

# X-Ray Hesitancy: Patients' Radiophobic Concerns Over Medical X-rays

Paul A. Oakley<sup>1</sup>  and Deed E. Harrison<sup>2</sup>

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## Abstract

All too often the family physician, orthopedic surgeon, dentist or chiropractor is met with radiophobic concerns about X-ray imaging in the clinical setting. These concerns, however, are unwarranted fears based on common but ill-informed and perpetuated ideology versus current understanding of the effects of low-dose radiation exposures. Themes of X-ray hesitancy come in 3 forms: 1. All radiation exposures are harmful (i.e. carcinogenic); 2. Radiation exposures are cumulative; 3. Children are more susceptible to radiation. Herein we address these concerns and find that low-dose radiation activates the body's adaptive responses and leads to reduced cancers. Low-dose radiation is not cumulative as long as enough time (e.g. 24 hrs) passes prior to a repeated exposure, and any damage is repaired, removed, or eliminated. Children have more active immune systems; the literature shows children are no more affected than adults by radiation exposures. Medical X-rays present a small, insignificant addition to background radiation exposure that is not likely to cause harm. Doctors and patients alike should be better informed of the lack of risks from diagnostic radiation and the decision to image should rely on the best evidence, unique needs of the patient, and the expertise of the physician—not radiophobia.

## Keywords

X-ray hesitancy, medical radiology, radiophobia, LNT, hormesis, low-dose radiation

## Introduction

All too often healthcare practitioners including the family physician, orthopedic surgeon, dentist and chiropractor are met with concerns and opposition to receiving radiological imaging in the setting of the clinical doctor-patient encounter.<sup>1-3</sup> Many of these concerns, however, are simply unwarranted fears based on common, but ill-informed and perpetuated ideology versus current understanding of the lack of risks from low-dose medical radiation that are in the exposure ranges of X-rays and CT scans (Figure 1<sup>4</sup>).

The use of diagnostic radiation leads to definitive and timely diagnosis, guides particular healthful interventions, is cost-effective, leads to more efficient medical triage, and reduces unnecessary hospital admissions and surgeries.<sup>5</sup> Thus, diagnostic radiological imaging is essential for effective and efficient health care. Alternatively, those patients who refrain from medical imaging due to fears from the perpetuated linear no-threshold (LNT) radiation risk ideology (and the presumed harms from “any and all” radiation) may face potential real harm from a “misdiagnosis.”<sup>6-8</sup>

Herein, we explore common concerns expressed by patients toward impending radiological investigations in the

setting of the clinical encounter. The current authors have greater than 35 years' of combined clinical experience; from this, we outline 3 main streams of thought on “X-ray hesitancy” that we have encountered clinically, read in mainstream media, and that has been reported in the peer-reviewed literature.<sup>1-3,9-12</sup> The first is the general concern about being exposed to any radiation, as “isn't radiation dangerous?” (i.e. “all radiation is harmful”). The second concern revolves around the patient who has had several X-rays in recent years and feels (or has been told) that they should avoid any further exposures (i.e. collective effective dose/dose additivity concept). The third concern revolves around parental apprehension over protecting their child from radiation as “they are

<sup>1</sup> Private Practice, Newmarket, ON Canada

<sup>2</sup> CBP Non Profit, Inc., Eagle, ID, USA

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## Corresponding Author:

Paul Oakley, Private Practice, Newmarket, Ontario, Canada L3Y8Y8.  
Email: docoakley.icc@gmail.com



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Medical Diagnostics mGy (Estimated maximum organ dose)	
<b>X-ray films</b>	
A – Chest (PA & Lat)	0.14
B – Dental Panoramic	0.7
C – Lumbar-Sacral Spine	2 – 3
D – Mammogram	2 – 4
<b>Radiotracer Imaging</b>	
E – Heart Stress (Tc-99m)	6 – 12
F – Bone (Tc-99m)	4 – 15
G – Dual Isotope Stress Test	40 – 45
H – PET: F-18 FDG (bladder)	55 – 80
<b>CT Scans (X-ray)</b> (multiple scan average dose)	
I – Chest CT	20 – 30
J – Head CT	30 – 50
K – Abdominal CT	22 – 60
L – Full Body CT	50 – 100
<b>Fluoroscopy/Procedures</b>	
M – Barium Contrast G.I.	10 – 22
N – Cardiac Catheterization	12 – 40
O – TIPS Procedure	400 – 1400

**Figure 1.** Radiation doses from different medical imaging.<sup>4</sup> Note typical CT ranges from 2-30 mGy; shown is “multiple scan average.”

only a child” (i.e. the presumption of extra susceptibility of children to radiation).

We summarize the common notions underpinning these 3 primary radiophobic patient concerns fueling X-ray hesitancy as follows:

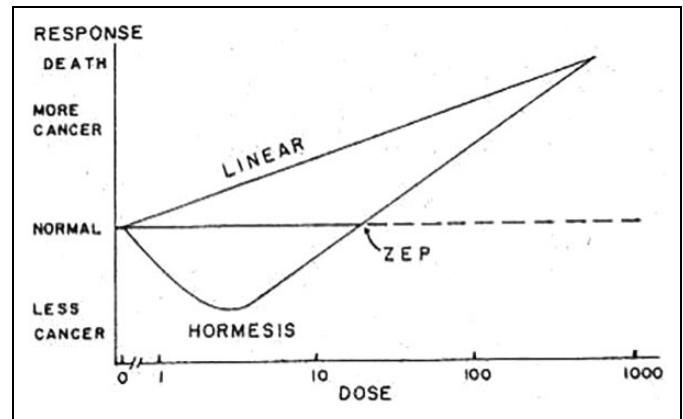
- All radiation exposures are harmful (LNT ideology for carcinogenicity);
- Radiation exposures are cumulative (dose additivity);
- Children are more susceptible to radiation.

Herein we discuss each notion and how it relates to the prevailing risk assessment ideology, why X-ray hesitancy is so common and likely will continue to be, and finally, how to work towards abating these misplaced concerns.

### Radiophobic Concern #1: All Radiation Exposures Are Harmful

“I don’t want to be exposed to any radiation,” “I would rather avoid the radiation exposure,” or “Isn’t radiation bad for you?” are common statements from patients concerned about impending exposures associated with medical imaging when an X-ray is proposed for assessment and diagnosis. These statements resonate with the common misconception spawned by LNT ideology that “any and all radiation is harmful.”

Conceptualized during the 1950s,<sup>13</sup> the LNT hypothesis is a simple model that extrapolates historic high-dose data, e.g. from the atomic bomb Life Span Study (LSS), linearly down

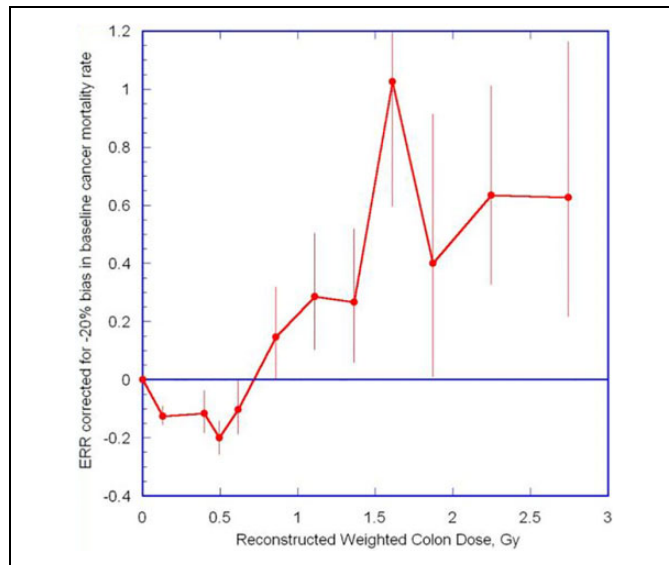


**Figure 2.** The linear no-threshold (LNT) model versus the hormesis model. “Linear” in the LNT model which is the linear extrapolation from the high dose atomic bomb Life Span Study data drawn linearly down to zero. This model assumes that any exposure has a cancer risk, and that the addition of exposures experienced at different times can be added to determine a cumulative effective dose. “Hormesis” is the quadratic shaped curve (U-shaped curve), where between zero and the zero-equivalent point (ZEP), there is less risk of cancer and health benefits occur. The ZEP represents the threshold where further doses increases the risk of cancer with increasing doses (Adapted from Luckey, 1991<sup>14</sup>).

to the zero point (Figure 2).<sup>14</sup> The LNT ideology assumes all radiation is harmful. This is because high-dose data extrapolation to the zero creates an assumption that *any* and *all* radiation above a zero dose is harmful, whereby harm implies radiation sickness, cancer or death. It must be mentioned that all of the national and international regulatory bodies (i.e. NAS BEIR, NCRP, ICRP, etc.) continue to use the LNT model for radiation risk assessment.

Importantly, the adoption of the LNT model that is used for radiation risk assessment is based on Hermann J. Muller’s original fruit fly experiments, where very high doses of X-rays were shown to produce transgenerational phenotypic changes that were claimed to occur from gene mutations.<sup>15</sup> It has only recently come to light that Muller’s Nobel prize research was likely not even peer-reviewed,<sup>16</sup> and also, decades later, shown to be incorrect.<sup>17-20</sup> It is pointed out that this research would have been heavily criticized at the time, but Muller evaded peer-review to claim primacy for the discovery of gene mutation.<sup>15</sup> Problematically, the belief that X-rays caused gene mutations (as opposed to the actual occurrence of gene deletions and other chromosomal rearrangements) quickly dominated the research field “misdirecting radiation genetics, environmental mutagenesis and cancer risk assessment until finally shown to be incorrect decades later.”<sup>16</sup>

The LNT ideology is underpinned by the LSS data which is used to assess exposure risks; in fact, the National Research Council states “the LSS cohort of Atomic-bomb survivors serves as the single most important source of data for evaluating risks of . . . radiation.”<sup>21(p.141)</sup> The BEIR VII report continues to be referenced as a primary source or “proof” for the LNT concept despite the fact that it has been heavily



**Figure 3.** Excess relative risk (ERR) correcting for a 20% bias in baseline cancer mortality rate for all solid cancers in atomic bomb survivors from the original data from Ozasa.<sup>27</sup> Error bars represent 95% confidence intervals. Threshold is at about 0.7 Gy (700 mGy) (Taken from Doss<sup>28,29</sup>).

criticized,<sup>22,23</sup> and importantly, basic radiobiology data (experiments examining molecular, cellular, and whole body responses to radiation exposures) shows failure of the LNT model to account for biological responses shown to occur following low-dose radiation exposures.<sup>24-26</sup> A recent update to the LSS data in 2012,<sup>27</sup> in fact, shows that the data better fits a non-linear, quadratic or hormetic dose-response model (Figure 3).<sup>28,29</sup> Thus, there is no longer evidential support from the LSS data for the LNT model. In actuality, a fatal criticism raised by Socol and Dobrzynski is that due to weak statistical power, the LSS data is unable to support the LNT concept.<sup>30</sup> Further, a recent panel has determined the LNT has no validity for risk assessment or radiation protection in the low-dose and dose-rate region and concluded that LNT use is actually “refuted by published epidemiology and radiation biology.”<sup>31</sup> Other independent assessments have come to the same conclusion.<sup>32,33</sup>

In contrast, the radiation hormesis ideology<sup>29,34,35</sup> suggests not all radiation exposures are equal; as goes the saying, “the poison is in the dose.” Low-dose exposures showing hormesis (biopositive dose-response) display health measures that go below the zero point, indicating a net increase in health parameters, including less cancers and less deaths (Figure 2).<sup>14</sup> The “zero-equivalent point” is the point where the dose is high enough that beyond this point, would then actually cause health detriment; this point is also the threshold of harm (i.e. bionegative dose threshold).

Current literature on radiation dose thresholds for carcinogenicity are fairly high and are legitimate evidence against the LNT model. For instance, Doss has pointed out that cancer induction was not observed in the atomic bomb survivors

exposed to doses less than 700 mSv.<sup>29</sup> Cuttler has recently pointed out that based on the 1958 UNSCEAR data, the dose threshold for leukemia in the LSS is much higher than previously thought at 1100 mGy (95% CI: 0.5-2.6 Gy); and importantly, only 0.5% of the population developed leukemia.<sup>36,37</sup> This is important as leukemia is the first type of cancer expected to occur after a latency period (peak ~ 5-7 years) following a pathologic radiation exposure.<sup>36</sup> Regardless of actual exposure level, even considering the lower threshold dose of 700 mGy, this represents about 2 to 3 orders of magnitude greater than the amount of radiation given from medical X-rays.

Any discussion of low-dose diagnostic radiation exposures needs to include consideration of background radiation exposures. Background exposures are inescapable and vary according to geographic location. In fact, background exposures can vary from 1-2 mGy per year to up to 260 mGy per year for known locations having super high background levels including Guarapari (Brazil), Karunagappally (India), Arkaroola (Australia), Yangjiang (China) as well as Ramsar (Iran) having 80 times the world average.<sup>38-40</sup> No known health risks have ever been documented to occur to people who live in super high background radiation locations. Only health benefits have been documented to occur to residents living in greater background radiation levels, for example, the incidence of cancers are significantly less for residents living at higher altitudes (e.g. Colorado vs. sea-level)<sup>41,42</sup> and lung cancer rates are significantly less in regions having greater radon levels.<sup>43,44</sup> Indeed, it is widely accepted that no harm has ever been documented from low-dose exposures of 100-200 mGy; only estimates based on the LNT predictions have fabricated harms from these innocuous exposure levels. The LNT model has yet to be validated at these low-levels.<sup>45,46</sup> Since X-rays are about 1-3 mGy, and CT scans are about 10-20 mGy, no harm should result from patients receiving medical X-rays.

## Radiophobic Concern #2: Radiation Exposures Are Cumulative

“I was told I couldn’t get any more X-rays,” “I’ve already had too many,” or the increasing scenario “I have had cancer and have to avoid any further radiation exposures” are common statements regarding patient concerns about receiving more radiation exposures. As discussed, the LNT ideology assumes all radiation is harmful (i.e. carcinogenic), but it also assumes that radiation is cumulative (i.e. dose additivity).

The dose additivity concept inherently presumes that all radiation doses received, regardless of source or exposure rate (i.e. acute/chronic), adds to a total effective cumulative dose (TCD). This TCD could then be tracked and limits could be set, so as to not surpass in order to avoid presumed health detriments associated with higher TCDs. In actuality, the LNT concept equates an increase in ones TCD to a linear increase in harm; that is, dose is used as a surrogate for risk.<sup>47</sup> In radiation protection terms, an example of the application of this concept is the use of a medical radiation tracking record which records

**Table 1.** Modern Low-Dose Radiation Paradigms.<sup>24</sup>

- Radiation mediated DNA damage is linearly evident across all doses, however LDR exposures do not alter cancer risk
- LDR activates DNA defense mechanisms which repair damaged DNA
- LDR removes damaged cells that are unable to be repaired by DNA repair systems via apoptotic and autophagic mechanisms
- LDR initiates G2/M cell cycle arrest thereby preventing unrepaired DNA alterations from undergoing mitosis while allowing time for DNA repair mechanisms to adequately restore the damaged DNA sequences
- LDR stimulates molecular gene/protein/miRNA expression profiles that are distinct from HDR exposed cells demonstrating that biological responses are not linearly related
- miRNAs are master regulators of LDR mediated cellular effects
- LDR elicits adaptive memory via epigenetic mechanisms by modifying gene-specific DNA methylation status
- LDR exposed cells communicate signals to the un-irradiated cells using bystander mechanisms thereby allowing tissues to respond as a whole and not as single cells
- LDR enhances immune-mediated removal of tumorigenic cancer cells
- LDR improves antioxidative capacity of normal cells thereby limiting tumor formation
- LDR protects against spontaneous neoplastic transformations

Note: LDR = low-dose radiation; HDR = high dose radiation.

all radiation exposures received throughout medical care to a patient over their lives. This concept has not only been proposed<sup>48</sup> but is currently practiced<sup>49</sup> as a model to help limit patient exposures as abiding with medical radiation reduction campaigns (e.g. Image Gently<sup>50</sup>; Image Wisely<sup>51</sup>; Choosing Wisely<sup>52</sup>; and ACR Appropriateness Criteria<sup>53</sup>).

The fatal flaw underpinning the concept of dose additivity as it relates to radiation is that the LNT concept is valid—which it is not—when used in the low-dose exposure range (e.g. X-rays; CT scans).<sup>45,46</sup> Harm, in terms of cancer for instance, is not linear with radiation dose. This is supported by substantial evidence showing adaptive responses from animals and humans after exposure to low-doses.<sup>53-56</sup> As mentioned, there has been an evolution in the understanding of radiobiological effects at the molecular, cellular and whole body level that is not consistent with LNT ideology; in fact, there are many now well accepted biological effects that occur at low-dose exposures and exposure rates, that do not occur at high-dose exposures and exposure rates (Table 1).<sup>24-26</sup> Divergent biological responses to low versus high radiation exposures and exposure rates are critical to consider in assessing any risks from radiation.

There have been several good reviews summarizing the understanding of the body's innate adaptive response system (DNA damage-control biosystem) to low levels of radiation.<sup>57-59</sup> At low-dose radiation exposures, it is noteworthy that there are numerous biopositive (healthful) effects that occur at different hierarchical levels including the molecular, cellular, organ, tissue and systemic levels.<sup>24-26,56-59</sup> More specifically, there are many adaptive defense mechanisms that get initiated

and/or upregulated upon low-dose exposures including DNA repair systems, programmed cell death, cell cycle delay, cellular senescence, adaptive memory, bystander effects (cells communicate to non-exposed cells), epigenetics, immune stimulation and tumor suppression.<sup>24,60</sup>

The ultimate expression of the biopositive cascading effects resulting from biological responses to low-dose radiation exposures (which are inhibited at high exposures) is the stimulation of immune system.<sup>54-56</sup> Due to this effect, many human inflammatory conditions, infections and diseases have been successfully treated with purposeful application of low-dose radiation either by exposing patients to radiation by imaging, or other means (e.g. radon inhalation) in the application of radiotherapy or low-dose ionizing radiation (LDR) therapy. Calabrese et al. have recently summarized historical evidence showing entrance exposures ranging from 30-100 roentgen proved to result in success rates of 75-90% for various diseases, and although relief was often reported after a single treatment session, most protocols delivered exposures in repeated sessions.<sup>61</sup> Cancers have also been successfully treated by LDR therapy by exposing patients to a total dose of 150 rad (1500 mGy) over a 5-week duration.<sup>62,63</sup>

The dose additivity concept implies that all exposures are additive, so theoretically, all images received and their corresponding radiation exposures will accumulate resulting in greater risks with the greater TCD. As mentioned, this LNT concept disregards the adaptive response system. Importantly, following an application of a single CT scan, Loubrich et al. determined that the DNA double-strand breaks (DSBs) that occurred after exposure were subsequently repaired between 5 and 24 hours after the scan.<sup>64</sup> The final DSB count was, in fact, less than it was prior to the original scan; this is evidence of hormesis.<sup>64</sup>

Thus, repeated medical imaging, as long as it is in the low-dose range (<100-200 mGy), will not result in an actual accumulation of radiation-induced DNA damage as long as the repeat imaging is done after a lag period (i.e. 24-hour) enabling the body's adaptive response systems to do their innate functions (i.e. prevent, repair, and/or remove DNA damage). This is why Oakley et al. argue that any valid risk assessment for spine deformity patients getting prolonged care (and repeated X-rays) should only be assessed for the exposure risks from a single X-ray event and not the TCD the patient will receive over several months or years of treatment.<sup>65</sup>

In a recent critical appraisal of methodological quality of studies investigating the risk of cancer from CT scans and other sources of radiation, Schultz et al. (2020) determined from 25 studies from an original 62 articles meeting the inclusion/exclusion criteria, that 21 did not support the notion of cancer induction from low-dose radiation.<sup>66</sup> They concluded: "The evidence suggests that exposure to multiple CT scans and other sources of low-dose radiation with a cumulative dose up to 100 mSv (approximately 10 scans), and possibly as high as 200 mSv (approximately 20 scans), does not increase cancer risk."<sup>66(p3)</sup>

In the end, the dose additivity LNT concept is not valid for exposures to low radiation doses from medical X-rays.

Adaptive protection systems will prevent, repair and remove any damage done such that the host is at the same or better level of health by the time the next medical radiation imaging is taken whether days, weeks, months or years apart. Thus, as discussed, the assumptions of dose additivity are not supported by the literature and we concur with Mitchel who argues “the use of dose as a surrogate for risk needs re-evaluation.”<sup>47(p287)</sup>

### Radiophobic Concern #3: Children Are More Susceptible to Radiation

“I don’t want my child exposed to radiation,” “Does my child have to get an X-ray?,” or “Can we skip the X-rays for little Johnny?” are common statements made by parents overly concerned about exposing their child to radiologic medical imaging. This is consistent with the common notion that children are more susceptible to harm from radiation exposures than adults. But is this notion true?

LNT ideology considers that younger people have a longer lifespan after radiation exposures to develop cancers and therefore are at a greater risk than older patients (i.e. all radiation is harmful and cumulative).<sup>67</sup> Also, children are traditionally viewed as having immature or less effective immune systems leading to a possible increased sensitivity to radiation and are therefore, thought to more easily succumb to the negative effects of radiation exposures.<sup>10</sup> Here, we show evidence that contradicts these views.

Doss has clearly demonstrated that cancer is more a function of aging and therefore associated with a less efficient immune status.<sup>68,69</sup> Thus, children would be expected to have a more efficient immune status, however, the best evidence to elucidate how children respond to low-dose radiation exposures is to review populations who were exposed to low-dose radiation as children. Such examples include studies of those who were treated for numerous diseases, infections and disorders historically treated by radiotherapy.

As mentioned, many medical conditions were treated by radiation exposures in the early and mid-twentieth century.<sup>61</sup> Calabrese et al. showed the treatment of asthma in about 6000 patients resulted in a 70%+ success rate documented in over 60 studies, many involving children.<sup>70</sup> The same authors documented the treatment of pertussis in about 1500 patients, mostly children under 3 years, and reported an 80% success rate in 20 studies.<sup>71</sup> Calabrese and Dhawan also reported on 3000 patients suffering from sinus infections treated successfully, and some involved children.<sup>72</sup> The same authors also reported on the successful treatment of otitis media and cervical lymphadenitis, many being children.<sup>73</sup> The radiation doses employed to treat these diseases ranged from 30-100 roentgen; importantly, no reports of long-term harm has ever been documented to occur from these treatments.<sup>61,70-74</sup>

It should be mentioned that the treatment for cervical lymphadenitis involved nasopharyngeal radium irradiation (NRI) treatment. This was used to shrink lymph tissues in the neck. Several studies have evaluated the long-term carcinogenic risks from this treatment, however no definitive evidence of harm

has been found.<sup>75-77</sup> In fact, the National Cancer Institute has even stated “A clear link between NRI exposure and cancer risk . . . has not been established.”<sup>78</sup>

When it comes to childhood radiation exposures, it is often argued that the definitive evidence of future carcinogenicity from childhood exposures comes from studies showing increased thyroid malignancies following nuclear power plant accidents.<sup>79,80</sup> Radionuclides (i.e. iodine-131 (<sup>131</sup>I) and cesium-137 (<sup>137</sup>Cs)) from the Chernobyl accident in 1986 and <sup>131</sup>I (and others) from the Fukushima Daiichi accident in 2011 were followed by reports of increased thyroid cancers in exposed persons who were children or adolescents at the time of exposure.<sup>79,80</sup> The main criticism regarding these reports, however, is the problem of thyroid cancer overdiagnosis.<sup>81</sup> For instance, in the region surrounding Chernobyl, even prior to the accident, rates of thyroid cancers were on a significant upward trend<sup>79</sup> as was also apparent around the world mainly due to new screening and testing methods.<sup>82</sup> In fact, testing of children after the Fukushima accident showed increased thyroid cancer rates up to 60x the expected incidence in both the exposed *and* unexposed residents<sup>83</sup> due to the overdiagnosis of small papillary lesions; that is, “diagnosis of thyroid tumors that would not, if left alone, result in symptoms or death.”<sup>81(p.615)</sup> We agree with Vaiserman et al. who state “the entire field of thyroid cancer epidemiology should be deemed irrelevant.”<sup>79</sup>

Regarding the Chernobyl accident, it must also be noted that a unique feature of the contamination effects was that <sup>131</sup>I gets localized to the thyroid gland, and doses to the thyroid were 3 to 4 orders of magnitude greater than to other body organs.<sup>84</sup> As explained by Vaiserman, even by 2005 (where 6000 thyroid cancers were diagnosed in 2 million “highly contaminated” children), there were only 15 deaths, and such a low death number can be attributed to surgeries’ complications alone.<sup>79</sup> Also in this population the accumulated dose to the thyroid reached several greys or more,<sup>79</sup> so even if there were substantially more cancers found it would not support carcinogenicity from low-dose radiation exposures such as from X-rays. Along the same argument, the data shown in the BEIR report on children showing increased cancers when exposed at age 10 years as presented in the summary of “age-time patterns in the radiation-associated risks for all solid cancer mortality” (Figures 12-A; 12-B) were after exposures of 1 Sievert.<sup>21(p.270-271)</sup> Again, these data do not support radiation induced carcinogenicity to children exposed to low-dose X-rays (and CT scans) as the exposures in these data sets are orders of magnitudes greater radiation levels.

The discussed articles show that long-term effects of childhood medical radiotherapy treatments do not cause harm, but there are studies that show actual benefit as consistent with hormesis. Tubiana et al., for example, showed less second cancers (secondary malignant neoplasms) per kg of tissue in patients who were treated by radiation for cancers in their childhood.<sup>85</sup> In fact, they determined no excess cancers for parts of the body having doses less than 1 Gy (1000 mGy), and importantly, less cancers for parts of the body which received

less than 500 mGy in childhood. This is evidence of radiation hormesis for children who were exposed to up to 500 mGy. Thus, it seems children and adolescents can well tolerate low-dose radiation exposures; they can benefit from it.

## Discussion

We have outlined 3 main streams of thought as they relate to hesitance regarding medical imaging—all present challenges in daily medical practice. Regardless of actual patient concerns, radiophobia results in the unnecessary wasting of time, energy and resources as doctors are forced to sympathize and abate X-ray hesitancy in order to pursue warranted radiological diagnostics for assessment, diagnosis and monitoring of specific medical conditions.<sup>5</sup>

In actuality, X-ray hesitancy should be viewed as a contemporary crisis to front line medical professionals who attempt to deliver efficient healthcare considering there is no evidence that X-rays and CT scans present any real health risk. We concur with Wagner who states “diagnostic radiology has an image problem.”<sup>86</sup> Of course, this refers to the widespread radiophobia propagated by medical radiation reduction campaigns including ALARA (“As Low As Reasonably Achievable”) that exclusively focuses on the risks from medical X-rays without adequately addressing the benefits experienced by patients.<sup>86-90</sup> The evidence as presented indicates that, in reality, patients only receive a benefit from receiving radiological imaging as part of their healthcare because when there are no risks, there are only benefits in a risk-to-benefit ratio.<sup>91</sup> Patient benefits are, in fact, orders of magnitude larger than the feared dangers of X-rays, and this is true even if the LNT model was appropriate for low-dose risk assessment.<sup>92</sup>

The bottom line is that there is no evidence showing detrimental health effects from low-doses of radiation (i.e. 100-200 mGy) that are above the realm of exposures from medical X-rays.<sup>66</sup>

The media has been very effective at communicating radiation fears by amplifying “doom and gloom” messages whenever studies come out using LNT modeling showing future projected cancers from medical imaging (e.g. Brenner et al.<sup>93</sup>; Pearce et al.<sup>94</sup>). These studies continue to get cited (both many 100 s of times) in the peer-reviewed literature despite the fact that they suffer from the major criticism of “reverse causation.”<sup>88</sup> This is the fact that children who get CT scans are predisposed to get more disease including cancers as normal and healthy kids generally do not get imaged.<sup>95</sup> This was proven in a recent study by Shibata et al. who found that children who received CT scans had congenital anomalies 13x that of the normal incidence; they conclude that “the population of children undergoing CT is completely different from that not undergoing CT. The 2 groups should not be compared.”<sup>95</sup> Ironically, even agencies that perpetuate LNT ideology, such as the ICRP as discussed in Socol et al.,<sup>96</sup> has stated that cancer deaths estimated using the LNT model for low doses (<100 mSv) are “speculative, unproven, undetectable, and “phantom”.”<sup>97</sup>

In fact, there is only evidence that at these low-doses, only beneficial hormetic effects occur which stimulate the adaptive protection systems.<sup>56</sup> Many reviews cite much evidence and valid arguments favoring hormesis over LNT for low-dose radiation exposures;<sup>24-26,28,56,98-101</sup>

These studies include molecular, cellular and animal experiments showing less cancers from low doses and dose rates of radiation exposures. Using Beagle dogs,<sup>102-104</sup> for example, it has been shown that although high exposures can induce cancers and increase death, lower doses and dose rates show either no statistically increased disease burden and can increase their lifespans. Cuttler et al. have stated that if “dogs model humans, this evidence would support a change to radiation protection policy.”<sup>104</sup> Unfortunately, these types of works do not get publicized; while in contrast, sensationalized articles projecting future cancers from medical imaging distort the mindset of the public and medical community and fuel the pervasive radiophobia.<sup>18,105,106</sup> The fact is however, “regulating very low doses (on the order of fractions of background radiation) is not radiation protection.”<sup>11(p597)</sup>

Although patient X-ray hesitancy may be considered a “misconception,” it is argued that the patient concerned over receiving X-rays along with the doctor who may also be reluctant to take an X-ray have long been indoctrinated into fearing radiation. In reality, fears over radiation is the precise narrative stemming from the national and international regulatory agencies and “authorities”. The radiation exposure clampdown accelerated after WWII and the adoption of the LNT model by the NAS for use of radiation risk assessment in 1956 created a domino effect causing agencies around the world to adopt the LNT. Doctors (via their education<sup>74</sup>) and the public (via media<sup>10,11</sup>) alike are have been taught the LNT fear-mongering narrative that all radiation is harmful, that it is cumulative, and that it is extra dangerous for our children for decades. This narrative is scientifically and medically wrong but continues to be perpetuated (e.g. BEIR VII<sup>21</sup>). Although a much larger issue than that addressed in this commentary, the real issue at hand is how society can find a way to prevent the production, proliferation and use of nuclear weapons without creating and sustaining a fear of all ionizing radiation, including that used in essential medical imaging.

Moving forward, continued support for the LNT model for radiation risk assessment by the major regulatory agencies and scientific advisory bodies (e.g. NAS BEIR committee, NCRP, ICRP) will only maintain the status quo fostering radiophobia. We hope as others do<sup>7,29,31</sup> that since there is no longer a valid scientific basis for the LNT as used in risk assessment in the low-dose radiation exposure range, that a universal rejection of the LNT model will occur and a threshold or hormesis model be adopted in its place or at least integrated.<sup>107,108</sup> This would aid in putting radiation risk assessment from low-doses, including medical imaging, into a realistic perspective; that is, having no carcinogenic risks.

Currently, the burden of communicating the risks and benefits to the patient falls on the front line doctors and radiologists who engage with patients face-to-face.<sup>87</sup> A great challenge

## What Are the Risks of X-ray Exposure?

While we must constantly work towards the reduction of health risks in all endeavors, we may be led to accept a minimal level as normal. While there is no data indicating diagnostic radiology has a present risk, any radiation dose must be compared to the benefits of useful information gained. The necessity for appropriate treatment selection is indeed an acceptable trade-off when put into perspective. The need for x-ray imaging is especially clear when one considers that radiographic (x-ray) imaging is the only valid method for determining abnormal spinal alignment and the presence of any spinal degeneration. However, since 1990, there has been a growing knowledge base that suggests medical x-rays may have health benefits. While an actual benefit from radiation exposure may seem outrageous, there is much scientific evidence for this phenomenon. This phenomenon/field of study is termed Radiation Hormesis.<sup>(1)(2-27,29-40)</sup>

Radiation Hormesis is the stimulatory or beneficial effect of low doses of ionizing radiation. This topic is in direct conflict with the "Linear No-Threshold Hypothesis" (LNT), which has been assumed to be true for more than 50 years. This LNT model comes from estimating the risks at lower doses of radiation, in the absence of data, by extrapolating in a linear model from the extremely large doses of radiation from atomic bombs dropped on Japan in the 1940s.

This LNT model has been used to set limits of radiation exposure by all official and governmental associations around the world.<sup>(1)(7)</sup> Recently in 2003, Kauffman<sup>(1)(2)</sup> reiterated that authors critical of exposure from diagnostic radiation always use the LNT model. This use of the LNT model includes the recent 2005 report by the USA National Research Council.<sup>(1)(2)</sup> This report stated, "there will be some risk, even at low doses (100 mSv or less), although the risk is small" and "there is no direct evidence of increased risk of non-cancer diseases at low doses."<sup>(1)(2)</sup> This 2005 report ignored and contradicted an earlier 2003 review by Kant et al.<sup>(1)(2)</sup>

For a comparison of exposures, USA citizens are exposed to an average annual natural background radiation level of 3 mSv, while exposure from a chest x-ray is approximately 0.1 mSv and exposure from a whole body computerized tomography (CT) scan is approximately 10 mSv.<sup>(1)(2)</sup> Also it is noted that 10mSv = 1,000mrem, which equates to about 46 cervical series or 8 lumbar series. Thus, the x-ray views taken to evaluate your spine in this office constitute a very small exposure compared to a CT scan or even annual background radiation from your natural environment.

Thus, it is obvious that the extremely small health risks (and maybe even some health benefits), associated with the x-ray exposure, needed to determine the state of health of your spine in this Report, are small indeed compared to the knowledge gained from this information.

From your radiographic examination at our office, we have determined the state of degeneration of your spine, and have determined the exact displacements of your spine. This knowledge not only gives us a working Clinical Impression/diagnosis of your spinal condition, but also determines the type of treatment that is needed to improve your spinal health condition.

We hope that you appreciate our thoroughness in examining and diagnosing your spinal health problems. In the next few pages, for each x-ray view obtained, we will present a normal view on the left hand side to compare to your x-ray on the right hand side. A table of values of normal measurements and your abnormal alignment will be provided on a Summary page after the x-ray photographs.

**Figure 4.** Example of a radiation safety statement in a generated patient X-ray report by the Posture Ray X-ray analysis EMR software system used to assess spinal alignment (PostureCo Inc., Trinity, FL).

**Table 2.** Strategies to Optimize Radiation Risk Communication by Alleviating Patient Concerns Over Radiological Medical Imaging.<sup>87</sup>

- Address the clinical appropriateness of the exam
- Describe the risks of exam in context of clinical benefits
- Manage negative perception through patient participation
- Maintain an effective flow of information within the institution
- Limit radiology technical jargon
- Describe familiar comparisons to effectively convey risk
- Use technology to supplement face-to-face communication
- Establish trust by appropriate tone and perception management
- Cite achievements and Accomplishments
- Use Visual aids and graphics to demonstrate risk
- Provide informational handouts
- Acknowledge sensationalized risks from popular media

however, is the fact that physicians/radiologists have traditionally been taught only LNT ideology, with no reference to health benefits and the lack of harm from low-dose radiation exposures.<sup>74</sup> This conundrum will lead physicians to “giving in” to patient anxiety and/or dose reduction campaigns and choose dose reduction triage options (avoiding radiation/choosing alternate assessments) that may affect patient care.<sup>109</sup> For best practices, however, doctors should stand fast with their clinical decisions for warranted radiological imaging, and should effectively communicate to abate patient concerns by discussing the issues surrounding the common concerns underpinning X-ray hesitancy. One tool to aid in the education of and to quell attention about radiation risks to the patient can be made by inclusion of accompanying radiation risk-benefit ratio/safety information as a part of the patient record, along with the diagnostic images (Figure 4). Kasraie et al. have discussed many radiation risk communication strategies that are useful for alleviating patient concerns over medical radiation exposures (Table 2).<sup>87</sup>

## Conclusion

Medical imaging that is within background exposures are not detrimental to one’s health and should not be feared or avoided over carcinogenic concerns. The 3 main themes of X-ray hesitancy discussed herein are false. All radiation exposures are not harmful, low doses and dose rates can be healthful and the thresholds for harm are quite high. Cumulative effective doses are not additive when radiation is delivered from low-dose X-rays, as well as when imaging is repeated with at least 24 hours separation. Children are not more susceptible to radiation effects as there is no evidence to show this, and they also have a more responsive immune system. The LNT/ALARA ideology as endorsed by the regulatory bodies and sensationalized by the media propagates radiophobia, and this, in turn, gets expressed as X-ray hesitancy in medical practice; unfortunately, there are no signs this trend will not continue. Therefore, the burden is on the medical professionals who are face-to-face with patients and who must continue to abate patient concerns about the safety of low-dose medical imaging. Medical professionals need to be well equipped to deal with this ongoing crisis.


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## ORCID iD

Paul A. Oakley  <https://orcid.org/0000-0002-3117-7330>

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