Reduction of Radiation Exposure during Radiography for Scoliosis

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Abstract: To reduce the radiation exposure received by young scoliosis patients during treatment, six changes in technique were instituted: (1) a posteroanterior projection, (2) specially designed leaded acrylic filters, (3) a high-speed screen-film system, (4) a specially designed cassette-holder and grid, (5) a breastshield, and (6) additional filtration in the x-ray tube collimator. Dosimeter measurements of the exposure to the thyroid, breast, and abdominal areas were made on an Alderson phantom. They revealed an eightfold reduction in abdominal exposure for both the posteroanterior and the lateral radiographs. There was a twentysixfold reduction in exposure to the thyroid for the posteroanterior radiograph from 100 to less than five milliroentgens and for the lateral radiograph there was a 100-fold reduction from 618 to six milliroentgens. For the breasts there was a sixty-ninefold reduction from 344 to less than five milliroentgens for the posteroanterior radiograph and a fifty-fivefold reduction from 277 to less than five milliroentgens for the lateral radiograph. These reductions in exposure were obtained without significant loss in the quality of the radiographs and in most instances with an improvement in the over-all quality of the radiograph due to the more uniform exposure.

The amount of radiation received during the treatment of scoliosis has become a matter of increasing concern in recent years. Nash et al. pointed out the risks of x-ray exposure to the breasts of young girls undergoing long-term treatment for scoliosis, showing that the entrance exposures were 1200 to 1700 millirems per radiograph. They also indicated a significant reduction in exposure, and hence reduced risk of carcinogenesis, by changing from an anteroposterior to a posteroanterior projection. DeSmet et al. showed that by other changes in technique they were able to reduce exposure to the breasts, and consequently they elected to continue to use the anteroposterior projection, since they found that by using the posteroanterior projection the radiographs were of inferior quality and there were differences in the measurements of the Cobb angle. Their concern about the Cobb-angle measurements was based on the work of Schock et al., in which a radiographic technique was not used to demonstrate this effect but rather the x-ray system was simulated using a point light source and a circular shape as a model of a vertebra.

In previous studies of this question 1,13 several important facts were overlooked. First, the distribution of active bone marrow can be considerably different in adolescents and adults, and the distribution of active marrow in adults varies significantly from one individual to another. Consequently, it is difficult to determine the bone-marrow dose for specific examinations and then apply the results to the population as a whole. Second, although Archer et al. measured the bone-marrow dose, they did not place dosimeters inside the appropriate bone but rather extrapolated their data from measurements near the bone. A recent paper by Gray et al. 7 indicated that the posteroanterior chest radiograph produces a lower bone-marrow dose compared with the anteroposterior radiograph when the measurements are made inside the appropriate bone spaces. The marrow distributions used by Archer et al. and by Gray et al. 7 were the same as those used by Rosenstein in his Monte Carlo calculations of specific organ doses. However, neither set of measurements can be considered either correct or incorrect, since the errors involved in such measurements are considerable depending on the locations of the dosimeters, the number of dosimeters used, and the actual volume irradiated. In all cases, one is attempting to estimate an integral volume measurement from point measurements. (Unless the exposure to the entire irradiated volume is measured, one can only estimate the total dose to the volume in question from measurements made at small points within that volume.) Third, and most important, previous studies did not consider the individual differences in sensitivity of the various organs as well as the changes in sensitivity of these organs with age. Most authors 2,11,12 indicated that the increase in the rate of breast cancer is much higher after irradiation during puberty than after irradiation later in life, but most published mortality figures have been based on mortality for the population at large. Boice and Monson indicated that the excess incidence (incidence above normally occurring cancer) of breast cancer for young women between thirteen and twenty years old is $162 \times 10^{-6} \text{rad}^{-1}$ (that is, 162 cases of cancer as a result of one million women being exposed to one rad of radiation); between twenty and twenty-nine years old, $108 \times 10^{-6} \text{rad}^{-1}$; and for women who are more than twenty years old (including the twenty to

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twenty-nine-year age group), seventy-eight $10^{-6}$ rad$^{-1}$. These data are similar to those derived from the studies of patients exposed to radiation from the atomic-bomb blasts in Japan$^{11}$. In the Japanese, the ratios of the observed to the expected death rates due to breast cancer were twenty-five for girls between ten and nineteen years old at exposure and 1.14 for women who were more than twenty years old at exposure. (Interestingly, in the newborn to nine-year-old age group there were no deaths due to breast cancer, but this group may show an increased death rate at a later age, when hormonal or other influences determine the full expression of the latent cancers.)

The amount of exposure to all radiation-sensitive organs must be considered, not just that to the bone marrow or the breasts. The 1977 report of UNSCEAR gave the excess death rates (death rates due to radiation exposure in excess of those due to natural causes) as fifty to $150 \times 10^{-6}$ rad$^{-1}$ for the thyroid; ten to sixty $10^{-6}$ rad$^{-1}$ for the breasts; and eleven to twenty-five $10^{-6}$ rad$^{-1}$ for active bone marrow. Therefore, the highest excess death rates are for the breast and thyroid, and both of those organs receive significantly more exposure with the anteroposterior projection than with the posteroanterior projection.

Exposure to the gonads has received little attention, since it is assumed that the gonads are shielded and are not exposed if the x-ray field is properly collimated. However, the gonads do receive a small exposure from internally scattered radiation. Shielding or other techniques cannot reduce this exposure. Only reducing the entrance exposure of the patient can accomplish this.

Materials and Methods

Studies were undertaken recently to explore ways to reduce the x-ray exposure received by patients under treatment for scoliosis$^{4,6}$. As a result of these studies, six changes were made in the radiographic technique used to make spine radiographs of patients with scoliosis. These changes made use of:

1. The posteroanterior rather than the anteroposterior projection
2. Specially designed lead-loaded acrylic filters and non-gradient intensifying screens in place of conventional gradient x-ray intensifying screens and aluminum filters$^{6}$
3. A high-speed non-gradient screen-film system
4. A specially designed cassette-holder (including a grid) that eliminates the need for grid cassettes and ensures better alignment of the grid and x-ray beam
5. A breast-shield to eliminate direct exposure of the breasts while making lateral radiographs$^{4}$
6. Additional filtration in the x-ray tube collimator

Posteroanterior Projection

As reported elsewhere$^{7}$, the x-ray exposure to the breasts and the thyroid, the most sensitive organs in the field, was studied using the posteroanterior and anteroposterior projections. Lack of detail in the images of the vertebral bodies on the posteroanterior radiograph was avoided by using a higher speed screen-film combination and a smaller (0.6-millimeter) focal spot rather than the larger (1.2-millimeter) focal spot and slower speed screen-film system that are used for the anteroposterior radiograph. Any losses in the quality of the image due to the increased distance between the vertebral bodies and the film were more than offset by the use of the small focal spot.

Specially Designed Lead-Loaded Acrylic Filters

In another part of the study, specially designed lead-loaded acrylic filters were developed to compensate for variations in the thickness of different body parts and to eliminate the need for the heavier aluminum filters and the gradient intensifying screens. These filters are made of an acrylic material, similar to Plexiglas or Lucite, and contain lead, an element that readily absorbs x-rays. The filters can be shaped using conventional machine-shop milling techniques (as we did for this study) or can be produced by molding or extrusion. Because lead absorbs x-rays efficiently, it is not possible to make filters from lead directly since the thickness would be on the order of just a fraction of a millimeter. With the lead dispersed in the thicker acrylic material, machinable dimensions can be used. (Our filters ranged from one or two to several millimeters in thickness.)

The gradient screens that we had used before ranged in speed from a detail-speed screen at one end to a high-speed screen at the other, representing about a fourfold change in speed. A detail-speed screen is much thinner than a conventional screen, absorbing less radiation and therefore requiring more radiation exposure to the patient to produce the same density on the film. Since the screen is thinner, there is less scatter in the screen and finer detail is recorded on the film. Similarly, the high-speed screen is thicker than a conventional screen, requiring less exposure but resulting in a loss of the ability to record fine detail.

Since only one-quarter of the radiation is absorbed by the detail end of the screen, the patient receives four times the exposure necessary to produce the radiograph in the upper thoracic and cervical regions. By eliminating the gradient screens and using a filter located at the x-ray tube to reduce the radiation intensity, unnecessary radiation exposure to the patient was eliminated. With this technique only one set of filters is required, regardless of how many cassettes and how many intensifying screens are used, and only less expensive single-speed screens are needed. In addition, the lead-loaded acrylic filters are lighter than the aluminum filters and eliminate any potential counterbalancing problems related to the x-ray tube and support.

High-Speed Non-Gradient Screen-Film System

The screen-film system that was used formerly employed gradient screens and Kodak XL film. In the new system Kodak Lanex regular screens and Kodak OH film were used, resulting in an eightfold reduction in the radiation exposure required to produce the radiograph. In addi-

Fig. 1-A: Without gradient screens and with no filtration.

Fig. 1-B: With gradient screens using the old technique and with an aluminum filter for the cervical and upper thoracic regions.

Fig. 1-C: Without gradient screens using the new technique and using lead-loaded acrylic filters for the cervical and upper thoracic regions.

REDUCTION OF RADIATION EXPOSURE DURING RADIOGRAPHY FOR SCOLIOSIS

TABLE I

<table>
<thead>
<tr>
<th>SCOLIOSIS RADIOGRAPH TECHNIQUES</th>
<th>Old Technique</th>
<th>New Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>AP</td>
<td>PA</td>
</tr>
<tr>
<td>Source-to-image distance</td>
<td>1.8 meters (72 inches)</td>
<td>1.8 meters (72 inches)</td>
</tr>
<tr>
<td>Grid ratio</td>
<td>8:1</td>
<td>8:1</td>
</tr>
<tr>
<td>Screen</td>
<td>Gradient</td>
<td>Lanex regular</td>
</tr>
<tr>
<td>Film</td>
<td>XL</td>
<td>OH</td>
</tr>
<tr>
<td>X-ray anode rotation speed</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Focal spot size</td>
<td>1.2 mm</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>Kilocvolt peak</td>
<td>83</td>
<td>83</td>
</tr>
<tr>
<td>Milliamperes</td>
<td>800</td>
<td>100</td>
</tr>
<tr>
<td>Time</td>
<td>0.1 sec.</td>
<td>0.1 sec.</td>
</tr>
<tr>
<td>Filters</td>
<td>Aluminum for cervical and upper thoracic anteroposterior and thoracic and lateral radiographs</td>
<td>Lead-loaded acrylic for cervical and thoracic anteroposterior and lateral radiographs</td>
</tr>
</tbody>
</table>

is produced for use with the newer green-light-emitting rare-earth intensifying screens. Since newer technology is being applied to the green-sensitive film, it is possible to reduce the silver content of the film, resulting in a slight reduction in cost without altering the imaging characteristics of the film.)

Specially Designed Cassette-Holder

When this cassette-holder is used, there is a significant financial savings since only one grid, which is part of the holder, is required and there is no need to purchase grid cassettes, with each cassette containing one grid. We did not consider using a grid that could be clipped onto a cassette and moved from one cassette to another because such large grids are fragile and are subject to damage from handling. A grid that is an integral part of the x-ray system ensures better, more consistent alignment of the grid and x-ray beam; reduces grid cut-off; improves the quality of the radiographs; and reduces exposure of the patient. (Cassette-holders incorporating grids, similar to our design, are now available commercially.)

Breast-Shield

To reduce exposure of the breasts in young women, when a lateral radiograph was made a conventional go-
TABLE II

<table>
<thead>
<tr>
<th></th>
<th>Anteroposterior</th>
<th>Posterocentral</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid&lt;sup&gt;4&lt;/sup&gt;</td>
<td>100</td>
<td>5</td>
<td>20 x</td>
</tr>
<tr>
<td>Sternum&lt;sup&gt;4&lt;/sup&gt;</td>
<td>160</td>
<td>9</td>
<td>18 x</td>
</tr>
<tr>
<td>Breast</td>
<td>344</td>
<td>29</td>
<td>12 x</td>
</tr>
</tbody>
</table>

<sup>4</sup> For the anteroposterior radiograph using the old technique (Table I), an aluminum filter was used to compensate for some of the differences in the thicknesses of body parts. This filter accounts for the lower exposure to the sternum and thyroid compared with the breast.

nadi-shield was attached to the housing of the x-ray tube and was positioned to exclude direct x-ray exposure of the breasts, as described elsewhere<sup>4</sup>. This arrangement does not eliminate all radiation exposure to the breasts, since they are still exposed to scattered x-rays. However, this modification does produce a significant (more than twofold) reduction in exposure.

It may be possible to collimate the x-ray beam so that the breasts are not included on the lateral radiograph. However, it has been our experience that this is successful in only a few patients, because such collimation prevents visualization of the spine. In patients with lordosis and kyphosis, especially, the breasts cannot be shielded by using tighter collimation.

**Additional Filtration**

The Bureau of Radiological Health requires that x-ray equipment, when it is installed, must have a minimum half-value layer of 2.3 millimeters of aluminum at an eighty-kilovolt peak. (The half-value layer is the amount of aluminum that is required to reduce the radiation exposure by 50 per cent. It is not the amount of aluminum filtration at the exit of the x-ray tube, but rather a measure of the quality of the radiation beam.) Additional filtration can reduce exposure to the patient without necessitating any increase in technique or additional load on the x-ray tube and generator. For example, by increasing the half-value layer by 1.0 millimeter of aluminum, the entrance exposure to the patient can be decreased by about 30 per cent. Consequently, we now try to ensure that all of our x-ray tubes have a half-value layer of at least 3.0 millimeters of aluminum at an eighty-kilovolt peak.

To measure the x-ray exposure during this study, we used an Alderson phantom (Alderson Research Laboratories, 390 Ludlow Street, Stamford, Connecticut 06904) and Harshaw TLD-100 thermoluminescent dosimeter chips which were read in a Harshaw 2000C reader. The

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Figs. 2-A, 2-B, and 2-C: Lateral radiographs of an Alderson phantom.
Fig. 2-A: Without gradient screens and with no filtration.
Fig. 2-B: With gradient screens using the old technique and with an aluminum filter for the upper thoracic region only.
Fig. 2-C: Without gradient screens using the new technique and using lead-loaded acrylic filters for the cervical and upper thoracic regions.


TABLE III

<table>
<thead>
<tr>
<th></th>
<th>Old System</th>
<th>New System</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid</td>
<td>100</td>
<td>&lt;5</td>
<td>20×</td>
</tr>
<tr>
<td>Sternum</td>
<td>160</td>
<td>&lt;5</td>
<td>32×</td>
</tr>
<tr>
<td>Breast</td>
<td>344</td>
<td>&lt;5</td>
<td>69×</td>
</tr>
</tbody>
</table>

heating chamber was purged with dry nitrogen during each readout. The dosimeter chips were calibrated using a conventional ionization-chamber dosimeter (MDH Industries). The measurements using the old and new techniques were made by placing the chips directly on the Alderson phantom and exposing the phantom at factors that were determined to produce adequate clinical radiographs. (The TLD-100 dosimeter chips are accurate to values as low as five milliroentgens. If exposures were below this level they were reported as less than five milliroentgens.)

The techniques and technical factors used before and after all of the changes had been accomplished are summarized in Table I.

Clinical Studies

Radiographs of fifty patients that had been made on previous visits, using the old technique, were compared with radiographs made using the new technique. Many more radiographs have been compared since this study was completed, because all of the radiographs made during previous visits are compared with the ones made during the latest visit. The comparisons were made subjectively, considering the ability to visualize important structures on the radiographs made with the old and with the new technique.

Results

Since all measurements were made on the Alderson phantom, the exposures that were recorded are those that typically are required for an average adult. Also, the

TABLE IV

<table>
<thead>
<tr>
<th></th>
<th>Old System</th>
<th>Without Breast-Shield</th>
<th>With Breast-Shield</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid</td>
<td>618</td>
<td>6</td>
<td>6</td>
<td>103×*</td>
</tr>
<tr>
<td>Breast</td>
<td>277</td>
<td>11</td>
<td>&lt;5</td>
<td>25-55×</td>
</tr>
</tbody>
</table>

* No aluminum cervical filter was used in the old system.
dosimeters were placed on the surface of the phantom, not in the actual location of the organ under investigation. Therefore, because the overlying tissues provide some filtration, the absolute exposure to an organ in a patient would be reduced compared with the value recorded for the phantom. For example, the thyroid lies about two centimeters beneath the surface of the skin, but the measurements labeled ‘thyroid’ were made on the surface of the phantom over the location of the thyroid. The differences in exposure comparing the anteroposterior and posteroanterior radiographs are shown in Table II. With the posteroanterior projection the exposures of the thyroid, sternum, and breasts are reduced twelvefold to twentyfold.

When the higher speed non-gradient screen-film system was substituted for the conventional system, the milliamperage could be reduced from 800 to 100 milliamperes (Table I) — an eightfold reduction. This reduction was possible despite the presence of the lead-loaded acrylic filter at the x-ray tube, because the filter only eliminated the radiation that was not used when the gradient intensifying screens were used in the old system. This reduction in milliamperage resulted in a significant reduction in the entrance radiation exposure in the abdominal region. When the gradient screens were used, the entrance exposure at the abdominal level (where the gradient screen has the highest speed) was 370 milliroentgens for the anteroposterior radiograph and 726 milliroentgens for the lateral radiograph. Using the higher speed non-gradient screen,
the exposures were reduced to forty-five and eighty-eight milliroentgens, respectively.

If the effects of all the technical changes are combined, the reductions in exposure for the posteroanterior and anteroposterior radiographs ranged from twentyfold to sixty-ninefold and for the lateral radiographs, from twenty-fivefold to 103-fold (Tables III and IV). The large reduction in the exposure of the thyroid in the lateral projection was explained by the fact that for this radiograph fold. The breast-shield also reduced the exposure to the sternal region.

The radiographs made of the Alderson phantom by the old and new techniques were compared to assess the quality of the images of the spine (Figs. 1-A through 2-C). Figures 1-A and 2-A were made without any gradient screens or any variable-thickness filtration at the x-ray tube. Figures 1-B and 2-B were made with the old technique, in which gradient screens and variable-thickness aluminum filtration were used for the anteroposterior radiograph of the cervical and upper thoracic regions and for only the lateral projection of the thoracic region. Figures 1-C and 2-C were made using the new system, with high-speed screens and lead-loaded acrylic filtration for both the anteroposterior and the lateral radiographs of the cervical and upper thoracic regions.

Fig. 5-A and 5-B: Lateral radiographs of a female patient made in 1978 (Fig. 5-A) and 1981 (Fig. 5-B). Fig. 5-A: With gradient screens using the old technique and with an aluminum filter for the cervical and upper thoracic regions. Fig. 5-B: Without gradient screens using the new technique and using lead-loaded acrylic filters for the cervical and upper thoracic regions and the breast-shield, which protects the breasts from any direct radiation exposure.

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The radiographs made with the old and new techniques for the anteroposterior and posteroanterior projections were similar despite the previously described significant reduction in exposure for the posteroanterior projection. On the lateral radiographs made with both techniques the thoracic and lumbar regions appeared similar, while visualization of the cervical region was better when the new system was used.

Radiographs of patients demonstrated the same differences as the phantom radiographs. Details were equally well visualized by the old system using the anteroposterior projection and by the new system using the posteroanterior projection (Figs. 3-A and 3-B). However, in almost all patients visualization of both the cervical and the thoracic areas was improved on the lateral radiograph made with the new technique (Figs. 4-A and 4-B). The effect of the breast-shield is shown by Figures 5-A and 5-B. The apparent penetration of the shield (Fig. 5-B) is caused by radiation scattered from the patient. The quality of the lateral radiographs made with the new technique was considered comparable with that of the radiographs made with the old technique in all other instances.

Discussion

Since the thyroid, breasts, and active bone marrow are radiosensitive, we believe that the posteroanterior projection minimizes the risk of carcinogenesis. Using the modifications in technique described, we have been able to reduce exposure of the thyroid to six milliroentgens or less and that of the breasts, to less than five milliroentgens for both the posteroanterior and the lateral projections. The maximum entrance exposure to a patient with scoliosis, which occurs in the lower abdominal region, was reduced from about 370 milliroentgens with the old system to forty-five milliroentgens with the new system for both the anteroposterior and the posteroanterior radiographs. Similarly, the maximum exposure for the lateral radiograph, which also occurs in the lower abdominal region, was reduced from 726 milliroentgens with the old to eighty-eight milliroentgens with the new system. Although no level of exposure to ionizing radiation is entirely safe, we believe that these improved techniques, which do decrease exposure and reduce risk, should be adopted in view of the multiple exposures that these adolescent patients receive throughout the course of treatment.

References