Radiation exposure of Certified Registered Nurse Anesthetists during ureteroscopic procedures using fluoroscopy

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Due to the use of fluoroscopy in the operating room, Certified Registered Nurse Anesthetists (CRNAs) frequently are exposed to the dangers of radiation emitted during surgical procedures using fluoroscopy. The purposes of this research were to determine the level of radiation exposure of the CRNA during fluoroscopic procedures in the operating room and to determine whether these levels are within the limits of maximum permissible dose equivalents published in the Code of Federal Regulations (CFR).

This research was conducted in an operating room specifically designated for urological procedures using fluoroscopy. A stationary dosimeter was used to measure radiation exposure. The dosimeter was exchanged monthly for 6 months.

Data from this study confirmed that the total radiation exposure was above the limit set by the CFR for whole body radiation exposure, thus exposing the thyroid, which is typically unprotected. The data from this study also supported earlier works that suggested that the radiation to the lens of the eye is of little concern since the exposure rarely exceeds the dose limits set by the CFR.

Key words: Fluoroscopy, radiation exposure, workplace hazards.

Introduction
Anesthesia personnel are exposed to ionizing radiation when fluoroscopy is used during surgical procedures. Ionizing radiation is defined as high-energy electromagnetic waves (x-rays and gamma rays) and particulate rays that dissociate substances in their paths into ions. Ionizing radiation can cause changes in the chemical balance of cells. Some of the changes can result in cancer. In addition, by damaging the genetic material (DNA) contained in all cells of the body, ionizing radiation can cause harmful genetic mutations that can be passed on to future generations.

The ionizing radiations of primary concern are alpha and beta particles, gamma rays, and x-rays. Alpha and beta particles and gamma rays can come from natural sources or can be technologically produced. Most of the x-ray exposure is technologically produced.

Ionizing radiation affects people by depositing energy in body tissue, which can cause cell damage or cell death. In some cases, there may be no effect. In other cases, the cell may survive but become abnormal, either temporarily or permanently, or an abnormal cell may become malignant. Large doses of radiation can cause extensive cellular damage and result in death. With smaller doses, the person or irradiated organs may survive, but the cells are damaged, thus increasing the risk of cancer. The extent of the damage depends on the total amount of energy absorbed, the time period and dose rate of exposure, and the particular organ(s) exposed.
Due to the risks associated with radiation exposure, annual limits are set to help decrease these risks. The occupational dose limits are published in the Code of Federal Regulations (CFR). Radiation exposure is measured in roentgen equivalent in man (rem), which is the amount of ionizing radiation required to produce the same biological effect as 1 roentgen of high penetration x-rays. Because 1 rem is a relatively large dose, the unit actually used most frequently is the millirem (mrem), which is equivalent to 1/1000 of a rem. The rem is applicable only for occupational exposure. The Nuclear Regulatory Commission (NRC) sets the standards and regulations for protection against occupational radiation exposure. As of April 1, 1996, the annual occupational dose limits for adults were as follows:

1. 5 rem (5,000 mrem) for total body (including the thyroid).
2. 15 rem (15,000 mrem) for the lens of the eye.

Due to the amount of fluoroscopy used in the surgical arena and the distance at which Certified Registered Nurse Anesthetists (CRNAs) typically stand from the fluoroscopy machine, we were concerned about the amount of radiation exposure CRNAs receive. Few data are available on radiation exposure to CRNAs. The concerns involve the health risks associated with high levels of radiation exposure, specifically to the thyroid gland and lens of the eye. The thyroid gland and lens of the eye are delicate organs that can be damaged easily by high levels of radiation.

According to Bushong, exposure without protection to the collar region during fluoroscopy is 10 to 20 times greater than exposure to the trunk of the body, which is protected by a lead apron.

Anesthesia frequently is administered to patients undergoing surgical procedures requiring fluoroscopy. When anesthetic medications are administered, the CRNA is required to be at the anesthesia machine or at the patient's side continuously to monitor and maintain stability of the patient's condition during the procedure. The anesthesia machine is located at the head of the operating table with room for only the CRNA to stand. Therefore, CRNAs are in a position to be exposed to high amounts of primary and secondary sources of radiation during fluoroscopic procedures when they are assigned to the urology operating room suite. Although standards and recommended practices have been documented for perioperative nurses, very little documentation is available regarding the occupational radiation exposure of the CRNA.

**Ionizing versus nonionizing radiation**

Radiation is a form of energy of which there are two types: ionizing and nonionizing. For this research, ionizing radiation was considered because it includes x-rays, fluoroscopy, and radioactive implants. When the photons, or packets of radiation energy, drive electrons out of their stable orbit, ionizing radiation creates free radicals and ionized molecules in the tissue. Kole documented that radiation can modify the molecules within cells. Thus, according to LeBel, "proteins become altered, and genes may be changed so that cellular growth becomes abnormal" leading to tissue damage. The cell physiology may be altered to result in chromosomal aberrations, cell death, malignant transformation, or cellular repair.

Two sources produce radiation during fluoroscopy. The major source is the fluoroscopy machine or C arm, which emits highly concentrated amounts of ionizing radiation (direct or primary). The second source is the backscatter radiation, which results from the interactions of the primary radiation with the patient and exits from the patient in all directions. The backscatter is a major source of radiation exposure to surgical personnel, including CRNAs.

Tissues that are at highest risk of radiation exposure are the lens of the eye, thyroid gland, active or red marrow, and gonads. With the wearing of lead aprons during fluoroscopic procedures, the main concern becomes the thyroid and lens of the eye, due to the lack of shielding to these areas.

The lens of the eye is sensitive to radiation exposure. It is made up of a large amount of actively dividing cells that when exposed to radiation may become damaged; with no way to dispel the injured cells, they bunch together, forming a cataract. The CFR recommends that radiation exposure to the lens of the eye be limited to 15,000 mrem annually.

The thyroid gland is also a sensitive organ that may be affected when exposed to high levels or long-term low levels of radiation. According to Bushong and Bush et al, it is difficult to state unequivocally that the cause of thyroid cancer is radiation exposure because thyroid cancer is so prevalent. However, Bushong and Bush et al also noted that with high-dose radiation, such as with fluoroscopy, there is an increased risk of thyroid cancer. Maximal permissible radiation exposure limits for the thyroid are included in whole body occupational dose limits. The CFR recommends that whole body exposure be limited to 5,000 mrem annually.

Protective measures against external radiation sources include time, distance, and shielding. These protective measures are used primarily to reduce the dose from any external source of radiation.
Bushong and Bush et al documented that distance from the x-ray source or scatter radiation source markedly decreases radiation exposure (inverse square law). The inverse square law states that the "intensity of radiation is inversely proportional to the square of the distance of the object from the source." The dose a person receives from external radiation is directly proportional to the length of time spent in a radiation field. By minimizing the amount of time spent in a radiation field, the dose received can be minimized. Limiting the use of fluoroscopy will decrease the amount of radiation emitted during surgical procedures. Along with distance and timing, all personnel working in the area of radiation emission must be protected with shielding. Shielding is one of the most effective ways of reducing radiation exposure. By wearing lead aprons between 0.25-mm and 0.5-mm thick, dose rates can be reduced, thus reducing the dose to CRNAs who cannot reduce their exposure time or work farther away from the source. Since the whole body is covered with a lead apron, the thrust of the present research was placed on the amount of radiation exposure the thyroid receives and comparison of these data with the limits set by the CFR.

Previous studies

The only study found in the literature for radiation exposure to anesthesia personnel was a study by Henderson et al. Their purpose was to determine the level of radiation exposure of anesthesiologists in operating rooms and the cardiac catheterization laboratory. The anesthesiologists wore standard radiation safety film badges clipped to the surgical cap at the forehead to measure radiation exposure of the thyroid and the eye lens. The study was conducted during a 2-month period and included 16 anesthesiologists. The anesthesiologists were divided into 2 groups; group 1 worked in the operating room, and group 2 worked in the cardiac catheterization laboratory.

Henderson et al concluded that radiation exposure in the operating room is negligible for anesthesiologists. However, it was noted that during prolonged exposure, such as procedures in the cardiac catheterization laboratory using fluoroscopy, anesthesiologists were exposed to a substantial amount of radiation. Therefore, appropriate precautions need to be taken to prevent high radiation exposure during fluoroscopic procedures.

Bagley and Cubler-Goodman performed a study that involved a urologist, circulating nurse, and patients. The study was related mainly to shielding. It involved measuring radiation exposure to the urologist and the circulating nurse during a total of 13 ureteroscopic procedures. Dosimeters were placed at the level of the thyroid outside the lead apron and at chest level under the apron on the urologist and the nurse.

Bagley and Cubler-Goodman noted from their study that the exposure rate was clearly related to protective shielding. Although the circulating nurse was farther from the x-ray machine, the circulating nurse received the same exposure to the unprotected thyroid that the urologist did. Therefore, as Bagley and Cubler-Goodman noted, "lead shielding is essential for all personnel in the room during ureteroscopic procedures using fluoroscopy."

Materials and methods

This study was conducted to determine the level of radiation exposure for CRNAs during urology procedures using fluoroscopy. It was based on the hypothesis that although routinely protected from radiation with lead aprons, CRNAs are exposed to levels of radiation beyond the maximum permissible dose equivalents during surgical procedures using fluoroscopy.

This study was performed at a level 1 trauma center in the southeastern United States. The study was conducted in a room equipped with a stationary fluoroscopy machine that was designated specifically for ureteroscopic procedures. Radiation levels were measured only when the fluoroscopy machine was used.

Radiation exposure was measured using Landauer Dosimeter Type Gardray G film badges (R.S. Landauer Company, Glenwood, Ill). This dosimeter has a minimum reporting value of 10 mrem for x-rays and gamma rays and 40 mrem for energetic beta particles. The film dosimeter was positioned on the anesthesia machine at a height of 60 in from the floor to approximate the level of the thyroid gland of the anesthesia personnel. Individual dosimeters were not worn by the CRNAs because they are scheduled randomly to that room throughout the day.

■ Procedure. The research began on the first Monday of June and continued for 7 months, ending the last day of December; however, data are available for 6 months (see "Data analysis"). Research data were collected via film badge dosimeter. A new dosimeter was placed on the anesthesia machine the first Monday of each month during the projected time of data collection. The exposed dosimeter removed from the anesthesia machine was given to the radiology department at the hospital. The radiology department sent the film badge dosimeter by mail to R.S. Landauer Company on the 20th of each month to obtain results of the
radiation exposure for the previous month. The report was received by the hospital radiation safety officer 10 days later. After the data were collected, the results were summed and then multiplied by two to determine the average annual exposure.

Data analysis. During the data collection period, 94 fluoroscopic procedures were performed. The number of cases ranged from 12 in October to 17 each in September, November, and December (Table 1).

During data collection, the dosimeter was positioned 60 in from the floor and 64 in from the fluoroscopy machine. The CRNA typically stands at a distance of 48 in from the fluoroscopy machine, a difference of 16 in. Due to this difference, the radiation exposure had to be calculated to the distance at which the CRNA stands by using the inverse square law equation. Table 2 shows the calculation using the inverse square law to determine the actual radiation exposure to the CRNA.

The radiation exposure data revealed a wide range of radiation exposure due to the varying number of fluoroscopic procedures done per month as noted in Table 1. The mrem ranged from 190 in October to 810 in November. After making the necessary adjustments, using the inverse square law to calculate the actual radiation exposure to the CRNA, the exposure ranged from 338.20 mrem in October to 1,441.80 mrem in November (Table 3).

The NRC has established the standards for protection against ionizing radiation. Although the NRC does not isolate the thyroid gland for radiation exposure, the thyroid gland is included in the whole body exposure limits. The occupational radiation exposure limit for adults for whole body radiation exposure is 5,000 mrem per year, or an average of 416.66 mrem per month. As displayed in Table 4, the adjusted radiation exposure data collected for each month was well above this limit except for October, which was 78.46 mrem below the monthly limit. The occupational dose limit set by the NRC for the lens of the eye is 15,000 mrem per year, for a monthly average of 1,250 mrem. Table 4 illustrates that the adjusted radiation dose was less than the CFR limits except

<table>
<thead>
<tr>
<th>Month</th>
<th>Inverse square law</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>520 = 2,304 4,096</td>
<td>( l_2 = 520 \times 1.78 = 925.6 \text{ mrem} )</td>
</tr>
<tr>
<td>August</td>
<td>320 = 2,304 4,096</td>
<td>( l_2 = 320 \times 1.78 = 569.6 \text{ mrem} )</td>
</tr>
<tr>
<td>September</td>
<td>290 = 2,304 4,096</td>
<td>( l_2 = 290 \times 1.78 = 516.2 \text{ mrem} )</td>
</tr>
<tr>
<td>October</td>
<td>190 = 2,304 4,096</td>
<td>( l_2 = 190 \times 1.78 = 338.2 \text{ mrem} )</td>
</tr>
<tr>
<td>November</td>
<td>810 = 2,304 4,096</td>
<td>( l_2 = 810 \times 1.78 = 1,441.8 \text{ mrem} )</td>
</tr>
<tr>
<td>December</td>
<td>490 = 2,304 4,096</td>
<td>( l_2 = 490 \times 1.78 = 872.2 \text{ mrem} )</td>
</tr>
</tbody>
</table>
for November, for which the adjusted radiation dose was 191.8 mrem above the CFR limit set for the lens of the eye.

**Discussion**

Radiation used in medicine is the largest source of human-made radiation to which people in the United States are exposed. Most of our exposure is from diagnostic x-ray procedures. Evidence of injury due to low or moderate doses of radiation may not be detected for months or even years. The NRC considers 5,000 mrem per year acceptable for adults who are not pregnant and are older than 18 years of age because the body can repair damages at that level. For insight on effects at high levels of exposure, scientists largely depend on epidemiologic data on survivors of the atomic bomb explosion in Japan and on people receiving large doses of radiation for medical reasons.

The data obtained in the present study demonstrated the amount of radiation exposure on a monthly basis. The calculations for exposure were made assuming that the same CRNA was assigned to every fluoroscopy case in that particular room. However, urologic procedures using fluoroscopy were randomly scheduled and so were the CRNAs. Thus, the chances of a particular CRNA being subjected to high amounts of radiation is unlikely.

In the present study, distance remained the same. The distance that the dosimeter was placed for measuring radiation exposure simulated the actual place occupied by the CRNA. This distance did not change due to the way the operating room was arranged. Since the CRNA is unable to move from this point during procedures using fluoroscopy, shielding becomes an important variable.

Radiation exposure is controlled by the amount of time fluoroscopy is used. CRNAs should be aware of fluoroscopy time even though they are not in control of the duration of fluoroscopy used. The major factor of fluoroscopy time control is left to the discretion of the surgeon. The surgeon should be alert to the risks of radiation exposure and control the fluoroscopy time by using short bursts of fluoroscopy.

The lens of the eye also is exposed to radiation during procedures using fluoroscopy. During the present study, the radiation exposure for the lens of the eye was high during November. The reason for this level results from lengthy procedures, procedures using prolonged amounts of fluoroscopy, or both. The present study demonstrated high exposure for 1 month; however, the annual exposure still remained below the limits set in the CFR. We recommend that further studies be conducted to validate our findings.

**Conclusion**

While administering anesthesia during surgical procedures using fluoroscopy, the CRNA is responsible for the safety and the stable condition and recovery of the patient. CRNAs are potentially at risk for high radiation exposure during surgical procedures using fluoroscopy. Thus, CRNAs are advised to:

1. Wear wrap-around lead aprons.
2. Use thyroid protective shields.
3. Distance themselves as much as possible while caring for the anesthetized patient.
4. Wear approved eye protection that includes side shields.

Other recommendations include:

1. Each CRNA should wear a personal dosimeter that would permit individual radiation exposure readings.
2. Monitor actual fluoroscopy time during urology procedures while CRNAs wear personal dosimeters.

Following these recommendations would provide data comparing fluoroscopy time and radia-

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**Table 4. Adjusted radiation exposure compared with the Code of Federal Regulations exposure limits**

<table>
<thead>
<tr>
<th>Month</th>
<th>mrem</th>
<th>ARE</th>
<th>Total body limit</th>
<th>O/U exposed</th>
<th>Eye lens limit</th>
<th>O/U exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>520</td>
<td>925.60</td>
<td>416.66</td>
<td>+ 508.94</td>
<td>1,250</td>
<td>- 324.40</td>
</tr>
<tr>
<td>August</td>
<td>320</td>
<td>569.60</td>
<td>416.66</td>
<td>+ 152.94</td>
<td>1,250</td>
<td>- 680.40</td>
</tr>
<tr>
<td>September</td>
<td>290</td>
<td>516.20</td>
<td>416.66</td>
<td>+ 99.54</td>
<td>1,250</td>
<td>- 733.80</td>
</tr>
<tr>
<td>October</td>
<td>190</td>
<td>338.20</td>
<td>416.66</td>
<td>- 78.46</td>
<td>1,250</td>
<td>- 911.80</td>
</tr>
<tr>
<td>November</td>
<td>810</td>
<td>1,441.80</td>
<td>416.66</td>
<td>+ 1025.14</td>
<td>1,250</td>
<td>+ 191.80</td>
</tr>
<tr>
<td>December</td>
<td>490</td>
<td>872.20</td>
<td>416.66</td>
<td>+ 455.54</td>
<td>1,250</td>
<td>- 377.80</td>
</tr>
<tr>
<td>Total</td>
<td>2,620</td>
<td>4,663.60</td>
<td>2,499.96</td>
<td>+2163.64</td>
<td>7,500</td>
<td>-2,836.40</td>
</tr>
</tbody>
</table>

ARE — actual radiation exposure
O/U — over/under
mrem — millirem
tion exposure. It also would give individual radiation exposure rates according to fluoroscopy time. The use of proper lead shielding and the awareness of timing and distance will provide important protection and safety for the CRNA.

This study should be reproduced in other operating rooms during various surgical procedures using fluoroscopy. It also should be replicated in the urology operating room using personal dosimeters and measuring the fluoroscopy time whenever it is used. By studying these issues, research results could further validate the findings of this study, giving further insight and documentation regarding radiation exposure during surgical procedures using fluoroscopy.

REFERENCES

AUTHORS
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