The Effect of Vertical Off-Centering on Breast Dose During CT Simulation in Accelerated Partial Breast Irradiation Planning

Timmerie F Cohen, PhD, R.T.(R)(T), CMD
Jeffrey S Legg, PhD, R.T.(R)(CT)(QM)
Melanie C Dempsey, MS, R.T.(R)(T), CMD, FAAMD

Purpose To determine whether vertical off-centering during computed tomography (CT) simulation of accelerated partial breast irradiation influences breast dose.

Methods Using an adult anthropomorphic phantom, researchers placed thermoluminescent dosimeters (TLDs) in various locations and depths in the phantom's breast tissue. The phantom underwent multiple CT exposures at various table heights. Exposures were compared to the optimal midplane exposure.

Results Eighty-five TLDs were analyzed. When compared to centering at the isocenter midplane, lowering the CT scanner table increased TLD exposure by 1% to 23%. Conversely, raising the table decreased TLD exposure by 4% to 17%.

Discussion Because of breast tissue's radiosensitivity, it is important to position patients in the center of the CT bore. Lowering the CT table has the potential to increase breast dose whereas raising the table has the potential to exclude the area of interest.

Conclusion Patients undergoing accelerated partial breast irradiation often enjoy a long disease-free survival; thus, care should be taken in radiation oncology to minimize the patient's lifetime dose. Limiting CT simulation procedures in favor of nonionizing imaging studies (eg, ultrasonography) and proper CT optimization that includes properly centering patients can reduce radiation dose to breast tissue.

Ionizing radiation is used for the diagnostic imaging and treatment of disease, and its use has increased sevenfold since the 1980s. This increased use has led to additional concerns about the negative effects of ionizing radiation.[1,2] The biggest contributor to diagnostic medical radiation dose is computed tomography (CT).[3] The effective dose of CT varies significantly—by as much as 13 times across institutions—making it difficult to provide technologists and therapists with a concrete example of dose per scan. For example, CT doses can range from 2 mSv to 8 mSv.[4] Variation of effective radiation dose in CT is dependent on the various imaging techniques used, device employed, and patient body habitus. The U.S. Food and Drug Administration (FDA) states that precise CT doses for individual patients are unavailable. The FDA relies on the linear nonthreshold theory, which acknowledges uncertainty regarding the risk of adverse effects of low-dose radiation but assumes that as radiation dose increases, the risk of adverse effects also increases.[5]

In the United States, providers have little to no indication of how much radiation exposure a patient has received in his or her lifetime. The International Atomic Energy Agency researches and tests cumulative lifetime radiation dose tracking, with European countries leading the way in the work.[6] Because patient cumulative radiation dose in the United States is not typically recorded, operators of machines producing ionizing radiation should be even more careful during procedures they perform and strive to keep dose as low as reasonably achievable (ALARA).[6-8]

Literature Review

The use of CT is a mainstay in radiation oncology for simulation before radiation treatment. Radiation therapy professionals have a duty to recognize that as with diagnostic examinations, simulation procedures add to patients' lifetime radiation dose. Therapists must be cognizant of the quantity and quality of simulation procedures patients undergo. Therapists should produce acceptable CT images and pay attention to image optimization. Image optimization reduces radiation dose while producing quality images and includes minimizing scan range, setting scanning exposure parameters for corresponding body habitus, avoiding vertical off-centering, and taking advantage of tube current modulation.[6-9] The articles for the literature review were discovered by searching for the key words, *CT dose, CT optimization, high-dose-rate breast irradiation, radiation safety,* and *Image Wisely* in a comprehensive university database.

When considering patients undergoing multiple CT simulation procedures before and possibly throughout their course of treatment, patients with early-stage breast cancer were a suitable population for this investigation. High-dose-rate accelerated partial breast irradiation (APBI) is a therapeutic brachytherapy option in the treatment of limited-stage breast cancer. APBI is an acceptable treatment option for women older than 45 years with early-stage breast cancer who are candidates for lumpectomy. Selection guidelines state that candidates for APBI also must have tumors with negative tumor margins and no positive lymph nodes.[10,11]

APBI uses a catheter, usually a spherical fluid-filled balloon, surgically implanted into the lumpectomy excision cavity. A total radiation dose of 3400 cGy is typically delivered to the excision cavity. This dose is fractioned twice a day for 5 days. APBI allows for breast conservation and a shortened treatment time compared with whole breast irradiation, which is delivered in 5 or more weeks.[10,11] Correct catheter placement is essential for treatment planning and delivery. CT is used to verify the initial catheter placement before high-dose-rate delivery. The initial CT scan allows for 3-D treatment planning including determining balloon symmetry, balloon cavity conformity, and balloon-to-skin distance. CT, ultrasonography, or both are then employed daily throughout the course of treatment to verify symmetry and the volume of the catheter, because the catheter can sometimes move within the lumpectomy cavity.[10-13]

Radiation exposure is linked to the development of breast cancer.[14] Although radiation exposure is more detrimental to the developing tissues of adolescents and young women, documenting exposure to breast tissue from CT simulation procedures in patients undergoing APBI adds to the knowledge base of the radiation therapist community. Once the initial CT scan is approved, ultrasonography can be used to verify catheter placement, symmetry, and volume in place of daily CT scans, decreasing patient dose from repeated CT scans.[10,12] However, women undergoing CT simulation before or during APBI are receiving ionizing radiation from radiation oncology procedures, and their lifetime radiation dose could be significant because of past and future imaging examinations.

Fazel et al demonstrated that patient radiation doses over time can be substantial. The authors reported that women aged 60 to 64 years received a mean effective dose of 4.9 mSv ± 8.3 mSv annually.[2] In 2007, the International Commission on Radiological Protection increased the tissue weighting factor, which accounts for differences in radiosensitivity in various organs and tissues, for breast tissue from 0.05 to 0.12.[3] The Commission acknowledged that breast tissue is included in chest CT scans, but absorbed dose usually is not of interest.[1,2] When performing CT simulation before and during APBI, both breasts often are included in the scan, which exposes the disease-free breast to radiation.

Although the benefits of using CT for APBI outweigh the risks, dose reduction principles such as those promoted by the Image Wisely campaign should be applied. Developed jointly by the American College of Radiology, Radiological Society of North America, American Society of Radiologic Technologists, and the American Association of Physicists in Medicine, the Image Wisely campaign provides ordering physicians, radiologists, and technologists resources and information about reducing radiation dose.[15] The radiation oncology community can adhere to the campaign's tenets by finding ways to reduce radiation dose during the verification and simulation procedures.

Breast dose from CT scanning varies. In 2008, Parker et al placed thermoluminescent dosimeters (TLDs) in the breast tissue of an anthropomorphic phantom; the study demonstrated an average absorbed breast dose of 13.8 mGy to 20.5 mGy during diagnostic thoracic CT scans.[16] Vollmar and Kalender used the Monte Carlo measurement system to determine that an average dose to simulated breast tissue during dose reducing tube-current modulation was 0.598 mGy.[17] In 2014, Kaasalainen and colleagues demonstrated that vertically off-centering patients during CT scanning affected dose distributions. They found that when CT couches were positioned at the lowest table height, radiation doses were higher than when the couch was centered at the highest table height. In an adult phantom, relative dose was 38% higher when the table was at the lowest height.[18]

These studies show that vertical off-centering causes misoperation of the CT automatic tube current modulation system; tube current will fluctuate with distances not at the midplane or center in the CT bore. The automatic tube current modulation system is calibrated for a general patient size and area to be scanned at the center of the CT bore.[19] No research was found regarding radiation exposure levels to breast tissue during CT simulation. Because CT scanning has increased, medical professionals—including radiation oncologists, medical physicists, dosimetrists, and radiation therapists—should be aware of the radiation doses to patients during routine procedures such as CT simulation.[16-18]

The American Society for Radiation Oncology reported in 2014 that 98% of APBI patients were cancer-free 7 years after treatment.[20] Nevertheless, the stochastic effects of radiation delivered by medical imaging should be recognized and monitored. APBI patients have limited disease and high survival rates; therefore, the cumulative lifetime dose to their breasts could increase with repeated simulations to check for balloon placement and poor CT optimization.

CT has become the biggest contributor to medical radiation exposure. Radiologic technologists and therapeutic radiation science professionals should consider this when delivering radiation to patients.[21] Use of appropriate scanning methods reduces dose to sensitive normal tissues. This research focuses on a common simulation procedure used before, and often during, breast brachytherapy to determine whether vertical off-centering during simulation can influence patient breast dose.

Methods

An ATOM (Computerized Imaging Reference Systems Inc) adult anthropomorphic phantom with breast attachments was used to measure TLD exposure to radiation. The breast attachments have a volume of approximately 350 ccs and are composed of 50% glandular-equivalent and 50% adipose-equivalent material. The manufacturer-drilled holes are in predetermined locations in the breast attachments to house TLDs (see **Figure 1**). The TLD holes were placed at varying depths because of the phantom breast contour (see **Table 1**).

The phantom set-up on the CT table was consistent with department protocol for APBI patient simulation: the patient is centered in the CT bore and the lasers at the approximate midplane. The area of interest includes the thorax with both breasts. The patient is centered

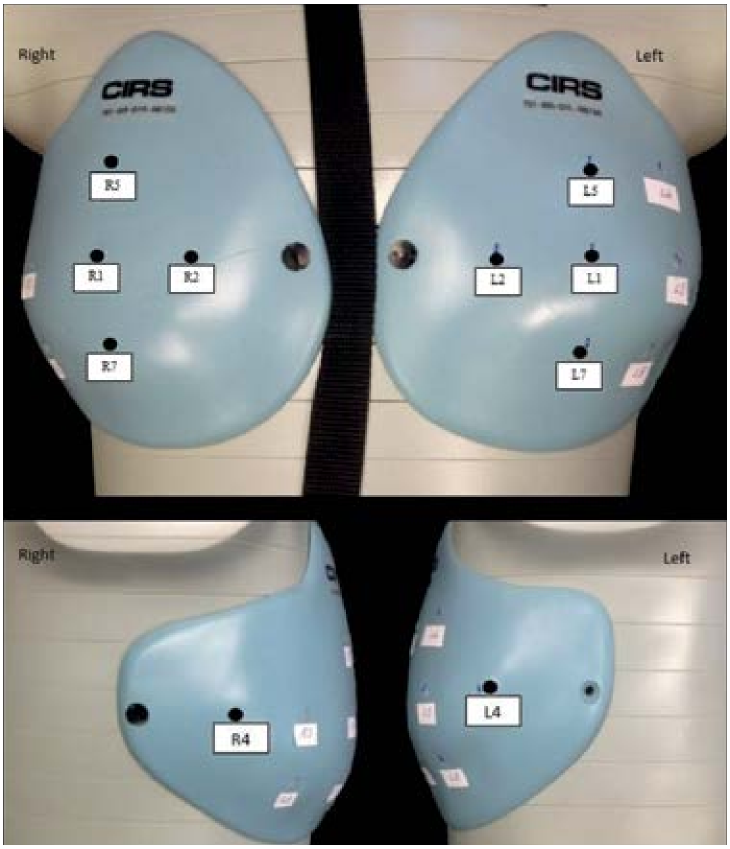

Figure 1. *ATOM adult anthropomorphic phantom with breast attachments (Computerized Imaging Reference Systems Inc, model #701-BR-350) and thermoluminescent dosimeter (TLD) locations and identifiers.*

Table 1

Depth of Thermoluminescent Dosimeter From Surface of the Phantom (in mm)

R1	9.8
R2	6.8
R4	5.9
R5	4.4
R7	12.5
L1	8.3
L2	3.9
L4	11.8
L5	4.4
L7	10.4

on the table with the sagittal laser running along the sternum.

The separation (the anterior-to-posterior thickness at the nipple line) of the phantom measured 24 cm. The phantom was marked prior to the scans, so the CT isocenter from anterior to posterior (AP) was set at a depth of 12 cm as was the posterior-to-anterior (PA) isocenter (both located at the phantom's midaxillary line). The sagittal laser was used to ensure the phantom was centered on the table right to left. The field-of-view included the phantom thorax with both phantom breasts (2 cm superior to the clavicle and 2 cm past the most inferior portion of the phantom breasts).

Nine scans were performed. In scans 1 through 3 the anthropomorphic phantom was centered to the axial midplane of the phantom (midbore in the CT scanner). The couch height (z axis) was different in scans 4 through 6 and 7 through 9. In scans 4 through 6 the couch height was lowered so that the isocenter was 3 cm anterior to the midplane, thereby placing the AP isocenter at 9 cm and the PA isocenter at 15 cm. In scans 7 through 9 the couch was raised so the isocenter was 3 cm posterior to the midplane, placing the AP isocenter at 15 cm and the PA isocenter at 9 cm. The right to left (x axis) centering and longitudinal (y axis) centering was the same for all scans; only the isocenter depth (z axis) was manipulated. Five TLDs (Thermo Scientific) were placed in each breast for each scan, for a total of 10 TLDs per scan. The right breast phantom used holes R1, R2, R4, R5, and R7. The left breast phantom used holes L1, L2, L4, L5, and L7. One TLD was placed in each location for each scan.

Exposures were made using a Brilliance CT Big Bore simulator (Philips) consistent with the standard predetermined technique for APBI patients (120 kV, 400 mAs). The field of view was set for "all scans," using digital readouts with each scan using 3-mm slices according to departmental protocol. A scout image was taken before each scan (start −513, end 852.5). The CT dose index volume ($CTDI_{vol}$), the standardized measure of dose, was 21.1 mGy for each scan.

The exposed TLDs were processed by the University of Wisconsin Radiation Calibration Laboratory. Exposure data were reported in nanocoulombs (nC), the SI unit for electrical charge. Results for this study are presented in nC (as opposed to milligray) because the effective energy of the scanner is unknown, and reporting data in milligray would lead to an increased level of uncertainty. The kilovolts were set to 120, which also is an approximate energy. The effective energy changes throughout the scanning process because of individual scanner filtration. According to Hammer, a radiation monitoring specialist from the University of Wisconsin Radiation Calibration Laboratory, "the effective energy is elusive because the effective energy deposited on each TLD is unknown" (oral communication, March 2015).

Average exposure data was gathered for each TLD site. Because the radiation safety community follows the linear nonthreshold model, the authors assumed that increasing radiation dose increases the risk of adverse effects. As a result, the authors believe assigning a statistical significance value would be problematic; therefore, means testing was not employed.

Results

Eighty-five of the 90 TLDs exposed during the scans were analyzed. Five TLDs at the following locations were damaged:

- R2 – 3 cm posterior to the phantom midplane.
- L1 – phantom midplane.
- L2 – 3 cm posterior to phantom midplane.
- L5 – phantom midplane.
- L7 – 3 cm posterior to phantom midplane.

Thus, the mean data for these locations were based on an average of 2 TLD readings while the remaining average readings were based on 3 TLD readings. **Tables 2** and **3** summarize the average exposure to the TLD in each breast for all 3 CT table heights as well as the percent change in exposure using the midplane reading as the baseline.

For example, in the right phantom breast, the average electrical charge for the R1 location at midplane was 2171.6 nC, the 3-cm anterior to phantom midplane reading was 2394.3 nC, and the 3-cm posterior to phantom midplane reading was 1966.1 nC. Comparing the R1 phantom midplane reading with the 3-cm anterior reading showed a 10% increase in the electrical charge of the TLD. The R1 phantom midplane reading was 9% less when compared with the 3-cm posterior to midplane reading (see **Figure 2**).

In the left breast phantom, the L1 midplane location had an average reading of 2004.9 nC. When the isocenter was set 3 cm anterior to midplane at L1 (2034.8 nC), the reading was 2% higher than the L1 midplane reading. The L1 3-cm posterior to midplane reading was 1757.9 nC, which was a decrease of 12% when compared with the L1 midplane reading (see **Figure 3**).

Overall, a trend appears that the exposure to the breast tissue, measured in nC, increased as the isocenter was anterior to midplane and decreased as the isocenter was posterior to midplane. Lowering the CT scanner

Table 2

Thermoluminescent Dosimeter Readings for Right Breast Phantoms

Isocenter Location	Number of TLDs	Average Electrical Charge of TLDs in nC	Percent Change in Electrical Charge Compared to Midplane (%)[a]
R1			
Midplane	3	2171.6	
3 cm anterior to midplane	3	2394.3	Increased 10
3 cm posterior to midplane	3	1966.1	Decreased 9
R2			
Midplane	3	2145.6	
3 cm anterior to midplane	3	2407.4	Increased 12
3 cm posterior to midplane	2	2065.3	Decreased 4
R4			
Midplane	3	2272.7	
3 cm anterior to midplane	3	2298.0	Increased 1
3 cm posterior to midplane	3	1902.4	Decreased 16
R5			
Midplane	3	2227.3	
3 cm anterior to midplane	3	2307.8	Increased 4
3 cm posterior to midplane	3	2082.6	Decreased 7
R7			
Midplane	3	2102.0	
3 cm anterior to midplane	3	2400.4	Increased 14
3 cm posterior to midplane	3	1942.8	Decreased 8

[a] *Percentages rounded to the nearest whole number.*

Abbreviations: nC, nanocoulombs; TLD, thermoluminescent dosimeter.

Table 3

Thermoluminescent Dosimeter Readings for Left Breast Phantoms

Isocenter Location	Number of TLDs	Average Electrical Charge of TLDs in nC	Percent Change in Electrical Charge Compared to Midplane (%)[a]
L1			
Midplane	2	2004.9	
3 cm anterior to midplane	3	2034.8	Increased 2
3 cm posterior to midplane	3	1757.9	Decreased 12
L2			
Midplane	3	2024.9	
3 cm anterior to midplane	3	2149.2	Increased 6
3 cm posterior to midplane	2	1739.7	Decreased 14
L4			
Midplane	3	1768.8	
3 cm anterior to midplane	3	1884.8	Increased 7
3 cm posterior to midplane	3	1800.5[b]	Increased 2[b]
L5			
Midplane	2	1867.2	
3 cm anterior to midplane	3	2296.7	Increased 23
3 cm posterior to midplane	3	1772.0	Decreased 5
L7			
Midplane	3	2011.9	
3 cm anterior to midplane	3	2295.1	Increased 14
3 cm posterior to midplane	2	1675.2	Decreased 17

[a] *Percentages rounded to the nearest whole number.*

[b] *Outside the observed trend.*

Abbreviations: nC, nanocoulombs; TLD, thermoluminescent dosimeter.

table 3 cm increased TLD exposure by 1% to 23% depending on their locations in the breast. Conversely, raising the table 3 cm decreased breast exposure by 4% to 17%, depending on the location of the TLD. This trend was observed for each table setting comparison excluding the L4 location, in which raising the table increased the exposure reading 2%.

Discussion

This study explored the effect of vertical off-centering during CT simulation on breast tissue exposure in APBI patients. When the table was lowered 3 cm, isocenter anterior to midplane, breast exposure increased as much as 23%. A decrease of as much as 17% in exposure occurred when the table was raised 3 cm. These findings followed the same trend as previous research by Kaasalainen and colleagues.[18]

Keeping in mind that breast tissue has a high sensitivity, radiologic technologists should avoid performing simulations on patients using a low table height to prevent increased dose to breast tissue due to misoperation of the automatic tube current modulation of the CT scanner.[1,2,16-19] However, because the breasts are located anteriorly, increasing the table height also should be avoided to ensure breasts are included in the scan even though increasing table height decreases breast dose.

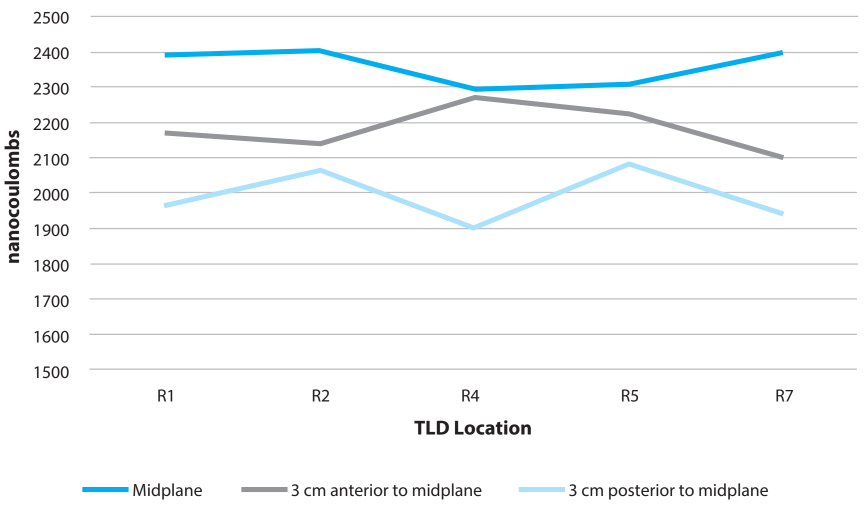

Figure 2. *Right phantom breast average TLD readings.*

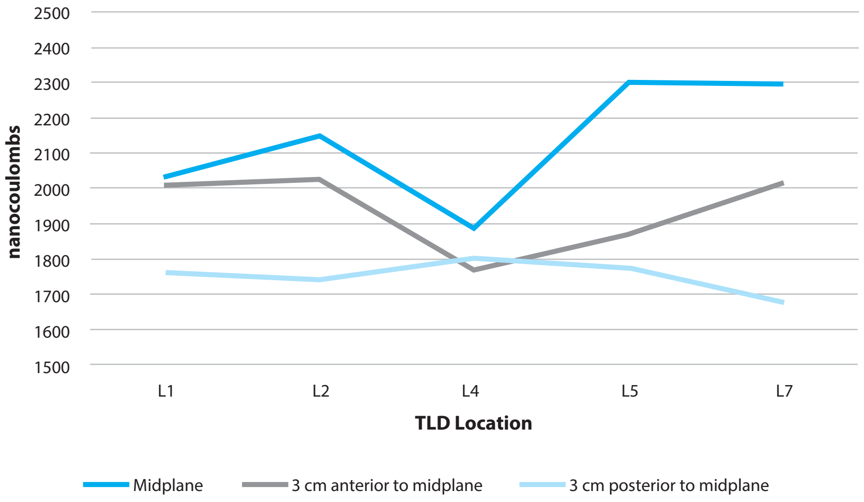

Figure 3. *Left phantom breast average TLD readings.*

Every radiation science professional, including radiation therapists performing simulation, should consider radiation protection for their patients. Imaging that uses ionizing radiation is generally in the patient's best interest, with the benefits outweighing the risks. This also is the case with APBI for the treatment of early, highly curable breast cancer. Regardless of the benefits, the stochastic effects of ionizing radiation should be acknowledged and reduced wherever possible. Even decisions that seem mundane, such as table height in a CT simulation, can affect sensitive tissues such as the breast.

Based on the results of this research, the authors recommend that radiation oncology departments ensure their CT simulators are used with proper optimization. Image optimization for APBI patients includes limiting scan range to the area of interest, avoiding vertical off-centering, and using the appropriate tube current modulation.[6-9] Setting the isocenter at midplane (approximately the midaxillary line) should be the standard of care in CT simulation to avoid increased radiation to the breast. Consideration also should be given to the subsequent use of ultrasonography to verify catheter placement in patients undergoing APBI after the initial CT scan used to verify catheter placement and to plan treatment. The Image Wisely campaign advocates "lowering the amount of radiation used in medically necessary imaging studies and eliminating unnecessary procedures."[14] Radiation dose from multiple CT scans in APBI treatment could be reduced by using ultrasonography in place of CT scans when verifying balloon placement daily.

This study has limitations. Only one type of CT simulator and one type of phantom were used. Measurements using multiple CT scanners across a variety of institutions and the use of multiple breast size phantoms would further support this research. A standard phantom cannot provide complete information regarding breast exposure because of differences in body and breast sizes. The measurement tool itself has limitations because the TLDs used have an overall uncertainty of 3.6% in their readings according to Hammer (oral communication, March 2015). Nevertheless, this study provides evidence that simulation techniques can affect radiation dose to sensitive tissues.

Conclusion

Radiation therapy simulation procedures should be conducted with the goal of producing the best images for treatment planning while limiting dose and the need for repeat examinations caused by a less than optimal patient set-up. Patients undergoing APBI for breast cancer often have long disease-free survival. However, CT scans obtained during treatment add to a patient's lifetime radiation dose. Centering APBI patients properly in the CT bore will reduce the dose to disease-free breast tissue. The radiation therapy community should be active participants in reducing patients' lifetime radiation dose by applying ALARA principles to radiation therapy simulation.

All of the authors work for Virginia Commonwealth University. Timmerie F Cohen, PhD, R.T.(R)(T), CMD, is assistant professor and clinical coordinator of radiation therapy, Department of Radiation Sciences, School of Allied Health Professions. She can be reached at tfchoen@vcu.edu.

Jeffrey S Legg, PhD, R.T.(R)(CT)(QM), is associate professor and chair of the Department of Radiation Sciences. He also is associate editor for the Americas for Radiography.

Melanie C Dempsey, MS, R.T.(R)(T), CMD, FAAMD, is program director of radiation therapy, Department of Radiation Sciences, School of Allied Health Professions. She was recently elected to Fellow of the American Association of Medical Dosimetrists.

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