Lifetime exposure to radiation from imaging investigations

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ABSTRACT

OBJECTIVE To assess levels of radiation exposure from diagnostic imaging among family practice patients, the degree to which these levels exceed recommended levels, and whether radiation exposure level is associated with a diagnosis of cancer.

DESIGN Chart abstraction.

SETTING Six practices in an academic family medicine centre and 1 family practice in the community.

PARTICIPANTS Two hundred fifty patients between the ages of 45 and 65 years with at least 20 years' information on their charts.

MAIN OUTCOME MEASURES All x-ray procedures, the dates they were performed, the amount of radiation exposure from each procedure based on standard charts, and whether diagnosis of any form of cancer was noted on the chart.

RESULTS Mean lifetime radiation exposure was 14.94 mSv. No patients had exceeded the lifetime occupational limit of 400 mSv; however, 4.4% of patients had exceeded the annual occupational exposure limit of 20 mSv at some point in their lives. Mean lifetime exposure of those with cancer was found to be significantly higher than exposure of those without cancer. This difference was due to the extra radiation exposure after the cancer was diagnosed; hence a causal relationship was not shown. Mean level of annual radiation exposure from diagnostic imaging has been slowly increasing since the 1960s.

CONCLUSION The current lifetime level of radiation to which patients are exposed by diagnostic imaging appears to be far below the maximum recommended level. Some patients do exceed the maximum recommended annual level, but this overexposure is generally warranted due to serious medical illness or injury, and the benefit outweighs the risk. We found no evidence of an association between these low levels of radiation and development of cancer.

EDITOR'S KEY POINTS

- This retrospective chart abstraction research aimed to determine how much radiation patients are being exposed to and whether it exceeds the recommended level. Do current practices increase risk of overexposure? Is there an association between the amount of prior radiation exposure and a diagnosis of cancer?
- No patients were found to have exceeded the proposed 400-mSv lifetime radiation exposure limit, yet 4.4% of patients were found to have exceeded the annual exposure limit of 20 mSv at some point during their lives.
- Patients' annual exposure to diagnostic radiation has steadily increased over the past 45 years.

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Radiologic diagnostic procedures are an important and widely used part of patient care. In industrialized countries, diagnostic x-ray examinations have been reported at frequencies ranging from 200 to 2000 examinations per thousand inhabitants yearly.[1-3] Each of these procedures exposes patients to a certain amount of radiation.

While the relationship between low levels of radiation and adverse health effects is not entirely clear,[4-6] many studies have shown that, in some patients, accumulated doses of low-level radiation can cause adverse health effects, such as leukemia and other cancers.[7-10] Government agencies formulated guidelines for occupational exposures to regulate how much radiation people may be exposed to with negligible risk.[11-15] Most guidelines are given as annual radiation limits, usually at 20 millisieverts (mSv/y). Some authors have suggested, however, that a lifetime maximum radiation limit of 400 mSv also is appropriate.[14]

Guidelines do not specify how much radiation patients may receive from medical procedures. Radiation protection principles suggest that procedures must produce a net benefit to be justified.[11] Many standard procedures are assumed to be of net benefit because radiation exposure per procedure is relatively low. If an average person accumulates too much radiation through these procedures, however, not every case would have a net benefit. Very few studies have looked at how much radiation people are exposed to through diagnostic imaging over the course of their lives.

We searched MEDLINE using such key words as "radiation exposure," "diagnostic imaging," and "lifetime." Many of the reports we found were based on simulations estimating population-based exposures or reported the amount of radiation per procedure rather than per patient over time from multiple procedures. In 1996, Hart and Le Heron[16] examined records of general practitioners and a district general hospital in order to estimate radiation exposure. They found that less than 1% of patients had an effective lifetime dose of more than 100 mSv. The maximum lifetime recommended dose is 400 mSv.

The past decade has seen increased use of computed tomography, increased use of imaging other than x-rays (such as magnetic resonance imaging), and decreased use of gastrointestinal imaging (such as upper gastrointestinal series). It is difficult to know how these changes have affected diagnostic radiation exposure among patients. We conducted this study to determine how much radiation our patients are being exposed to and whether it exceeds the recommended level. Do current practices increase risk of overexposure? Is there an association between the amount of prior radiation exposure and a diagnosis of cancer?

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METHODS

A chart review assessed 250 charts randomly selected from 6 practices at the Queen's University Family Medical Centre of Hotel Dieu Hospital (200 charts) and from a community physician's practice in Kingston, Ont (50 charts). To be eligible, charts had to contain at least 20 years of medical history and belong to patients between 45 and 65 years old. The age range was chosen to allow sufficient time for exposure to have occurred and for potentially related cancers to have developed, but to exclude older patients who would be more likely to have received large amounts of radiation for end-of-life care, which is less likely to cause any harm.[15]

All reports of or references to diagnostic imaging that involved exposure to ionizing radiation were recorded. Radiation therapy was not included in this study. The total effective dose of radiation exposure for each procedure was determined based on values reported by the Advisory Committee on Radiological Protection for the Atomic Energy Control Board of Canada[17] and others.[18] Total annual and lifetime effective doses were calculated for each patient and compared with established annual occupational limits and with a proposed lifetime occupational exposure limit.[13,14] All diagnoses of cancer were recorded, and the mean effective radiation doses of patients with and without cancer were determined. The mean lifetime radiation exposure of those with and without cancer was compared using a 2-tailed Student *t* test. The proportion of patients over the annual occupational exposure limit in these 2 groups was also compared using chi-square analysis.

The sample size of 250 provided a 95% confidence level, with a 5% margin of error, that the exposure level we determined would accurately reflect the exposure level in our population of patients. This project received approval from the Queen's University Research Ethics Board.

RESULTS

Average age of the 250 patients was 54.3 years (SD 5.9). There were 152 (61%) female and 98 (39%) male patients.

Mean lifetime radiation exposure was 14.94 mSv. No patients were found to have exceeded the proposed 400-mSv lifetime radiation exposure limit; 4.4% of patients, however, were found to have exceeded the annual exposure limit of 20 mSv at some point during their lives (**Table 1**).

Table 1. Lifetime radiation exposure among those with and without cancer diagnoses

PATIENT CHARACTERISTICS	ALL PATIENTS	NO CANCER DIAGNOSIS	CANCER DIAGNOSIS	*P* VALUE*
N	250	219	31	
Female patients (%)	152 (61%)	129 (59%)	23 (74%)	.1
Mean age (SD)	54.3 (5.9)	54.9 (6.1)	54.2 (5.9)	.5
Mean lifetime radiation dose in mSv (95% CI)	14.94 (12.8-17.0)	12.79 (10.9-14.6)	30.13 (21.2-39.0)	<.001
Mean number of procedures (95% CI)	13.93 (12.6-15.2)	12.65 (11.4-13.9)	23.00 (17.8-28.1)	<.001
Number over annual recommended limit (%)	11 (4.4%)	4 (1.8%)	7 (22.6%)	<.001

*Student *t* test for means and chi-square test for proportions, comparing patients with and without cancer.

According to their charts, 31 people had been diagnosed with some form of cancer. Mean effective dose among patients diagnosed with cancer was significantly higher ($P<.05$) than among those who had not been diagnosed with cancer. The percentage of patients who exceeded the annual recommended exposure limit was also significantly higher ($P<.05$) among patients with cancer (**Table 1**).

Patients with cancer, however, generally were exposed to more radiation immediately before and after their diagnosis in connection with diagnosing, staging, and monitoring their disease. For those patients, the annual occupational limit was exceeded in the year of diagnosis or the year immediately following diagnosis. In order to adjust for this discrepancy, we randomly matched a patient of the same age and sex who did not have cancer to each patient who did, essentially conducting a small case-control study within the sample. We then looked at the exposure to diagnostic radiation for each person with cancer before the diagnosis of cancer and compared it with the exposure to diagnostic radiation for the matched person before that same age. There was then no difference in the radiation exposure between the 2 groups (cases 8.2 mSv vs controls 7.4 mSv, $P=.79$).

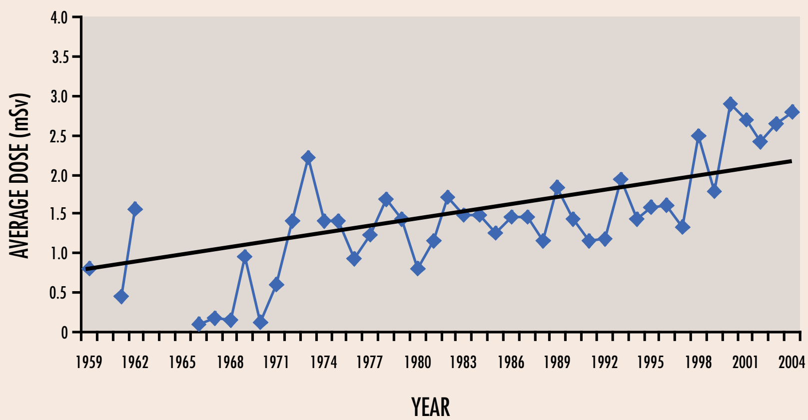
We also looked at the change in mean annual dose of radiation over time (**Figure 1**). Annual diagnostic radiation exposure of patients has steadily increased over the past 45 years.

DISCUSSION

Our results suggest that current practices result in lifetime radiation exposure well below the proposed lifetime limit of 400 mSv. Our methods probably underestimated the actual radiation exposure because dental x-ray examinations were not included and charts often did not include the entire history. It is also possible that some imaging procedures were omitted from consultant reports or were done while patients were away from home, and the results might not have been sent to family physicians' offices. Because the average exposure was so far below the limit, however, it is unlikely that these additions would place anyone over the proposed limit.

It is notable that the researchers who proposed the 400-mSv lifetime occupational exposure limit concluded that this limit did not need to be monitored because it was well above what most people are exposed to in their occupations.[14] Our study shows that this limit is also well above what patients are exposed to from diagnostic imaging. A more useful limit could be the annual limit for occupational radiation exposure. This limit is used by government regulators for occupational exposure.[12,13] Some people exceed this annual limit because of medical imaging and could be at increased risk of adverse health outcomes. Patients who exceeded annual limits, however, often did so in a year when they had serious trauma or developed serious illness requiring multiple computed tomographic scans, angiographic procedures, or other procedures involving relatively large doses of radiation. In these cases it is likely that the benefit of exceeding the annual limit outweighed the associated risk.

Figure 1. Mean annual radiation dose to those undergoing diagnostic imaging procedures



Mean yearly radiation exposure among those undergoing imaging procedures was found to be rising over the years recorded (**Figure 1**). This trend is likely due to the increased availability and use of computed tomography, which has a relatively high radiation dose per procedure.[19] Previous doses could have actually been higher than calculated in this study because older x-ray machines tended to deliver higher doses of radiation.[16] Nevertheless, this trend suggests that average radiation exposure and potential risk of overexposure could be higher in future generations.

Lifetime exposure to radiation was higher among patients with cancer. This higher exposure, however, did not occur before the diagnosis of cancer but was probably caused, at least in part, by the procedures used to diagnose cancer. Previous studies have shown a relationship between cancer and low levels of radiation,[7-9] yet we found no evidence that diagnostic radiation exposure causes cancer among primary care patients. Large-scale database linkage studies would be needed to determine causation more accurately.

CONCLUSION

Current practices in diagnostic imaging do not lead to patients' exceeding proposed lifetime limits for occupational radiation exposure. Annual limits for occupational exposure are exceeded by 4.4% of patients. While significantly higher levels of radiation exposure were seen among patients diagnosed with cancer than among patients not diagnosed with cancer, much of the exposure seemed to be related to diagnosis and monitoring of the cancer itself and did not suggest causation. Patients' exposure to diagnostic radiation has been increasing steadily over the past 4 decades. This increase could have health consequences that we do not yet recognize; it would be prudent to continue to limit radiation exposure whenever possible and to order imaging involving radiation only when perceived benefit would outweigh potential risk.

Contributors

Mr Hall *helped with the development of the research protocol, collected the data, and did the initial reporting of the data.* **Dr Godwin** *contributed to the development of the research idea and protocol, monitored the study, and prepared the article for publication.* **Dr Clarke** *conceived the original idea, helped conceptualize the study, and provided editorial input.*

Competing interests

None declared

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