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Evaluation of Work-Related Medical X Rays in Epidemiological Studies of Nuclear Workers

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Introduction

Occupational epidemiological studies provide an opportunity to evaluate the health risks from exposure to low levels of ionizing radiation. These studies rarely include exposures from medical sources. In two studies of atomic bomb survivors, the authors concluded that medical X-ray exposures should be evaluated to better understand the effects of low-level exposures to ionizing radiation (*1*, *2*). The aim of this study was to investigate multiple sources of worker exposures to external ionizing radiation at a uranium enrichment plant (a low-level exposure facility) between the early 1940s and 1990s and determine if work-related X-ray exposures added substantially to their cumulative occupational dose.

Methods

Bone marrow doses from work-related X rays were estimated for 297 workers, who are cases and controls for a multiple myeloma study, at a gaseous diffusion plant between the early 1940s and the late 1990s. Only 45 of these workers had other occupational radiation exposures monitored with personal dosimeters. Radiation exposure from work-related X rays was determined by the number and type of X rays conducted on the 297 workers at the facility. Cumulative bone marrow doses due to these X-ray exposures were calculated by converting entrance skin exposures to bone marrow doses (*3*). Conversion factors account for different types and energy of radiation, partial-body irradiation, exposure times, orientation, type of X-ray examination, and the configuration and composition of the body.

Work-related X-ray exposure data from all 297 workers were evaluated to describe the distribution of bone marrow doses associated with X-ray techniques used in the medical surveillance program. A comparison of bone marrow doses from external radiation exposure and from work-related X rays was performed on the subset of 45 workers to investigate the significance of each source of radiation exposure to their respective cumulative dose. Also evaluated was the potential for misclassification resulting from excluding work-related X-ray exposures from the cumulative dose and the presence of any statistical relationships between these sources of radiation exposure.

Results

Several findings are noted as a result of this study: (1) Among these 297 workers, the chest X ray was performed most frequently (78.6%), followed by extremities (12.3%), lumbar spine (2.3%), and skull (2.2%). Seven different examinations account for the remaining X rays (4.6%). (2) Chest X rays using the photofluorographic technique during the 1940s and 1950s delivered a bone marrow dose that was two orders of magnitude greater than the conventional method [about 800 mrad (8 mGy) compared to $<$10 mrad (0.1 Gy), respectively]. (3) Among the subset of 45 workers having radiation exposure from both chest X rays and external sources, bone marrow doses from work-related chest X rays were about 50 times greater than the doses from occupational sources, accounting for over 90% of their combined-source cumulative dose estimate. (4) Over 75% of the 45 workers would have been misclassified among the five groups if work-related chest X-ray exposure had not been not included in their estimate of cumulative bone marrow dose. (5) As a group, radiation workers were expected to receive more work-related chest X rays because they were subject to more frequent medical monitoring than non-radiation workers. Thus it was expected that external radiation exposure measured with the personal dosimeter would be related to exposure from work-related chest X rays. However, no statistically significant relationship was identified.

Discussion

Previous occupational epidemiological studies of radiation workers have not included radiation exposure from work-related X-ray examinations for several reasons. First, the historical radiation monitoring records did not include work-related X-ray exposure estimates. Second, there is a perception that the contribution from chest X rays would be very low compared to other sources of radiation encountered at the workplace (*4*). Third, epidemiologists have traditionally assumed that exposure from work-related X rays would be distributed randomly throughout the working population, so effects associated with this exposure would not influence the analysis (*5*). Fourth, the time and effort necessary to retrieve, interpret and evaluate this source of radiation exposure is large and costly. More recently, the practice of excluding health-related radiation exposure from occupational exposure records has been supported by recommendations from technical advisory committees and federal regulations.

Excluding work-related chest X rays as a source of radiation exposure, the largest contributor to cumulative dose at this low-dose facility, resulted in many individuals being misclassified. Historical documents indicated that radiation workers received more chest X rays than other, nonexposed workers. This suggests that work-related chest X-ray exposures may not be distributed randomly among the population. Failure to detect this association in this study may be due to the limited number of workers in this analysis ($n = 45$). An assessment of the full study population would provide additional insights.

Conclusions

Radiation exposure from work-related chest X rays accounts for more than 90% of the cumulative bone marrow dose received by workers employed at a low-dose facility in the U.S. between the early 1940s and the late 1990s. The photofluorographic chest X-ray technique used in the medical surveillance program was responsible for delivering the large dose to the bone marrow compared to the conventional technique. This study suggests that work-related chest X-ray exposures should be considered as a source of radiation exposure in epidemiological studies involving workers with low cumulative doses (e.g. cumulative dose $<$20 cGy), especially when high-dose X-ray examinations of the workforce were routinely conducted.

The results of this study may be applicable to other facilities that followed similar medical surveillance activities or used similar technology to obtain X-ray images. Ongoing research at NIOSH suggests that these activities and technology have been employed at other sites under study, but they occurred at different periods in history and may vary with regard to surveillance frequencies. Therefore, generalization of the results of this study to other facilities must account for site-specific medical surveillance activities and technologies used over time.

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Medical Radiation Exposures in Occupational Studies: Discussion

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The presentations in this session are linked by the populations studied (occupational cohorts), by the exposure setting (incidental or intentional exposure to medical sources of ionizing radiation), and by the aim of the studies, which is to evaluate risk of cancer after exposure to ionizing radiation. Continued interest in the effects of low-dose exposure to ionizing radiation places these occupational radiation research studies at the forefront of the current debate about the limits of epidemiology. Among the most pressing aspects of these potential limits is the ability within low-dose studies to adjust for sources of bias (e.g. due to selection and information) and error (e.g. in measurement of exposures or confounding factors) (*1, 2*). All four presentations made in this session illustrate attempts to circumvent these limitations and to improve the ability to measure low-dose effects of exposure to ionizing radiation.

Studies of Low-Dose Radiation Exposure in Medical Workers

As noted in Dr. Mabuchi's presentation, early studies of medical workers exposed to ionizing radiation have provided substantial qualitative evidence for the causation of skin cancer and leukemia at relatively high doses of X rays. Most of these early studies focused on male workers. More recent studies of radiological technologists, discussed by Dr. Sigurdson, include large cohorts of female workers, and they may prove highly relevant for breast cancer and malignant melanoma risk estimation, especially for low-dose, fractionated exposures among a healthy Western population. Until recently, the lack of available quantitative exposure information limited the ability to evaluate risks in these studies quantitatively.

Challenges in Quantitative Exposure Assessment

Many of the sources of uncertainty identified in the previous session on diagnostic patient exposures apply to workers exposed to medical radiation sources. Some procedures (e.g. fluoroscopy and mammography) use very low-energy photon exposures to improve contrast in soft tissues. The doses from these exposures are highly dependent on features of the medical examinations, and they are specific to instrumentation as well as the characteristics of patient (*3, 4*).

The incidental nature of the radiation exposure of medical personnel makes exposure assessment in these cohorts similar to that conducted for nuclear worker studies. The recent linkage of cohorts to national databases containing badge dosimetry data should facilitate exposure assessment for these studies from the 1970s onward; however, uncertainties still exist regarding the placement of these badges with respect to protective shielding, their orientation with respect to source, and the adequacy of monitoring for the range of photon energies encountered. A greater challenge is the ability to obtain subject-specific information for exposures occurring during the 1940s and 1950s, when doses were likely highest and individual monitoring did not occur. Dr. Neton's approach to imputation and Dr. Cardarelli's evaluation of subjects' medical records suggest two reasonable exposure assessment alternatives in cohort and case–control studies, respectively.

Medical Exposures in Nuclear Worker Studies

Few studies have evaluated medical exposures in nuclear workers. A study of multiple myeloma among five nuclear worker cohorts indicated no change in the dose–response coefficient for external badge dose after qualitative information about medical X-ray exposures was incorporated (*5*). A sensitivity analysis of doses among Hanford workers also suggests that bias in the dose–response relationship would be minimal if distributed non-differentially with respect to measured exposure (*6*). Dr. Cardarelli's discovery that higher-dose photofluorographic X-ray procedures were used routinely before the 1960s at a uranium processing facility raises questions about how widespread these practices may have been across the DOE complex and whether their use is associated with the recorded occupational dose.

Considerations for Future Evaluation of Medical Radiation Exposures in Occupational Studies

It is anticipated that medical exposures in occupational studies will receive greater attention as techniques improve for reducing sources of bias and uncertainty in studies of low-dose ionizing radiation exposure. The ability to identify interactions (both exposure–environment and gene–exposure–environment) within studies of current radiological technologists and, within nuclear worker studies, to reduce important sources of exposure bias and uncertainty greatly increases the relevance of these studies in low-dose epidemiology and risk assessment of ionizing radiation.

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EXTENDED ABSTRACTS

American Statistical Association Conference on Radiation and Health

Howard Johnson Plaza Resort, Deerfield Beach, Florida, June 23–26, 2002

The 15th ASA Conference on Radiation and Health, held June 23–26, 2002 in Deerfield Beach, FL, offered a unique forum for radiation researchers from a variety of disciplines to present and discuss recent findings and current issues related to the effects of radiation exposures on human health. The Conference also furnished investigators the opportunity to learn about new approaches to problems within their disciplines.

The focus of the 2002 conference was current issues in radiation and health with sessions on:

1. lung cancer related to residential radon exposures and cancer risk from plutonium exposure;
2. novel efforts at low doses such as the bystander effect, i.e. the response of neighboring cells not directly irradiated;
3. diagnostic medical radiation, which is the primary source of U.S. population exposure from man-made radiation;
4. sensitive subpopulations and novel approaches to characterize genetic predisposition to radiogenic cancers; and
5. exposure and cancer risks in medical radiation workers, plus a recent finding that work-required X-ray examinations account for the bulk of radiation exposure in a cohort of nuclear workers.

The Conference also included a timely and provocative banquet presentation on ‘‘Nuclear and Radiological Terrorism.’’ The 15th biannual conference on Radiation and Health proved to be as stimulating and informative as in previous years. The participants enthusiastically look forward to the 16th conference to be held in 2004!

Susan Preston-Martin, Co-Chair
James M. Smith, Co-Chair