ABSTRACT

A second follow-up was conducted of 1742 women with tuberculosis who were treated in one of two sanatoria in Massachusetts between 1930 and 1956. One hospital treated only children under the age of 17. Patient follow-up was extended from 1975 through 1980, and an additional 18 breast cancers were identified from hospital records, death certificates, and responses to a mailed questionnaire. Vital status was established for 97% of the subjects. Among 1044 women who were examined an average of 101 times with X-ray fluoroscopies during lung collapse therapy, 55 breast cancers were observed in contrast to 35.8 expected, based on incidence rates from the general population. No excess was found for 698 women treated by other means (19 observed versus 22.8 expected). Excess breast cancer risk did not appear until 15 years after initial exposure and was present at the end of 50 years of observation. Risk appeared to decrease with increasing age at exposure. Estimates of radiation dose to the breast for individuals (mean = 96 rad) were based on the most current information for the numbers of fluoroscopies, reconstruction of exposure conditions, and absorbed dose calculations. The relation between dose and breast cancer risk was consistent with linearity up to 400 rads (4 Gy). For 10-year survivors, the absolute excess risk was 5.5/1 million woman-year-rad, the excess relative risk per rad was 0.73%, and the relative risk at 100 rad was 1.7. These data indicate that a woman's lifetime risk of breast cancer is decreased with increasing age at exposure.

INTRODUCTION

Cancer of the breast will occur in 1 of every 11 women and only cardiovascular disease will result in more deaths (1). The breast is one of the most sensitive human tissues to the carcinogenic effects of ionizing radiation, and increased risks have been seen among atomic bomb survivors (2), patients with tuberculosis given multiple chest fluoroscopies (3–6), women given radiotherapy for various benign disorders (7–9), and women occupationally exposed to radiation (10–11). Understandably, these findings raise concern about the possible long-term risks associated with radiation, such as mammography screening of asymptomatic women (12), the general use of diagnostic radiology (13), radiotherapy in conservative treatment of breast cancer (14), and occupational exposures (10). Studies of women with tuberculosis have been particularly informative because of the fractionated nature of their exposure, the relative ease in dose reconstruction based upon numbers of fluoroscopies, and the potential for long follow-up, spanning up to six decades. This report represents a second follow-up for patients admitted for tuberculosis to two sanatoria in Massachusetts (5).

SUBJECTS AND METHODS

Study Population. The methods of identifying study subjects and of data collection have been described (5, 15–17). Females discharged alive between 1930 and 1956 after treatment for tuberculosis in two sanatoria in Middlesex County, Massachusetts, were followed to determine cancer incidence and causes of death through December 31, 1980. A review of medical records at these institutions identified 1044 patients who received pneumothorax or pneumoperitoneum treatments, which involved lung collapse and repeated fluoroscopic X-ray exposures (exposed), and 698 patients who received therapy modes not dependent on fluoroscopy (nonexposed). Excluded from these counts are eight exposed and eight nonexposed subjects for whom no additional follow-up information could be obtained after hospital discharge. The original publication listed 1047 exposed and 717 nonexposed subjects (5). Six subjects were subsequently excluded because the diagnosis of pulmonary tuberculosis could not be confirmed. Following an extensive update of exposure information, including information obtained from other sanatoria, five subjects originally classified as nonexposed were moved to the exposed category.

Dosimetry. The methods used to estimate absorbed doses to the breast from fluoroscopy have been presented in detail and were based on the number of fluoroscopies, reconstruction of exposure conditions, and absorbed dose calculations (15, 17). Estimates of the number of fluoroscopy examinations (mean = 101 among the exposed) were obtained from medical records of the original hospitalization and from records of hospitals to which the subjects were subsequently transferred. All hospitals in Massachusetts were surveyed. Additional information was obtained from interviews with the study subjects and with physicians who practiced at the institutions involved, and by physical measurements on X-ray equipment used during pneumotherapy. The average absorbed dose to the glandular tissue in the breast per roentgen of entrance skin exposure, free-in-air, was calculated for 26 specific exposure situations. The method used in these computations is given in the Appendix. Cumulative absorbed doses now range from 1 to 640 rad with a mean of 96 rad (0.96 Gy). Compared to the first follow-up (15), the average breast dose is now 36% less, 38% for adults and 29% for adolescents.

Patient Follow-up. Study subjects were followed for survival and cancer incidence by a variety of mechanisms. A comprehensive effort was launched in 1972 to determine the vital status of all subjects and to obtain a questionnaire from those alive (5). The follow-up methods then used were continued and extended (15, 16). They now include periodic questionnaire mailings, monitoring of the patients' medical contacts and relevant vital statistic events in the states of their residence, examination of city directories, searches of state driver registries, contacts with relatives, credit bureau searches, post office address correction requests, and requests for address information for women receiving benefits from the Health Care Financing Administration. Mortality was ascertained through these sources, as well as the Social Security Administration, the National Death Index, and the death indices of several states. An intensive effort during 1979–1981 to contact 998 study subjects not known to be deceased resulted in updated follow-up information for 77%. Nonrespondents for whom no evidence of cancer was uncovered in the sources surveyed were assumed to be free of breast cancer. The overall location rate increased from 94 to 97% (Table 1).

The current analysis includes 74 reports of primary breast cancer,
one exposed subject, a malignancy in one breast was diagnosed in 1966 verified by the review of medical records and pathology reports. For code 174 in the eighth Revision of the International Classification of Diseases Adapted for Use in the United States (19). These cancers were verified by the review of medical records and pathology reports. For one exposed subject, a malignancy in one breast was diagnosed in 1966 and another, in the opposite breast, in 1976. For another exposed subject, a breast malignancy in 1970 was followed by one in the opposite breast in 1979.

Data Analysis. WY3 of follow-up began with the date of discharge from the index hospitalization (mean, 1942). The end of follow-up was taken as the date of death for those who died, the date lost to follow-up for those unlocatable, the date of breast cancer diagnosis for those who developed breast cancer, or December 1980 if the above events had not intervened. The average age at the start of follow-up was 25.5 years, and the average length of follow-up to December 1980 was 30.2 years. Age at first exposure was determined from the date of first pneumotheraphy treatment for the exposed, or from the date of the first fluoroscopic diagnosis for the nonexposed. The mean year of first "exposure" was 1940, and the corresponding mean age was 24.1 years for both groups combined.

Expected numbers of breast cancers were estimated by multiplying the age- and calendar year-specific woman-years of observation times the appropriate incidence rates from the population of Connecticut (20). The cancer O/E ratios were computed. CI for the O/E ratios were calculated by exact methods. Standardized RR were obtained as the ratio of the O/E among the exposed to the O/E among the nonexposed. Absolute excess risks have been estimated (Fig. 1), using observed cases and WY by methods described elsewhere (21). In order to maintain consistency of definitions with the Connecticut population rates, second cancers in the contralateral breast were also included in computing the O/E ratios.

A Poisson regression modeling breast cancer incidence was fitted to the data for 10-year survivors stratified on absorbed dose, age at exposure, attained age, and time after exposure. The methods used were essentially those previously described (22). The nonexposed were assigned a value for absorbed dose D = 0. Linear, quadratic, and linear-quadratic models were evaluated for goodness of fit. Parameter estimates of the excess RR per rad were made.

The risks attributable annually to 1 rad of absorbed dose to the breast per million WY were also evaluated by using Poisson regression modeling (22). Because ionizing radiation is known to result in excess cases of breast cancer, one-sided statistical tests were usually applied. A 90% CI which does not embrace 1.0 implies that the RR is significantly different from unity at the 5% level on a one-sided test.

RESULTS

Among the 1,742 women with tuberculosis, 74 primary breast cancers were identified, including 56 cases reported previously (5). Five of the 18 new cancers occurred prior to 1975, the date of the last follow-up. All but two of the newly detected cases occurred 25 or more years after first diagnosis or pneumothorax treatment. The principal findings are summarized in Table 2. Among the 1,044 women repeatedly exposed to chest fluoroscopies, 30,932 woman-years of observation accumulated, and 55 breast cancers developed, in contrast to 35.8 expected (O/E = 1.54; 90% CI = 1.2–1.9). The 698 nonexposed subjects accumulated 21,486 woman-years of observation, with 19 cases observed versus 22.8 expected (O/E = 0.83; 90% CI = 0.6–1.2).

Compared with the nonexposed, the exposed women were at an 86% increased risk of developing breast cancer (RR = 1.86; 90% CI = 1.2–2.8) (Table 3). No clear excess of breast cancer has yet occurred among those first exposed to chest fluoroscopies under age 15 years or among those over age 35 years. Average absorbed doses varied by age at exposure, and were highest for those under age 20 years. Doses were higher among adolescents with tuberculosis due to a greater number of treatments and due to the higher average energy delivered per unit mass per roentgen to the thinner adolescent breast (see Appendix). Risk was highest in the 15–19 year age group, and was lower at older ages.

Among the exposed, increased risk of breast cancer was seen only after the first 15 years of follow-up (Table 4), and it remained high throughout the subsequent follow-up periods. When the exposed women were compared to those not exposed, there was a suggestion that risk was highest among patients followed for more than 35 years after initial irradiation.

Risk of developing breast cancer appeared to increase with increasing absorbed dose and was highest among those exposed to more than 300 rad (3 Gy) (Table 5; Fig. 1). Among 10-year survivors, the overall estimates of excess breast cancers was 8.6/106 WY-rad. Overall, the excess RR per 100 rad (1 Gy) was 1.01, which implies a doubling dose of about 99 rad (0.99 Gy) (Table 6). The excess risk was highest for those exposed under age 20 years. At higher exposure ages the excess RR was not statistically significant.

Poisson regression analysis estimated the incidence attributable to fluoroscopic exposure of 5.5 breast cancers/1 million women/year/gy (5.5/106 WY-rad) (Table 7). The trend over time was not significant on statistical testing.

The parameter estimates from fitting of linear, quadratic, and linear-quadratic models by Poisson regression are given in Table 8. From the linear model, the excess RR per rad was estimated as 0.73 ± 0.36% (SE). It fitted the data well as

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Table 1 Number of women with tuberculosis by follow-up status as of December 31, 1980, and exposure group

<table>
<thead>
<tr>
<th>Follow-up status</th>
<th>Exposed (%)</th>
<th>Nonexposed (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alive</td>
<td>653 (62.6)</td>
<td>462 (66.2)</td>
<td>1,115 (64.0)</td>
</tr>
<tr>
<td>Dead</td>
<td>367 (35.2)</td>
<td>215 (30.8)</td>
<td>582 (33.4)</td>
</tr>
<tr>
<td>Lost</td>
<td>24 (2.3)</td>
<td>21 (3.0)</td>
<td>45 (2.6)</td>
</tr>
<tr>
<td>Total</td>
<td>1,044 (100)</td>
<td>698 (100)</td>
<td>1,742 (100)</td>
</tr>
</tbody>
</table>

---

Table 2 Observed and expected breast cancers and woman-years at risk by exposure group

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Exposed</th>
<th>Nonexposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of women*</td>
<td>1,044</td>
<td>698</td>
</tr>
<tr>
<td>Breast cancer cases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed (O)</td>
<td>55*</td>
<td>19</td>
</tr>
<tr>
<td>Expected (E)</td>
<td>35.8</td>
<td>22.8</td>
</tr>
<tr>
<td>O/E</td>
<td>1.54</td>
<td>0.83</td>
</tr>
<tr>
<td>Woman-years at risk</td>
<td>30,932</td>
<td>21,486</td>
</tr>
<tr>
<td>Incidence/1,000 WY</td>
<td>1.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* Includes 2 second primary tumors in the contralateral breast.
Table 3  Observed and expected breast cancer cases and woman-years at risk by age at first fluoroscopic exposure (exposed) or at first tuberculosis diagnosis (nonexposed)

<table>
<thead>
<tr>
<th>Age at first exposure or diagnosis (yr)</th>
<th>Statistic</th>
<th>6–14</th>
<th>15–19</th>
<th>20–24</th>
<th>25–29</th>
<th>30–34</th>
<th>35–39</th>
<th>40–66</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed</td>
<td>Breast cancer cases</td>
<td>98</td>
<td>243</td>
<td>265</td>
<td>198</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>1,044</td>
</tr>
<tr>
<td>Observed (O)</td>
<td></td>
<td>2</td>
<td>19</td>
<td>11</td>
<td>14</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>Expected (E)</td>
<td></td>
<td>1.8</td>
<td>6.3</td>
<td>8.6</td>
<td>8.3</td>
<td>4.6</td>
<td>3.6</td>
<td>2.5</td>
<td>35.8</td>
</tr>
<tr>
<td>O/E</td>
<td></td>
<td>1.09</td>
<td>3.01</td>
<td>1.28</td>
<td>1.68</td>
<td>0.65</td>
<td>1.40</td>
<td>0.40</td>
<td>1.54</td>
</tr>
<tr>
<td>Woman-years at risk</td>
<td></td>
<td>2,710</td>
<td>7,565</td>
<td>7,937</td>
<td>6,292</td>
<td>2,957</td>
<td>2,131</td>
<td>1,340</td>
<td>30,932</td>
</tr>
<tr>
<td>Excess breast cancer cases/10^5 WY/rad</td>
<td></td>
<td>0.4</td>
<td>15.2</td>
<td>3.0</td>
<td>10.3</td>
<td>-7.4</td>
<td>8.5</td>
<td>-23.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Mean absorbed dose, rad</td>
<td></td>
<td>133</td>
<td>110</td>
<td>101</td>
<td>88</td>
<td>73</td>
<td>79</td>
<td>49</td>
<td>96</td>
</tr>
</tbody>
</table>

Nonexposed

<table>
<thead>
<tr>
<th>Breast cancer cases</th>
<th>193</th>
<th>138</th>
<th>98</th>
<th>92</th>
<th>77</th>
<th>53</th>
<th>47</th>
<th>698</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed (O)</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Expected (E)</td>
<td>4.9</td>
<td>3.8</td>
<td>3.1</td>
<td>3.6</td>
<td>3.3</td>
<td>2.4</td>
<td>1.8</td>
<td>22.8</td>
</tr>
<tr>
<td>O/E</td>
<td>1.03</td>
<td>0.52</td>
<td>1.61</td>
<td>0.56</td>
<td>0.31</td>
<td>1.26</td>
<td>0.56</td>
<td>0.83</td>
</tr>
<tr>
<td>Woman-years at risk</td>
<td>6,911</td>
<td>4,450</td>
<td>2,957</td>
<td>2,725</td>
<td>2,128</td>
<td>1,359</td>
<td>956</td>
<td>21,486</td>
</tr>
<tr>
<td>Relative risk</td>
<td>1.06</td>
<td>5.79</td>
<td>3.00</td>
<td>2.10</td>
<td>1.11</td>
<td>0.71</td>
<td>1.86</td>
<td></td>
</tr>
</tbody>
</table>

* Includes 21 subjects with unknown dose.
* Includes 2 second primary tumors in the contralateral breast.
* P < 0.05.
* Excludes subjects with unknown dose.

Table 4  Observed and expected breast cancer cases and woman-years at risk by time after first exposure (exposed) or after first tuberculosis diagnosis (nonexposed)

<table>
<thead>
<tr>
<th>Time after first exposure (yr)</th>
<th>Statistic</th>
<th>0–4</th>
<th>5–9</th>
<th>10–14</th>
<th>15–19</th>
<th>20–24</th>
<th>25–29</th>
<th>30–34</th>
<th>35–39</th>
<th>≥40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed</td>
<td>Breast cancer cases</td>
<td>1,044</td>
<td>953</td>
<td>899</td>
<td>863</td>
<td>836</td>
<td>787</td>
<td>698</td>
<td>512</td>
<td>336</td>
</tr>
<tr>
<td>Observed (O)</td>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Expected (E)</td>
<td></td>
<td>0.7</td>
<td>1.5</td>
<td>2.5</td>
<td>3.9</td>
<td>5.3</td>
<td>6.5</td>
<td>6.4</td>
<td>5.3</td>
<td>3.7</td>
</tr>
<tr>
<td>O/E</td>
<td></td>
<td>1.38</td>
<td>1.31</td>
<td>0.80</td>
<td>1.56</td>
<td>1.89</td>
<td>1.54</td>
<td>1.56</td>
<td>1.72</td>
<td>1.34</td>
</tr>
<tr>
<td>Woman-years at risk</td>
<td></td>
<td>3,491</td>
<td>4,512</td>
<td>4,386</td>
<td>4,251</td>
<td>4,065</td>
<td>3,749</td>
<td>3,031</td>
<td>2,141</td>
<td>1,305</td>
</tr>
<tr>
<td>Incidence of breast cancer/100,000 WY</td>
<td></td>
<td>28.6</td>
<td>44.3</td>
<td>45.6</td>
<td>141.1</td>
<td>246.0</td>
<td>266.7</td>
<td>329.9</td>
<td>420.3</td>
<td>383.1</td>
</tr>
<tr>
<td>Excess breast cancer cases/10^5 WY/rad</td>
<td></td>
<td>1.6</td>
<td>1.2</td>
<td>-1.3</td>
<td>4.2</td>
<td>15.0</td>
<td>10.8</td>
<td>16.4</td>
<td>15.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Mean absorbed dose, rad</td>
<td></td>
<td>50</td>
<td>84</td>
<td>93</td>
<td>120</td>
<td>77</td>
<td>87</td>
<td>72</td>
<td>110</td>
<td>120</td>
</tr>
</tbody>
</table>

Nonexposed

<table>
<thead>
<tr>
<th>Breast cancer cases</th>
<th>698</th>
<th>636</th>
<th>608</th>
<th>582</th>
<th>563</th>
<th>544</th>
<th>470</th>
<th>349</th>
<th>256</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed (O)</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Expected (E)</td>
<td>0.5</td>
<td>0.9</td>
<td>1.4</td>
<td>2.2</td>
<td>3.1</td>
<td>3.9</td>
<td>3.8</td>
<td>3.3</td>
<td>3.7</td>
</tr>
<tr>
<td>O/E</td>
<td>0.00</td>
<td>3.29</td>
<td>0.70</td>
<td>0.00</td>
<td>0.65</td>
<td>1.54</td>
<td>1.31</td>
<td>0.30</td>
<td>0.27</td>
</tr>
<tr>
<td>Woman-years at risk</td>
<td>2,418</td>
<td>2,979</td>
<td>2,904</td>
<td>2,844</td>
<td>2,769</td>
<td>2,585</td>
<td>2,038</td>
<td>1,506</td>
<td>1,444</td>
</tr>
<tr>
<td>Relative risk</td>
<td>&gt;1.00</td>
<td>0.40</td>
<td>0.14</td>
<td>&gt;1.00</td>
<td>2.91</td>
<td>1.00</td>
<td>1.20</td>
<td>5.66</td>
<td>4.96</td>
</tr>
</tbody>
</table>

* * * See footnotes to Table 3.
* * * P < 0.05.

indicated by comparing the deviance to that of the two-parameter model. The pure quadratic model provided the worst fit to the data. The larger value of α1 in the linear-quadratic than in the linear model reflects the negative sign of α2, which has no biological interpretation.

DISCUSSION

Multiple chest fluoroscopies were found to increase the risk of breast cancer among women followed for up to 50 years after initial exposure. The most notable finding from our second follow-up is the absence of a reduction in risk among women observed for the longest intervals. In contrast to studies of radiation-induced leukemia, where risk approaches background rates after 20 or more years (23), the risk of radiation-induced breast cancer may very well remain throughout life and never return to normal levels. Since risk was concentrated among women exposed during ages of early reproductive life, it appears that environmental insults occurring during these ages may permanently determine subsequent risk for developing breast cancer (24).

The influence of age at exposure is perhaps the second most notable finding. Although based on small numbers, women over age 30 years when exposed appeared to have lower risks than younger women. This observation is generally consistent with the decreasing risk of breast cancer with increasing age at exposure seen among atomic bomb survivors (2), Swedish patients treated for benign breast disease (7), and Canadian women with tuberculosis (6). Exposure in mid-life or later may carry with it little additional risk of breast cancer for women, perhaps because of reduced hormonal stimulation of the breast tissue or because death from other causes may intervene before breast cancer occurs.

No excess of breast cancer was seen for women younger than 15 years at exposure; however, few women were exposed at these ages. Studies of A-bomb survivors have shown an in-
increased risk for those exposed under the age of 10 years (2), as have studies of women treated with radiation during childhood for thymic enlargement (25).

Although a minimum latent period for radiation-induced breast cancer of 5 years after exposure has been assumed (26), empirical data do not show a convincing excess of risk until after 10 years, and in our study until after 15 years. To some extent, our finding may reflect the relatively young age of women treated with pneumotherapy, since radiation-induced cancers tend to appear at the same ages as naturally occurring ones, i.e., in later life. These data further suggest that subsequent hormonal or other influences later in life appear necessary for an initiated tumor to develop (27).

A linear relationship between absorbed dose and breast cancer incidence is supported by the present analysis and by the studies of the A-bomb survivors and of women given radiotherapy for postpartum mastitis (28, 29). These studies have produced fairly consistent estimates of excess risk that range between 3.0 and 9.5 cases per 10^5 WY-rad in the age groups 10–39 years. A study of tuberculosis patients treated with pneumotherapy in the 1930s and 1940s in Canada, and followed for mortality during 1950–1977, is the only one that suggests a nonlinear dose-response relationship (6). In our data, there was little evidence of such nonlinearity.

Similarities in age-specific risk coefficients and the dose-response relationships of our results and those of the A-bomb survivors and women with postpartum mastitis suggest that dose fractionation does not affect the risk of breast cancer appreciably. This finding is contrary to animal experiments where dose fractionation or protraction clearly reduces the subsequent mammary cancer risk for most low-linear energy transfer exposures (30); however, the influence of dose fractionation on mammary tumor induction in animals does appear to be less than for other tissues (27).

The results of our study should be viewed in the light of several methodological concerns. Risk estimates and patterns of risk by absorbed dose categories are based upon certain assumptions for dosimetry. While the number of fluoroscopies has been accurately counted, the conversion to absorbed dose to the breast is primarily dependent upon the length of time the fluoroscopy machines were on during the examination and the orientation of the patient. Although these parameters were estimated from patient and physician interviews, different assumptions could change the risk estimates (15). The updated doses are based on essentially the same methods and they did not result in risk estimates appreciably different from those reported previously (5). Breast cancer incidence could be underestimated if some nonrespondents to the questionnaire had breast cancer or if women dying with breast cancer did not have this fact noted on their death certificate or discharge summary. There is no reason to believe, however, that the level of underreporting would differ between exposed and nonexposed women. Further, the high location rate, over 97%, minimizes the influence that lost to follow-up might have on the findings.

The studies that report an association between radiation...
exposure and subsequent breast cancer also exhibit latent period
distributions that appear inversely related to age at exposure, i.e.,
younger women at exposure seem to have a longer time to
appearance of excess breast cancers than older women. The
evidence to date suggests that radiogenic risk increases in
proportion to the population background risk from other causes
and that the relative risk model is applicable for prospective
risk projections (31). None of the studies have followed appreciable
numbers of women exposed early in life to the oldest
ages, however, so estimates of lifetime risks cannot be verified
empirically. The experience of this cohort is far from complete
since, as of 1980, 63% were known to be alive. Useful informa-
tion on the not yet resolved questions will be obtained
through continuing follow-up.

ACKNOWLEDGMENTS

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Daniel Martin of the Health Care Financing Administration provided
assistance in follow-up of subjects in the roster of Medicare recipients
in Massachusetts. Dr. Dale Preston of the Radiation Epidemiology
Branch, National Cancer Institute, kindly computed estimates of the
excess cases per rad and of the parameters of the dose-response models,
and Dr. Charles Land of that organization provided helpful suggestions
and comments on the manuscript.

APPENDIX

Table. Absorbed dose (rad) to glandular tissue in the breast per roentgen (R) of
entrance exposure, free-in-air (units are rad/R).*

<table>
<thead>
<tr>
<th>Patient orientation</th>
<th>Shutter setting</th>
<th>Shutter setting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open</td>
<td>Shut</td>
</tr>
<tr>
<td>Anterior-posterior</td>
<td>Posterior-anterior</td>
<td></td>
</tr>
<tr>
<td>(OAP)</td>
<td>(OPA)</td>
<td>Same side#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other side#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Same Other side#</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>Exposure yr</td>
<td>Anterior-posterior (SAP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Posterior-anterior (SPA)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Same side#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other side#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Same Other side#</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>&lt;1948c</td>
<td>0.324</td>
</tr>
<tr>
<td></td>
<td>≥1948</td>
<td>0.408</td>
</tr>
<tr>
<td></td>
<td>≤17</td>
<td>0.555</td>
</tr>
<tr>
<td></td>
<td>&lt;17</td>
<td>0.673</td>
</tr>
<tr>
<td>Pneumoperitoneum</td>
<td>Adult</td>
<td>0.0060</td>
</tr>
<tr>
<td></td>
<td>&lt;1948c</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

Absorbed dose computation

\[ Q = N \times T \times X, \text{ total entrance exposure, } R. \]

From pneumothorax:

\[ D = Q [0.81 (0.25 OAP + 0.75 OPA) + 0.19 (0.25 SAP + 0.75 SPA)]. \]

From pneumoperitoneum:

\[ D = Q (0.25 OAP + 0.75 OPA). \]

Computative example: The absorbed breast dose for a woman who
received 18 pneumothorax treatments in 1947 when 16 years old
and 30 treatments in 1948 when 17 is computed as:

\[ Q_{1947} = 18 \times 15 \times 0.8533 = 379.3 \text{ R} \]

\[ Q_{1948} = 30 \times 15 \times 0.4017 = 230.7 \text{ R} \]

\[ D_{1947} = 379.3 \times [0.81 (0.25 \times 0.55 + 0.75 \times 0.006) + 0.19 (0.25 \times (0.510 \times 0.002)/2 + 0.75 \times (0.100 + 0.001)/2)] = 31.2 \text{ rad} \]

\[ D_{1948} = 230.7 \times [0.81 (0.25 \times 0.408 + 0.75 \times 0.010) + 0.19 (0.25 \times (0.366 + 0.003)/2 \times 0.75 \times (0.015 + 0.001)/2)] = 17.8 \text{ rad} \]

The absorbed dose to the breast (15).

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