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Radiation Exposure to the Operator Performing Cardiac Angiography With U-Arm Systems

STEPHEN BALTER, PH.D., F. MASON SONES, JR., M.D., AND RUSSELL BRANCATO, M.D.

SUMMARY We measured the radiation exposure received by a group of operators performing 700 coronary angiograms. All studies were performed using the brachial artery approach and the Philips Cardio Diagnost. Nineteen sites were monitored on each operator, using lithium fluoride thermoluminescent dosimeters. Four hundred examinations were performed with a table-mounted protective shield in place. Three hundred were performed without the shield. The average exposures (in mR per study) with and without the shield were 1.9/6 for the eyes and 1.4/8.3 for the thyroid.

The resulting operator exposure with the shield in place is low enough so that an operator performing 25 procedures per week on a continuous basis will not exceed the recommendations of the National Commission on Radiological Protection and Units. We therefore strongly recommend the use of a properly designed and appropriately positioned shield with all U-arm systems.

SEVERAL INVESTIGATORS HAVE STUDIED the radiation doses received by physicians performing cardiac angiography.1-4 The ten-fold differences in reported exposure to the lens of the eye, the thyroid and the hands cannot be explained by a simple analysis of the literature. If the highest reported exposures are generally true (Malsky's report of 30-38 mR to the thyroid/procedure), operators would be limited to the performance of only a few procedures in any week. If the lowest reported exposures are generally true, the operator's permissible workload is essentially unlimited.

The organs of special interest when considering the radiation doses received by angiographers include the lens of the eye and the thyroid (these organs are not shielded by the typical lead apron). Exposure of the trunk is not as important with the universal use of adequate lead aprons. Exposure of the extremities to scattered radiation is of secondary importance due to less radiation sensitivity in these areas.5-8

Methods

Because of the wide differences in operator exposure reported in the literature, we repeated the measurements under controlled conditions, with a minimum number of variables. The clinical studies were all performed using a dedicated U-arm cardiac angiography system (Philips Cardio Diagnost). This apparatus is shown in figure 1. The major variable was the presence or absence of the table-mounted operator's protective shield. This shield is shown in place in figure 1. Figure 2 shows a close-up of the shield before the application of sterile drapes. The second significant variable was the nature of the medical problems encountered and the nature of the manner in which they were approached.

Further technical information on the apparatus and its operation are given in table 1. The experiment was divided into seven series of 100 consecutive adult examinations each. The first three

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Received April 3, 1978; revision accepted June 22, 1978.
TABLE 1. Equipment Characteristics

<table>
<thead>
<tr>
<th>Equipment Characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips Cardio Diagnost U-arm rotates from 60° LAO to 60° RAO.</td>
<td></td>
</tr>
<tr>
<td>Fixed 73 cm (29-inch) focal spot to input screen distance.</td>
<td></td>
</tr>
<tr>
<td>Fixed collimator provides 9 cm × 12 cm rectangular field at input screen.</td>
<td></td>
</tr>
<tr>
<td>Fixed tube current (m amp). Fixed cine pulse width.</td>
<td></td>
</tr>
<tr>
<td>Variable high voltage to automatically control brightness level.</td>
<td></td>
</tr>
<tr>
<td>Cesium iodide image intensifier 15 cm (6-inch) input screen.</td>
<td></td>
</tr>
<tr>
<td>35 mm cine at 30 frames/sec.</td>
<td></td>
</tr>
</tbody>
</table>

series were run, four months later, in the same three rooms at the Cleveland Clinic. Protective shields were used for these final three series. In all seven series, the goal was to monitor 100 consecutive examinations; this goal was met for five series. The St. Joseph's Hospital series resulted in 104 monitored examinations. One of the Cleveland Clinic series performed with the shield in place resulted in only 99 monitored examinations.

Patient data was logged for each examination (height, weight and chest diameters). Elapsed fluoroscopic and cineradiographic times were recorded by meters installed on the equipment.

Radiation dosimetry was performed with Lithium-fluoride chips (TLD-100 extruded rod 3 mm × 3 mm × 0.9 mm). Dosimeters, selected for uniform response, were obtained in two batches from Harshaw Chemical, Inc. Dosimeters from batch 1 were used for the first four series. Dosimeters from batch 2 were

Figure 1. Cardio Diagnost with protective shield in position on cart.

Figure 2. Protective shield and arm board before draping.
used for the final three series. A single set of dosimeters was used to integrate the cumulative exposure to the operators during each series of 100 examinations.

There were 19 sites investigated during each series. The locations of these sites are shown in figure 3. Three dosimeter chips, packaged in a black polyethylene pouch and sealed with Scotch Magic Tape, were placed at each site. The five dosimeter sets used to measure the exposure around the eyes were taped to the outside of the soft plastic goggles with Scotch Plastic Tape. The dosimeter sets used to measure exposure to the hands were attached to leather wrist bands, using the same material. The remaining dosimeter sets were fastened to the surfaces of lead aprons. The Cleveland Clinic aprons were 0.5 mm lead equivalent and the St. Joseph's Hospital apron was 0.75 mm lead equivalent. Identically packaged control dosimeters were used in the conventional manner.

Since the Cardio Diagnost is completely controlled by a single operator, only the operator was monitored. In routine practice, no other person in the laboratory works within 3 m of the x-ray source.

All examinations were performed using the brachial artery approach to the coronary arteries, left ventricle, left atrium and bypass grafts. Right heart catheterization was performed via the median basilic vein.

All of the examinations performed at the St. Joseph's Hospital were done by one of the investigators. The examinations performed at the Cleveland Clinic were done by 11 staff physicians and 24 members of the fellowship staff of the Department of Cardiology. Twenty-three percent of these cases were performed jointly by a staff physician with a member of the fellowship staff. For these cases, the dosimetry equipment was transferred from one operator to the other during the examination. Fluoroscopic times and cineradiographic times were recorded for each. The sum of these are equal to the total procedure times used in the following discussion. A series of calibration dosimeters (packaged identically to the measuring dosimeters) from each of the two batches were given a graded series of known exposures by the Memorial Sloan-Kettering Cancer Center. Each batch of calibration dosimeters was irradiated during the midportion of each of the two Cleveland Clinic runs. For the first Cleveland Clinic run, one dosimeter (in each package of three) per site was read by Harshaw; the remaining two dosimeters per site were read by Memorial. For the second Cleveland Clinic run, one dosimeter per site was again read by Harshaw, and the remaining dosimeters were read by one of the investigators. The entire set of dosimeters from the St. Joseph's series was read by the investigators. Mean agreement between Harshaw and Memorial was within 7%. Mean agreement between Harshaw and our readings was within 15%.

**Results**

The exposure as measured at each of the 19 sites is given in table 2. For each site we have indicated the mean exposure, the range of measured exposures, and a probable maximum exposure. The Cleveland Clinic entries represent nine dosimeters per site (all three rooms were pooled); the St. Joseph's entries represent three dosimeters per site.

Probable maximum exposure is defined as the observed mean exposure plus two sample standard deviations. The possibility of exceeding the probable maximum exposure is 1 in 40. We have used this extremely conservative concept of probable maximum exposure in our analysis of operator exposure relative to accepted guidelines. The differences in operator exposure per case for the two runs using the table-mounted protective shield cannot be fully explained. More than half of this difference is due to a difference in the average procedure times at the two institutions (12.7 min fluoroscopy and 110 sec cine fluorography at Cleveland Clinic, vs 8.7 min fluoroscopy and 62 sec cine fluorography at St. Joseph's). The remaining differences may be due to differences in the positioning of the shield or operators and to differences in dosimeter interpretation. It is to be noted that Begg reported values of exposure to the eye and thyroid intermediate to those observed at our two institutions (table 3).

**Discussion**

Table 2 shows that the operator's legs receive the highest exposure. This result is due to the strong
angular dependence of the intensity of scattered radiation in the diagnostic energy range. J. den Boer has measured the radiation scattered from a RANDO phantom on the Cardio Diagnost. The scattered radiation fields for two orientations of the unit, 30° LAO and 30° RAO, are shown in figure 4. With U-arm equipment, the intensity of scatter reaching the operator is strongly dependent upon the angle of projection. Because of this angular dependence on the intensity of scattered radiation and because of the absorption of forward scatter by the patient, minimum scatter reaches the operator for those projections in which the primary x-ray beam is directed toward the operator (RAO for a right arm approach). Conversely, studies in the LAO projection produce significantly higher scatter exposure to the operator.

The relative exposure of different sites on the operator's body depends on the position of the television monitor relative to the U-arm. Figure 5 illustrates the difference in monitor position at the two institutions.

With the monitor located at the head of the table

TABLE 2. Measured Exposures by Sites (mR per examination)

<table>
<thead>
<tr>
<th>Site operator</th>
<th>Cleveland Clinic–no shield</th>
<th>Cleveland Clinic–with shield</th>
<th>St. Joseph's Hospital–with shield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Average</td>
<td>PME</td>
</tr>
<tr>
<td>01 Nose</td>
<td>5.6-9.3</td>
<td>7.0</td>
<td>10.0</td>
</tr>
<tr>
<td>02 R Cheek</td>
<td>3.2-8.8</td>
<td>6.1</td>
<td>11.3</td>
</tr>
<tr>
<td>03 L Cheek</td>
<td>7.2-10.8</td>
<td>8.3</td>
<td>11.3</td>
</tr>
<tr>
<td>04 R Temple</td>
<td>2.6-4.1</td>
<td>3.6</td>
<td>4.5</td>
</tr>
<tr>
<td>05 L Temple</td>
<td>5.6-6.7</td>
<td>6.0</td>
<td>6.7</td>
</tr>
<tr>
<td>06 R Wrist</td>
<td>5.0-9.9</td>
<td>5.7</td>
<td>7.8</td>
</tr>
<tr>
<td>07 L Wrist</td>
<td>4.6-10.1</td>
<td>6.5</td>
<td>11.1</td>
</tr>
<tr>
<td>08 R Shoulder</td>
<td>X</td>
<td>1.6-7.7</td>
<td>5.2</td>
</tr>
<tr>
<td>09 Thyroid</td>
<td>X</td>
<td>8.7-13.6</td>
<td>8.3</td>
</tr>
<tr>
<td>10 Thyroid</td>
<td>I</td>
<td>0.2-0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>11 L Shoulder</td>
<td>X</td>
<td>4.4-8.2</td>
<td>6.0</td>
</tr>
<tr>
<td>12 R Hip</td>
<td>X</td>
<td>0.3-0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>13 Umbilicus</td>
<td>X</td>
<td>4.6-7.6</td>
<td>5.8</td>
</tr>
<tr>
<td>14 Umbilicus</td>
<td>I</td>
<td>0.0-0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>15 L Hip</td>
<td>X</td>
<td>2.0-5.3</td>
<td>3.5</td>
</tr>
<tr>
<td>16 R Calf</td>
<td>X</td>
<td>9.5-23.0</td>
<td>15.8</td>
</tr>
<tr>
<td>17 Mid Calf</td>
<td>X</td>
<td>44.0-68.0</td>
<td>51.2</td>
</tr>
<tr>
<td>18 Mid Calf</td>
<td>I</td>
<td>2.0-3.7</td>
<td>2.9</td>
</tr>
<tr>
<td>19 L Calf</td>
<td>X</td>
<td>13.0-27.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Abbreviations: X = dosimeters outside of lead apron; I = dosimeters inside of lead apron; M = exposure less than 0.1 mR/exam; PME = probable maximum exposure (see text).

TABLE 3. Reported Personnel Exposures During Coronary Angiography

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Mean fluoro time (min)</th>
<th>Mean cine time (sec)</th>
<th>Average exposure (mR/exam)</th>
<th>Equipment</th>
<th>Intensifier diameter</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ardran</td>
<td>18.6 35</td>
<td>-</td>
<td>3.5 1.5 4.6</td>
<td>Cradle</td>
<td>23 cm</td>
<td></td>
</tr>
<tr>
<td>Begg</td>
<td>8.4 54</td>
<td>0.9 1.2</td>
<td>1.5 2.8</td>
<td>U-arm</td>
<td>15 cm With shield</td>
<td></td>
</tr>
<tr>
<td>Begg</td>
<td>- -</td>
<td>10.7 21.4</td>
<td>- 49</td>
<td>U-arm</td>
<td>15 cm No shield</td>
<td></td>
</tr>
<tr>
<td>Malisky</td>
<td>5-20 0-240</td>
<td>18 30</td>
<td>x&lt;10 135</td>
<td>Cradle</td>
<td>23 cm Staff M.D.</td>
<td></td>
</tr>
<tr>
<td>Malisky</td>
<td>5-20 0-240</td>
<td>30 38</td>
<td>x&lt;10 145</td>
<td>Cradle</td>
<td>23 cm Resident M.D.</td>
<td></td>
</tr>
<tr>
<td>Properzio</td>
<td>14.7 39</td>
<td>7 16</td>
<td>1 17</td>
<td>Cradle</td>
<td>23 cm Adult patients</td>
<td></td>
</tr>
</tbody>
</table>

Results from this study

| Cleveland Clinic | 12.1 104 | 6 8.3 0.4 8 | U-arm 15 cm No shield |
| Cleveland Clinic | 13.2 117 | 1.9 1.4 0.1 2.1 | U-arm 15 cm With shield |
| St. Joseph's     | 8.7 62  | 0.4 0.2 0.1 0.3 | U-arm 15 cm With shield |

*Data not given in investigator's report.
(fig. 5A), the operator turns his right side to the table during injection, resulting in higher right-sided exposures. With the monitor located across the table from the operator (fig. 5B), the operator's left side is closer to the x-ray beam, resulting in higher left-sided exposure.

The effect that the cine frame rate has on exposure of both the patient and operator should also be considered. We note that exposure to both the patient and operator is proportional to the exposure at the input of the image intensifier. The sensitivities of our image intensifier tubes were measured using copper phantoms and a calibrated Keithley dosimeter system. An average exposure of 30 µR (range 20–40) is required either for 1 second of fluoroscopy or for one cine frame.

Using the average procedure times measured at the Cleveland Clinic (12.7 min of fluoroscopy and 110 sec of cine at 30 frames/sec), we calculated the fluoroscopic contribution to be 20% of the total exposure (762/4062). Therefore, 80% of the total exposure, even at 30 frames/sec, is due to the cine study.

With the shield in position, and using the measured results in table 4, we can then estimate that one cine frame or 1 second of fluoroscopy will expose an unprotected operator (i.e., no lead apron) to between 0.5–1 µR. It is important to compare simulated effects of performing cineradiography at 60 frames/sec. Under these conditions, the total exposure will be multiplied by 1.81 (7362/4062), an 80% increase. Therefore, whenever clinical conditions permit, it would be wise to limit cineradiography to 30 frames/sec.

The decrease in operator exposure when the protective shield is installed on the table side is impressive in Begg’s series and in our own. As we are unable to
demonstrate a significant difference in procedure times with or without the shield, we strongly recommend the use of a properly designed and appropriately positioned shield with all U-arm systems.

The possibilities of radiation-induced cataracts is important. Numerous studies of the radiosensitivity of animal lenses have been reported in the literature.\textsuperscript{12-14} While some workers have demonstrated low thresholds for cataract induction in the lenses of certain animal species, they caution that interspecies differences make extrapolation to human lenses difficult. The results of irradiating a series of lenses in the pediatric age group was reported by Quist and Zachav-Christiansen.\textsuperscript{15} A definitive study on radiation-induced cataracts in humans was performed by merriam and Focht.\textsuperscript{16} They described the irradiation of 173 human lenses during the course of radiation therapy and the consequent formation of cataracts in 100 of these lenses. Merriam defined a lens as having a cataract on the basis of post-radiation slit-lamp examinations demonstrating the presence of lens opacity whether or not these produced a visual defect. From this study, we conclude: a) no cataracts were observed if the exposure of the lens on a single day was below 200 R; b) no cataracts were observed if the exposure of the lens, protracted over three months or more, was below 550 R; and c) the speed of cataract induction was proportional to the exposure of the lens.

To obtain a practical scale for the magnitude of such exposure levels, we will assume that an individual's eyes are exposed to the current guidelines of the International Commission on Radiological Protection (ICRP) of 15 R per year. We will also assume that an individual accumulates exposure at this extreme 15 R per year rate for an entire 40-year work life (ages 25-65). It is evident that the lifetime accumulated exposure of 600 R will be close to the 550 R threshold for the induction of cataracts (three months). The National Commission on Radiological Protection and Units (NCRP) takes the more restrictive guideline of five per year, yielding a projected lifetime occupational exposure of 200 R, equivalent to only the single exposure threshold for cataract induction. We conclude that a radiation-induced cataract in such an individual is not very likely.

Radiation-induced neoplasia of the thyroid gland is another area which should be considered.\textsuperscript{7, 8, 17, 18} Based on the Biologic Effects of Ionizing Radiation (BEIR) report,\textsuperscript{17} we have assumed a linear dose response curve and a 1.2% increase in the relative mortality rate from thyroid cancer per Roentgen (BEIR table b-1). Thus a 40-year career exposure at a rate of 5 R/year would increase the probability of fatal thyroid cancer from an initial annual rate of 5 cases per million per year (before any occupational exposure) through an annual rate of 11 cases per million per year (after 20 years in the angiographic laboratory), to a final annual rate of 17 cases per million per year (at retirement). One may gauge the impact of these numbers by postulating a population of 10,000 cardiac angiographers. If there is no occupational exposure to this group, there will be one fatal thyroid cancer in the group every 20 years. If the entire group's thyroids are exposed at a rate of 5 R/year, then there will be one fatal thyroid neoplasm appearing in the group per decade. Thus, the risks of radiation-induced thyroid neoplasia appear negligible.
to a real population of cardiac angiographers.

Table 4 lists our results, as well as the relevant NCRP and ICRP guidelines concerning the measured radiation exposure to the several sites on the operator's body. Taking an extremely conservative approach to setting a permissible number of procedures per year for a single physician, we have used the probable maximum exposure (one chance in 40) as measured at the Cleveland Clinic for all the following computations and analyses.

Without the shield the largest fraction of the maximum permissible dose (MPD)\(^*\) is to the operator's feet and lower legs. The operator may only perform 6.5 examinations per week, averaged over a 50 week working year (NCRP guidelines). The exposure of other organs under these conditions will only be between 7%-20% of the MPD.

With the shield in position, the largest fraction of the MPD is to the operator's eyes. The operator may perform an average of 29 examinations per week without exceeding the MPD for the eyes following the more restrictive NCRP guidelines. Under these circumstances, the feet will receive 25% of the MPD. Since it is unlikely that any single operator will be called upon to perform more than an average of 20 procedures per week on a sustained basis, it is unlikely that any operator would receive as much as 70% of the maximum permissible dose for any organ.

**Summary**

Based upon a study of 700 cardiac angiograms performed using the brachial artery technique and a dedicated U-arm examination system (the Philips Cardio Diagnost), we conclude that it is unlikely that a physician performing cardiac angiography under these conditions will receive as much as three-fourths of the maximum permissible dose to any organ as defined by the NCRP. Under these circumstances, it is highly unlikely that any competent physician will accumulate a radiation dose equal to the minimum probably required for the demonstration of either radiation-induced cataracts or thyroid neoplasia.

These conclusions are not relevant to cardiac angiography in general. Operator exposure depends on many variables, including image intensifier field size and sensitivity, fixed or variable collimation, the use of a rotating cradle, angulated views, fixed or variable focus-intensifier distance, cine materials, frame rates, the clinical approach to the patient and total examination, and the use of available protective shielding.

Finally, the ICRP and NCRP recommend that "doses be kept as low as readily achievable."\(^5\)\(^,\)\(^18\) Many factors in the typical angiographic installation and its operation may be considered in attempting dose reduction. For example, anything that can be done to lower patient dose without compromising the clinical quality of the examination will usually reduce operator dose. Equipment layout and operation should ensure that extraneous personnel are removed from the high exposure rate regions surrounding the procedure table. Also, shielding attached to either the equipment or to the operator should be used as completely as possible without encumbering the examining physician or in any other way jeopardizing the welfare of the patient.

In conclusion, good equipment design, appropriate choices of medical and technical operating factors, and proper attention to radiation hygiene can reduce to a small fraction of the maximum permissible dose the radiation dose received by the busiest coronary angiographer.

**References**


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*In this paper, an exposure of one roentgen will be considered to deliver a dose of one rad to tissue.*
Temporary, Catheter-Induced Block in Accessory Pathways

THOMAS L. NOVICK, B.S.E., EDWARD L. C. PRITCHETT, M.D.,
RONALD W. F. CAMPBELL, M.D., GARRETT C. ROGERS, M.D.,
ANDREW G. WALLACE, M.D., AND JOHN J. GALLAGHER, M.D.

SUMMARY Catheter-induced conduction delay or block in the accessory atrioventricular pathway of four patients with the preexcitation syndrome was observed. Block in the accessory pathway occurred during routine catheter placement and lasted from 90 seconds–14 hours.

All of the pathways were in locations readily accessible to catheter trauma, located in the right anterior septal/paraseptal area in three patients, and in the posterior septum near the orifice of the coronary sinus in the fourth. The location of the accessory pathway was confirmed at surgery by endocardial mapping in three of the four patients. The fourth patient did not undergo surgery.

These findings suggest the need for caution in performing and interpreting electrode catheter studies which are undertaken to document the presence of accessory pathways.

CATHETER-INDUCED CONDUCTION DELAY or block in the bundle of His\(^1\) and right bundle branch\(^2\) have been previously observed during right heart catheterization. The purpose of this study is to extend this observation to the case of accessory atrioventricular (AV) pathways underlying the preexcitation syndrome. Block of the accessory pathway occurred during routine catheter placement in four patients, and lasted from 90 seconds–14 hours.

Methods

The four patients were among those referred to Duke University Medical Center for evaluation of symptomatic tachyarrhythmias related to preexcitation syndromes. The method of study in the Clinical Electrophysiology Laboratory has been previously published.\(^5\)–\(^10\) These studies were done using multiple electrode catheters\(^5\) to simultaneously record from several regions of the heart:

1) A specially designed \#7F bipolar electrode catheter was percutaneously introduced via the right femoral vein and advanced to the right atrium for mapping the right atrial activation sequence. The lumen of this catheter accepted a 0.032-inch diameter spring-guide wire or a blunt trocar designed to resemble a Brockenbrough needle.

2) A \#6F quadripolar electrode catheter was per-
Radiation exposure to the operator performing cardiac angiography with U-arm systems.
S Balter, F M Sones, Jr and R Brancato

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