Dose-Response:
An International Journal
April-June 2020:1-12
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DOI: 10.1177/1559325820921641
journals.sagepub.com/home/dos
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Death of the ALARA Radiation Protection Principle as Used in the Medical Sector

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Abstract

ALARA is the acronym for "As Low As Reasonably Achievable." It is a radiation protection concept borne from the linear no-threshold (LNT) hypothesis. There are no valid data today supporting the use of LNT in the low-dose range, so dose as a surrogate for risk in radiological imaging is not appropriate, and therefore, the use of the ALARA concept is obsolete. Continued use of an outdated and erroneous principle unnecessarily constrains medical professionals attempting to deliver high-quality care to patients by leading to a reluctance by doctors to order images, a resistance from patients/parents to receive images, subquality images, repeated imaging, increased radiation exposures, the stifling of low-dose radiation research and treatment, and the propagation of radiophobia and continued endorsement of ALARA by regulatory bodies. All these factors result from the fear of radiogenic cancer, many years in the future, that will not occur. It has been established that the dose threshold for leukemia is higher than previously thought. A low-dose radiation exposure from medical imaging will likely upregulate the body's adaptive protection systems leading to the prevention of future cancers. The ALARA principle, as used as a radiation protection principle throughout medicine, is scientifically defunct and should be abandoned.

Keywords

ALARA, LNT, radiation protection, X-ray, CT scan, low-dose radiation

Introduction

Radiological imaging (eg, X-rays and computed tomography [CT] scans) by medical doctors, dentists, chiropractors, and others in the setting of health care is clearly an evidence-based practice. Imaging of human anatomy leads to a definitive diagnosis, including ruling out suspected pathology, as well as guides particular healthful interventions, for example, in the treatment of dental caries, spinal deformity/subluxation, coronary artery disease, and in the triage of physical traumas such as for the assessment of intracerebral hemorrhage and spine and pelvic fractures.

ALARA or "As Low As Reasonably Achievable" is the acronym used for the concept of dose reduction in radiation protection.[1] Although first introduced for the nuclear energy sector, it was later adopted for use in the medical sector to caution doctors, radiologists, and the like to use radiological imaging judiciously. This is because of the prevailing ideology borne from the linear no-threshold (LNT) model and its assumption that any, and all ionizing radiation is harmful (ie, carcinogenic), and that it is also cumulative (dose additivity).[2]

ALARA, of course, is the corollary of the LNT model.[3,4] The LNT is the prevailing model used for radiation protection standards as formally adopted in 1977.[5] Recently, however, there has been a surge of evidence that has surfaced that points to the fact that the LNT ideology was adopted for political over scientific reasons.[6,7] There has also been an increasing amount of criticism of the continued use of the LNT model as used in radiation protection as it lacks scientific support in the low-dose range.[8] Further, and most importantly, a recent analysis of the life span study (LSS) data for which the entire premise of the LNT rests has been found to be better represented by a hormetic (linear-quadratic) model rather than a linear one.[9,10] Validity pitfalls of the LNT have been extensively discussed in its use for risk assessment from medical imaging.[11-13]

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Received 09 January 2020; received revised 31 March 2020; accepted 03 April 2020

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The most current evidence does not support the use of the LNT model for use in radiation protection in low-dose exposure ranges.[8,14] Thus, the ALARA concept as used in the medical sector has no scientific basis. Herein, we provide examples where the use of the ALARA principle does more harm than good as used in the crusade to limit radiation exposures to patients receiving X-rays during the delivery of health care.

Reluctance to Order Radiological Exams

At the highest level of ALARA employment is the pressure on doctors to only choose radiological imaging when *absolutely* necessary (eg, "Image Wisely"[15]; "Image Gently"[16]; "Choosing Wisely"[17]; and "ACR Appropriateness Criteria"[18] campaigns). Caught between balancing the practice of ethical and conscientious medicine ("better being safe than sorry") and limiting a possible source of presumed future carcinogenicity ("first do no harm"), the choice toward opting for a radiological image is made within this tug-of-war of competing interests.

In reality, the choice for a radiological image should only be weighed on the merits of scientific evidence and the "working diagnosis" based on an attending doctor's medical assessment. Unfortunately, there are doctors who are becoming more and more reluctant to take radiographic imaging stemming from unwarranted carcinogenic fears from medical imaging from radiation reduction campaigns and/or patient pressures to avoid them, and therefore, are skewing their practice more toward the practice of uncertain medicine. As the practice of medicine is often a sea of uncertainty,[19] when it comes to simply ruling out (or ruling in) a certain diagnosis, it would seem doctors should practice in the realm of most certainty (ie, take an image to make a definitive diagnosis/undiagnosis) versus uncertainty.

An example of how health-care providers are becoming more reluctant in ordering radiological imaging is demonstrated when they are asked to base their decision on the patient's radiation exposure history. Griffey et al showed that among emergency physician's, 87% would reconsider radiological imaging if made aware of a patient's previous cumulative CT count as well as if they have had multiple CTs for a similar health condition.[20] Pandharipande et al demonstrated that 92% of radiologists would incorporate past exposure history "risks" into current risk–benefit decision-making analysis and that this typically leads to the recommendation for lower dose imaging options.[21] Alternatively, when patients are informed of the risks of radiological imaging prior to an X-ray, more become concerned about carcinogenicity[22] and many elect to withdraw consent.[23] For this reason, there is current dialogue about whether even to disclose potential (perceived) risks prior to performing CT scans.[24] Obviously, initiating this type of conversation constrains the physician with the burden of having a difficult dialogue, and for which they may not be able to effectively communicate,[25,26] or have the time for.

As can be seen when faced with ordering a radiological image, "doctors are stuck between the proverbial rock and a hard place when it comes to ordering these tests."[27] One may argue, however, that imaging will always be favorable due to insurance structures that are "fee for service" compensation. While it may be logical to suspect that imaging may be ordered more often than not to increase compensation, since the 1970s, physicians have been facing increasing numbers of medical malpractice claims.[28] Medical imaging is one specialty most liable to claims of medical negligence.[28] Thus, avoiding malpractice fuels pro-imaging to ascertain timely and accurate diagnosis unrelated to considerations over compensation and insurance coverages.[20] Further, newer diagnostic guidelines and decision tools attempt to dissuade physicians from overutilizing radiological imaging[29]; thus, it is assumed that the majority of health-care providers strive for evidence-based and ethical practice, where radiological imaging use always ultimately comes down to a physician's clinical expertise.

It is ironic that when faced with LNT-based ALARA (ie, radiophobia misinformation), different patient management decisions are taken (or are forced to be taken due to patient nonconsent) than if there were no concerns about radiation exposures—this affects diagnostic accuracy. The fact is the use of X-rays and CT scans have transformed medical diagnostic accuracy. A spinal surgeon's surgical success is dependent upon a preoperative full-spine radiographic analysis of essential spinopelvic parameters for which surgical outcomes can be accurately predicted.[30,31] An emergency consultation for many common presentations (eg, abdominal complaints, chest pains, and headache) has routinely had diagnostic changes to the "leading diagnosis" after obtaining a CT image[32,33]; this is also consistent in primary care general practice.[34] Accurate diagnosis leads to more efficient health care and better patient outcomes. It is tragic and unacceptable when "relieving anxiety has taken precedence over diagnostic accuracy"[35] in the arena of medicine.

Resistance of Patients/Parents to Receive Radiological Exams

On the other side of the doctor–patient encounter is the resistance of patients and parents of children who require diagnostic imaging that emit radiation. Spinal X-rays are commonly used to assess bone breaks, fractures, spinal subluxation, and deformities, and CT scans are the technique of choice for assessing head injury, spine, pelvis, or abdominal trauma, characterizing parenchymal lung diseases, as well as staging and treatment planning for solid tumours.[36] As mentioned, medical imaging including X-rays are essential in effective health-care management.

A patient who is fearful to receive diagnostic imaging based on authentic but misinformed understanding of radiation effects (ie, unaware of the safety of low-dose exposures) are expressing "radiophobia."[37,38] Due to propagating dangers of future cancers from medical imaging throughout the media,[35] radiophobia is ubiquitous in the eyes of the patient who is presented with the referral for radiological imaging. Often a patient/parent raises concerns and objections which constrains the medical management of their condition.[22,23]

Parents informed of theoretical cancer risks associated with CT scans, for example, as compared to parents not informed of the risks are 20% less likely to consent for a head CT scan for their child who had just received a head injury and requires screening for possible brain hemorrhage.[23] This is concerning for several reasons. First, a CT scan is low dose (5-30 mSv[36]) and there is no evidence of carcinogenic effects at such low exposures. In fact, it is universally accepted that there is no harm at doses below 100 to 200 mSv.[39-41] Second, there is evidence showing upregulation of the body's adaptive protection systems at low-doses consistent with exposures from CT scans[40-42] and for this reason, head CT scans are being used in a clinical trial, not for the imaging but for the purposeful delivery of radiation for the treatment of Alzheimer disease.[42] Third, the needless avoidance of important medical imaging may lead to actual real harm for the child from a "missed diagnosis."[40,41] Finally, real harm may also result from alternate procedures used to avoid radiation exposures, such as using magnetic resonance imaging (MRI) which often requires the use of general anesthesia for children; this adds considerable risk.[43] Further, sedation is potentially detrimental for the cognitive development of children.[44]

Recent reports confirm that more patients are indeed more aware of the perceived dangers of medical radiation (ie, LNT ideology of risks). Zwank et al found an increase of patient awareness from only 3% in 2002 to 25% in 2010.[45] A more recent study showed nearly half of all patients were aware of CTs theoretical risks of future carcinogenicity.[23] Despite this increased awareness, many patients are still not educated in radiogenic risks; however, half of all patients will inquire about imaging risks on their own[46]; in fact, most all perceive radiation as a "unique hazard."[47] This is why patient resistance remains a factor in radiological imaging because in this day and age of "shared decision-making," it is highly encouraged to properly inform the patient of potential risks of radiation imaging.[48-50] When these risks are discussed there is more resistance to this type of imaging.[22,47]

The problem of patient radiation hesitance is a greater issue in certain types of clinical scenarios. For instance, in emergency medicine, a physician has limited knowledge of a patients' medical history as well as limited time and would be more inclined to choose radiological imaging.[51] When a patient is provided with a choice between "observation" and CT, the patient tendency is to avoid the radiation.[22] However, taking the CT is likely more cost-effective and ethical, for example, for nontraumatic, nonspecific abdominal pain, since it has been shown that a substantial proportion of these patients will continue to suffer,[52,53] even 5-years later.[54] Thus, initial CT imaging often aids to provide a definitive and timely diagnosis and changes the intended medical triage.[33,55-58] More specifically, patients initially assessed and deemed for "admittance for observation" have up to a two-thirds reduction in admittances after receiving an abdominopelvic CT scan.[33,56-58] Computed tomography scans have also reduced unnecessary surgical interventions.[33,57,58] Thus, radiological imaging, often considered costly, is actually cost-effective as they often avoid costly hospital stays and surgeries that both present risks of iatrogenic errors[59] and nosocomial infections (ie, hospital-acquired infections, otherwise known as "superbugs").

Radiological reduction campaigns such as ALARA, lead to "racing to the bottom"[60]; that is, the overly aggressive attempt to reduce radiation exposures, and in turn, may compromise the quality of the images required for medical review. Further, the usual application of ALARA tends to "amplify" detrimental aspects of radiation.[61-63] In fact, often associated with fears over radiation exposures, "media-driven social amplification" occurs[47,64] which stigmatizes radiation in medicine and fuels the radiophobia and the reluctance of patients to receive necessary imaging. Problematically, all too often only the (presumed) risks of medical diagnostic radiation exposures are propagated, and as Wagner states "with only casual, incidental, or no reference to the benefits experienced by patients."[63] It has been suggested that any estimates of cancers thought to be caused by medical imaging be conveyed with a cautionary statement that such estimates are "highly speculative" and should also only be presented with simultaneous estimates of the reductions in morbidity and mortality from the use of these imaging procedures.[13]

Another point is in relation to incidental findings (IFs), which are potentially relevant findings on medical imaging which were not anticipated or screened for but were inadvertently discovered. While IFs are unintentionally diagnosed, they are important and can be medically urgent. Rogers et al, for example, determined the incidence of IFs in assessing head CT scans in children due to recent head trauma was 4%, and importantly, 1% "warranted immediate intervention or outpatient follow-up."[65] Although the rationale to take imaging is not primarily for screening for IFs, they are important and can lead to urgent or altered medical treatment that would not have occurred if the imaging had not been performed.

Doctors, dentists, and radiologists are inundated by patients with concerns over receiving medically necessary X-rays, and the overestimation of radiation risks from imaging may deprive patients of the benefit of medically indicated imaging.[66] This constrains the practitioner and impedes the practice of efficient and effective health care. Those patients that are stern against radiological imaging are outright sabotaging best practices and sadly this reluctance or hesitancy stems from propagated misinformation and radiophobia by ALARA and image avoidance campaigns.

Increased Radiation Exposures by Aligning With ALARA

In the attempt to better align with ALARA, many practices lead to increased radiation exposures rather than achieving the goal of decreasing them. These include the use of lower exposure parameters, use of lead shielding, and the elimination of "unnecessary" initial screening X-rays in the triage of some pathologies.

Although efforts to optimize radiological imaging parameters to obtain quality images is encouraged, the reduction of settings (eg kilovoltage potential) to decrease patient exposure may lead to suboptimal image quality which may either lead to a retake which would essentially double the exposure or lead to a missed diagnosis[40,41,67]; either scenario is undesirable. Doubling the exposure to the patient, although not harmful, is ironically contradictory to practicing the principle of ALARA. Missing a diagnosis due to poor image quality resulting from suboptimal imaging parameters in the attempt to reduce patient exposures by an infinitesimal amount is practically negligent.

The use of gonadal shielding was originally adopted in the mid-twentieth century to protect radiosensitive tissues from exposure; however, its use has recently been called into question.[68,69] Some agencies, for example, the American Association of Physicists in Medicine, advocate for its discontinued use.[70] Gonadal shielding does little to reduce patient radiation exposures as it cannot stop internal scatter from the exposed anatomy desired to be imaged. Further, shielding is often poorly placed, obscuring anatomy needed to be viewed leading to repeated imaging. Also, even if the shielding is properly placed (ie, over the ovaries), the automatic exposure control photo timing cells may be covered leading to increased radiation output from 63% to 147%![71] McKenney et al argues that gonadal shielding is nothing more than “good intentions.”[71]

In the attempt to decrease patient radiation exposures, traditional X-ray screening of many conditions (eg, low back pain [LBP] and hip dislocations) have been called into question.[72,73] Ironically, these efforts are not proving successful. In assessing degenerative spinal conditions, for example, it has been shown that routine X-ray examinations prove cost-effective as they often eliminate the need for more costly CT or MRI imaging.[74] Further, even with doctors not specialized to treat LBP, patients who requested and received imaging of their backs were more satisfied and had better long-term prognosis than comparative patients.[75,76] It should be mentioned that certain conditions such as osteoarthritis, spondylolisthesis, and the essential biomechanical parameters of the spine and pelvis can only be assessed by X-ray which is why there is a parallel movement endorsing the routine use of X-ray imaging of all spine care patients.[30,77-82]

Concerning hip dislocations, the pre-CT screening by plain X-rays have, to some, been considered wasteful, as it is argued the patient should triage straight to a CT scan (skipping the plain X-ray screen).[73] Since hip dislocations are highly morbid injuries, a prompt reduction is necessary as well as postreduction assessment for both fracture and incarcerated fragments. In assessing the choice of pre-hip reduction imaging in the treatment of acute hip dislocations, however, Walker et al determined that the choice of *not* taking a plain film pre-CT X-ray often resulted in repeated CT scanning and therefore much more radiation exposures.[83] Also, the time to hip reduction was longer in patients not receiving a screening X-ray prior to the CT scan. They conclude “Initial trauma pelvic radiography prior to CT is still important in the setting of suspected hip pathology to decrease time to hip reduction and unnecessary radiation exposure.”[83]

Stifling of Low-Dose Radiation Research and Treatment

When unwarranted concerns exist about low-dose radiation imaging being harmful, the openness toward the same low-dose radiation for actual treatment of disease is stifled. Long forgotten were the days of effective treatments to various diseases by the purposeful exposure to radiation, so-called low-dose irradiation (LDI) or radiotherapy.[42]

It has been recently documented[42] that many common ailments including arthritis,[84] bronchial asthma,[85] carbuncles,[86] cervical adenitis,[87] deafness,[87] furuncles,[86] gas gangrene,[88] necrotizing fasciitis,[89] otitis media,[87] pertussis,[90] pneumonia,[91] sinus infection,[92] tendonitis,[93] and bursitis[93] have all been successfully treated by radiotherapy. Typical success rates ranged from 75% to 90% and relief was often reported after even a single exposure.[94] It is important to note the estimated doses for these traditional treatments were in the range of 30 to 100 roentgen[94] (263-877 mSv)—which is a dose many times larger than typical X-ray imaging (1-3 mGy) or CT scanning ($\sim$10 mGy).

Further, other trials have previously shown that the treatment of cancers from LDI therapy had good success rates as opposed to today’s standard high-dose radiation.[95] In fact, patients with non-Hodgkin’s lymphoma, ovarian, colon, and hematological cancers have been shown to be successfully treated.[96-100] The typical LDI protocol for cancer is an exposure to a total dose of 150 rad (1500 mGy) over a 5-week duration.[101,102] Again, it is noted that health benefits are shown to occur from radiation doses many times higher than that given by X-ray and CT scans.

It must be mentioned that the benefits of radiotherapy are found in the body’s innate adaptive response systems (ie, DNA damage-control biosystem).[101-109] Numerous and redundant tissue inherent innate mechanisms collectively either prevent, repair, or remove any damage resulting from radiation exposures (Figure 1).[106] These repair mechanisms are also fast-acting and result in an “over-repair” and therefore cause a net loss of damage or essentially a higher level of fitness in living organisms. For example, Lobrich et al[110] showed that CT scans do cause DNA double-strand breaks (DSB) immediately after exposure in humans; however, as early as 24 hours post-scan, there is an overall reduction in baseline DNA DSB damage.

One last consideration is that radiation damage caused by X-rays are only about one 1-millionth the damage caused from endogenous production of reactive oxygen species and hydrogen peroxide from aerobic respiration (breathing air).[81,103,106] Thus, the amount of damage from X-rays is negligible, and of course, this damage along with the damage many orders of magnitude greater from normal metabolism gets mitigated.[81,103-110] The evidence as discussed shows the reality of radiation hormesis and the failure of LNT ideology for low-dose radiation exposures. Thus, critics who clutch to outdated

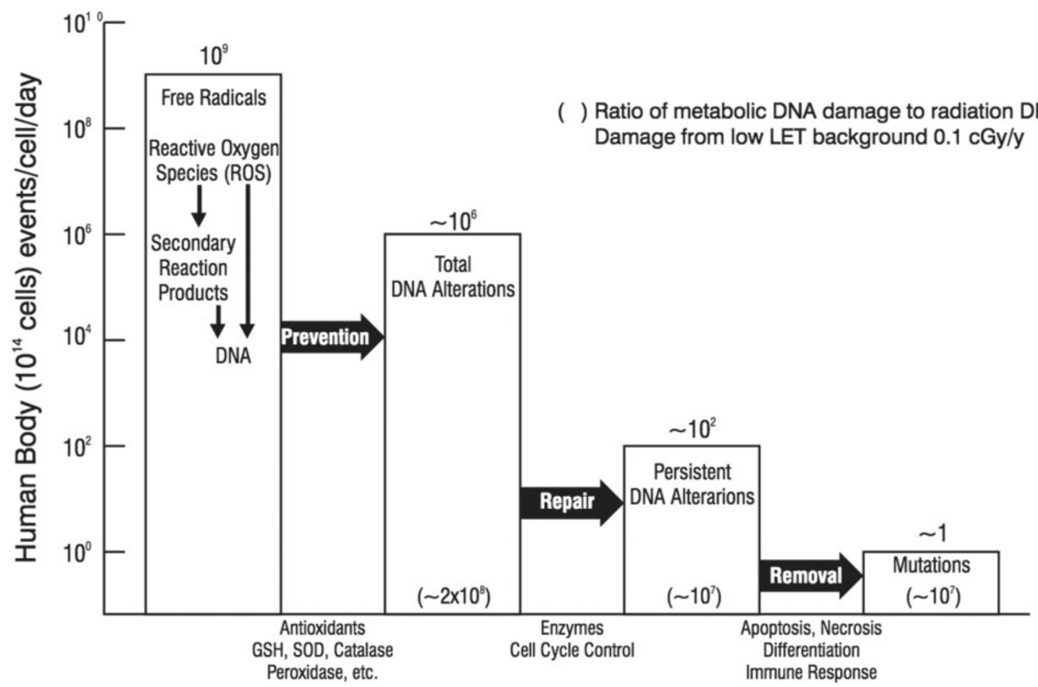

Figure 1. The adaptive response systems very efficiently prevent, repair, or remove virtually all DNA alterations.[106]

single-hit theory[111] and dose additivity[112] for risk assessment are misguided as these concepts are both considered invalid for lower radiation exposures, certainly for doses from diagnostic X-rays. The reality of nonlinearity and failure of LNT concepts has led to newer theories concerning human health and disease including cancer etiology.[113,114]

It is only through the reexamination of the evidence of LDI radiotherapy can one fathom the exciting possibilities for rediscovering effective treatments for human diseases, as has begun to emerge recently.[42,115-119] Again, radiation doses that are healthful cannot simultaneously be harmful; it is the LNT mythology that continues to perpetuate false notions of low-dose radiophobia that only stifles the research and acceptance of using LDI for treating human disease.

Propagation of Radiophobia

The real problem with ALARA and movements to this end (eg, "Image Wisely," "Image Gently," etc) is the propagation of radiophobia.[120,121] Radiophobia can manifest as apprehension and anxiety and can escalate to obsessive thinking or compulsive behaviors; all of this stemming from fear.[38] Once a person has an emotional fear of something, it is difficult, if not impossible to sway them from their misguided belief with any amount of science, data, or logic. Thus, we concur with Cohen who stated: "These campaigns attempt to solve a problem that does not exist and, in turn, creates problems."[122]

It is no surprise that the current radiophobia originated from the historic atom bomb droppings on Hiroshima and Nagasaki during World War II that continues to this day.[123] The fact is, however, the LSS data clearly show that those exposed to even fairly high radiation doses outlived controls.[124] Further, considering Cuttler has shown that the threshold for leukemia in this same population is quite high at 1100 mGy (95% confidence interval: 500-2600 mGy),[125] only demonstrates humans can tolerate surprisingly high levels of radiation without deleterious health consequences.

Radiophobia to medical imaging stems from unwarranted fears and false beliefs. This leads patients and doctors to fear radiological imaging based on the erroneous assumptions of the ALARA/LNT as applied to low-dose imaging. The fact is, however, there are no data supporting the notion that low-dose radiation exposures as given by radiographs (X-rays or CT scans) lead to future cancers.[8,14,39-41,126-128] All studies that have propagated radiophobia from medical imaging have been found to be flawed or have misplaced conclusions.[30,35,40,41,129]

The original studies that led to the adoption of the ALARA principle in medicine were those associating exposure to CT scans with increased cancers.[130,131] These papers continue to be published (eg, Pearce et al,[132] Matthews et al,[133] and Miglioretti et al[134]) and are advertised through major media outlets which, unfortunately, go unabated.[35] Other articles consistent with propagating radiophobia are ones calculating excess cancers from repeated X-rays in patients with scoliosis (eg, Nash et al,[135] Levy et al,[136] Ronckers et al,[137] and Simony et al[138]).

The obvious flaws with studies that predict (no actual follow-up) future cancers from CT scans[134] or scoliosis X-rays[135,136] are that they use the LNT model and weighting factors—these are purely theoretical and not applicable for low-dose radiation exposures.[79] The studies with actual cohort follow-up, finding increased cancers in those receiving previous CT scans,[132,133] suffer from the criticism of reverse causation (ie, "confounding by indication"); that is "the early symptoms of undetected cancer, or of factors that predispose to cancer, that are indications for the CT scans, rather than the CT scans per se that are causing the apparent excess risk of cancer."[139] This concept is illustrated in the paper by Journy et al who examined the relative risk of cancer incidence in patients who received CT scans prior to the age of 10 years.[140] The purpose was to assess how cancer-predisposing factors (PFs) affect the assessment of radiation-related risk calculations. They determined that excess relative risks for cancers from CT exposures were reduced by up to 56% when adjusted for PFs and stated: "This study made it possible to assess for the first time the cancer risks associated with exposures to CT scans while taking into account major PF, including rare genetic defects and acquired immune deficiencies." The conclusion was that "no significant excess risk (for cancer) was observed in relation to CT exposures."[140]

Scoliosis cohorts who were followed-up[137,138] and showed increased cancers are argued to be having the side effects of the spine deformity itself and not from previous low-dose X-rays that would be expected to mitigate future cancers.[79] It is estimated that these patients had received a total average cumulative exposure of less than 150 mGy.[137] The blame for this amount of exposure to have caused the cancers in this cohort is presumptuous and beyond doubtful, especially considering the fact that one cannot assess risk based on the cumulative dose concept as any damage caused by repeated spinal X-rays (1-3 mGy per session) would be repaired prior to the next imaging session. Oakley et al state "Since the body's adaptive response will repair damage done at each X-ray event, X-ray exposures of about 1 to 3 mGy will always remain at a level that is 367 to 1100 times below the radiogenic dose threshold."[79]

As mentioned, the media often release sensationalized articles socially amplifying the dangers of medical imaging.[35,47,64] Cohen, for example, documented dozens of fear-mongering media headlines about dangerous CT scans released in major media articles.[141,142] This sensationalism comes from erroneous projections taken out of context; in fact, the International Commission on Radiological Protection (ICRP) clearly states: "the calculation of the number of cancer deaths based on collective effective doses from trivial individual doses should be avoided."[143] Any attempt to assess the average adult for individual effective dose effects is associated with great uncertainty ($\pm$40%) due to age, gender, mass, and so on.[144,145] Thus, "Risk is always a population-based metric and as such, its ascription to an individual patient should never be interpreted deterministically."[146] Unfortunately, patients who hear these headlines typically cannot decipher elements of statistics, probability, and causation[147] to disengage from the fearmongering but alternatively get caught up in the hype, misinformation, and social amplification of the perceived risks.[64]

Oftentimes, the most difficult aspect of obtaining an X-ray is in convincing the patient/parent that it is warranted; that is, its benefits outweigh its risks. Sadly, in the escalating environment fostering radiophobia surrounding medical imaging, little discussion is given to the health benefits, only the risks.[61-63,139] Brody, for example, urge clinicians to always remember to discuss the benefit side of the risk-to-benefit equation; assuming LNT projected cancer risks, he states:

> we say that if a million children get CT scans, 100 will have a risk of getting cancer. But we don't say that if a million kids receive CT scans, one half of them will avoid unnecessary surgery, 100,000 of them will receive surgery that is better because the surgeon is guided by the CT results, and 300,000 of them won't have to go into the hospital unnecessarily.[148]

In a risk-to-benefit ratio when there is no risk from low-dose radiation, it only amounts to benefit and certainty within the practice of health care. As stated previously:

> If there is zero risk, then that leaves only benefit in a risk to benefit ratio. Therefore, as long as an imaging procedure can provide meaningful data in terms of diagnosis, differential diagnosis, monitoring treatment progress, IFs, patient satisfaction, and so on, the benefit will always outweigh a risk of zero.[81]

Thus, within the practice of evidenced-based medicine, as long as the use of radiological imaging materially changes patient management, the action is justified.[149] To help physicians, many discipline-specific radiological guidelines have been created; however, sometimes duplicate guidelines can be conflicting[150] and often have a bias based on who created them (ie, for or against imaging in similar clinical scenarios).[83,151,152] Clinical guidelines are just that, a "guideline" for the purpose of assisting the clinician in navigating patient triage. The final decision to opt for radiological imaging always comes down to the doctor and patient. Radiological imaging consideration should never be based on fears of radiation, but only whether it is medically justified for the specific patient at the specific time course in the management of their particular clinical presentation; in fact, "all medical procedures require justification in the form of medical indication, but radiation exposure levels have no place in that process."[41] We concur with Wijetunga et al who states: "for justified and optimized examinations there will always be a net benefit to the patient."[149]

It must be mentioned that dose optimization for CT scans, particularly for children, is more commonplace. This practice is obviously reasonable as long as the practice does not result in suboptimal images that may lead to nondiagnostic scans, which has been documented to occur.[43,148,153] The subset of patients who may be exposed to repeated scans over time, for example, children with adolescent idiopathic scoliosis or those being monitored with recurrent conditions such as inflammatory bowel diseases should not be concerned about harmful radiogenic consequences as the adaptive response systems will mitigate any damage caused.[42,79,101-110] Based on the best available evidence, including the LSS data, children are not more radiosensitive to radiation than adults.[41-43,154,155] Parents must realize that it is more risky to spend a week in the hospital under "clinical observation" (due to medical errors and/or nosocomial infections) than to get a CT scan for a definitive and timely diagnosis.[148]

The LNT model of radiation damage is dead[156] and so with it dies the ALARA concept. Continued endorsement of the LNT model by regulatory and advisory bodies (eg, National Academy of Sciences Biological Effects of Ionizing Radiation Committee, National Council on Radiation Protection and Measurements, ICRP, etc) will continue to perpetuate radiophobia by giving support to the ALARA concept and the Image Gently/Wisely campaigns. Due to the detrimental impact of ALARA and image reduction campaigns, we strongly concur with others who demand that these actions be terminated.[12,35,40,41,120-122,157,158]

Conclusion

Currently, there is no evidence supporting the use of the LNT model as a surrogate for radiation risk in the low-dose exposure range such as from medical imaging. Thus, the use of the ALARA radiation protection principle in the medical sector is obsolete. Continued use of an outdated and erroneous principle unnecessarily constrains medical professionals attempting to deliver high-quality care to patients by leading to a reluctance by doctors to order images, a resistance from patients/parents to receive images, subquality images, repeated imaging, increased radiation exposures, the stifling of low-dose radiation research and treatment, and the propagation of radiophobia and continued endorsement of ALARA by regulatory bodies. All these factors result from the fear of radiogenic cancer, many years in the future, that will not occur. We strongly urge for the discontinuation of the ALARA concept and the campaigns it underpins be terminated.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: P.A.O. is a paid research consultant for CBP NonProfit, Inc.; D.E.H. teaches spine rehabilitation methods and sells products to physicians for patient care that require radiography for biomechanical analysis.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by funds from CBP NonProfit, Inc.

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