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# Radiation-attenuating Surgical Gloves: Effects of Scatter and Secondary Electron Production[1]

*PURPOSE:* To evaluate the effects of scatter and secondary electron production on the protection provided by flexible radiation-attenuating gloves.

*MATERIALS AND METHODS:* Four sets of radiation-attenuating flexible gloves and one set of standard surgical gloves were tested for scattering characteristics and secondary electron production caused by the interactions of x rays inside the gloves. A thin-window ion chamber was used to measure the penetration of secondary electrons in polyethylene. A diagnostic-type chamber was used to measure forward-scattered and backscattered x rays produced by the gloves.

*RESULTS:* Forward-scattered and backscattered x rays added an average of about 13% to the exposure of the hands. Secondary electrons increased the signal in the thin-window chamber by large factors but were weakly penetrating, and only a small fraction produced by x rays of 90 kVp and higher energies contributed to dose to basal cells.

*CONCLUSION:* Forward-scattered and backscattered x rays reduce the effectiveness of radiation-attenuating gloves, and secondary electron dose to basal cells in the back of the hand can further reduce effectiveness.

DETERMINISTIC effects in the hands of fluoroscopists were a hazard experienced by physicians early in the history of radiography (1,2). Such effects have been seen in the finger of a dentist as late as the 1980s subsequent to chronic exposure to dental radiation (Russell JGB, written communication, January 10, 1995). The dentist habitually hand-held film during radiography. With evolution of applications of fluoroscopy, fingers and hands are placed at greater risk for radiation exposure because table-side attention by the physician is required. Effects of such chronic exposure are not likely to be apparent for many years. Management of radiation is an important issue for the long-term health of physicians.

Radiation-attenuating flexible gloves are intended to offer some protection to the hands of physicians who perform fluoroscopic procedures. The gloves are designed as a substitute for standard sterile gloves and must be sufficiently thin to preserve tactility. To provide protection, such gloves are manufactured from materials that contain elements with atomic numbers sufficiently large to attenuate x rays better than standard surgical gloves. The amount of protection is modest, and the cost-effectiveness of use of such gloves has been challenged (3). Bowsher et al (4) tested a pair of gloves that demonstrated unusually high attenuation. Vañó et al (5) investigated the attenuation of 11 such gloves from different manufacturers and concluded that gloves made from tungsten offered the best compromise between tactility and protection. These authors designed their study to reduce scatter radiation. However, scatterless beam attenuation exaggerates the true level of protection provided by gloves because these and other interactions degrade protective value (Fig 1). The actual amount of protection provided depends on several facets of the interactions between x rays and the gloves. These are the photoelectric absorption of x rays with concomitant production of photoelectrons and characteristic x rays, the forward scatter of x rays and compton electrons, and backscattered x rays.

The purpose of our study was to determine how these factors affect the overall protection provided by such gloves and what role radiation-attenuating gloves may play in radiation management.

## MATERIALS AND METHODS

Radiation-attenuating gloves were obtained from four manufacturers or distributors (Cone Instruments, Solon, Ohio; F & L Medical Products, Vandergrift, Pa; International Biomedical, Austin, Tex; Medi-Tech/Boston Scientific, Natick, Mass). Two were made from a lead-based material, one from a tungsten-based material, and the other from unknown proprietary materials that exclude lead. A set of common surgical gloves was also obtained. A

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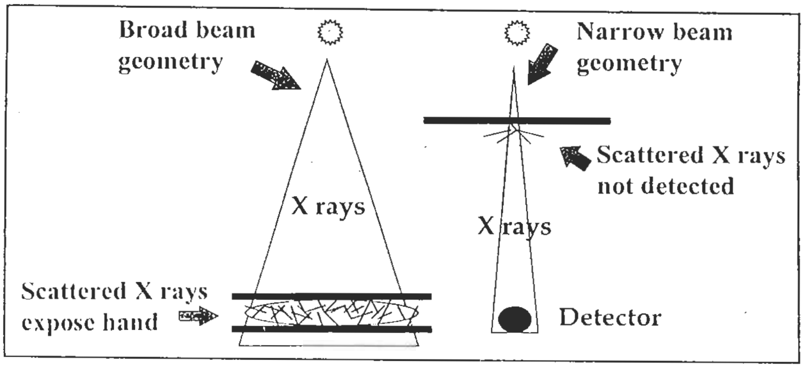
See also the editorial by Marx and Ellis (pp 24–25) in this issue.



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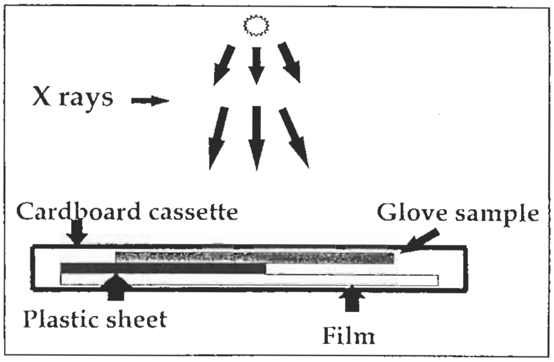

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**Figures 1, 2.** (1) Diagram demonstrates broad-beam exposure to the hand inside a glove and narrow-beam exposure measurements. Forward scatter and backscatter both contribute to hand exposure. (2) Diagram shows setup to demonstrate secondary electron production.

square section of about 50 × 50 mm was cut from each type of glove.

Measurements of exposure were made with use of a 6-mL mammographic ionization chamber with a Mylar window of 7 $\mu g/mm^2$ and a 6-mL diagnostic chamber (Radcal, Monrovia, Calif). Both had been recently calibrated and agreed in exposure measurement to within a few percent at the diagnostic energies used in this study. The mammographic chamber was selected because its thin Mylar window permits low-energy electrons to enter the active volume, whereas the thicker chamber wall of the 6-mL diagnostic chamber does not. Another 6-mL chamber was used to monitor output of the x-ray machine for each measurement; this eliminated errors due to variations in machine output. To test reproducibility, many of the data points were collected multiple times. Because a monitor chamber was used, results were generally reproducible to within 1%. A narrow section of approximately 20 × 40 mm was cut from the palm area of two gloves to help demonstrate secondary electron production.

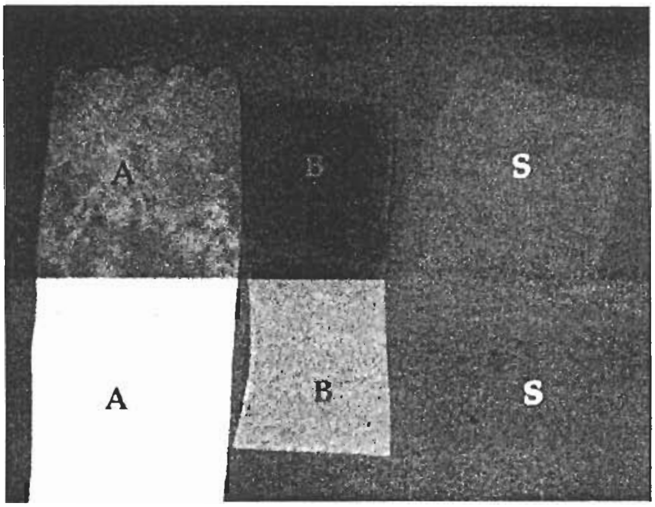

**Figure 3.** Image of secondary electron production. In the area of the film shielded by plastic (lower half), only x rays that penetrate the glove darken the film. Outside the plastic (upper half), the two attenuating glove sections (*A*, *B*) produce secondary electrons that darken the film. The surgical glove (*S*) is almost uniform in shade under and outside the glove area, which demonstrates that few secondary electrons are produced by this glove.

## Demonstration of Secondary Electron Production

When x rays interact in the gloves, photoelectrons and Compton electrons are produced. The presence of these secondary electrons was demonstrated with single-emulsion mammographic film. In the darkroom, a mammographic film was placed emulsion-side up on the counter. A small square (about 50 × 50 mm) of thin (< 1 mm) plastic was placed on top of part of the emulsion. The narrow strips of each piece of glove were then placed on top such that half of each strip was over the plastic and half was in contact with the film emulsion (Fig 2). While this configuration was maintained, the materials were placed in a cardboard cassette with the emulsion side facing the tube side of the cassette. Images were acquired at each of the three beam energies. Secondary electrons expose the emulsion that is in direct contact with the strips of glove, but the plastic prevents electrons from exposing the other half of the emulsion.

To demonstrate that secondary electrons are backscattered from the glove pieces, the same configuration was used but the materials were placed in the cassette in the reverse order.

## Narrow-Beam Attenuation

With use of a source-to-chamber distance of about 0.8 m, the x-ray field was collimated to the area of the mammography chamber. A 6-mL diagnostic chamber was used to monitor output of the x-ray machine. Exposures were made at 60, 90, and 120 kVp with and without the square glove sections placed in the beam near the collimator. This created a large air gap between the sections and the chamber. The half-value layers in aluminum at each of the beam energies was 3.1, 4.1, and 6.0 mm, respectively. The experiment was repeated with the diagnostic-type chamber as the detector.

## Broad-Beam Attenuation with and without Secondary Electrons

With use of the previously described x-ray beam and chamber configuration, exposures were made with and without the gloves lying just above the mammographic chamber. In this configuration, scattered x rays and secondary electrons produced by the glove are detected by the chamber. This test was repeated with the diagnostic-type chamber. Since the diagnostic-type chamber has a thick air-equivalent wall, no secondary electrons can be detected.

## Broad-Beam Attenuation with Reduced Secondary Electrons

With use of the same broad-beam configuration as before, various thicknesses of common plastic food wrap (pure polyethylene) were placed on the mammographic

**Table 1**
**Contributions of Forward-scattered and Backscattered Radiation to Hand Exposure**

| Glove | Forward Scatter as a Fraction of Unattenuated Exposure | | | Backscatter as a Fraction of Unattenuated Exposure | | |
|---|---|---|---|---|---|---|
| | 60 kVp | 90 kVp | 120 kVp | 60 kVp | 90 kVp | 120 kVp |
| A | 0.06 | 0.06 | 0.05 | 0.09 | 0.08 | 0.07 |
| B | 0.07 | 0.06 | 0.06 | 0.08 | 0.07 | 0.06 |
| C | 0.06 | 0.07 | 0.07 | 0.04 | 0.06 | 0.09 |
| D | 0.08 | 0.09 | 0.07 | 0.11 | 0.09 | 0.08 |

**Table 2**
**Narrow-Beam Penetration as a Fraction of Unattenuated Exposure**

| Glove | Penetration | | |
|---|---|---|---|
| | 60 kVp | 90 kVp | 120 kVp |
| A | 0.79 | 0.85 | 0.88 |
| B | 0.65 | 0.75 | 0.80 |
| C | 0.44 | 0.54 | 0.59 |
| D | 0.60 | 0.72 | 0.77 |

**Table 3**
**Exposure Inside Gloves Relative to Unattenuated Exposure**

| Gloves | Broad-beam Exposure with Backscatter* | | |
|---|---|---|---|
| | 60 kVp | 90 kVp | 120 kVp |
| A | 0.93 | 0.98 | 1.00 |
| B | 0.78 | 0.87 | 0.91 |
| C | 0.52 | 0.65 | 0.72 |
| D | 0.75 | 0.88 | 0.91 |

* Does not include secondary electrons.

chamber. Exposures were made with and without the square glove sections on top of the plastic food wrap (the food wrap was between the glove material and the chamber). Measurements were made with each of the various food wrap thicknesses, which ranged from 12.2 $\mu g/mm^2$ to 195 $\mu g/mm^2$ (about 12–200 $\mu m$). Exposures were made for three gloves at the previously specified energies.

## Backscatter with and without Secondary Electrons

The mammography chamber was turned upside down and supported from a stand to create a large air gap between it and the tabletop. Exposures were made with and without the gloves lying just below the face of the mammographic chamber. The experiment was repeated with the diagnostic-type chamber.

## Backscatter with Reduced Secondary Electrons

With use of the same backscatter configuration as before, various thicknesses of common plastic food wrap were placed just below the mammographic chamber that was turned upside down. Exposures were made with and without the square glove sections under the plastic food wrap (the food wrap was between the glove sections and the chamber). Measurements were made with the same various food wrap thicknesses used previously. Exposures were made for two gloves at the previously specified energies.

## RESULTS

The gloves were arbitrarily assigned identifications of A, B, C, and D. Figure 3 demonstrates that secondary electrons are produced at 120 kVp. The dark areas of gloves A and B were caused by the electrons. No dark area appeared under the standard surgical glove outside the plastic shield because the glove did not contain the materials with higher atomic number. The lighter areas under the plastic blocker demonstrate that a good portion of the radiations for the high-Z gloves do not penetrate thin plastic and are therefore electrons. Images that were similar except for reduced electron intensity demonstrated the presence of secondary electrons at lower kilovolt-peak values and in both the forward and backscattered directions. The standard surgical gloves did not backscatter or attenuate x rays and did not produce electrons to any great extent (scattered x rays and electrons were 1% or less). Tables 1–3 and Figure 4 summarize quantitative results with the attenuating gloves. Figure 4 shows the secondary electron penetration data. These data were fit by a single exponential curve.

## DISCUSSION

The amount of reduction of broad-beam dose provided by attenuating gloves depends on the beam quality and the type of glove. Forward-scattered x rays, backscattered x rays, and secondary electrons combine to reduce the effectiveness of the gloves.

Basal cells of the epidermis are believed to be the primary target cells for some radiation effects in the skin (2). Secondary electrons released from the glove material contribute some dose to those basal cells that are relatively superficial, such as those on the dorsal surface of the hand. For example, the epidermis on the back of the hand is about 70 $\mu m$ thick on the average with a minimum thickness of about 40 $\mu m$ (6). Figure 4 indicates that the secondary electrons produced at 120 kVp are sufficiently energetic to penetrate about 15% of the basal cells on the dorsal surface of the hand. For a 50 $\mu g/mm^2$ depth (approximately 50 $\mu m$) the boost in signal in the thin-window chamber is approximately 5%. As x-ray energy is reduced, electron dose decreases and at 90 kVp the elevated signal is very small at 40 $\mu g/mm^2$ (approximately 40 $\mu m$). The actual electron dose was not calculated because an accurate means to assess dose at this shallow depth was not available. Some gloves have a thin film coating and/or powder on the inside, which helps reduce electron dose. Also, electrons are not a concern for the ventral aspect of fingertips because the epidermis is about 400 $\mu m$ thick in this area (6) and electrons do not penetrate to the basal cells.

Assessment of the effectiveness of gloves to protect against x rays must include both the forward-scattered and backscattered radiation produced by the gloves. Table 1 shows the forward scatter produced by a field approximately 50 × 50 mm as a percentage of the unattenuated exposure. On the average, forward-scattered x rays contribute an additional exposure of about 7% to the hand. Those x rays that penetrate the hand may interact in the glove and be backscattered into the hand. Table 1 also shows the backscatter exposure, which was expressed as a percentage of the unprotected exposure. In general, this exposure is about 8%.

Table 2 presents narrow-beam penetration through one layer of glove. The narrow-beam penetration of Table 2 should be compared with the relative broad-beam exposure with backscatter, which is calculated from the following equation: $X_i = (P + F) \cdot (1 + B)$, where $X_i$ is the exposure inside the glove relative to unshielded exposure, $P$ is the penetration through one layer of glove (Table 2), $F$ is the forward-scatter fraction (Table 1), and $B$ is the backscatter fraction (Table 1). Values for $X_i$ are given in Table 3. These values were verified by placing a 6-mL chamber inside an intact glove and measuring the exposure under broadbeam conditions.

Our data on x-ray attenuation and secondary electron production show that attenuating gloves provide a moderate to insubstantial reduction in dose to the hand, depending on the beam energy, direction of the beam, and type of glove. Additionally, the amount of protection may be perceptually exaggerated when viewed with a fluoroscope. The fluoroscope displays the hand inside two layers of attenuating glove, but the dose to the hand results after penetration through only one layer and the second layer detracts from protection by scattering x rays back into the hand. To our knowledge, secondary electron dose to the back of the hand has never been considered. The visual exaggeration of the protective value may lead to a false sense of security about the true reduction in dose.

Attenuating flexible gloves should never be used as a primary means of radiation protection. The first line of defense is to keep hands out of the primary field and to work on the low-dose side where x rays exit the patient. Attenuating gloves can be an expensive means to achieve only a small reduction in risk (3). Others have suggested ways to increase cost-effectiveness (7). Some gloves provide a modest amount of net protection, but physicians must always remember that protection is moderate at best, that the image of the hand inside the glove exaggerates the actual protection, and that they should not be lured into a false sense of security regarding placement of hands in the direct beam. ■

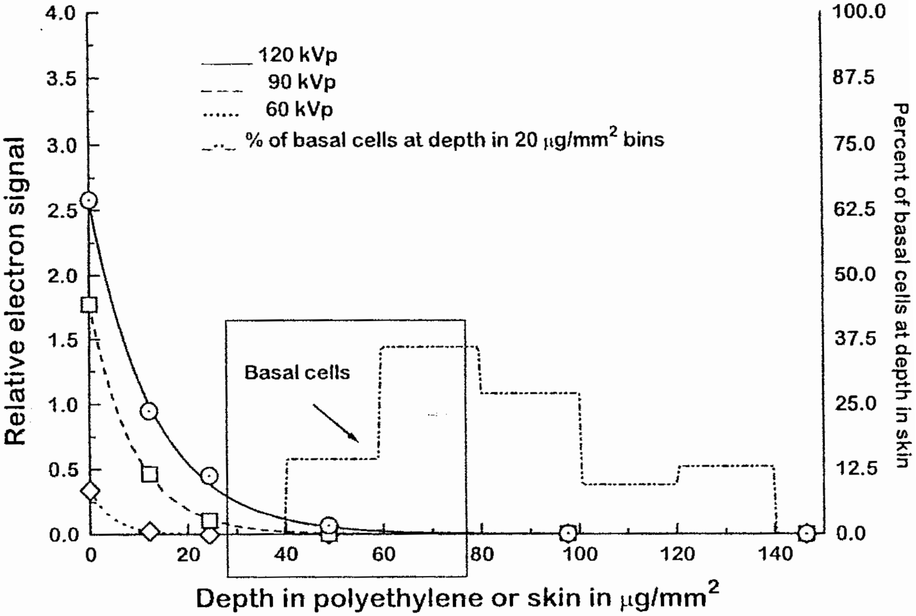

**Figure 4.** Absorption of secondary electrons in polyethylene produced in one of the gloves by 60 (◇), 90 (□), and 120 (◉) kVp x rays (left vertical axis). The data are fitted by an exponential curve. For comparison, the depth of basal cells of the epidermis on the dorsal aspect of the hand is also shown (right vertical axis). Depth is given in micrograms per square millimeter. For skin, the depth in micrograms per square millimeter is about the same as the depth in micrometers.

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