ORIGINAL ARTICLE

Effectiveness of Policies on Reducing Exposure to Ionizing Radiation From Medical Imaging: A Systematic Review

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Abstract

Purpose: The use of medical imaging has expanded greatly in the past three decades, raising concern about potential unwanted carcinogenic harms associated with exposure to ionizing radiation among patients. This study summarizes evidence of efficacy of interventions that have prompted policies, and structural-level interventions aimed at reducing radiation dose and risk of cancer, especially among women.

Methods: Using standard terms, we conducted searches in MEDLINE, Scopus, and Web of Science, and de-duplicated retrieved citations. We hand-searched the reference section of eligible studies and contacted radiology experts to identify studies missed from electronic searches. Two reviewers screened retrieved citations based on predefined eligibility criteria, to identify relevant studies, extract key information from each, rate the quality of evidence, and summarize data in tabular and graphical format.

Results: From a total of 1,543 unique citations identified from all sources, 16 were included for data extraction. Half of the studies focused on reduction of ionizing exposure from CT, and half on x-ray or fluoroscopy. Identified interventions were broadly categorized as: policy or structural intervention (two; 13%); multipronged (four; 25%); dose-feedback system (five; 31%); provision of training (four; 25%); and quality-control audit (one; 6%). In general, multipronged programs had a higher range for dose reduction (22%-74%), followed by policy/structural interventions (37%-50%).

Conclusions: Existing evidence on the effectiveness of policies aimed at reducing patient radiation dose is disperse and low in quality. Compared with other approaches, multipronged efforts may offer more patient protection.

Key Words: Systematic review, health policy, ionizing radiation, medical imaging, medical diagnosis

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INTRODUCTION

The use of medical imaging technology has become indispensable in modern health care, and its role in diagnostic and therapeutic procedures has expanded greatly in the past three decades. The overall volume of CT procedures, the most significant contributor to radiation dose, have increased from 3 million in 1980, to 26 million in 1998, to more than 70 million in 2008 [1,2]. Consequently, patient exposure to ionizing radiation has increased significantly. The annual per capita radiation dose was 3.6 (mSv) in the early 1980s, and radiation from medical sources contributed only 0.54 mSv to this dose, with the remainder attributable to cosmic rays, radon, soil, and construction materials. In 2006, medical radiation contributed 3 mSv to the annual dose, which raised the per capita dose to 6.2 mSv, averaged over the US population [1].

Radiation dose for CT is often represented as the "effective dose" and reported in mSv, calculated by multiplying the dose to each irradiated organ by a biologic weighting factor and summing the products for all exposed organs. The effective dose is defined as the dose that, if delivered uniformly to the whole body, would produce the same health consequences caused by a dose delivered to one

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or more specific organs. The effective dose is more usefully viewed as a concept for developing radiation protection standards and setting dose limits for occupationally exposed individuals. The International Commission on Radiological Protection (ICRP) has stated [3]:

> Effective dose is intended for use as a protection quantity. The main uses of effective dose are the prospective dose assessment for planning and optimization in radiological protection, and demonstration of compliance with dose limits for regulatory purposes. Effective dose is not recommended for epidemiological evaluations, nor should it be used for detailed specific retrospective investigations of individual exposure and risk.

The ICRP estimates that the incidence risk of cancer in all organs among individuals exposed to ionizing radiation increases by 5% per Sievert [3], although several assumptions are inherent in this estimate, and it has been criticized in other studies as being highly speculative [4]. Risk assessment modeling studies have predicted thousands of radiation-induced cancers and cancer deaths based on such assumptions; in 2007, Brenner and Hall estimated that 1%-2% of all cancers in the United States are caused by CT studies, and Berrington de González et al predicted in 2009 that 29,000 additional cancers and 14,500 cancer deaths are caused by CT examinations each year [2,5].

In recent years, many policy interventions have been developed at various levels, including institutional, state, and federal, to improve radiation reporting in health care, limit medical radiation dose to certain thresholds, and develop industry-level standards. For example, major academic medical centers and hospitals typically require employees who may be exposed to radiation to monitor and report their radiation exposure, with a typical annual limit of 50 mSv [6]. Many states now require formal reporting of radiation dose when patients undergo procedures that expose them to ionizing radiation. Most prominently, a California law that was enacted on July 1, 2012 requires the reporting of certain dose parameters for all diagnostic CT examinations in the radiology report [7].

Federal regulations regarding the quality (and dose limits) for mammography have long been in place, formalized by the Mammography Quality Standards Act (MQSA), which became law in October 1992 [8]. Finally, guidelines have been created at the level of professional societies, such as the ACR's Appropriateness Criteria®, which are evidence-based guidelines to assist physicians in making the most-appropriate imaging or treatment decision for a specific clinical condition, while taking dose into prominent consideration [9].

In many cases, the efficacy of these institutional and government policy interventions in reducing ionizing radiation exposure is not known. This review seeks to summarize the effectiveness of policy interventions that are aimed at reducing ionizing radiation exposure resulting from diagnostic imaging, as currently reported in the literature, with a focus on breast cancer, using standard systematic review methods. Another purpose of the review is to potentially inform a research-funding initiative by the California Breast Cancer Research Program (CBCRP) aimed at reducing environmental sources of exposure to carcinogens [10].

METHODS

Protocol Development

We generally applied standard systematic review methods for our data collection process. For protocol development, we first created a detailed protocol for searching, extracting, and analyzing the data. We applied the PICO (population, intervention, control, and outcome) framework to inform our protocol development. Although the primary objective of this review was to assess the evidence of effectiveness of interventions in the context of breast cancer among women, our initial database searches led us to conclude that our search strategies should be expanded beyond breast cancer among women. Thus, we defined our **PICOs** of interest to reflect that concept: **P** (populations at risk of exposure to ionizing radiation, owing to medical imaging for diagnostic purposes); **I** (policies or interventions with potential policy implications aimed at reducing risk of exposure to ionizing radiation associated with medical imaging); **C** (no intervention, existing policies, or standard of care); and **O** (health endpoints, measure of exposure, quality improvement).

Search for Relevant Studies

The data collection process began with identification of relevant studies using three sources: (1) electronic databases; (2) references cited in relevant citations; and (3) radiology experts. First, a medical librarian, in consultation with the authors, created a PubMed search designed to locate articles from both MEDLINE and the portion of PubMed not in MEDLINE. The search strategy contained MeSH (main subject heading) keywords reflecting radiation exposure sources (eg, "diagnostic imaging," "ionizing radiation"); patient protection (eg, "patient safety"); and radiation exposure (eg, "radiation