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Children, medical radiation and the environment: An important dialogue☆

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ABSTRACT

There are unique considerations in the medical care of children, which includes the use of medical imaging. Medical imaging is frequently necessary and is essential in diagnosis and management of children with illness and injury. Much of medical imaging requires ionizing radiation. While virtually all diagnostic imaging radiation is considered low-dose level, there is still a broad misperception about what modalities use ionizing radiation and how much radiation risk exists in the medical environment. A discussion of radiation exposure is especially relevant in children due to their increased vulnerability, including to radiation-induced cancer. Ionizing radiation is both naturally occurring and man-made, including medical sources that have been increasing over the past few decades and can vary in radiation dose both between different modalities and for similar examinations. Perspectives vary regarding cancer risk and levels of radiation resulting from diagnostic imaging, however most medical and scientific organization support the perspective that the risk of cancer at these levels is uncertain. It is important to have balanced and informed resources for the use of ionizing radiation in the care of children, and it is equally important to assure that the delivery of this content is appropriate to the audience to which it is intended. For these reasons, it is valuable to review the issues related to use of ionizing radiation in medical imaging in children.

Medical imaging is an essential and valuable tool in the healthcare of children (Fuchs and Sox, 2001; Hricak et al., 2001; Rubin, 2014; Pandharipande et al., 2016a, 2016b). Many of the diagnostic medical imaging examinations depend on a type of radiation called ionizing radiation. These are the majority of all imaging examinations and include radiography (standard x-rays), fluoroscopy, nuclear medicine (also called nuclear imaging), and computed tomography (CT) (Dorfman et al., 2011). The word radiation, whether related to medical imaging or not, is emotive with reactions that can range from concern to fear (Cohen, 2015). Part of this is due the more familiar higher levels of radiation exposure, such as the atomic bombs in Hiroshima and Nagasaki, or nuclear disasters such as those resulting from reactor failures in Chernobyl and Fukushima. The fact the radiation is more or less silent, outside of the range of human senses, is also a contributing factor in public perception. Children are unique and often a more vulnerable population to environmental hazards including radiation exposure. There is a great deal of misunderstanding, as well, about the use of radiation in diagnostic imaging, resultant doses, and potential risks, mostly related to the possibility of developing a radiation induced cancer. Given the above points, medical radiation exposure in children is a relevant environmental topic. The following discussion is not intended to be exhaustive but will cover salient aspects of ionizing radiation use in diagnostic imaging, emphasizing aspects in children. These include the use of radiation in medical imaging (including unique considerations in children, patterns of medical imaging use, radiation dose, variability in exposures, and radiation-related risks), awareness (or lack thereof) about radiation in diagnostic imaging, the general landscape of care of children relevant to the imaging providers, the need for informed dialogues, and resources and strategies for improved communications.

In this discussion, it will be important to understand a few definitions. When the word “radiation” is used in this article, it refers to ionizing radiation, a higher energy form of radiation on the electromagnetic spectrum. When radiation “dose” is used, that generally implies a dose *estimate* as we did not know the actual patient dose for virtually any patient. In addition, when discussing about “parents”, this includes other caregivers who may not be parents. For the purposes of this discussion, “radiation risks” are limited to the biological effect of development of cancer. Finally, the range of exposures for virtually all medical imaging is considered low level. The relative radiation dose

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(estimates) delivered from medical imaging examinations will be discussed in greater detail in the following material.

1. Radiation in medical imaging

Children are in general more vulnerable to ionizing radiation primarily due to their growing tissues. About 25% of cancer types have increased radiation susceptibility in childhood (e.g. leukemia, thyroid, skin, breast and brain cancer); about 15% are equal in childhood and adult (e.g. colon cancer) and a minority, 10% are more susceptible to radiation in adults (e.g. lung cancer). Twenty percent of cancer types have uncertain age related susceptibility (United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR, 2013). In addition, it is important to realize that all cancers are not radiation sensitive. Indeed, for about 30% of all cancer sites there is a weak relationship or none at all, between radiation exposure and risk at any age. For example, melanoma and Hodgkin lymphoma are such types of cancer. Children also have a longer lifespan in which radiation induced tumors can develop. Finally, for similar radiation exposures, doses to small children's organs and tissues will be greater than that to an adult size patient. Together, these factors make consideration of radiation use in children especially topical.

The care of children can be challenging (Frush and Frush, 2008). This is amplified in the preverbal years when initial assessment is dependent on clinical signs, and care provider reporting. Disorders can be different in children than in adults and even when similar may warrant different imaging strategies. A prime example in the United States is in the evaluation of acute abdomen pain, especially compelling for a diagnosis of appendicitis. In this setting, ultrasound is the first line modality to use for children but CT is the first line for use in most anyone over 18 years of age, even with an identical clinical scenario (Frush et al., 2009). Not all referrers are familiar with childhood diseases and this may promote increase imaging use, or use of incorrect imaging strategies. In acute, especially emergent settings, caregiver anxiety, lack of control, surrogate status (parents making decisions for children), and general health care setting unfamiliarity (e.g., in a CT scanner) may exist; these factors may influence care pathways. In the emergency setting in the U.S., 87.3% of CT examinations are performed outside of centers for pediatric focus care (Larson et al., 2011). There are technical considerations as well that are more appropriate for pediatric imaging and imaging practices and providers may be unfamiliar with techniques appropriate for pediatric imaging care. In one example, Kim et al. found that about 40% of all CT examinations performed outside of their institution did not have the correct number of series (or phases) for evaluation of appendicitis in these children in whom CT was felt to be warranted (Kim et al., 2015). Just as with care at the point of service, the imaging care of children requires knowledge of appropriate pediatric techniques and attendant radiation exposure.

It is important to understand that radiation exposure can be a result of medical imaging but radiation is also naturally occurring and children and adults are exposed to small amounts of radiation each day (Table 1). An estimation of the exposure due to these natural sources in the United States is about 3.0–3.2 milli Sievert (mSv) annually (NCRP Report No 160, 2009). Natural radiation levels vary due to geological differences; exposure in certain areas can be more than 200 times higher than the global average. Natural radiation comes from many sources including more than 60 naturally-occurring radioactive materials found in soil, water and air. Radon, a naturally-occurring radioactive gas, emanates from rock and soil and is the main source of natural radiation. Every day, people inhale and ingest radionuclides from air, food and water. People are also exposed to natural radiation from cosmic rays, particularly at high altitude. On average, 80% of the annual dose that a person receives from background radiation is due to these naturally occurring terrestrial and cosmic radiation sources.

Human exposure to radiation also comes from man-made sources ranging from nuclear power generation to medical uses of radiation diagnosis or treatment. Today, the most common man-made sources of ionizing radiation are X-ray machines and other medical devices. Diagnostic imaging doses in children range from < 0.01 mSv (a routine frontal chest x-ray in a small child) to about 5–10 mSv for an abdomen/pelvis CT depending on indication (how the CT is performed) and age. Radiation doses in fluoroscopy studies vary and may be slightly higher than most x-rays. Doses in nuclear imaging examinations generally are around routine fluoroscopic doses although doses in nuclear cardiology and PET imaging, including for PET CT, can be higher. CT doses can range from < 1 mSv for a straightforward extremity evaluation (for example ankle or wrist) through about 2–3 mSv for a brain CT, 4–6 mSv for a chest CT and 4–10 mSv for an abdomen and pelvis CT in the pediatric population. Comparison of doses for common examinations can be seen in Table 2.

The use of medical imaging that depends on ionizing radiation to create images stands at about 4 billion examinations annually globally (UNSCEAR, 2008). Given this wide performance, the radiation used (and tentative concern) have been considered a public health issue. In addition the use of medical imaging has grown substantially over the past three decades, and in the U.S about the resultant medical imaging radiation exposure is 600% higher than it was about 30 years ago (NCRP Report No 160, 2009) although there is a recent slight decline in performance in children (Parker et al., 2015; Townsend et al., 2010; Menoch et al., 2012). In the U.S., about 50% of the per capita annual exposure to ionizing radiation is from medical sources and half of that (or a total of 25% of the annual exposure levels) is from CT alone. The other half of the annual exposure to radiation of the US population is almost exclusively from natural sources (occupational exposure accounts for a small percentage) (UNSCEAR, 2008). Radiography is still the most common imaging examination in children (Perez et al., 2015) (Tables 3, 4). Pediatric CT accounts for 5–11% of all CT exams performed across all ages (Dorfman et al., 2011; Perez et al., 2015; Mettler et al., 2000; Frush et al., 2015). In the pediatric age group, head CT in children accounts for the majority of the CT examinations performed (Frush et al., 2015). Of note, up to about 25% of head CTs are performed in young children, under 7 years of age (Frush et al., 2015).

Doses for pediatric examinations can vary (Miglioretti et al., 2013;

Table 1
Annual average radiation doses and ranges per person worldwide.
Source: Adapted, with permission, from UNSCEAR (2010): UNSCEAR 2008 Report. Sources and effects of ionizing radiation. Volume I: Sources: Report to the General Assembly, Scientific Annexes A and B. UNSCEAR 2008 Report. United Nations Scientific Committee on the Effects of Atomic Radiation. New York: United Nations.) used with permission

Source or mode	Annual average doses worldwide and their typical ranges (mSv[a])
Natural sources of exposure	
Inhalation (radon gas)	1.26 (0.2–10)[b]
Ingestion (food and drinking water)	0.29 (0.2–1)
External terrestrial	0.48 (0.3–1)[c]
Cosmic radiation	0.39 (0.3–1)[d]
Total natural	2.4 (1–13)[e]
Human-made sources of exposure	
Medical diagnosis (not therapy)	0.6 (~0–20+)
Others (e.g. nuclear energy and previous nuclear weapons tests)	~0.005
Total artificial	0.6 (~0–20+)
Total	3 (1–20+)

Table borrowed with permission WHO (Perez et al., 2015)
[a] mSv: millisievert, a unit of measurement of effective dose
[b] The dose is much higher in some dwellings
[c] The dose is higher in some locations
[d] The dose increases with altitude
[e] Large population groups receive 10–20 mSv