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Proactive Strategy for Radiation Dosages

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ABSTRACT: "At certain threshold, nuclear radiation (like x-rays and gamma-rays) may adversely impact the health of living tissues. The exposure to these radiations in nuclear facilities is measured by devices called dosimeters. The devices are generally worn on the torso and are monitored by health physics division to report the radiation dose received by the personnel. However, this approach is not proactive--since the dosimeters reflect the dose that has already been absorbed in the body of the wearer.

This work presents a scheme to proactively avoid large dose acquisition at radiation-prone facilities. The work was divided into three major segments: (i) identify and characterize radioactive source(s), (ii) determine the impact of localized source(s), and (iii) estimate the integrated doses in traversing/evacuating the facility. The scope of this work does not extend to the development of "proactive" dosimeter. However, the approaches developed in these segments will be integrated into a dose monitoring system that would prevent or mitigate large dose acquisition. This work also has applications in nuclear facilities, hospitals, homeland security, and border protection"

KEYWORDS: Proactive strategy, radiation dosages, India, x-rays, gamma rays, monitoring, protection

I. INTRODUCTION

High-end CT systems allow acquisition of isotropic volumetric data sets that permit images less than 1 mm thick and high quality reformatted images. These capabilities have greatly expanded the utility of CT, and CT usage has correspondingly increased, replacing more and more radiographic examinations. In 1990, approximately 13 million CT scans were performed in the United States¹. In 2000, the number of CT scans more than tripled to approximately 46 million. The estimated number of CT scans for 2006 is 62 million. With high quality CT imaging being performed more frequently, patients can benefit from a quicker and more accurate diagnosis and precise anatomic information for planning therapeutic procedures. However, in spite of the tremendous contributions of CT to modern healthcare, some attention must also be given to the very small health risk associated with the ionizing radiation received during a CT exam. CT scanners create cross-sectional images by measuring x-ray attenuation properties of the body from many different directions. Currently, the radiation dose associated with a typical CT scan (1–14 mSv depending on the exam) is comparable to the annual dose received from natural sources of radiation, such as radon and cosmic radiation (1–10 mSv), depending on where a person lives². Hence, the health risk to an individual from exposure to radiation from a typical CT scan is comparable to background levels of radiation. However, considering the growing population of people undergoing CT scans, the implications of CT radiation dose on public health effects may be significant, although considerable debate exists regarding this assumption. One study suggested that as much as 0.4% of all current cancers in the United States may be attributable to the radiation from CT studies based on CT usage data from 1991–1996. When organ specific cancer risk was adjusted for current levels of CT usage, it was determined that 1.5–2% of cancers³ may eventually be caused by the ionizing radiation used in CT. This study and a similar series of previous articles received considerable attention from the public media. One positive effect of the media attention was that the CT community was obliged to review the amount of radiation prescribed for CT scans, especially for pediatric patients. This ultimately resulted in an aggressive effort to minimize CT doses and optimize image quality. Concurrently, new technologies such as automatic exposure control (AEC) were in development and eventually made commercially available for all current CT systems. The use of AEC greatly enhances and simplifies efforts to decrease patient dose.⁴

However, the media reporting on the risk of CT radiation doses has had a negative effect on the public's perception of CT imaging and radiation, influenced by the sensationalist and alarmist tone of the news stories.⁵ Phrases such as "...dangerous radiation from 'super X-rays'..." and comparisons to atomic bomb survivors⁶ exploit the public's

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general apprehension of radiation. Although informing the public of potential health risks—even small risks—is not inappropriate, journalistic responsibility should ensure that the data be presented so as not to exaggerate or present the risk estimates in a manner that can be easily misinterpreted by a population that, in general, is not sufficiently knowledgeable in radiation or radiobiology to accurately assess the information. Such alarmist articles are a public disservice in that they cause unnecessary stress to patients, or in some cases, may persuade a patient to decline a CT scan that could have a positive impact on their health.⁷ The latter case cannot be overstated because low-level radiation risk estimates, which are derived primarily from atomic bomb survivors and have considerable uncertainties at low doses (<100 mSv), give no consideration to the medical benefit of a CT scan. There is no question that the benefit of an appropriately indicated CT scan far exceeds the associated estimated risk or that CT providers need to prescribe the minimal amount of radiation required to obtain images adequate for evaluating the patient's condition. Additionally, the medical community needs to better educate the public to the risks and benefits associated with CT, such that they can make informed decisions regarding their healthcare.⁸

The Computed Tomography Dose Index (CTDI) is the primary metric used in CT to describe the radiation output from a scanner. It is a measure of the amount of radiation delivered from a series of contiguous irradiations to a pair of standardized acrylic phantoms. It is, however, measured from one axial CT scan (one rotation of the x-ray tube)⁷⁻¹⁰. The CTDI was defined in the early days of CT, when dose assessments were made using thermoluminescent dosimeters (TLDs) and multiple axial scans,⁹ each one incremented from the previous scan by the nominal beam width. This procedure was not only time consuming and laborious, but also required many scans (exposures) for each beam width, phantom size, tube potential setting (kV), and position in the field of view (FOV, periphery or center). The resultant parameter was referred to as the multiple-scan average dose (MSAD), which was typically a factor of 2–3 times higher than the peak radiation dose from one axial scan. Shope and Gagne⁹ demonstrated the mathematical equivalence between the scan intensive MSAD and the CTDI, which is able to be measured using only one scan (one gantry rotation), when certain criteria are met with regard to the length of the ionization chamber and the length of the clinical scan being assessed.¹⁰

The theoretically perfect equivalence of MSAD and CTDI is not achieved in many clinical scenarios, but due to the speed and ease of CTDI measurements, the use of MSAD declined. CTDI is now used internationally based on a standardized measurement technique. Several variants of CTDI exist that describe specific steps in the measurement and calculation processes. These include the CTDI₁₀₀ and the weighted CTDI (CTDI_w). These parameters are described in multiple publications¹¹.

The CTDI variant that is currently of most relevance is the Volume CTDI (CTDI_{vol}). This parameter accounts for gaps or overlaps between the x-ray beams from consecutive rotations of the x-ray source and variations in dose across the FOV. The CTDI_{vol} provides a single parameter, based on a directly and easily measured quantity, which describes the radiation delivered to the scan volume for a standardized (CTDI) phantom. The SI units are milli-Gray (mGy). CTDI_{vol} is a useful indicator of the radiation output for a specific exam protocol, because it takes into account protocol-specific information such as pitch. However, it is important to realize that CTDI_{vol} is not a direct measurement of dose; it is a standardized measure of radiation output in the CT environment.¹²

To better represent the overall energy delivered by a given scan protocol, the CTDI_{vol} can be integrated along the scan length to compute the Dose-Length Product (DLP)⁷, where the DLP (in mGy-cm) is equal to CTDI_{vol} (in mGy) times scan length (in cm). The DLP reflects the integrated radiation output (and thus the potential biological effect) attributable to the complete scan acquisition. Thus, an abdomen-only CT exam might have the same CTDI_{vol} as an abdomen/pelvis CT exam, but the latter exam would have a greater DLP, proportional to the greater z-extent of the scan volume.¹³

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Effective dose, E , is not a measurement of dose, but rather a concept that reflects the stochastic risk (e.g. cancer induction) from an exposure to ionizing radiation. It is typically expressed in the units of milli-Sieverts. Effective dose reflects radiation detriment averaged over gender and age and its use has several limitations when applied to medical populations. In particular, it uses a mathematical model for a “standard” body in its calculation and is hence not an appropriate risk indicator for any one individual. However, it does facilitate the comparison of biologic effect between diagnostic exams of different types or having different acquisition parameters. By comparing patient effective dose to background radiation dose from natural sources, which in the U.S. averages 3 mSv per year with a range across the U.S. from 1–10 mSv patients and their families are better able to put the risk associated with medical doses into perspective.¹⁴

II. DISCUSSION

Even as nuclear and radiological security has been a global issue for several decades, it has never gained as much attention as it has following the 9/11 terrorist attacks in the United States (US). The bold and unparalleled nature of the attacks generated fear that terrorists could acquire nuclear and radiological materials to cause massive destruction in the US and elsewhere. According to the International Atomic Energy Agency (IAEA) Incident and Trafficking Database (ITDB), 36 States reported a total of 189 incidents in 2010, including the trafficking and malicious use of nuclear and other radioactive material. There were 3,686 incidents and events between 1993 and 2010.¹⁵

While nuclear and radiological security are often discussed together, the potency and impact of the two differ significantly, and accordingly, there is a graded approach to these materials. Given the disastrous nature of nuclear materials (such as fissile material used for a nuclear weapon – Plutonium (Pu)¹⁵ or Highly Enriched Uranium (HEU))—i.e., they can cause immediate death and destruction, and create long-term impacts—they are considered most dangerous. On the other hand, radiological materials are more widely spread out in over 100 countries due to their large-scale use in civilian sectors including medical, industrial, agricultural and research utilities. Well-known applications include sterilisation and food irradiation, single- and multi-beam tele-therapy, industrial radiography, high- and medium-dose brachytherapy, research and blood irradiators, level and conveyor gauges, and radioisotope thermoelectric generators.¹⁶

Indeed, radiological sources have been found to bring enormous positive benefits. However, if these materials fall in the wrong hands such as terrorists and criminals, they could be used for developing a Radiological Dispersal Device (RDD), or what is popularly called a “dirty bomb.” They are easily accessible and in the absence of a comprehensive regime that covers radioactive sources “from cradle to grave”, they can pose serious risks. Unlike nuclear materials, radiological sources are not weapons of mass destruction but they have the potential to create fear and panic in an affected society in addition to resulting in major economic, social and psychological impacts.¹⁷ Speaking about the horrific impacts of an RDD attack, Anne Harrington, the US National Nuclear Security Administration’s Deputy Associate Administrator for Defense Nuclear Nonproliferation said this at a Senate Homeland Security and Governmental Affairs Committee Hearing on 12 June 2012: “An RDD detonated in a major metropolitan area could result in economic costs in the billions of dollars as a result of evacuations, relocations, cleanup, and lost wages. Radioactive sources such as Cobalt, Cesium, Americium, and Iridium are used worldwide for many legitimate purposes In looking at the risk, we must include not only outside terrorists attempting to steal radioactive sources as potential adversaries, but also insiders who work at these facilities who could have intimate knowledge of security procedures and vulnerabilities.”¹⁸ RDDs can also be used to make a Radiation Emission Device (RED), which when kept in a restricted place such as in a train or a crowded market place, can cause radiation exposure to a large group of people.

To be sure, not all radiological sources are equally radioactive. The high-risk radiological sources include Cobalt-60, Cesium-137, Iridium-192, Strontium-90, Americium-241, Californium-258, Plutonium-238, and Radium-226. Even with these few high-risk radioisotopes, the radiation impact is not the same. The radiation impact depends on a number of factors including the amount of a particular radioisotope present in a source, the type of exposure, whether it is internal or external, the kind of radiation emitted, and whether it is alpha, beta or gamma, among other things.¹⁹ If one were to assess these sources from a threat perspective, Cesium-137 has generated quite some interest

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because it has been seen as a “favourite” among terrorist groups and criminals. A number of incidents over the years reveal the smuggling and illicit trade of this particular source. Cesium-137 is particularly attractive because of its large-scale use in the medical and commercial sectors. This particular feature of Cesium-137 has prompted the IAEA and the UN to identify it as a source useful for making RDDs.²⁰

III. RESULTS

Radiation dose management is a growing concern in the diagnostic imaging field – rightfully so – as too much radiation exposure can lead to adverse health consequences for both patients and physicians. Monitoring radiation levels is of critical importance for both providers and manufacturers, especially in light of The Joint Commission’s new standards introduced in July 2011 that now require hospitals to establish stricter radiation dose management processes.²¹

While radiation exposure is necessary for physicians to perform life-saving procedures, the average radiation dose levels received are staggering. In fact, it is estimated that interventional radiology physicians receive approximately 3 mSv of radiation dose per year, which is more radiation than a nuclear power plant worker receives (1.23 mSv) over the same time period.

Recently there has been a boon of new health care technology to help manage radiation dose to patients, namely automated “dose tracking software” that collects patient radiation dose from imaging exams and performs detailed analysis. Healthcare providers are already seeing this help drive the improvements required by the Joint Commission.²²

In addition to managing patients’ radiation dose, it’s also critical to manage radiation exposure to physicians and caregivers. Tools are also now available to read in real time radiation exposure in the operating room.

While these advancements are promising, Philips remains committed to driving further innovation in radiation dose management and continuous improvement for its DoseWise Portal and DoseAware products in 2011 and beyond – turning its tools into comprehensive, program-based solutions for providers and risk bearers. For these solutions to work, both hospital systems and care teams must adopt a new philosophy – one of understanding, integrating, educating and improving – in order to provide the most continuous and innovative quality of care. This new world of enhanced radiation safety oversight can be grouped into four “pillars” to build and sustain a thorough and effective radiation safety program.²³

1. Understand: Establish technical evaluation and analysis of the care providers’ radiation protection program for a baseline view of the current radiation dose management protocols.
2. Integrate: Enable customized tools and solution implementation to drive improvement in managing radiation exposure to patients and staff.
3. Educate: Enable a collaborative learning environment within the health care institution to make appropriate training available so that staff knows how to use the tools they have invested in. Don’t forget about patients! Educating patients on the risk and benefits of their medical radiation exposure is an important part of transparent care that is currently underdeveloped.
4. Improve: Use industry benchmarking and other comparative analysis in collaboration with professional support to drive improvements and lower dose levels to both patients and staff.²⁴

Utilizing health care data efficiently and effectively empowers clinicians/providers. With the right solutions, quality of care can improve, allowing for increased precision and personalization in medicine. In the year ahead, imaging manufacturers will assist in data-driven decisions that are backed not only with innovative tools to effectively monitor and track radiation dose levels, but also with sustainable programs to further educate providers and improve radiation dose management – ultimately allowing for a safer future in diagnostic radiology.²⁵

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IV. CONCLUSIONS

As in many aspects of medicine, there are both benefits and risks associated with the use of CT. The main risks are those associated with

1. test results that demonstrate a benign or incidental finding, leading to unneeded, possibly invasive, follow-up tests that may present additional risks and
2. the increased possibility of cancer induction from x-ray radiation exposure.

The probability for absorbed x-rays to induce cancer or heritable mutations leading to genetically associated diseases in offspring is thought to be very small for radiation doses of the magnitude that are associated with CT procedures. Such estimates of cancer and genetically heritable risk from x-ray exposure have a broad range of statistical uncertainty, and there is some scientific controversy regarding the effects from very low doses and dose rates as discussed below. To date, there is no evidence of genetically heritable risk in humans from exposure to x-rays. Under some rare circumstances of prolonged, high-dose exposure, x-rays can cause other adverse health effects, such as skin erythema (reddening), skin tissue injury, and birth defects following in-utero exposure. But at the exposure levels associated with most medical imaging procedures, including most CT procedures, these other adverse effects do not occur.²⁶

Because of the rapidly growing use of pediatric CT and the potential for increased radiation exposure to children undergoing these scans, special considerations should be applied when using pediatric CT. Among children who have undergone CT scans, approximately one-third have had at least three scans. The National Cancer Institute and The Society for Pediatric Radiology developed a brochure, Radiation Risks and Pediatric Computed Tomography: A Guide for Health Care Providers, and the FDA issued a Public Health Notification, Reducing Radiation Risk from Computed Tomography for Pediatric and Small Adult Patients, that discuss the value of CT and the importance of minimizing the radiation dose, especially in children.

The quantity most relevant for assessing the risk of cancer detriment from a CT procedure is the "effective dose". The unit of measurement for effective dose is millisieverts (abbreviated mSv). Effective dose allows for comparison of the risk estimates associated with partial or whole-body radiation exposures. It also incorporates the different radiation sensitivities of the various organs in the body.

Radiation dose from CT procedures varies from patient to patient. The particular radiation dose will depend on the size of the body part examined, the type of procedure, and the type of CT equipment and its operation. Typical values cited for radiation dose should be considered as estimates that cannot be precisely associated with any individual patient, examination, or type of CT system. The actual dose from a procedure could be two or three times larger or smaller than the estimates. Facilities performing "screening" procedures may adjust the radiation dose used to levels less (by factors such as 1/2 to 1/5 for so called "low dose CT scans") than those typically used for diagnostic CT procedures. However, no comprehensive data is available to permit estimation of the extent of this practice and reducing the dose can have an adverse impact on the image quality produced. Such reduced image quality may be acceptable in certain imaging applications.²⁷

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