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Review Article

Dentistry Section

The Road To Radiation Protection: A Rocky Path

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ABSTRACT

Radiation has intrigued us with its magnificent properties of imaging and healing. But this discovery, like many others, came with a heavy price. The pioneers of this form of energy themselves often succumbed to its devastating effects and hence, paved a way for future generations to be wary of it, while continuing to use it. This paper attempts to salute those masters who have helped make the radiation world a safer place to live and work in.

Keywords: Radiation protection, Rem

INTRODUCTION

Much has been known and publicized on Roentgen's discovery of X-rays. But the genesis of radiation protection, its exodus and the revelation of modern day radiation protection, have not been widely read. Even today, radiologic technology serves as an on-going study on the harmful effects of low dose ionizing radiation late effects. The sum of these studies, observations, and statistical analyses has brought our profession to respect that there is no such thing as a safe dose of ionizing radiation.

On the night of November 8, 1895, Wilhelm Conrad Roentgen, a professor of Physics and Director of the Physical Institute of the University of Wurzburg, discovered "X-rays", which have been so named after the mathematical symbol for the unknown and he ultimately called them 'Roentgen rays' [1-3]. Roentgen then proceeded to make the first radiograph of the human body. He placed his wife's hand on a photographic plate and exposed it to the 'unknown rays' for 15 minutes. Thus, the first medical radiograph which was taken was of Mrs Roentgen's hand and the first industrial radiograph which was taken was of Roentgen's shot gun [1]. He was awarded the first Nobel Prize in Physics in 1901.

The toxicity of X-rays became apparent soon after Roentgen discovered them. In May 1896, he noticed hair loss, followed by skin toxicity. He used to hold a lead plate between his fingers while taking radiographs and thus, fortuitously protected himself from the radiation [1,4].

In 1895, Dr. Otto Walkoff of Braunschweig, Germany, took the first dental radiographs with an exposure time of 25 minutes [5,6].

In 1896, a New Orleans dentist, Dr. C. Edmund Kells, obtained the first intraoral radiograph. Kells had to place his hands between the tube and a fluoroscope to adjust the tube voltage, until the best image of hand appeared on the screen. After 12 years, cancerous tumours appeared on the fingers of both his hands. Finally, C. Edmund Kells, the father of dental radiology, after a series of unsuccessful surgeries, ended his life on May 7,1928, at the age of 72 [7,8].

In 1902, the first dose limit of about 10 rad per day (or 3000 rad per year), was recommended. By 1903, animal studies had shown that X-rays could produce cancer and kill living tissue and that the organs most vulnerable to radiation damage were the skin, the blood-forming organs, and the reproductive organs [9].

By 1915, the British Roentgen Society had adopted a resolution to protect people from overexposure to X-rays.

In September 1924, at a meeting of the American Roentgen Ray Society, Arthur Mutscheller was the first person to recommend a "tolerance" dose rate for radiation workers, a dose rate, that in his judgement, could be tolerated indefinitely [10].

Three distinct periods have been noted in the early chronology of Radiation Protection:

- Pioneer Era (1895-1905), in which recognition of the gross somatic hazards occurred, and relatively simple means were devised to cope with them [10].
- Dormant Era (1905-1925), in which the major concern was applications, but in which great gains were made in technical and biological knowledge, which were later applied to protection [10].
- Era of Progress (1925-1945), which saw the development of radiation protection as a science in its own right, along with the birth of health physics in the Manhattan District [10,11].

In the Pioneer Era, William Herbert Rollins, a Boston dentist, made numerous original contributions to radiation protection: leaded tube housings, collimators, and other techniques (including the development of high voltage tubes) to limit patient dose. Rollins' experiments included exposure of a pregnant guinea pig, which resulted in killing of the foetus and which led to him to express concern about the use of X-rays in pelvic examination of pregnant women. Rollins was the quintessential promulgator of radiation protection techniques and he was a true pioneer of X-ray protection [10].

The Dormant Era was a period of two decades, in which applications of X-rays and radium, along with the development of improved equipment seemed to be dominant. In the protection area, little overt progress was made, although latent effects of radiation exposures, particularly at low levels, began to be recognized [10].

In October 1907, at the meeting of the American Roentgen Ray Society, Rome Vernon Wagner, an X-ray tube manufacturer, reported that in an effort to control his personal exposures, he had begun to carry a photographic plate in his pocket and to develop the plate each evening, in order to determine as to whether he had been exposed. This practice, which apparently did not come into widespread use until later, was clearly the forerunner of the film badge. Unfortunately, Wagner's concerns for his personal exposure came too late, for he had already developed cancer and died 6 months later, in 1908 [10].

A major development was the adoption of radiation protection recommendations by the British Roentgen Society (1915). This was probably the first organized effort at Radiation Protection. The American Roentgen Ray Society (1922) too was a pioneering attempt which was made for doing radiation checks. They provided a sound basis for users of X-rays, and more importantly, signified an active organizational interest in X-ray protection [10].

The year 1925 marked the start of what might be termed, “Era of Progress”. Arthur Mutscheller, a German-American physicist, put forth the first tolerance dose or permissible exposure limit, which was equivalent to about 0.2 rem per day. He based this limit on 1/100 of the quantity which was known to produce a skin erythema per month, noting that recovery would occur swiftly enough to obviate any untoward effects. Swedish physicist, Rolf Sievert also put forth a tolerance dose- 10% of the skin erythema dose - in the same year [11].

The 1920s saw other gains in radiation protection: the introduction of film badges for routine personnel monitoring, recognition of the genetic effects of X-rays (for which Hermann Muller won the Nobel Prize in 1946), and the adoption of a unit for measuring radiation by the Second International Congress on Radiology in 1928. The definition and adoption of the Roentgen, as this unit was named, provided a physical basis for the quantitative measurement of radiation, which was heretofore lacking, thus permitting in a more or less unequivocal way, documentation of radiation exposures [11].

Recognition of radiation hazards and the need for their control, led to the formation of the International X-ray and Radium Protection Committee, forerunner of the current International Commission on Radiological Protection (ICRP), and the formation of the U.S. Advisory Committee on X-ray and Radium Protection (ACXRP), direct ancestor of the modern day National Council on Radiation Protection and Measurements [12,13]. These bodies undertook a study of the so-called tolerance dose and promulgated the establishment of definitive, scientifically based radiation protection guides, the first of which was published in 1931. It was a 114 page document, which among other things, considered the hazards of toxic chemicals which resulted from burning X-ray films, as well as protective measures for protection of both patients and those who were occupationally exposed [10,13].

In 1936, the ACXRP recommended the reduction of the so-called tolerance dose to 0.1 R/day, reducing it by half. Five years later, in 1941, the ACXRP established the first permissible body burden from radioactivity in the body –0.1 microcurie for radium. The body burden was based on the pioneering work of Robley D. Evans, MIT physicist, with radium dial painters. The year 1941 also saw an article written by Lauriston Taylor, that recommended an even further reduction in the permissible level for external exposure to 0.02 R/day, or roughly the equivalent of 5 rem/year [12].

It was in the Manhattan District of U.S. Army Corps of Engineers, that the name, “Health Physics” was born, and great advances were made in radiation safety. From the onset, the leaders of the Manhattan District recognized that a new and intense source of radiation and radioactivity would be created. Thus, in the summer of 1942, Ernest O. Wollan, a cosmic ray physicist at the University of Chicago, formed a group to study and control radiation hazards and he was the first to bear the title of ‘health physicist’. Within the Manhattan District, the name “health physicist” seemed to have been derived in part from the need for secrecy (and hence was a code name for radiation protection activities) and the fact that there was a group of mostly physicists working on health related problems. Thus, their activities included development of appropriate monitoring instruments, developing physical controls and administrative procedures, monitoring areas and personnel, radioactive waste disposal - in short, the entire spectrum of modern day radiation protection problems. It was in the Manhattan District, that many of the modern concepts of protection were born, including the rem unit, which took into account the biological effectiveness of radiation, and the maximum permissible concentration (MPC) for inhaled radioactivity. Indeed, it was in the Manhattan District, that modern day radiation protection effects, born in the early days of X-ray and radium, realized their maturity [10].

Since the mid-1950s, radiation-safety standards have included provisions for incorporating the philosophy of As Low As Reasonably Achievable (ALARA) in radiation-safety work practices. The external whole body dose which was allowed in a calendar year in the mid-1950s was 15 rem. This was reduced in 1960 to 12 rem per year, if detailed lifetime exposure records were maintained and the individual’s lifetime exposure did not exceed an average of 5 rem per year [14].

UK government has framed ‘The Health and Safety at Work Act, 1974’ and this complies with the provisions of the European Council Directives 96/29/Euratom and 97/43/Euratom:

- *The Ionizing Radiations Regulations, 1999 (SI 1999 No. 3232)* (IRR 99) replaced the Ionizing Radiations Regulations, 1985 (SI 1985 No. 1333).
- *The Ionizing Radiation (Medical Exposure) Regulations, 2000 (SI 2000 No.1059)* (IR(ME)R2000) replaced the Ionizing Radiation (Protection of Persons Undergoing Medical Examination or Treatment) Regulations 1988 (SI 1988 No. 778) [15-19].

Prior to the adoption of the risk-based system in 1994, internal exposure was controlled by controlling the amount of radioactive material that could be taken into the body. These limits were based on the estimated annual dose to the irradiated organs, that would exist after 50 years of continuous intake. The organ which received the highest dose was referred to as the “critical organ.” The amount of allowable intake was based on not exceeding 15 rem per year, to any “critical organ” after 50 years of continuous intake. The primary exception was in cases where the bone was the critical organ, in which case the limit was related to an equivalent intake of radium, and was not directly related to dose. The current risk-based system for controlling internal exposure is based on controlling (1) the estimated risk that the exposure delivered over the next 50 years to an irradiated organ from an intake will result in a cancer or, in the case of the gonads, a genetic effect and (2) the exposure to prevent an “acute” injury to the organ. Since each organ has a different estimated risk of developing a cancer or a genetic effect, the allowable doses to an organ under the new system can range from approximately 20 rem to 500 rem, which are based strictly on the risk of one of these effects. However, an additional limit of 50 rem is imposed to prevent an acute injury from occurring. Therefore, in general, the internal exposure which was allowed under the earlier separate dose limitation scheme was lower than that which was allowed in the newer, risk-based scheme of dose limitation [20].

The gradual reduction in the external dose limit is often cited as a concern for the adequacy of the earlier dose limits. However, the change in individual dose limits over time is the result of three interrelated considerations: One is the continually increasing scientific knowledge on radiation health effects, that permitted evolution from a system which was based on prevention of injury, to one which was based on reduction of risk. Second is the advance in technology that has resulted in the actual reduction of the average annual doses to occupational workers. The third consideration is the state of occupational safety in general, as it relates to an “acceptable” occupational risk. In the mid-1970s, the international and national scientific committees [21, 22] charged with developing the consensus *reports* on radiation health effects (NAS 1972, UNSCEAR 1972) provided the first attempt which was made at quantifying the risk of delayed effects (i.e., genetic effects and cancer induction) from radiation exposure [21, 22].

Imaging personnel are occupationally exposed to low dose ionizing radiations which primarily result from scatter. The potential effects of this low dose ionizing radiation exposure over many years, are what are meant by late effects. The two most important concerns that are considered as late effects are carcinogenesis and genetic effects [23]. During the time of foetal growth, foetal exposure can result in birth defects which can manifest as congenital disorders. Ionizing radiation is one of the most potent teratogenic agents which are known. Dental X-rays, particularly when they are obtained frequently and at young ages, may be associated with an increased risk of intracranial meningioma [24].

The 1980 Low-level radioactive waste (LLRW) Policy Act, which was amended in 1985, established a framework for the states to provide safe disposal of LLRW and encouraged the creation of regional compacts to develop an appropriate network of disposal sites. The current state of affairs for LLRW disposal has led the Health Physics Society to take the following positions:

1. The goal of managing LLRW is to ensure the safety of workers and the public and to protect the environment. To achieve this goal, disposal, not long-term storage, is the best and safest long-term approach.
2. The Health Physics Society believes that lack of competition in LLRW disposal options results in excessively high costs to waste generators, which impede the use of nuclear technologies that provide significant benefits to society.
3. The Health Physics Society believes that the regulatory framework for management and disposal of LLRW needs a complete and coordinated overhaul [25].

Today, genetic effects can only be observed in animal studies and increases in cancer induction can only be seen in groups of people who are exposed to high doses of radiation at high rates, such as the survivors of the Japanese atomic bomb blasts. Therefore, the use of these animal studies and atomic bomb survivor studies for assessing the adequacy of occupational radiation standards requires the extrapolation of the study results from animals to humans and from high-dosed populations of Japanese civilians to low-dosed populations of United States workers [26].

With the adoption of the new system in 1994, the dose limit became a limitation of the total estimated risk which results from both external and internal exposures, which is equal to the estimated risk which results from an external exposure of 5 rem per year [26].

There are agencies like ICRP and AERB (Atomic Energy Regulatory Board), which are formed by international and national authorities. The competent authority may issue safety codes and safety standards from time to time, prescribe the requirements for radiation installation, seal sources and radiation generating equipment and the licensee shall ensure compliance with the same. These recommendations are equally applicable for institutions and private clinic setups, but the limited space which is available and the intention of saving few pennies are the factors which increase the risk of unwanted radiation exposures.

Protection of Staff and Personnel

1. During an exposure, operator should not be exposed to the primary radiation beam and he/she should keep a distance of at least 3 metres from the X-ray tube.
2. Shielding should be used wherever necessary, floor, walls, ceiling and doors, taking into account, distance, maximum expected X-ray tube voltage, and workload. The orientation factors for the equipment, along with the occupancy factors for the adjacent areas, should be considered when more detailed shielding calculations are made.
3. While shielding is being constructed for forming an unbroken barrier, care should be taken in the use of shielding materials, especially lead, which must be adequately supported to prevent sagging.
4. The irradiation switch for the dental X-ray equipment should be located outside the room, at a sufficient distance from the X-ray tube, or behind an adequately shielded barrier.
5. The final plans of the installation should be arranged to be reviewed by the appropriate government agency, when a new facility is being constructed or when modification is being done to an existing one. The plans and accompanying documents must be shown.
6. Proper warning should be given, by installing a symbol of danger outside the X- ray room, to instruct the people who are waiting there [27].

CONCLUSION

No doubt, we are now better equipped to handle unwanted radiographical exposures, but some considerations for the future in radiation protection should include trends in exposure levels and improvements in risk estimation; question of life time limits, de minimis levels and partial body exposures, plus problems of high LET radiations and synergisms Current standards assume that, for purposes of radiation protection, dose and detriment are linearly related, with no threshold. Hence, the appropriate basis for protection is an acceptable risk rather than absolute safety. Strict adherence to regulatory body norms will go a long way in curbing radiation harm. The premise of this article is to revisit history, so that we learn from others' mistakes and take radiation safety to greater heights.

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