

Medical radiation exposure and accidents. Dosimetry and radiation protection. Do we only benefit the patient?

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Abstract

This article presents and discusses new information on the old Hippocratic motto of "...not to harm but to benefit the patient". Some radiation accidents are due to medical errors. Millions of medical tests exposing radiation are performed every day worldwide increasing and sometimes exceeding the annual permissible dose administered to the general population. Public authorities are now seriously concerned about medical radiation overuse. In U.S.A. both the House of Representatives and the Food and Drug Administration have recently dealt with this problem. Others and we have suggested before and the International Atomic Energy Agency now proposes: a "Smart Card" for every individual who receives medical radiation. In this card the amount of medical radiation administered will be recorded. It is time to issue rules for protection of the public from medical radiation overdose.

Introduction

Many years ago, Hippocrates the father of medicine suggested to medical practitioners: "to benefit not harm the patients" [1]. Sometime ago, medical radiation exposure (MRE) constituted only about 15%-20% of the overall average dose we received from natural radiation, derived from earth, the cosmic rays and specifically from radon, food, water, etc. [2, 3]. Now this proportion has risen to about 50% [4]. Radiotherapy, fluoroscopy, computerized tomography and nuclear medicine procedures may cause increased MRE and sometimes medical radiation accidents (MRA). Increased MRE and MRA have triggered state officials asking for regulations to better protect the public. We shall try to describe the above and present suggestions for radiation protection in medicine.

Medical radiation exposure

The National Council on Radiation Protection and Measurements in the USA has reported that the per capita dose from medical imaging increased during 1980-2009 by a factor of nearly six [5, 6].

Fazel et al (2009) have reported that myocardial perfusion accounted for 22%, and computerized tomography (CT) of abdomen, pelvis and chest for 38%, of the total effective dose from medical imaging procedures administered to the population studied [7]. The fact that the CT scan is not covered by many insurance companies does not deter patients from paying 750-1500 US dollars for it [8]. More than 62 millions of CT scans per year were performed in the USA in 2007 as compared to 3 millions in 1980 [9].

Today we realize that medical procedures using internal or external radiation are adding, sometimes unnecessarily, an increased radiation burden to the public and that no legislation exists to prevent accidents or

regulate the correct use of radiation emitting diagnostic or therapeutic equipment!

Medical radiation accidents and rules to avoid them

Accidents and risks from MRE have been described before. Several millions of medical diagnostic and therapeutic radiation procedures are performed annually worldwide, so MRA may be expected, some of them late to recognize. Most of MRA are easy to manage, do not usually cause casualties and are small part of all radiation accidents worldwide. Discussing them is a way to try to avoid them [10].

One may suppose that during the last 60 years there were at least 600 radiation events due to various reasons and causing significant exposure to 6000 individuals and a total of 200 lethal issues [11]. In an analytical review out of 44 radiation accidents, 14 were MRA. All these MRA were due to errors in radiotherapy treatment and occurred after 1974 [10]. Furthermore we shall describe in this text some MRA due to radiology and nuclear medicine procedures. Radiation accidents of all causes are increasing with time and it is interesting that they do not relate to economic and technical development and that most of them are recognized late.

Although MRE from diagnostic and treatment procedures is usually safe, several apparent weak links in the diagnostic and treatment chain can lead to severe overdose injuries. These weak links include among others, faulty computer software, quality-assurance procedures, and also insufficient staffing.

Much of the recent concern over MRE has focused on CT scans. Many of the scans done today are questionable on the grounds of medical justification. The average radiation dose of one CT scan may increase a patient's lifetime risk of cancer, especially if CT scans are repeated [12,13]. Every day, more than 19,500 CT scans are performed in the US that subject each patient to the equivalent of 30-442 chest radiographs [14].

A MRA on a 2 years old boy in 2008 was well publicized. The boy underwent a CT scan at his cervical spine because he had fallen out of bed and had difficulty moving his head. A lady technologist R. K. administered to the boy a radiation overdose that caused an immediate local bright erythema and substantial chromosome damage. It was estimated that the boy received at his head and neck area between 1.5-7.3Gy and was expected to develop cataracts within 3-8 years. The technologist was fired, her license was suspended and the hospital was fined with 25,000\$. The technologist claimed that the CT scanner displayed a failed code. The boy's family has reached a settlement with the hospital where the incident occurred.

The U.S. Food and Drug Administration (FDA) reported that has found cases of radiation overexposure related to CT brain perfusion scans in various hospitals which involved more than one manufacturer [15].

Others have mentioned that a CT scan commonly gives 25mSv to the subject examined [16]. A recent study reported that a routine multiphase abdomen and pelvis CT scan administers an overall median effective dose to the patient of 31mSv [17]. Multiple CT examinations have administered to some patients with renal colic, a dose of 19.5-153.7mSv [18]. According to Mettler Jr. et al (2008) the adult effective dose from a head CT and from an abdomen CT are equivalent to the adult effective dose from roughly 100 and 400 chest X-rays, respectively [19]. Nuclear medicine procedures may be equivalent to 10-2050 chest X-rays referring to lung ventilation ^{99m}Tc DTPA as the lowest and a stress $^{201}\text{TlCl}$ cardiac test as the highest, respectively [19].

The National Academy of Science on Biological Effects of Ionizing Radiation of USA (BEIR VI) indicated that a 10mSv single population dose is associated with a lifetime attributed risk for developing a solid cancer or leukemia in 1:1000 [20]. It has been reported recently, that 1 in 270 women who underwent angiography at the age of 40 years will develop cancer from that CT scan compared to an estimate that 1:8100 women who had undergone a routine head CT scan will develop cancer [17].

It was recently shown that the new prospectively gated 16-sliced coronary CT angiography (CTA) is lowering the radiation dose to the patient as compared to the standard retrospectively gated 64-slice coronary CTA, from 10-25mSv to about 1mSv [21].

While scanning times today are much shorter, taking little more than a minute compared to as much as 15 minutes a few years ago, this does not mean that patients are receiving lower doses of radiation. They receive the same amount of radiation as before, or even more.

However, significant image noise reduction allows for up to 60% radiation dose reduction in CT routine clinical use. Using iterative reconstruction techniques a decoupling of spatial resolution and image noise is obtained; enhancement of spatial resolution in areas with higher contrast and reduction of image noise in low contrast areas, enable the user to perform CT scans with lower radiation dose. Computerized tomography dose index reductions of 32%-65% can be obtained when adaptive statistical iterative reconstruction is used [22, 23].

An international study, coordinated by Madan Rehani, IAEA Radiation Safety specialist, has shown that some countries are over-exposing children to radiation when performing CT scans. These children are receiving adult-sized radiation doses, although experts have warned against this practice for over a decade [24].

A hopeful study though, presented at RSNA, showed a reduction of 25 to 30 percent in radiation dose for paediatric chest and abdominal CT scans with the use of 2D non-linear adaptive filters (2D-NLAF) [25].

Fluoroscopy is another imaging procedure that can pack a radiation wallop. In some cases patients are leaving the fluoroscopy table unaware that they've received enough radiation to cause skin injury. Skin injuries up to necrosis may appear due to multiple coronary angiography and angioplasty procedures [26].

For handling beta-emitters like yttrium-90- ^{90}Y -DOTATOC or ^{90}Y -Zevalin and for calculating their Bremsstrahlung radiation it is advised to use shielding by Perspex (10mm) or aluminum (5mm) and add lead [1mm] on the outside. It is also advised to divide handling among several individuals [27-29].

In the past during 1960-1980, eleven fatalities were reported due to internal exposure most of them caused by errors in medical administration of radiopharmaceuticals. In 1968 a patient scheduled for a liver scan was injected with mCi and not μCi of gold-198 (^{198}Au) and died [30].

In Paediatric Nuclear Medicine imaging, Sheehy et al (2009) have established the feasibility of reducing the total administered radiopharmaceutical activity in paediatric patients by at least a factor of two, without sacrificing image quality. They compared the standard reconstruction method filtered back projection (FBP) with the ordered subset expectation maximization with three-dimensional resolution recovery (OSEM-3D) method, in ^{99m}Tc -dimercaptosuccinic acid (DMSA) renal single photon emission tomography (SPET) in children. The published results showed that by OSEM-3D reconstruction and reducing the radiopharmaceutical activity by half, image quality was the same with a consequent radiation dose reduction [31-33].

Severe penalties are issued to individuals, physician groups, or hospitals for reimbursement claims for radiation oncology treatments to federal healthcare agencies or in order to settle alleged violations regarding the use and handling of radioactive materials.

Early this year the US Government dealt with the matter of MRE. "Before we move on any legislation, we'll need to have more hearings to get answers to our questions." That's what Rep. Frank Pallone Jr. chairman of the US House of Representatives subcommittee on Health, told invited witnesses after several hours of hearings.

It is obvious that quality assurance requirements, accreditation and licensing are absolutely and urgently required for the equipment used and for the every day practice of technologists, radiologists, radiotherapists, radiophysicists and nuclear medicine physicians. One never knows if someone of the above mentioned personnel or a relative or a friend, may later be a cancer patient and needs to be diagnosed or treated with procedures that do not meet quality and safety assurance requirements.

A protective program suggested by Medical Imaging and Technology Alliance (MITA) and presented in the US House of Representatives on 26 February 2010 involves software that can be installed on CT scanners to alert operators with a yellow ("warning") or red ("don't scan at this dose level") pop-up screen. Manufacturers are working on the new patient safeguards and will be able to include them in new scanners and offer them to their existing customers before the end of 2010. The institution that purchases the equipment will have to make a decision during installation as to whether they want to prevent scanning, if the dose reaches that level. Threshold levels for new scans will establish diagnostic reference dose values.

Key principles for reducing unnecessary radiation are: a) to have specific criteria for physician's decision-making, b) to have also, a national dose registry, c) electronic records d), accreditation for advanced imaging facilities, e) training and education standards for the personnel, f) to report medical errors, g) to have, radiation dose reference values, h) quality control procedures, i) to check the CT scanner display panels before and after every study and j) to individualize the dose injected to every patient [12, 31-33].

Medical radiation and dosimetry. Some previous and recent views

The World Health Organization (WHO) in order to categorize all nuclear medicine and radiology procedures has long ago (1987) suggested the effective dose equivalent (EDE). Effective dose equivalent is defined as a weighted sum of the dose equivalents administered to individual tissues. It is a single figure specifying a hypothetical uniform whole body dose equivalent which would involve the same risk as the actual dose distribution [2]. It was suggested that the limit of 30mSv could be approached but not exceeded, except if there was a benefit to the individual and if the dose administered was difficult to reduce or prevent [34, 35]. As nuclear medicine tests that could give a considerable MRE to patients, the WHO categorized the following: a) Static brain imaging with technetium-99m (^{99m}Tc)-pertechnetate for an injected dose of 500MBq. b) Gated cardiac imaging with ^{99m}Tc red blood cells for an injected dose of 800MBq. c) Bone imaging with ^{99m}Tc- methyl diphosphonate (MDP) for an injected dose of 550MBq; today the usual dose is about 700MBq. d) Quantitative haemodynamics with ^{99m}Tc-pertechnetate for a dose of 600MBq. e) Myocardial imaging with thallium-201 (²⁰¹Tl) chloride for a dose of 75MBq. f) Abscess imaging with gallium-67 citrate for a dose of 80MBq. The first of these procedures (a) induces an EDE of 5.5mSv and the last one (f) an EDE of 9mSv [2,34]. Others consider that above 3-5mSv per examination the possible harm to the patient and/or to their relatives should be explained and balanced against the benefit of the examination [36, 37]. Of course, in every day practice, by performing angiography, radiotherapy, treatment with radio nuclides or CT imaging, the limit of 30mSv is often or may be exceeded [34, 35]. Many agree that there is no low radiation dose threshold for inducing cancer [38, 39].

According to Wakeford and Tawn (2010) in order to better describe the biological effects of low dose and low dose rate and differentiate these doses from high doses, we should consider the elapsing time between radiation exposures, the number of tracks of ionization traversing cell nucleus, the ionization density of these tracks and the rate of traversal [39]. Due to DNA repair process, when time interval between successive brief exposures is more than 6h (as happens in nuclear medicine departments day after day for their acting personnel) the radiological effect is directly proportional to the total dose [39, 40]. This "operationally" linear response can be sufficiently modified if the same dose is received acutely, thus the low dose rate is equally important [39]. On the other hand, high dose and high dose rates do not have a linear biological response but have a much higher response curve. The authors consider that for sparsely ionizing radiations, a low dose delivered acutely is <100mGy and a low dose-rate is <5mGy per hour [39].

Drugs and rules for radiation protection in nuclear medicine

Specific protective agents to the MRE effects in nuclear medicine are not really available today. After treatment of differentiated thyroid cancer, amifistine [Ethylo] has not moved effective in xerostomia and colchicine and maleic acid being toxic to the kidneys may not be used in peptide receptor radionuclide treatment (PRRT) cases where amino-acids are used to protect kidneys from the toxic effects of PRRT [26].

A lead collar is partially protecting the environment of patients who have received high ¹³¹I doses for the treatment of differentiated thyroid cancer [41].

A recent information statement of the American Society of Nuclear Cardiology (ASNC) (2010) describes in detail the appropriate and the inappropriate indicators for performing myocardial perfusion imaging [42]. The ASNC considers important to lower the actual MRE to these patients and recommends: a) to properly select the patients, b) adjust the administered dose according to patients weight and to the characteristics of imaging system, c) prefer ^{99m}Tc than ²⁰¹Tl, d) use the stress test only, e) use new technologies that can lower MRE up to 50%, f) use image reconstruction etc. [42].

Because in our days cancer is not a death sentence we should not consider that cancer patients examined by nuclear medicines or radiologists or treated by radiotherapy may well receive an unacceptable radiation burden [43]. Radiation effects may not manifest until 5-20 years after the scan [12]. One may suggest that this is an important issue and interesting field of research.

Radionuclide tests and airport security

A false MRA if we may call it so is detected in individuals who are travelling by air and had undergone nuclear medicine diagnostic tests before. The airport radiation detector alarms in these cases may be triggered and the individuals may be detained at the airport for a few days. The number of days that after a diagnostic nuclear medicine test may trigger false radiation detector alarms varies from 1-3 days for fluorine-18, ^{99m}Tc and iodine-123 to about 30 to 67 days for ¹³¹I [44].

Federal U.S. regulations describe when and how licensed health care facilities can release patients who have been treated with unsealed radioactive material or with implants containing radioactive material [45, 46]. Safety instructions must be provided to patients or to their guardians, to ensure that doses to other individuals remain "As Low As Reasonably Achievable". Many facilities provide patients with adequate safety documentation, educational materials, and verifiable letters or cards for presentation to law enforcement personnel. In other facilities, however, the educational emphasis appears to be on patients receiving therapeutic treatments and it is less likely, patients undergoing diagnostic procedures be informed about the possibility that, for a period of time after their procedure, they may trigger radiation alarms [47].

The Smart Card issue

A Smart Card project to log how much radiation a person receives in the course of a lifetime is among the latest efforts by the International Atomic Energy Agency (IAEA) [13] and its partners to ensure better protection of patients from any unnecessary MRE that may later induce a risk of cancer, especially, if CT scans are repeated [21]. Data about MRE could be included in medical records and on the electronic health cards, already carried by people in many developed countries. The Medical Imaging and Technology Alliance has agreed to begin reporting dose information in a consistent fashion, for all new CT scanners by the end of 2010 [48].

In this Journal, van Isselt et al (2004) suggested that it would be diagnostically helpful for patients who are re-examined in a foreign country to present to physicians of this country a record of the radioactive tests and doses they had received before in their own country [49].

Others have previously suggested that a reference dosimetric card would be useful to the patient. This card

was called: "dosage card" by Grammaticos [50] and the problem was also postulated by Sinzinger et al (2005) [51]. Palumbo et al (2009) published in this Journal a detailed record of radiation alarm incidents that could have been avoided if patients had a certificate of the radiation dose they had previously received [52].

A Smart Card project according to the IAEA is in many ways useful [13]. If the Smart Card is generally applied, medical radiation physicians will be doing every effort not to report and inform the public that they have administered an unnecessarily high radiation dose to their patient.

It is time to suggest that all papers related to MRE, when published should include MRE dosimetry. Hippocrates said also that: "Physician is worth of many men" and "Physician who likes wisdom is a semi-God". We need hard work and modesty in order to only benefit the patient.

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