ABSTRACT. Exposure of children to ionizing radiation most commonly is from the environment, chiefly through cosmic rays and radon, or from medical technology. Medical radiation exposure occurs during diagnosis, therapy, and dental radiography. More is known about the biological effects of exposure to ionizing radiation than to nonionizing radiation from microwaves, radiowaves, and the electrical fields of other electrical appliances. This review applies only to sources of ionizing radiation and does not include the potential risks of indoor radon. The effects on children of ionizing radiation have been studied from war activities and environmental accidents. Projections are made from that data to help pediatricians evaluate risk from radiation when ordering radiographs.

Epidemiologic studies have shown that persons exposed to high levels of ionizing radiation have an increased risk of cancer, particularly leukemia, and later in life, breast and thyroid cancer. In addition, some epidemiologic studies have found that radiation exposure during childhood carries a higher risk of cancer than exposure at other ages. However, it should be noted that these reports studied exposures at relatively high doses (such as those seen at Hiroshima and Nagasaki in Japan). Therefore, the risks of developing cancer from childhood exposure to low levels of radiation from diagnostic x-ray examinations are not well-quantified but are probably very small. The Figure shows the measurements used in determining radiation exposure.

LEUKEMIA

Studies of atomic bomb survivors showed the risk of mortality from leukemia to be elevated at doses above 0.4 Gray (40 rad), with the excess relative risk ranging from 4.2 to 5.2 per Sievert (100 rem). The risk of leukemia was also found to be elevated (RR = 1.9) in adult populations exposed to x-rays for treatment of ankylosing spondylitis at an average dose of 3.2 Gray (320 rad). Similar risk ratios have been found in patients treated with high doses of radiotherapy for cancer. The risk of leukemia may be higher in children exposed to diagnostic radiation in utero than in unexposed children. In a study of childhood cancer mortality, Monson and MacMahon found that children exposed prenatally to diagnostic x-rays had a 1.5 times higher risk of dying of leukemia than unexposed children. However, other similar studies of prenatal radiation have not found the risk of leukemia to be higher than that associated with childhood exposure.

BREAST CANCER

Epidemiologic studies indicate that the risk of breast cancer is increased in women who were exposed to high levels of radiation during childhood. Breast cancer rates were higher among female atomic bomb survivors who were 10 to 19 years of age when exposed to the bomb than among those who were older at that time. The excess relative risks found in this study were 2.42 per Sievert for women exposed between 10 and 19 years of age, 1.25 per Sievert (100 rem) for women aged 20 to 39 years at exposure, and 0.48 per Sievert for women aged 40 years and older at the time of the bomb. A higher occurrence of breast cancer was also observed among women who were younger than 10 years at the time of the bomb—a surprising finding because it is an age at which they would have had very little breast tissue. The latent period for radiogenic breast cancer is a minimum of about 10 years. Radiation-related breast cancers have age distributions and histopathologic characteristics similar to those of breast cancer from other causes, known or unknown. Breasts should be shielded when possible when obtaining necessary diagnostic or therapeutic radiation.

BRAIN CANCER

The Japanese atomic bomb survivor data do not show an increase in brain cancer; however, studies of individuals exposed to therapeutic medical radiation do show an increased risk of brain tumors. In addition, there is evidence that the risk is higher in those exposed before age 20 years. In a follow-up study of children treated for tinea capitis, an increased risk of meningiomas was found in children exposed to 1 to 2 Gray (100 to 200 rad, average = 140 rad) of radiation to the brain.

THYROID CANCER

Irradiation in childhood for benign conditions including enlarged thymus, enlarged tonsils, tinea capitis, acne, and others have been shown to increase risk for thyroid cancer. Studies have shown that these individuals received high-dose x-rays; however, some children treated for tinea capitis received estimated average thyroid doses as low as 0.09 Gray (9 rad). Excess relative risks, in the range of 2.1 to 27 per Gray (100 rad), have been found in studies of therapeutically exposed populations. In Hiroshima survivors, a significant linear association was found between dose and increased risk of thyroid...
cancer, predominantly in those exposed at ages less than 19 years. A large increase in thyroid cancer has been reported in children exposed to the fallout at Chernobyl in the former USSR. Early reports of an increased risk were met with some skepticism. However, a consensus now exists among the scientific community that the increased incidence of thyroid cancer in children is real even though the magnitude of the increase may be influenced by factors such as iodine deficiency.

MENTAL RETARDATION

In Nagasaki and Hiroshima, fetal exposure of 0.12 to 0.23 Gray at 8 to 15 weeks' gestational age was associated with severe mental retardation, the frequency and severity of which were related to the magnitude of the radiation dose. A smaller increase in the frequency of mental retardation was seen in those exposed at 16 to 25 weeks' gestation. A recent evaluation of children exposed in utero at Nagasaki or Hiroshima does not demonstrate a threshold for changes in IQ scores or school performance due to in utero radiation exposure. Special populations, such as extremely low birth weight infants, may undergo multiple radiologic examinations over a short period. Because the radiation dose to the head in a computed tomographic scan in a 25-week-old infant can be 78 to 105 mGray (7.8 to 10.5 rads), computed tomography should be used sparingly for premature infants particularly when other imaging techniques are available.

SECONDARY CANCERS

Children who have received radiotherapy for cancer are at risk of secondary cancers later in life. Some of the risk appears to be associated with the combination of radiation exposure and/or genetic predisposition. An increase in risk of secondary cancers has been demonstrated up to 25 years after exposure. Leukemia, thyroid cancer, and sarcomas of bone and soft tissue are common secondary cancers.

CONCLUSIONS

The report of the National Council on Radiation Protection provides guidance for pediatricians, outlining methods for limiting the radiation dose administered to children during radiologic procedures. In addition, the report provides guidance for determining whether a procedure is warranted. For physicians with patients who have been exposed to high levels of environmental radiation, such as that from the Chernobyl disaster, guidelines are available for medical follow-up.

The risk of cancer associated with most diagnos-

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**TABLE.** Estimates of the Radiation Dose From Medical Diagnostic Procedures, the Three Mile Island Accident, and Background Radiation

<table>
<thead>
<tr>
<th>Exposure/Procedure</th>
<th>Gray</th>
<th>Rad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Mile Island accident: average whole-body dose*</td>
<td>0.0001–0.00025</td>
<td>0.01–0.025</td>
</tr>
<tr>
<td>Dental radiography:†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bite wing: surface dose in 1981</td>
<td>0.00334</td>
<td>0.334</td>
</tr>
<tr>
<td>Cephalometric examinations: surface dose in 1981</td>
<td>0.00062</td>
<td>0.062</td>
</tr>
<tr>
<td>Chest x-ray:†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface dose</td>
<td>0.00020</td>
<td>0.02</td>
</tr>
<tr>
<td>Marrow dose</td>
<td>0.0001</td>
<td>0.01</td>
</tr>
<tr>
<td>Abdomen x-ray:†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface dose</td>
<td>0.00063</td>
<td>0.063</td>
</tr>
<tr>
<td>Marrow dose</td>
<td>0.00147</td>
<td>0.147</td>
</tr>
<tr>
<td>Background radiation (excluding radon)</td>
<td>0.00089–0.0049</td>
<td>0.069–0.49</td>
</tr>
<tr>
<td>Mammography: glandular absorbed dose in 1985†‡</td>
<td>0.0007–0.0089</td>
<td>0.07–0.890</td>
</tr>
<tr>
<td>Pediatric angiocardiotherapy†</td>
<td>0.00055–0.00162 per sec</td>
<td>0.055–0.162 per sec</td>
</tr>
<tr>
<td>Coronary angiographic fluoroscopy—36 minutes: skin dose†</td>
<td>0.6</td>
<td>60</td>
</tr>
<tr>
<td>Computed tomography: dose to lens of eye in 1978§</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerebral angiography</td>
<td>0.10</td>
<td>5–10</td>
</tr>
<tr>
<td>Skull examination (head)</td>
<td>0.015</td>
<td>1.5</td>
</tr>
<tr>
<td>Computed tomography:‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface dose (skin): single slice</td>
<td>0.02–0.1</td>
<td>2–10</td>
</tr>
<tr>
<td>Marrow dose: per head examination</td>
<td>0.0022</td>
<td>0.220</td>
</tr>
<tr>
<td>Marrow dose: per body examination</td>
<td>0.0035</td>
<td>0.350</td>
</tr>
</tbody>
</table>

† From NCRP, 1989.
‡ From Hendee, 1995.
§ From Isherwood et al, 1978.
¶ From Wilson-Costello et al, 1996.

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Figure. For x-rays and gamma rays, rad = rem and Gray = Sievert. However, for particle radiation, such as neutrons and alpha particles, a quality factor of 10 to 20 is applied to account for the different biological effect of this type of radiation. For example, 1 rad of alpha radiation = 20 rem.
tic radiation is low, and its use should not be restricted when needed for correct diagnosis. Any medical procedure has a risk and diagnostic radiography is no exception. A comparison of medical procedures and their respective radiation doses is provided in the Table, which can help the clinician, the patient, and the family have a more informed opinion concerning risk. Limitation of radiation, shielding sensitive body parts like the thyroid, and assuring a nonpregnant state are all components of good medical practice. Therapeutic doses should only be used when the indications are unmistakable and the risk justified as in the treatment of malignant tumors.

COMMITTEE ON ENVIRONMENTAL HEALTH, 1996 to 1997
Ruth A. Etzel, MD, PhD, Chairperson
Sophie J. Balk, MD
Cynthia F. Bearer, MD, PhD
Mark D. Miller, MD
Katherine M. Shea, MD, MPH
Peter R. Simon, MD, MPH
LIAISON REPRESENTATIVES
Henry Falk, MD
Centers for Disease Control and Prevention
Robert W. Miller, MD
National Cancer Institute
Walter Rogan, MD
National Institute of Environmental Health Sciences
CONSULTANT
Christie Eheman, PhD

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