Radiation Exposure to the Pediatric Patient During Cardiac Catheterization and Angiocardiology

Emphasis on the Thyroid Gland

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SUMMARY Thermoluminescent dosimetry was used to measure the radiation exposure to the skin, thyroid and gonads in 50 consecutive pediatric patients undergoing cardiac catheterization and angiocardiology using cine photofluorography. Average exposures were 17.1 R to the skin, 2.3 R to the thyroid and 0.1 R to the gonads. Fluoroscopy accounted for approximately 80% of the skin and thyroid exposure and cine photofluorography for 20–25%. Occasional primary-beam irradiation was the major contributor to gonad exposure. Internal scatter of the incident x-ray beam was primarily responsible for thyroid exposure, so that infants received relatively high exposures; one receiving 7.3 R. The thyroid was not frequently in the primary beam.

The significance of high radiation exposure to the thyroid, and in particular its relationship to thyroid carcinoma, are discussed. The results are compared with other series in the literature and relative exposures of cine photofluorography and serial filming are contrasted.

CARDIAC CATHETERIZATION may result in a high radiation exposure to the patient, but few studies have measured the dosage received by pediatric patients and most are incomplete.1–7 Because children are smaller and therefore have increased exposure from internal scatter, both the thyroid and gonad doses are higher in children. Children also apparently have an increased sensitivity to radiation.4 Their longer life span makes the overall consequences of radiation exposure greater than in adults, and recent work has linked radiation exposure and thyroid carcinoma.9

Martin and Olson suggested that the method of recording the angiogram contributes particularly to the thyroid dose.5 We measured the radiation exposure to the skin, thyroid and gonads in 50 consecutive pediatric patients undergoing cardiac catheterization and angiocardiology using cine photofluorography.

Material and Methods

Exposure measurements were made in 50 consecutive pediatric patients undergoing cardiac catheterization and angiocardiology in the Columbia-Presbyterian Medical Center Cardiac Catheterization Laboratory. All patients were catheterized percutaneously from the groin. The average age of the patients was 2 years; 40% were under 1 year of age. The exposures were measured using lithium fluoride thermoluminescent dosimeters (TLD-100) placed in Tygon tubing and taped to the patient (fig. 1). Individual TLD readings were obtained for each patient using the peak of the glow curve readout on a Victoreen model 2600 TLD reader. Each dosimeter was calibrated at 80 kVp (3 mm Al HVL), comparing its reading to an ionization chamber measurement. Individual calibration factors were assigned to each dosimeter and multiplied by the TLD reading to obtain patient exposure. The calibration procedure was repeated several times during the investigation to ensure reproducibility. We estimate the error in measuring the exposure to be less than 10%.

Posteroanterior fluoroscopy was performed during catheterization using a Philips 9–6-inch image intensifier with a 6:1 grid in front of the input phosphor. The output of the x-ray tube used for fluoroscopy was measured at the entrance to the patient with a Keithley 35055 dosimeter system and a 35-ml ionization chamber (table 1). The x-ray tube was approximately 100 cm from the image intensifier and about 50 cm from the patient entrance dosimeter. The circular field size at the entrance to the patient was approximately 100 cm². A variable kilovolt peak automatic brightness control was used during fluoroscopy, so no one fluoroscopic kilovolt peak was used. It varied between 60 and 90 kVp; the tube current was approximately 1.0 mA. An electronic elapsed timer was connected to the foot switch of the fluoroscopy unit to measure total fluoroscopy time for each patient.

Posteroanterior cinefluorography used the same x-ray tube and image intensifier. Simultaneous lateral cinefluorography was performed using the same type of tube and intensifier. The lateral tube was positioned 100 cm from the image intensifier and about 60
cm from the surface of the patient. The resulting circular field size was about 150 cm². Both anteroposterior and lateral cinefluorography was performed at either 50 or 80 frames/sec using 0.13–1.0 mA per frame, depending on the kilovolt peak used. A pair of Philips 1200-mA generators supplied a tube potential of 60–100 kVp to both tubes. For each patient the frame rate and kVp were recorded.

The number of cine frames was determined from a direct frame counter. The image was recorded on Kodak CFR film processed at 28°C at 150 cm/min. The cinefluorographic output was measured at the entrance to the patient for both tubes, and typical exposures (mR/frame) were obtained for the range of kilovolt peaks used (table 2). The entrance exposure to the image intensifier was approximately 25 μR/frame on the 6-inch mode.

**Table 1. Fluoroscopic Exposure Measurements**

<table>
<thead>
<tr>
<th>Tube</th>
<th>kVp</th>
<th>mA</th>
<th>Output (mR/min)</th>
<th>Half value layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
<td>1.0</td>
<td>0.67 R/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1.0</td>
<td>1.0 R/min</td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>80</td>
<td>1.0</td>
<td>1.4 R/min</td>
<td>3.2 mm Al</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>1.0</td>
<td>2.0 R/min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>1.0</td>
<td>2.5 R/min</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: PA = posteroanterior.

**Table 2. Cinefluorographic Exposure Measurements**

<table>
<thead>
<tr>
<th>Tube</th>
<th>Distance</th>
<th>kVp</th>
<th>Half value layer</th>
<th>Entrance exposure† per frame</th>
<th>Entrance exposure‡ per exam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 cm</td>
<td>80</td>
<td>0.7 mR</td>
<td>1.4 R</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1.0</td>
<td>1.0 mR</td>
<td>2.1 R</td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>50 cm</td>
<td>80</td>
<td>3.2 mm Al</td>
<td>1.6 mR</td>
<td>3.3 R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>2.1 mR</td>
<td>4.3 R</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>2.7 mR</td>
<td>5.6 R</td>
<td></td>
</tr>
</tbody>
</table>

*Using 2060 frames per examination.
†Using 80 mA 5 msec.
‡Abbreviation: PA = posteroanterior.

**Results**

The patient exposure measurements are shown in table 3. The average entrance exposure was 17.1 R, the average thyroid exposure was 2.3 R, and the average gonad exposure was 0.1 R, with a mean fluoroscopy time of 15.1 minutes. An average of 2060 cine frames per patient were taken in both anteroposterior and lateral modes. This data are presented in figure 2 as histograms.

The average entrance exposure of 17.1 R results from both fluoroscopy and cinefluorography. The relationship between fluoroscopy time and entrance exposure is shown in figure 3. The trend of this plot indicates that the entrance exposure increases as fluoroscopy time is increased.

The relative contribution of fluoroscopy and cine to the entrance exposure may be approximated mathematically. By multiplying the average number of cine frames (2060) by the average cine output, the average exposure from cine may be calculated. Although the output is a function of kilovolt peaks (table 2) and 60–100 kVp were used, most examinations were performed using approximately 80 kVp, at which the output is 1.6 mR/frame. This results in an average entrance exposure of 3.3 R from cinefluorography (20%), leaving by subtraction a fluoroscopic contribution of 13.8 R (80%) if these approximations are correct.

Multiplying the average fluoroscopic output (1.4 R/min at 80 kVp) by the average fluoroscopy time (15.1 minutes), the total fluoroscopy exposure would be 21.1 R. The disparity can be accounted for by the approximations involved and the time the heart is not in the fluoroscopy field.

The average thyroid exposure was 2.5 R although 29 patients received less than 2 R (fig. 2B). Thyroid exposure comes from both primary beam irradiation and as a consequence of internal scatter. The amount of radiation from internal scatter using cinefluorography should relate to the number of cine frames and the proximity of the heart to the thyroid. Using fluoroscopy, it should relate to the total fluoroscopic time and again to the proximity of the heart to the thyroid.

We found no relationship between the number of cine frames and the thyroid exposure, and only a coarse relationship between fluoroscopy time and thyroid exposure (fig. 4). There was a much better correlation between patient age (i.e., size) and the thyroid exposure (fig. 5). This supports our observations that the thyroid was seldom in the primary beam and that the majority of thyroid exposure is secondary to inter-
THYROID EXPOSURE/Martin et al.

Figure 2. (A) Frequency distribution of entrance exposure. (B) Frequency distribution of thyroid exposure. (C) Frequency distribution of gonad exposure.

Discussion

The investigation was undertaken to determine the radiation exposure to pediatric patients in our laboratory, where biplane cinefluorography is used.
Figure 4. Thyroid exposure as a function of fluoroscopy time.

Figure 5. Thyroid exposure as a function of patient age.
Table 4. Comparison with Results in Literature

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Type of patient</th>
<th>Recording media</th>
<th>Average fluoroscopy time (minutes)</th>
<th>Entrance Exposure</th>
<th>Thyroid Exposure</th>
<th>Gonads Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ameil et al.1 (1975)</td>
<td>Infants</td>
<td>Cine</td>
<td>12.5</td>
<td>8.3 R</td>
<td>1.5 R</td>
<td>0.125 R</td>
</tr>
<tr>
<td>Gustafsson and Mortensson2 (1976)</td>
<td>Children, infants</td>
<td>Serial film plus cine</td>
<td>12</td>
<td>—</td>
<td>0.37 R</td>
<td>—</td>
</tr>
<tr>
<td>Kaude and Svahn3 (1974)</td>
<td>Children</td>
<td>Serial film plus cine</td>
<td>16</td>
<td>—</td>
<td>—</td>
<td>0.28 R</td>
</tr>
<tr>
<td>Langmead and Wall4 (1976)</td>
<td>Children</td>
<td>Serial film plus cine</td>
<td>16.4</td>
<td>9.3 R</td>
<td>—</td>
<td>0.023 R</td>
</tr>
<tr>
<td>Martin and Olson5 (1980)</td>
<td>Infants, children</td>
<td>Serial film</td>
<td>18.5</td>
<td>29.6 R</td>
<td>7.7 R</td>
<td>0.35 R</td>
</tr>
<tr>
<td>Present study</td>
<td>Infants, children</td>
<td>Cine</td>
<td>15.1</td>
<td>17.1 R</td>
<td>2.3 R</td>
<td>0.1 R</td>
</tr>
</tbody>
</table>

almost exclusively. Our results show a wide variation in patient exposure. Table 4 is a comparison of our results with those published previously. However, only minimal information is available. The range of exposure is great; more information is needed, and clinicians should not accept these values unless their radiographic equipment and performance are similar.

The range of gonad exposures (0.01–0.66 R) supports the theory that occasional primary beam exposure during catheter insertion will heavily influence the total gonad exposure. Lead rubber shielding is of value, but the occasional high gonad dose appears to occur when catheters are held up in lumbar veins or there is some similar difficulty.

In a previous study, the average entrance exposure from serial filming was about 10.8 R, while the total entrance exposure was 29.6 R. The fluoroscopic contribution was therefore about 18.8 R, or approximately 65%. Using cinefluorography, the fluoroscopic contribution increases to 80% because the average cine exposure (3.3 R) is about one-third the exposure received from serial filming. However, one must appreciate the significance of the fluoroscopic contribution in both imaging systems, and any method of reducing the fluoroscopic exposure is valuable. Pulsed fluoroscopy with a video disc system has been suggested and appears of considerable value.

The average thyroid exposure in this study was 2.3 R, and we have observed that when using cine fluorography to record angiocardigrams, the relatively small size of the input phosphor and the use of collimation serve to keep the thyroid out of the primary beam in most patients. This is reflected in the radiation exposure to the thyroid, which is markedly decreased compared with our previous study using cut film, where the average thyroid exposure was 7.7 R. At least in our experience, primary beam irradiation of the thyroid is more common when using serial film changers because of poor collimation, and this inevitably leads to larger thyroid exposures. Cinefluorography shifts the determinant of thyroid exposure from the primary beam to internal scatter, predominantly from fluoroscopy. Because of geometrical considerations, scatter is highest in smaller infants; i.e., it is proportional to age.

Patient exposure is also directly related to the sensitivity of the image intensifier, and it is important that the entrance exposures be checked periodically. The fluoroscopic entrance exposure should be no greater than 5 R/min and adequate images are obtained at 1–2 R/min. The cine exposure should be approximately 25 μR/frame at the entrance to the 6-inch image intensifier, as recommended by the International Commission on Radiation Units and Measurements.

The significance of gonad exposure has long been realized, but the consequences of thyroid sensitivity have only recently been appreciated. Studies indicate the incidence of thyroid cancer to be 1.6–9.3 cases per million per year per rad. Assuming an average life span for our patients, the risk of developing thyroid carcinoma is about 0.7 per thousand, while the national incidence is about 0.04 per thousand, or an increase of about 20 times. Radiation-induced thyroid cancer has a low mortality; only 3–4% of the cases would be fatal.

While such a risk would appear to be acceptable, we believe that thyroid and gonad exposures can be significantly reduced by careful positioning of the incident fluoroscopic beam and proper collimation of all x-ray beams. Proper calibration of the x-ray equipment also reduces patient exposure. We also feel that cinefluorography is preferable to serial filming because of increased efficiency of the detector and the use of smaller field sizes, apart from any discussion about information content.
We know of no reports of thyroid carcinoma being associated with cardiac catheterization. Awareness of a potential association is desirable in all clinicians examining such patients.

References
7. Rowley KA: Patient exposure in cardiac catheterization and cinefluorography using the Eclair 16 mm camera at speeds up to 200 frames per second. Br J Radiol 47: 169, 1974

Radiation Exposure to the Child During Cardiac Catheterization

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SUMMARY Few data are available regarding radiation exposure to children during cardiac catheterization. Using lithium fluoride thermoluminescent dosimeters, radiation exposure was measured during precatheterization chest roentgenography, fluoroscopy (hemodynamic assessment phase of catheterization) and cineangiography in 30 infants and children, ages 3 days to 21 years. Dosimeters were placed over the eyes, thyroid, anterior chest, posterior chest, anterior abdomen, posterior abdomen and gonads.

Average absorbed chest doses were 24.5 mR during chest roentgenography, 5810 mR during catheterization fluoroscopy and 1592 mR during cineangiography. During the complete catheterization, average doses were 26 mR to the eyes, 431 mR to the thyroid area, 150 mR to the abdomen and 11 mR to the gonads.

Radiation exposure during pediatric cardiac catheterization is low to the eyes and gonads but high to the chest and thyroid area. To decrease radiation dosage we suggest (1) low pulse-rate fluoroscopy; (2) substitution of contrast echocardiography for cineangiography; (3) large-plate abdominal/gonadal shielding; (4) a selective shield for thyroid area; (5) a very small field during catheter manipulation. Minimum radiation consistent with accurate diagnosis is optimal; however, erroneous or incomplete diagnosis is more dangerous than radiation-related hazards.

THIS STUDY was intended to answer four questions relating to cardiac catheterization in children: How much radiation is the child exposed to during a routine study? What differences are there in exposure to various areas of the body? How much radiation is related to cineangiography compared with fluoroscopy? How might radiation exposure be reduced?

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Materials and Methods
Thirty infants and children chosen randomly were evaluated during clinically indicated cardiac catheterization studies between April and July 1979. Age ranged from 3 days to 21 years (table 1). Fourteen had left-to-right shunts, 10 had cyanotic congenital heart disease, four had right- or left-heart obstruction, one had Ebstein’s anomaly, and one child had no significant heart disease. Balloon septostomy was performed in two neonates.

Lithium fluoride thermoluminescent dosimeters (TLDs) were applied to the body during precatheterization chest roentgenography, during the hemodynamic assessment (fluoroscopy) phase of cardiac catheterization and during cineangiography. The TLDs, $0.3 \times 0.3 \times 0.09$-mm chips of high-sensitivity
Radiation exposure to the pediatric patient during cardiac catheterization and angiocardiography. Emphasis on the thyroid gland.

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