Gonadal Shielding in Radiography: A Best Practice?

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Purpose To investigate radiation dose to phantom testes with and without shielding.

Methods A male anthropomorphic pelvis phantom was imaged with thermoluminescent dosimeters (TLDs) placed in the right and left detector holes corresponding to the testes. Ten exposures were made of the pelvis with and without shielding. The exposed TLDs were packaged securely and mailed to the University of Wisconsin Calibration Laboratory for reading and analysis.

Results A *t* test was calculated for the 2 exposure groups (no shield and shielded) and found to be significant, $F = 8.306$, $P < .006$. A 36.4% increase in exposure to the testes was calculated when no contact shield was used during pelvic imaging.

Discussion Using a flat contact shield during imaging of the adult male pelvis significantly reduces radiation dose to the testes.

Conclusion Regardless of the contradictions in the literature on gonadal shielding, the routine practice of shielding adult male gonads during radiographic imaging of the pelvis is a best practice.

Keywords | *gonadal shielding, pelvic imaging, radiation dose, best practice*

Minimizing patient radiation exposure during routine diagnostic imaging is a fundamental practice of radiography. Patient shielding is an important step to reduce patient radiation exposure, yet the practice of shielding patients' radiosensitive organs is inconsistent.[1-5] In addition, research suggests that improper shielding could lead to repeat exposures, further increasing the patient's radiation dose.[6] Recently, the efficacy of shielding male and female gonads has been in question.[5-9]

The risk of low-dose medical radiation exposure continues to be debated in radiology. Stochastic effects, such as cancer and hereditary diseases (ie, genetic mutations), have been associated with low-dose radiation exposure[10,11]; however, critics say that little evidence supports low-dose cancer risk.[12-14] Regardless of this debate about low-dose radiation risk, it generally is recognized that medical radiation exposure should be minimized.[15,16]

Minimizing radiation exposure to patients is emphasized throughout the radiologic technology profession's practice standards, and gonadal shielding is considered a best practice.[17,18] However, it is not routinely practiced and conflicting reports on its effectiveness have been published.[8,19] These contradictions regarding the efficacy of gonadal shielding, the profession's promotion of shielding, and the reality that shielding is not routinely practiced by radiographers prompted this investigation into the effectiveness of male gonadal shielding during pelvic radiography.

This study experimentally measured the radiation dose to the male gonads with and without shielding. Radiographers need to become more aware of gonadal shielding and its effect on patient dosimetry. Empowering radiographers, educators, and students with the knowledge of how gonadal shielding affects patient radiation dose will result in improved patient radiation safety practices.

Literature Review

A dramatic increase in radiographic imaging procedures during the past few decades has resulted in a "significant increase in the population's cumulative

exposure to ionizing radiation."[20] Concerns about low-dose radiation exposure and stochastic effects, such as cancer and hereditary diseases, continue to be investigated. The general consensus among regulatory agencies regarding radiation risk is to adhere to the linear nonthreshold dose response.[21,22] This means that the greater the exposure to ionizing radiation, the greater the potential for biologic harm. Although some would argue there is a threshold of radiation dose before biologic harm, uncertainties about the risk of low-dose radiation exposure remain.[15] Directly attributing cancer to low-dose radiation exposure has been problematic, and to date there is little evidence to support the low-dose cancer risk.[23,24] Factors such as human variability in terms of lifestyle, age at exposure, sex, weight, time since exposure, type of tissue, and the similarity of low-dose medical radiation exposure to the levels of background radiation make it difficult to link low-dose radiation exposure directly to biologic harm.[13]

Estimates about risks of low-dose exposure are extrapolated from data obtained as a result of high-dose exposure, such as animal studies and studies of the Japanese survivors of the atomic bomb.[11-13,22] Critics of the linear nonthreshold risk model believe extrapolating data from high-dose to low-dose exposures is problematic.[11-13] For example, evidence suggests that humans have defense mechanisms against low-dose exposure and might exhibit adaptive responses, such as stimulation of defenses and DNA repair.[12,14] In addition, translating data from animal studies to humans has limitations.[13] Yet, supporters of the linear nonthreshold radiation risk model maintain that "the available data on biologic mechanisms do not provide general support for the idea of a low-dose threshold or hormesis [beneficial effects]."[11]

Draper believed that "human germ-cell mutations do occur" and the lack of sensitive laboratory techniques might be the obstacle to detect mutations.[25] In its most recent publication, the International Commission on Radiological Protection verified the uncertainties about risk by acknowledging that genomic instability and bystander effects might result from low-dose radiation exposure.[26] According to Ojima et al, radiation-induced bystander effects happen when damage occurs in cells that did not directly absorb the radiation, such as double-strand breaks.[27] Kadhim and Hill suggested that these biological effects are "a consequence of cellular communication with irradiated cells."[28] Double-strand breaks are considered a significant and deleterious effect on cellular response to low doses of radiation exposure.[27] If double-strand breaks are not repaired or misrepaired, genetic changes might result.[27] In addition, genomic instability can result in heritable changes in the "progeny [offspring] of irradiated cells," thereby extending the risk of low-dose radiation exposure.[29] These heritable changes, such as "delayed gene mutations and chromosomal damage can occur many generations after the original exposure and might play a role in radiation induced cancer."[28] Because the stochastic effects of radiation exposure are cumulative, repeated low-dose radiation exposure from routine imaging has the potential for health risks.[15,23]

Research regarding risk to offspring as a result of paternal and maternal preconception radiation exposure has demonstrated contradictory results. Studies focusing on radiation exposures to patients, health care workers, nuclear workers, cancer survivors, and atomic bomb survivors have found limited evidence to support health effects to their offspring.[25,30,31] However, compelling evidence regarding spontaneous abortions, infertility, and increased risk of infant leukemia have been found in the literature and should not be discounted.[32-34]

The tissue-weighting factor (WT) is a means to specify the relative radiosensitivity of organs. The gonads have a tissue-weighting factor of 0.08, which is higher than that of organs such as the bladder, liver, and thyroid (0.04).[10,26] Because the testes are sensitive to ionizing radiation and paternal preconception radiation exposures could cause reproductive or offspring health effects, epidemiological research on animals is warranted. Giovanetti et al found long-lasting and increasing DNA damage in mice following a single exposure at 0.1 Gy (100 mGy).[35] In addition, Gong et al showed that low-dose-rate radiation exposures significantly damaged the testes and sperm.[36] Damage to the testes included a decrease in their weight, "increase in the proportion of abnormal tubules," and a decrease in the sperm count following exposure to 3.49 mGy per hour over a period of days, totaling a dose of 2 Gy.[36] Epidemiological studies involving animals provide important information regarding low-dose exposure

to the testes; however, finding direct evidence of reproductive harm in humans remains challenging. Although research on low-dose radiation exposure in humans is inconclusive, limiting radiation exposure to the gonads is an important radiation safety practice[37] and is endorsed by the American Society of Radiologic Technologist as a practice standard.[17]

For lumbar and pelvic radiographic imaging, the greatest percentage of exposure to the gonads is from scattered radiation within the irradiated tissues; however, exposure does occur from the primary beam when the gonads are in close proximity and to some extent from x-ray tube leakage and off-focus radiation.[7] Gonadal shielding is a standard practice in radiography when radiosensitive organs lie within 4 cm to 5 cm of the primary x-ray beam.[38] Two types of shields commonly used in pelvic imaging are contact shields (flat and shaped) and shadow shields, which are placed below the collimator. Both types of shields require careful positioning to eliminate interference with the anatomy of interest.[38,39] Professional standards of practice and regulatory guidelines continue to recommend gonadal shielding as one method of reducing radiation exposure to radiosensitive germ cells.[17,18,21] Although recommended as a best practice, evidence suggests that the use of routine gonadal shielding is inconsistent.

International studies on pediatric and adult male gonadal shielding during pelvic imaging have confirmed that a high percentage of patients are not shielded.[2-5] Kenny and Hill investigated pediatric patients who had received a diagnosis of slipped capital femoral epiphysis and who had multiple radiographic imaging examinations.[1] The authors found a lack of consistency in the use of gonadal shielding. Subsequent studies also found problems with gonadal shielding in boys and girls.[5,6,40] Frantzen et al reviewed 500 pelvic images in children and found that the shielding placement was incorrect on radiographs for girls in 91% of cases and in 66% of cases for boys.[6] The authors concluded that the risks of radiographic repeats due to incorrect gonadal shielding outweigh the benefits of shielding.[6] In addition, Warlow et al found inadequate gonadal shield placement in 41% of the pediatric male pelvic radiographs.[5] Although male gonadal shielding was found to be inadequate, the authors continued to recommend shielding male patients during pelvic imaging.[5]

In addition to research on the lack of consistent or proper gonadal shielding, some studies have questioned whether shielding actually reduces the dose to the gonads[6,8] because "surface shields can only protect against external scatter and leakage radiation."[7] Daniels and Furey investigated the effectiveness of surface shielding by measuring the gonadal air kerma exposure with and without shielding for a variety of kV values (60, 80, 100, and 120) and at varying distances (0-20 cm) between the gonads and the inferior edge of the primary beam. According to their findings, the radiation air kerma decreased significantly as the distance between the inferior edge of the primary field and the gonads increased, yet the authors found no difference in gonadal exposure with and without shielding.[7] For the male gonads in the anteroposterior (AP) projection, the authors estimated that 85% of the exposure was from internal scatter and a much smaller percentage was due to external radiation. Therefore, they contended that gonadal shielding had minimal effect and other dose minimizing techniques should be used, such as higher kVp and collimation.[7] Interpretation of the findings is limited because the authors reported the data as averages for the 4 kV groups (60-120); however, the greatest amount of exposure occurred when the gonads were located at the collimated edge of the x-ray beam.[7]

Similar findings by Mekis et al suggested no difference in the radiation dose to the testes when using a contact shield for the AP projection of the sacroiliac joints, and they recommended imaging them in the posteroanterior (PA) projection.[8] However, a study by Clancy et al investigated the effectiveness of gonadal shielding and found that the testes received a significantly lower exposure (42%) when shielded during AP lumbar spine imaging.[19] Clancy et al measured organ radiation exposures with thermoluminescent dosimeters (TLDs) placed in the detector holes corresponding to the phantom's testes.

Contradictions regarding the effectiveness of gonadal shielding in the literature only add to the confusion regarding the need for consistent and proper shielding as a best practice in radiography. Therefore, it is important to further investigate whether shielding actually reduces radiation exposure to the gonads. An experimental study investigating the effect of gonadal

shielding during a pelvic radiographic examination would add important data to the literature and contribute to the profession's discussion about the value of shielding as a best practice. The null hypothesis used for this investigation states that no difference is seen in the radiation dose to the testes with shielding and without shielding during radiographic pelvic imaging.

Methods

This study used an experimental design to investigate male phantom gonadal dose with and without shielding. TLDs were placed in the 2 detector holes corresponding to the area of the testes on a male anthropomorphic phantom and the pelvis was radiographed. A flat contact shield was used for shielding the phantom's testes. This type of shield was selected because it is more typically found in diagnostic x-ray rooms. The independent variable was gonadal shielding and the dependent variable was the radiation dose to the testes. Ten exposures of the AP pelvis were taken without gonadal shielding and 10 exposures with gonadal shielding. Organ radiation dose was investigated by measuring the TLDs exposure to the phantom's testes.

Equipment

An Axiom Multix M radiographic unit (Siemens Healthcare) was used to image an adult male anthropomorphic phantom. The radiographic unit allows imaging with film-screen, computed radiography, and flat panel detector image receptor technology. The flat panel detector is a mobile direct radiography (DR) image receptor that can be positioned in the table or upright Bucky units. The mobile detector is a 14-bit amorphous silicon DR image receptor sized 43 cm × 35 cm.

The anthropomorphic adult male phantom is a tissue-equivalent patient used in medical imaging and radiation therapy (Computerized Imaging Reference Systems Inc). The phantom is "manufactured to provide tissue equivalent substitutes with tolerances better than 1% for bone and soft tissue and 3% for lung tissue at photon energies from 30 keV to 20 MeV."[41] The phantom is designed with sectional slabs manufactured with holes for TLD placement in specific organs. The male phantom's pelvis was radiographically exposed with TLDs placed in the 2 detector holes corresponding to the area of the testes (see **Figure 1**). The testicular detector holes are located at a depth of 5 mm from the top surface of the phantom.

A flat contact shield was placed over the area of the phantom's testes. The 0.5-mm lead equivalent shield was tested for its ability to absorb ionizing radiation. Two exposures were made with and without the flat contact shield and the milliroentgen measured with a calibrated dosimeter (Radcal). The milliroentgen reading with the flat contact shield was reduced by 98%.

Before initiating the study, a variety of quality control tests were performed on the radiographic system, including a DR system calibration and self-test (all tests were passed), exposure reproducibility (variance < 0.05) and linearity (variance < 0.10), kilovoltage accuracy (within $\pm$ 5%), exposure timer verification (within $\pm$ 5%), and measurement of tube filtration (3.6 mm). All tests indicated the imaging system was functioning properly with adequate tube filtration.

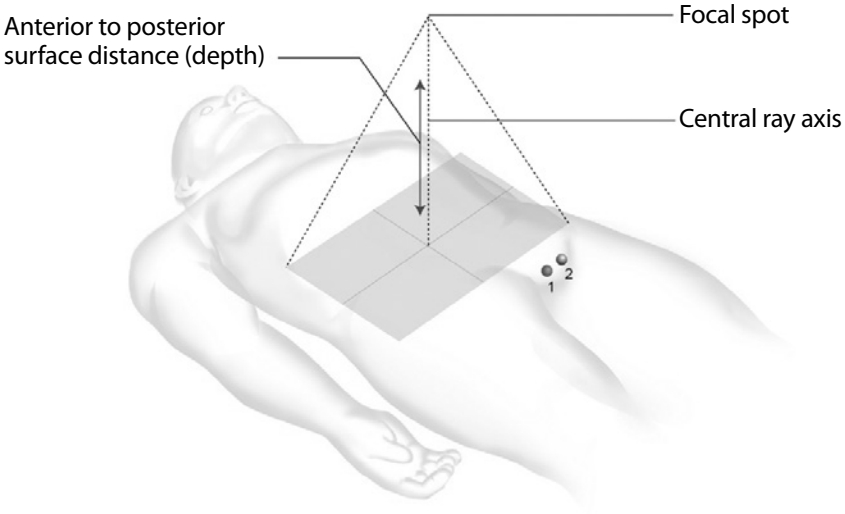

Figure 1. *Location of thermoluminescent dosimeters 1 and 2 shown within the anthropomorphic phantom. This illustration is not drawn to scale. Image courtesy of the author.*

Experiment Procedure

A DR image was produced using 81 kVp with 22 mAs to replicate a typical technique used for an AP pelvic image without gonadal shielding. The automatic exposure control device was used to determine the appropriate mAs without shielding and yielded a mAs of 22, which was used for each of the exposures for shielding and no shielding. A 40-inch (100-cm) source-to-image distance was used with a small focal spot, and the x-ray light field was collimated to 12 inch × 15.5 inch (30 cm × 38 cm) to include the pelvic anatomy. The testes were located 2 cm below the bottom edge of the collimated x-ray field light.

Ten exposures were made of the pelvis with and without shielding to provide sufficient data for statistical analysis. The flat contact shield was placed consistently at the bottom edge of the collimated x-ray field light for each of the exposures. The TLDs were placed in the right and left detector holes of the testes, exposed, and replaced for each of the 20 exposures, totaling 40 exposed TLDs. In addition, one TLD was placed on the anterior surface of the pelvis at the central ray location for each of the 10 exposures for shielding and no shielding (totaling 20 exposed TLDs) to measure air kerma at the central ray. The precise location of the central ray was marked on the phantom so the centering point was consistent. The experimental parameters were reproduced consistently for each of the 10 exposures for shielding and no shielding.

Data Analysis

The exposed TLDs were packaged securely and mailed to the University of Wisconsin Calibration Laboratory for reading and analysis. The report generated by the laboratory provided the TLD readings in milliroentgen radiation units. The central ray exposure milliroentgen values were converted to air kerma in milligray units using the 0.881 correction factor,[42] and the gonadal exposure readings were converted to microgray radiation units using the 0.90 F-factor conversion.[43]

Data were entered into SPSS 22 software (IBM) for statistical analysis. Descriptive statistics were performed to determine the mean and standard deviation of the data collected. A *t* test was calculated to determine any differences in the air kerma exposures at the central ray location for both exposure groups. In addition, the *t* test for independent means statistic was performed to determine whether significant differences existed in the gonadal dose for no shielding and shielding. The *t* test statistic was used because there were 2 groups with interval type data for both analyses.

Results

Figure 2 shows the air kerma exposures in milligray at the central ray location for the 2 groups, no shield and shielded. A *t* test was calculated and found not to be significant, $F = 1.144$, $P = .299$ (see **Table 1**). This indicates that the exposure to the pelvis for both groups was consistent. **Figure 3** shows the gonadal exposure (μGy) for the groups. A *t* test was calculated for the 2 exposure groups and found to be significant, $F = 8.306$, $P < .006$ (see **Table 2**). The average exposure to the gonads for the no shield group was 254.1 μGy (222.8-270.5) and 186.4 μGy (178.7-198.9) for the shielded group, resulting in a 36.4% increase in exposure to the testes when no contact shield was used during pelvic imaging. Therefore, the null hypothesis stating no difference is seen in radiation dose to the testes with shielding and without shielding was rejected.

Discussion

This study demonstrated that the organ radiation dose to the testes during radiographic pelvic imaging was reduced with statistical significance when using a flat contact shield. These findings conflict with the studies by Daniels and Furey and Mekis et al who believed that radiation exposure to the testes is not significantly reduced by the use of a flat contact shield.[7,8] However, the findings support the study by Clancy et al, which showed that radiation exposure to the testes can be reduced significantly when using a flat contact shield.[19]

It is important to note that the radiation exposure during pelvic imaging in this study was in the microgray range (100 μGy = 10 mrad). Although this is in the lower range of radiation exposure, little evidence of a threshold for stochastic effects following testicular radiation exposure exists.[11] The linear nonthreshold dose response remains the profession's accepted theory and, as a result, even very low radiation doses have the potential for biologic harm. Until undisputed evidence reveals that low-dose exposure has no harmful effects on the radiosensitive

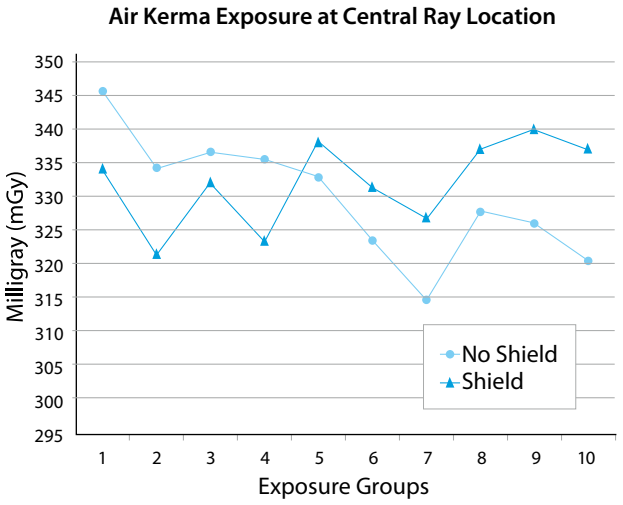

Figure 2. *Air kerma in milligray at the central ray location for no shielding and shielding groups.*

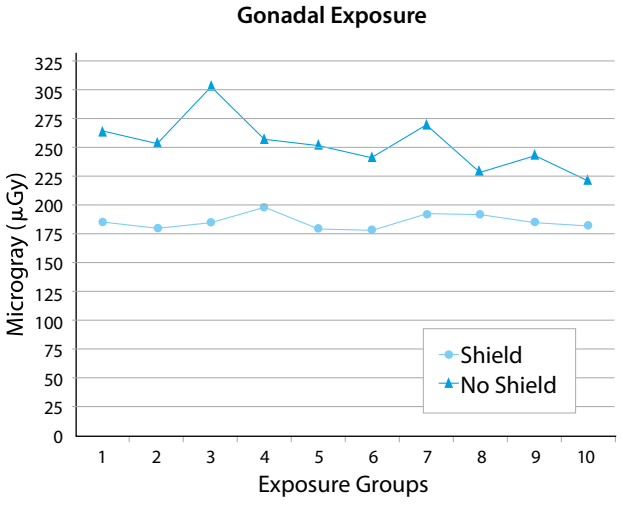

Figure 3. *Gonadal exposure in microgray for no shielding and shielding groups.*

Table 1

Air Kerma in Milligray at Central Ray Location

Exposure Groups	No Shielding	Shielding
1	345.9	334.3
2	334.3	321.7
3	336.7	332.3
4	335.7	323.4
5	333.2	338.9
6	324.0	331.8
7	314.9	327.2
8	327.9	337.4
9	326.3	340.3
10	320.7	337.3
Mean	330.0	332.5
Standard deviation	8.946	6.469
t test	F = 1.144	Significance = .299[a]

[a] > .05 and not significant.

Table 2

Gonadal Exposure in Microgray

Exposure Groups	No Shielding	Shielding
1	264.6	185.4
2	253.4	180.0
3	303.3	186.3
4	258.3	198.9
5	252.0	180.0
6	241.7	178.7
7	270.5	192.6
8	230.4	193.1
9	243.9	186.3
10	222.8	183.2
Mean	254.1	186.4
Standard deviation	22.60	7.52
t test	F = 8.306	Significance = .006[a]

[a] < .05 and significant.

testes or male reproductive health, shielding the testes during pelvic imaging should remain a best practice.

It is important to consider the findings of this study in light of its limitations. The contour and location of the testes in the phantom are fixed and might not represent the contour and location in an adult patient accurately. In addition, the decrease in absorbed dose to the phantom's testes with a flat contact shield can differ at varying kV levels. Future research investigating gonadal shielding by varying the kV/mAs levels, in addition to using a cup-type shield, could demonstrate a greater decrease in absorbed dose to the testes.

Although it is not practical to insert TLDs into a live patient, measuring gonadal dose during pelvic and lumbar imaging of cadavers would yield more realistic data.

Few studies exist regarding the attitudes of radiologic technologists about the importance of gonadal shielding and self-reported practices. MacKay et al found differences in attitudes about shielding and practices among Western Australian radiographers for age, sex, education level, and type of employment facility.[44] A large study in the United States on self-reported knowledge about the efficacy of gonadal shielding and its routine practice would provide important information on shielding as a radiation safety practice. Investigating the effectiveness of staff training on the practice of correctly shielding the gonads also would provide valuable information to encourage radiographers to use gonadal shielding routinely.

Conclusion

Using a flat contact shield during imaging of the adult male pelvis demonstrated statistically significant reduction of radiation dose to the testes. Regardless of the contradictions in the literature about the stochastic effects of low-dose radiation exposure and the efficacy of gonadal shielding, the routine practice of shielding the adult male gonads during radiographic imaging of the pelvis is a best practice. Radiographers should make considerable effort to shield the male gonads during radiography of the male pelvis.

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