older than 101 years, women with any breast abnormality (e.g., palpable lump, nipple discharge, breast pain), history of breast cancer, implantable defibrillator or pacemaker, indwelling catheter in the chest (ventriculoperitoneal shunt or dialysis catheter), or foreign material in the breast (including implants) were excluded from the study.

Before the routine screening mammographic examination, six OSL dosimeters (Fig. 1) were taped to the patient over the right thyroid lobe, left thyroid lobe, right submandibular gland, midline between eyes on the bridge of the nose, mid sternum, and 2 cm caudal to umbilicus (Fig. 2). The same two mammographic technologists placed the dosimeters and imaged the participants in this study. During screening mammography, the OSL dosimeters measured the skin entrance scattered radiation doses at each location. New dosimeters were used for each patient.

The detector material in OSL dosimeters is aluminum oxide crystals. These dosimeters are well suited for scatter radiation measurements because they have little angular dependence and are sensitive to energies as low as 5 keV. The accuracy is ± 10% according to the manufacturer's specifications. The lower limit of detection (LLD) of the OSL dosimetry system was 0.0335 mGy, as stated on the manufacturer's calibration certificate.

After mammograms were obtained in the four routine screening views and before acquisition of any additional views recommended by the radiologists, the OSL dosimeters were removed and stored with a control dosimeter until readout. Four breast imaging radiologists with combined experience of 58 years reviewed the mammograms and oversaw the study.

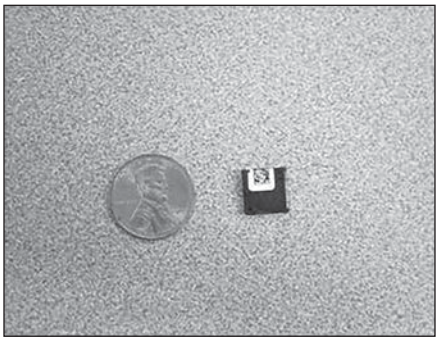

Fig. 1—Photograph shows optically stimulated luminescence (OSL) dosimeter, which is 1 × 1 cm noninvasive radiation detector.

All mammograms were obtained with the same mammography unit (Senographe Essential 2007, GE Healthcare) operated in standard automatic exposure control mode. Tube potential (peak kilovoltage) and tube current–time product (milliampere seconds); target-filter combination; and patient age, height, weight, and BMI were recorded. Breast density—an overall assessment of the volume of attenuating tissues in the breast—was described for all patients according to the standards outlined in the American College of Radiology BI-RADS, 5th edition [12]. For each mammographic projection, breast compression thickness, compression force, average glandular dose, and entrance skin exposure displayed on the mammography unit were recorded. There was no variation in the mammography unit used or mammography technologists participating in this study.

The dosimeters were analyzed on a dosimeter reader (microStar, Landauer) calibrated to an 80-kVp diagnostic x-ray beam. To account for differences in the beam calibration energy of the dosimetry system compared with the mammographic energies used in this study, a correction factor was applied to all results. To determine the correction factor, dosimeter results were compared with calibrated ion chamber readings obtained under the same exposure conditions. On each day of use, the accuracy of the dosimetry system was verified with quality control dosimeters provided by the manufacturer. Results were also adjusted for background radiation based on control dosimeter readings. These dosimeter results represented dose at the skin external to the organ of interest.

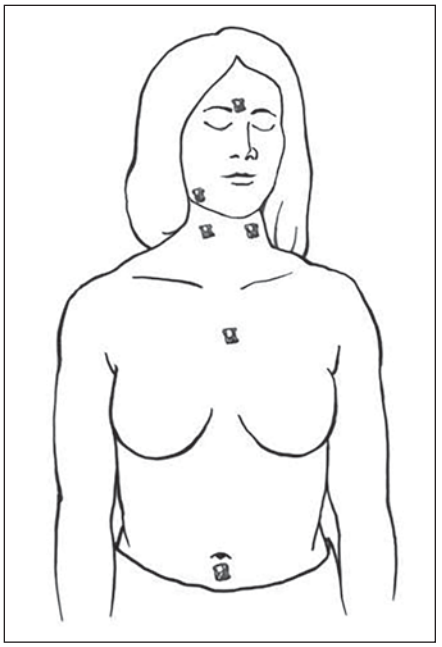

Fig. 2—Drawing shows placement of optically stimulated luminescence dosimeters.

Results

The average age of our study population was 55 years (range, 36–90 years).

Average Glandular Dose to Breast

The average tube potential in this study was 29 kVp. The average tube current–time product was 58 mAs, and the mean compression force was 8 daN (18 pounds). The average glandular dose (also referred to as mean glandular dose), which is a system-displayed average value for all mammographic views, was 1.36 mGy. The average glandular dose was less in the craniocaudal view than in the

TABLE 1: Parameters Measured for Each Mammographic View

View	Average Glandular Dose (mGy)	Entrance Skin Exposure (mGy)	Compression Thickness (mm)	Tube Potential (kVp)	Tube Current–Time Product (mAs)	Compression Force (daN)
Right craniocaudal	1.29 (0.47, 2.11)	5.87 (2.87, 11.71)	58 (27, 89)	29 (26, 31)	55 (35, 100)	8 (3, 15)
Right mediolateral oblique	1.44 (0.85, 3.28)	7.08 (3.00, 20.15)	62 (28, 94)	30 (26, 31)	62 (38, 173)	8 (4, 15)
Left craniocaudal	1.29 (0.83, 6.07)	5.94 (2.80, 12.30)	59 (24, 89)	29.2 (26, 31)	55 (36, 105)	8 (3, 14)
Left mediolateral oblique	1.42 (0.96, 2.79)	7.06 (2.68, 18.62)	63 (26, 98)	30 (26, 36)	62 (36, 150)	9 (4, 16)

Note—Values are averages with minimum and maximum in parentheses.

mediolateral oblique view. Other parameters, including entrance skin dose, breast compression thickness, tube potential, tube current–time product, and compression force reported on the equipment are detailed in Table 1 for each mammographic projection.

Scatter Radiation Dose Measurements

The average scatter radiation dose, minimum dose, and maximum dose to the skin overlying the thyroid gland, salivary glands, bridge of nose, sternum, and umbilicus are listed in Table 2.

Umbilicus

The umbilicus was chosen as the site for estimating relative exposure of the uterus during mammography. Measurements were below the LLD of the dosimeter in 195 of 207 patients. Therefore, the scatter radiation dose to the skin overlying the uterus was too low to report with any statistical confidence. The average dosimeter reading for the umbilicus OSL was 0.011 mGy.

Thyroid

Dosimeters taped over the thyroid were used to estimate exposure of the thyroid gland. All individual skin measurements for the thyroid glands were above the LLD of the dosimeters. The average scatter radiation doses to the skin overlying the right and left thyroid lobes were 0.24 and 0.25 mGy.

Salivary Gland

Dosimeters placed over the submandibular gland were used to estimate scatter radiation received by the salivary glands. One measurement for the salivary gland from one patient was below the LLD. All other individual entrance skin measurements for the salivary gland were above the LLD of the dosimeters. The average scatter radiation dose to the skin at the salivary glands was 0.2 mGy.

Sternum

Dosimeters placed over the sternomanubrial junction were used to estimate scatter radiation received by the sternum. All individual entrance skin measurements for the sternum were above the LLD of the dosimeters. The average scatter radiation dose to the skin overlying the sternum was 0.87 mGy.

Bridge of Nose

Dosimeters taped to the bridge of the nose were used to estimate scatter radiation dose to the lens of the eye. Individual skin dose measurements were below the LLD of the dosimeters in 151 of 207 patients. Therefore the scatter radiation dose to the skin at the bridge of the nose was too low to report with any statistical confidence. The average dosimeter reading for the other patients was 0.025 mGy.

TABLE 2: Dose From Scatter Radiation to Skin Overlying Organs of Interest

Organ	Average Dose (mGy)	Minimum Dose (mGy)	Maximum Dose (mGy)	SD (mGy)	Average Skin Dose as Percentage of Average Entrance Skin Exposure for All Views
Bridge of nose	0.025	< 0.0335	0.121	0.023	0.39
Right salivary gland	0.2	< 0.0335	0.7	0.103	3.1
Right thyroid lobe	0.24	0.05	0.82	0.113	3.70
Left thyroid lobe	0.25	0.06	0.73	0.116	3.80
Sternum	0.87	0.078	2.445	0.311	13.50
Umbilicus	0.011	< 0.0335	0.125	0.016	0.17

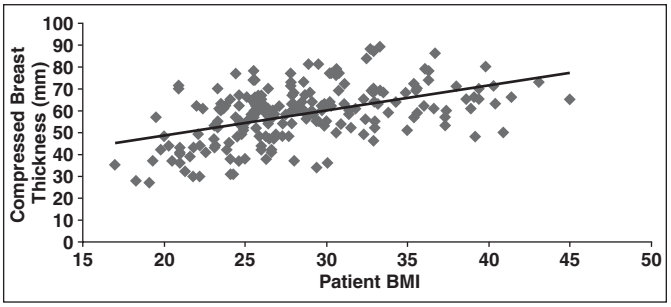

Fig. 3—Scatterplot shows compressed breast thickness increased linearly with body mass index (BMI).

Breast Compression Thickness

The average breast compression thickness in our study was 62 mm for all views. Compression thickness was 20–39 mm in 9% of women, 40–59 mm in 37%, 60–79 mm in 50%, and greater than 80 mm in 4%. Breast compression thickness increased linearly with BMI (Fig. 3). Scatter radiation dose increased linearly with increasing breast compression thickness. Figure 4 shows the scattered radiation dose to the skin measured at each location for the right craniocaudal view. Similar results were observed for the left craniocaudal and right and left mediolateral oblique views.

Body Mass Index

The average height of our representative patient population was 162.3 cm (range, 147–177 cm), and the average weight was 74.7 kg (range, 45.3–114.2 kg). The average calculated BMI was 28.3 (minimum, 17; maximum, 45). According to criteria from the U.S. Centers for Disease Control and Prevention, 33% of patients were obese (BMI > 30), 40% were overweight (BMI, 25–29.9), 27% were of normal weight (BMI, 18.5–24.9), and 1% were underweight (BMI < 18.5). The measured scatter radiation dose increased linearly with BMI (Fig. 5). Patients with fatty breast density had the highest BMI, and patients with extremely dense breasts had the lowest BMI on average (Fig. 6).

Discussion

Knowledge of radiation safety during an imaging study is of great interest to radiologists, referring physicians, and patients. The magnitude of the risks from low doses of radiation is one of the central questions in radiologic protection and is relevant when discussing the justification for diagnostic medical exposures [6, 10, 13–24]

In previous studies, investigators estimated the organ dose of scatter radiation by evaluating doses obtained from tissue-equivalent anthropomorphic phantoms simulating the human body of a woman undergoing mammography [10]. We measured scatter radiation skin entrance dose by using dosimeters placed on the skin of a representative population of women. We focused on tissues that have greater susceptibility to radiation effects, including the lens of the eye, thyroid and salivary glands, and bone marrow (sternum) [17, 25].

Direct exposure of a fetus to radiation occurs when the fetus is located within the field being imaged; indirect exposure is due to scattered radiation from maternal tissues

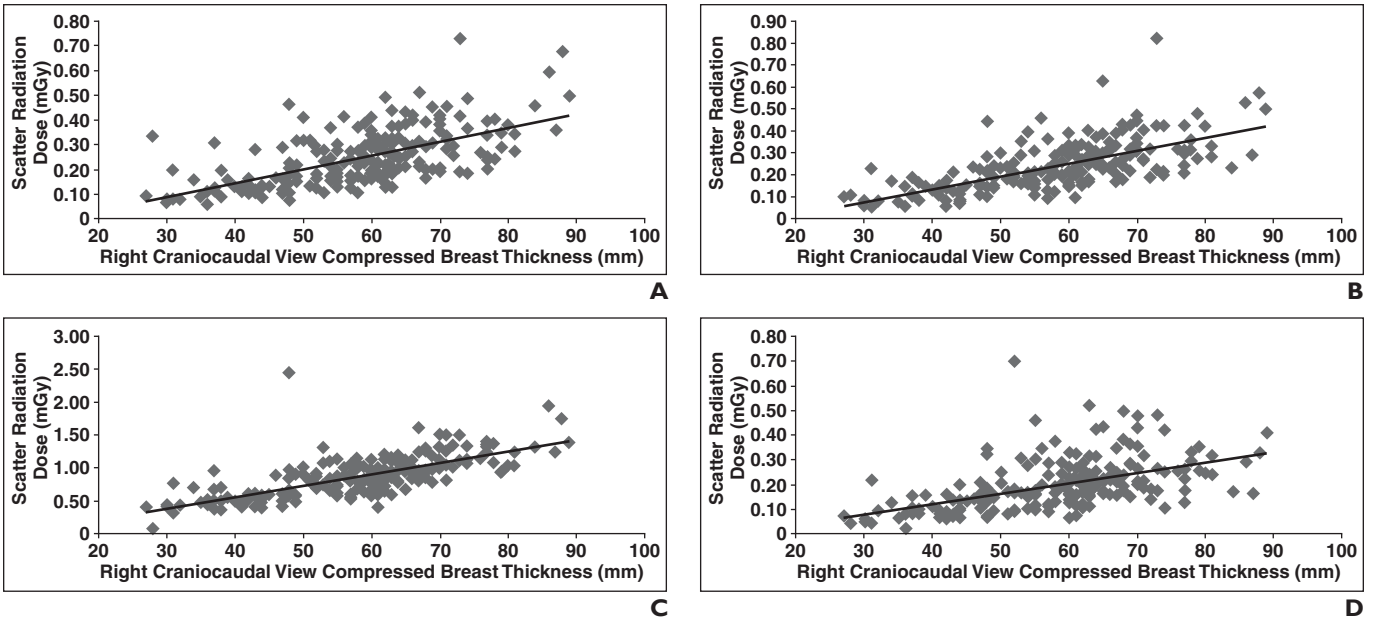

Fig. 4—Scatterplots show entrance skin doses for left (**A**) and right (**B**) lobes of thyroid gland, sternum (**C**), and salivary gland (**D**) during craniocaudal compression of right breast.

[26]. When the uterus is positioned outside the FOV, as in mammography, the fetus is exposed to scatter radiation only, and the dose is minimal. In mammography, the overall glandular and scatter doses both depend on the thickness of the imaged breast, which influences the required radiographic technique and subsequent scatter radiation [19]. As a result, the scatter radiation dose received by the fetus depends on the overall thickness and density of the breast tissue and on the distance between the fetus and the breast [19]. In our study, the scatter radiation dose at the skin surface overlying the uterus, as evaluated with an OSL placed at the umbilicus, could not be measured accurately because it was below the LLD of the OSL. This suggests that should mammography be necessary during pregnancy, the fetal dose is near zero because the average entrance skin dose was below detectable limits.

The recommendations from the National Council on Radiation Protection and Measurements state that the risk of fetal abnormality from radiation doses less than 50 mGy is negligible [19, 27–30]. The dose to the fetus from naturally occurring background radiation is approximately 0.5–1 mSv for the entire period of gestation [7, 31], whereas the average naturally occurring background effective radiation dose to a person is 3 mSv per year [7].

Imaging of pregnant women or women who may be pregnant presents challenges to breast imagers and can cause high levels of anxiety in women because of the concern about radiation to the fetus [7]. Many women are exposed to radiation from diagnostic imaging procedures before they know they are pregnant [26]. Pregnant patients and women who may be pregnant often question the potential effects of radiation exposure and may perceive the teratogenic risk of the test as high [7, 26, 32, 33]. Radiologists and other clinicians may also have unrealistic misperceptions about the harmful effects of fetal radiation exposure and overestimate the teratogenic effects associated with diagnostic radiation [26, 34–36]. When fetal risks are minimal and if a radiologic examination is thought to provide important diagnostic information, it should not be withheld from a pregnant woman [19]. An evidence-based, informed approach to counseling these patients can minimize the anxiety felt by both patients and health care providers.

The thyroid gland is not considered radiosensitive in the age group undergoing mammography [10, 15]. Sechopoulos and Hendrick [14] estimated that the maximum average dose to the thyroid from bilateral two-view digital mammography was 3.3 μGy (0.0033 mGy). They accounted for the fact that exposure of each breast results in scattered radiation to the thyroid. They estimated that the lifetime risk of thyroid cancer induction due to a single screening examination (consisting of bilateral two-view mammography of a 40-year-old woman) was 6 per billion (or 1 in 166 million). Yuan et al. [37] concurred in their prospective case-cohort study of more than 2 million women enrolled in the Taiwan National Health Insurance Research Database. After adjusting for age and comorbidity, they found that patients who had been exposed to radiation from mammography did not have significantly higher risk of development of thyroid and hematologic cancers. The average radiation scatter dose to the skin overlying the thyroid gland measured in our patient population, however, was slightly higher at 0.025 mGy. Although the use of a lead thyroid shield may seem a viable way to further reduce the extremely small risk of inducing thyroid cancer during mammography, it may interfere with imaging or cause artifacts that would necessitate repeat imaging of the breast. The additional risk to the patient from repeat imaging would be much greater than the additional risk reduction provided to the thyroid gland through the use of the thyroid shield.

Several salivary structures, including major salivary glands (parotid, submandibular, and sublingual glands) and minor salivary glands, line the mucosa of the oral cavity. The salivary glands are highly sensitive to radiation. Results of some studies suggest that radiation therapy can induce irreversible gland damage, possibly at doses as low as 6 Gy [38, 39]. Although the exact mechanism of radiation-induced gland destruction is unknown, it is hypothesized that radiation has direct cytotoxic

effects on salivary tissue and causes indirect changes in vascular blood flow to the gland [40, 41]. These effects result in salivary gland dysfunction that manifests as reduced salivary flow rates, reduction in saliva pH, changes in electrolyte and immunoglobulin saliva composition, and increased cariogenic mouth flora [40, 41]. The skin dose overlying the submandibular glands in our study was 0.2 mGy, well below the reported radiation doses associated with xerostomia.

Neriishi et al. [42] in 2012 examined the incidence of clinically important cataracts to address risks at low, brief radiation doses. They found that the risk of vision-impairing cataracts could be seen with lens doses less than 1 Gy, suggesting that the dose response was nearly linear. In that study, the best estimate of a threshold dose for clinically important cataracts was approximately 0.5 Gy. Our study showed that scatter radiation dose to the bridge of the nose was less than 0.0335 mGy, the LLD of the dosimeters, well below the estimated threshold.

Scatter radiation doses increased with increasing breast compression thickness as expected because thicker tissue mass generates increased scatter. In our study, the average breast compression thickness measured 5.9 cm on craniocaudal images and 6.2 cm on mediolateral oblique images, greater than reported in previous studies performed with GE Healthcare digital mammography units [9, 43, 44]. We also noted greater thickness of the compressed breast on mediolateral oblique images than on craniocaudal images (6% thicker), similar to the finding by Helvie et al. [45] that the compressed breast was 8% thicker on mediolateral oblique images.

The average glandular dose of 1.36 mGy for all views in our study was similar to that in other studies performed with GE Healthcare digital mammography units in which the mean average glandular dose was reported as 1.42 mGy [46] and 1.69 mGy [9]. Our mean compression force was 8.1 daN, which is less than the 10.22 daN for full-field digital mammography performed with GE Healthcare digital units in the study by Hendrick et al. [9].

More than one-third of adults in the United States are obese. From 2003 to 2012, the rate of obesity increased significantly among women 60 years old and older [47, 48]. The 28.3 average BMI in our study is classified as overweight according to the Centers for Disease Control and Prevention [49]. When BMI increases, compressed breast thickness increases, increasing the average glandular dose and scatter radiation dose. Scatter radiation dose measurements obtained with phantoms do not account for this variability and therefore can be underestimates of exposure. Our findings suggest that despite higher levels of scatter radiation associated with variably thick compressed breasts, most of the sites assessed for scatter radiation to the skin surface were below detectable limits (< 0.03 mGy). This finding suggests that exposure from mammography poses little risk to the patient.

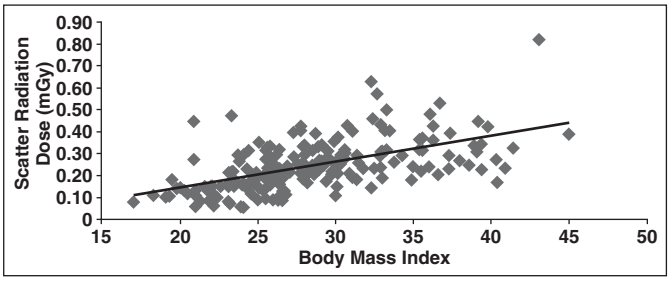

Fig. 5—Scatterplot shows average scatter radiation dose to right thyroid gland increasing as body mass index increases. Scatter radiation dose to skin overlying left thyroid gland, right salivary gland, and sternum followed same trend.

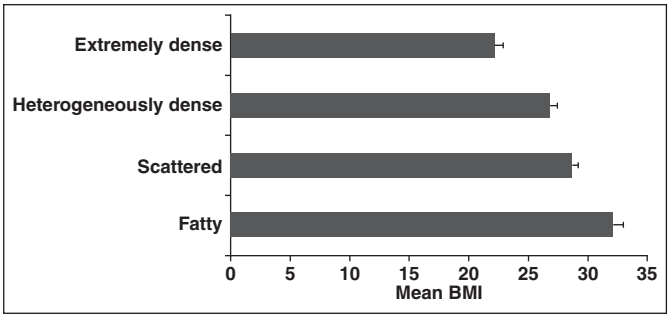

Fig. 6—Chart shows average body mass index (BMI) is highest in patients with fatty breast density. Whiskers indicate standard error of the mean.

Our dosimetry data should not be used as an exact measure of the scatter dose received by each organ but rather as a guideline for epidemiologists and radiologists reviewing patients' concerns regarding the amount of radiation exposure received during screening mammography. We measured the skin entrance dose overlying select organs of interest. The absorbed organ doses would be much lower and cannot be accurately estimated in such a varied population. One limitation of our study was that the measured scatter radiation was often below the lower limit of the detection system (including measurements at the umbilicus and lens of the eye), restricting our ability to accurately assess exposure at these sites. This is also valuable knowledge, however, because it indicates that the organ dose would be extremely small.

Effective doses from mammography, typically in the range of 0.1–0.6 mSv [8], fall below the lower limit of empiric data used to make risk estimates. Consequently, debate continues over whether the risks are actually lower than predicted from the classic linear, nonthreshold model. Even if the risk coefficients are accurate, the probability is extremely low that we could ever detect radiation-attributable breast cancers considering the background level of such cancers. Finally, because our institution has mammography units from only one vendor, the scatter radiation dose estimates for different manufacturers and models are unknown and may vary somewhat from our calculations.

Conclusion

Among a representative patient population, the scatter radiation entrance dose to the salivary glands, thyroid, lens of eye, and uterus from a screening mammographic examination is a small fraction of the entrance skin dose to the breast. The low levels of scatter radiation measured in our study do not support delaying mammography during early pregnancy when clinically indicated. Knowledge of the scatter radiation dose from screening mammography is valuable in counseling patients, who may be concerned about the effects of radiation exposure from an annual screening study, or for women who may be pregnant (recognized or unrecognized) during the mammographic examination.

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References

1. Yaffe MJ, Mainprize JG. Risk of radiation-induced breast cancer from mammographic screening. *Radiology* 2011; 258:98–105
2. Ahmed NU, Fort J, Malin A, Hargreaves M. Barriers to mammography screening in a managed care population. *Public Adm Manag* 2009; 13:7–39
3. Wong CS, Huang B, Sin HK, et al. A questionnaire study assessing local physicians, radiologists and interns' knowledge and practice pertaining to radiation exposure related to radiological imaging. *Eur J Radiol* 2012; 81:e264–e268

4. Zhou GZ, Wong DD, Nguyen LK, Mendelson RM. Student and intern awareness of ionising radiation exposure from common diagnostic imaging procedures. *J Med Imaging Radiat Oncol* 2010; 54:17–23
5. Huda W. Effective doses to adult and pediatric patients. *Pediatr Radiol* 2002; 32:272–279
6. Sadigh G, Khan R, Kassin MT, Applegate KE. Radiation safety knowledge and perceptions among residents: a potential improvement opportunity for graduate medical education in the United States. *Acad Radiol* 2014; 21:869–878
7. Wang PI, Chong ST, Kielar AZ, et al. Imaging of pregnant and lactating patients. Part 1. Evidence-based review and recommendations. *AJR* 2012; 198:778–784
8. Mettler FA, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology* 2008; 248:254–263
9. Hendrick RE, Pisano ED, Averbukh A, et al. Comparison of acquisition parameters and breast dose in digital mammography and screen-film mammography in the American College of Radiology Imaging Network digital mammographic imaging screening trial. *AJR* 2010; 194:362–369
10. Sechopoulos I, Suryanarayanan S, Vedantham S, D'Orsi CJ, Karellas A. Radiation dose to organs and tissues from mammography: Monte Carlo and phantom study. *Radiology* 2008; 246:434–443
11. Eklund S, Thilander A, Leitz W, Mattsson S. The impact of anatomic variations on absorbed radiation doses in mammography. *Radiat Prot Dosimetry* 1993; 49:167–170
12. D'Orsi CJ, Sickles EA, Mendelson EB, Morris EA, et al. *ACR BI-RADS Atlas, Breast Imaging Reporting and Data System*. Reston, VA: American College of Radiology, 2013
13. Wall BF, Kendall GM, Edwards AA, Bouffler S, Muirhead CR, Meara JR. What are the risks from medical x-rays and other low dose radiation? *Br J Radiol* 2006; 79:285–294
14. Sechopoulos I, Hendrick RE. Mammography and the risk of thyroid cancer. *AJR* 2012; 198:705–707
15. Ron E, Lubin JH, Shore RE, et al. Thyroid cancer after exposure to external radiation: a pooled analysis of seven studies. *Radiat Res* 2012; 178:AV43–AV60
16. American College of Radiology. ACR practice guideline for imaging pregnant or potentially pregnant adolescents and women with ionizing radiation. Resolution 26. In: *Practice guidelines and technical standards*. Reston, VA: American College of Radiology, 2008
17. Mettler FA. Medical effects and risks of exposure to ionising radiation. *J Radiol Prot* 2012; 32:N9–N13
18. Wall BF. Ionising radiation exposure of the population of the United States: NCRP report no. 160. *Radiat Prot Dosimetry* 2009; 136:136–138
19. McCollough CH, Schueler BA, Atwell TD, et al. Radiation exposure and pregnancy: when should we be concerned? *RadioGraphics* 2007; 27:909–917; discussion, 917–918
20. Judge MA, Keavey E, Phelan N. Scatter radiation intensities around full-field digital mammography units. *Br J Radiol* 2013; 86:20120130
21. Hendrick RE. Radiation doses and cancer risks from breast imaging studies. *Radiology* 2010; 257:246–253
22. Hatziioannou KA, Psarrakos K, Molyvda-Athanasopoulou E, et al. Dosimetric considerations in mammography. *Eur Radiol* 2000; 10:1193–1196
23. Brink JA, Amis ES Jr. Image Wisely: a campaign to increase awareness about adult radiation protection. *Radiology* 2010; 257:601–602
24. Bosmans H, Marshall N. Radiation doses and risks associated with mammographic screening. *Curr Radiol Rep* 2013; 1:30–38
25. Valentin J; International Commission on Radiological Protection. *The 2007 recommendations of the International Commission on Radiological Protection*. Oxford, UK: Elsevier, 2007
26. Ratnapalan S, Bentur Y, Koren G. "Doctor, will that x-ray harm my unborn child?" *CMAJ* 2008; 179:1293–1296
27. Berlin L. Radiation exposure and the pregnant patient. *AJR* 1996; 167:1377–1379
28. Swartz HM, Reichling BA. Hazards of radiation exposure for pregnant women. *JAMA* 1978; 239:1907–1908
29. Perisinakis K, Damilakis J, Vagios E, Gourtsoyiannis N. Embryo depth during the first trimester: data required for embryo dosimetry. *Invest Radiol* 1999; 34:449–454
30. International Commission on Radiological Protection. Pregnancy and medical radiation. *Ann ICRP* 2000; 30:1–43
31. Wagner LK, Lester RG, Saldana LR. *Exposure of the pregnant patient to diagnostic radiations: a guide to medical management*. Philadelphia, PA: Lippincott Williams & Wilkins, 1985
32. Bentur Y, Horlatsch N, Koren G. Exposure to ionizing radiation during pregnancy: perception of teratogenic risk and outcome. *Teratology* 1991; 43:109–112
33. Fink D, Glick S. Misinformation among physicians about dangers of fetal x-ray exposure [in Hebrew]. *Harefuah* 1993; 124:717–719, 739
34. Ratnapalan S, Bona N, Chandra K, Koren G. Physicians' perceptions of teratogenic risk associated with radiography and CT during early pregnancy. *AJR* 2004; 182:1107–1109
35. Shiralkar S, Rennie A, Snow M, Galland R, Lewis M, Gower-Thomas K. Doctors' knowledge of radiation exposure: questionnaire study. *BMJ* 2003; 327:371–372
36. El-Khoury GY, Madsen MT, Blake ME, Yankowitz J. A new pregnancy policy for a new era. *AJR* 2003; 181:335–340
37. Yuan MK, Chang SC, Hsu LC, Pan PJ, Huang CC, Leu HB. Mammography and the risk of thyroid and hematological cancers: a nationwide population-based study. *Breast J* 2014; 20:496–501
38. Seikaly H, Jha N, McGaw T, Coulter L, Liu R, Oldring D. Submandibular gland transfer: a new method of preventing radiation-induced xerostomia. *Laryngoscope* 2001; 111:347–352
39. Wescott WB, Mira JG, Starcke EN, Shannon I, Thornby JI. Alterations in whole saliva flow rate induced by fractionated radiotherapy. *AJR* 1978; 130:145–149
40. Chambers MS, Garden AS, Kies MS, Martin JW. Radiation-induced xerostomia in patients with head and neck cancer: pathogenesis, impact on quality of life, and management. *Head Neck* 2004; 26:796–807
41. Reddy SP, Leman CR, Marks JE, Emami B. Parotid-sparing irradiation for cancer of the oral cavity: maintenance of oral nutrition and body weight by preserving parotid function. *Am J Clin Oncol* 2001; 24:341–346
42. Neriishi K, Nakashima E, Akahoshi M, et al. Radiation dose and cataract surgery incidence in atomic bomb survivors, 1986–2005. *Radiology* 2012; 265:167–174
43. Sechopoulos I, Suryanarayanan S, Vedantham S, D'Orsi C, Karellas A. Computation of the glandular radiation dose in digital tomosynthesis of the breast. *Med Phys* 2007; 34:221–232
44. Sechopoulos I, Suryanarayanan S, Vedantham S, D'Orsi CJ, Karellas A. Scatter radiation in digital tomosynthesis of the breast. *Med Phys* 2007; 34:564–576
45. Helvie MA, Chan HP, Adler DD, Boyd PG. Breast thickness in routine mammograms: effect on image quality and radiation dose. *AJR* 1994; 163:1371–1374
46. Geeraert N, Klaus R, Muller S, Bloch I, Bosmans H. Breast characteristics and dosimetric data in xray mammography: a large sample survey. In: *International Conference on Radiation Protection in Medicine: setting the scene for the next decade*. Vienna, Austria: International Atomic Energy Agency, 2012:15
47. Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999–2002. *JAMA* 2004; 291:2847–2850
48. Flegal KM, Carroll MD, Kit BK, Ogden CL. Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999–2010. *JAMA* 2012; 307:491–497
49. Centers for Disease Control and Prevention website. Body mass index (BMI). www.cdc.gov/healthyweight/assessing/bmi. Accessed April 22, 2015

FOR YOUR INFORMATION

This article has been selected for *AJR* Journal Club activity. The accompanying Journal Club study guide can be found on the following page.

Study Guide

Scatter Radiation Dose From Digital Screening Mammography Measured in a Representative Patient Population

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Introduction

1. What was the clinical or research question that this study attempted to address?
2. Was the question addressed in this study clinically relevant and timely? Was an appropriate rationale provided for performing the study? Was the study based on an appropriate review of the medical literature?

Methods

3. What study design was used? What patient population was examined?
4. Did the study present a hypothesis?
5. What were the exclusion criteria? Did these exclusion criteria generate bias in this study?
6. What were the limitations of this study? Were these limitations adequately discussed?
7. Describe how the skin dose measurement techniques used in the study were standardized. Would these measurements be reproducible in another study or at another institution?

Results

8. Was the clinical or research question answered?
9. Did the study results corroborate findings from previous research?

Physics

10. Briefly review the mechanism by which ion chambers and optically stimulated luminescence dosimeters quantify dose. What limitations did these dosimeters have?

Discussion

11. How similar or dissimilar to your patients was the patient population in the study?
12. Did the study provide sufficient data to alter or reinforce your current practice pattern? Would you cite this study to clinical colleagues or to patients who express concerns relating to radiation dose?
13. How do you address patient concerns related to radiation exposure during routine medical imaging? Are the results of this study amenable to inclusion in such discussions?

Background Reading

1. Yaffe MJ, Mainprize JG. Risk of radiation-induced breast cancer from mammographic screening. *Radiology* 2011; 258:98–105
2. Hendrick RE. Radiation doses and cancer risks from breast imaging studies. *Radiology* 2010; 257:246–253
3. Wong CS, Huang B, Sin HK, Wong WL, Yiu KL, Chiu Yiu Ching YC. A questionnaire study assessing local physicians, radiologists and interns' knowledge and practice pertaining to radiation exposure related to radiological imaging. *Eur J Radiol* 2012; 81:e264–e268

*Please note that the authors of the Study Guide are distinct from those of the companion article.