

Radiation in medical practice & health effects of radiation: Rationale, risks, and rewards

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ABSTRACT

Radiation is important in health and disease. It is imperative to use properly and prevent misuse or overuse. Pertinent trends of increasing radiation in the environment need analysis. We gleaned important information, from published evidence and authoritative resources, for practicing safely and preventing harm. Science & technology progress is for the betterment of mankind, and all efforts should be made to prevent any untoward effects. Children and paediatric patients deserve special attention because of their vulnerability due to multiple reasons. Effective investigations & interventions in medical settings should be done based on best evidence. All those ordering radiological investigations should take into consideration the radiation exposure values & especially decide on clinical impact of the investigation. Prenatal exposure to radiation has risks. Computed Tomography is responsible for 24% of all radiation exposure. Dual-energy X-ray absorptiometry is useful for measuring changes in body tissue composition. Radiologists should tailor imaging individually. Radiotherapy is administered to more than half of all cancer patients. Acute toxicity alleviation and chronic toxicity consideration is important. Radiation emergencies can occur in isolation or as major catastrophe. Emergency life-support is needed. Decontamination along with using the ABCDE reduction approach components are elucidated. With increasing use of mobile phones the electro-magnetic fields produced by mobile phones use needs consideration. UV radiation overexposure prevention is with shade, clothing and hats. Applying sunscreen essential on those parts of the body that remain exposed like the face and hands. All the safety measures need popularization and continuous practice with precision & perfection.

Keywords: Decontamination, investigations, ionizing, radiation, radiation emergencies, radiotherapy, ultraviolet

Introduction

The medical community plays an important role not only in restoring health, but also protecting & promoting it. Scientific discoveries have benefits & harms. Radiation is important in health & disease, possibly with proper use and prevention of misuse or overuse. Rationale use of radiation for diagnosis & treatment is rewarding & hence the need that this practice be promoted & perfected. Pertinent trends in increasing radiation in the environment need to be analysed. Protection from radiation risks need to be reviewed.

Children & paediatric patients deserve special mention as they are more vulnerable because of multiple reasons (i) Rapid growth, their cells are dividing making the DNA vulnerable to damage (ii) Lifespan is more, hence exposure to radiation is more likely as compared to adults (iii) Long lifespan makes it possible for long term side-effects of radiation to manifest in their lifetime.

Primary care physicians are primary contacts with a vast and varied clientele, hence suited for wide and wonderful impact. Family practitioners are best suited for suggesting preventive strategies in an empathetic familial environment for persistent success.

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Methods

Glean important information, from published evidence and authoritative resources, for practicing safely and preventing harm.

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Thoughtful analysis for tactful advantageous applications. Put things in proper perspective.

Radiation types

Radiation is broadly ionizing & non-ionizing. Ionizing radiation is the energy or particles (protons, electrons or neutrons) produced by unstable atoms of radioactive materials. It is present in environment or produced by certain human activities. Radiation particles (neutrons, beta or alpha) are emitted by radioactive substances. Radionuclides are the unstable elements which disintegrate and emit ionizing radiation.

Electro-magnetic (EM) radiation occurs in different forms, differing in wavelength or frequency. These are (in the order of increasing frequency & energy): Radiowaves, Microwaves, Infrared light, Visible light, Ultraviolet (UV) light, X rays & Gamma rays. Non-ionizing radiation is that radiation which has insufficient energy to cause ionization. It includes radio waves, microwaves, infrared, visible radiation, and ultraviolet radiation.

Ionizing radiation

Ionizing radiation has many beneficial applications. These are used in medicine, industry, agriculture and research.^[1] With increasing uses of ionizing radiation there is a need of safe use policies and practicing safety measures.

The population radiation dose contribution from all artificial sources from medical uses is 98%. This represents 20% of the total population exposure. Annually more than 3600 million diagnostic radiology examinations are performed, 37 million nuclear medicine procedures are carried out, and 7.5 million radiotherapy treatments are given worldwide.^[1]

Not all medical imaging uses radiation. Ultrasonography and Magnetic resonance imaging are safe. X-ray films, Angiography/fluoroscopy, Computed tomography, Nuclear medicine (including positron emission tomography) imaging modalities are risky and should be used only when benefits outweigh the risks.

Radiation damage to tissue and/or organs is radiation dose dependent. The international (SI) unit of measure for absorbed dose is the Gray (Gy). The various factors for potential damage from an absorbed dose are the type of radiation and the sensitivity of different tissues and organs. Equivalent dose is the measure of the biological effect, which depends on the amount of the absorbed dose & the sensitivity (intensity of ionisation) in living cells caused by different type of radiations. The unit of equivalent dose is the Sievert (Sv). Practically smaller units such as millisieverts (mSv) or microsieverts (μSv) are used.

The typical effective doses in various imaging modalities in mSv are: (i) X-ray examinations- Limbs and joints <0.01, Chest (PA) 0.015, Abdomen 0.4, Lumbar spine 0.6 (ii) Computed Tomography (CT) scans- head 1.4, chest 6.6, abdomen/pelvis 6.7 (iii) Radionuclide studies- Lung ventilation 0.4, Lung perfusion 1, Bone 3,

PET (Positron Emission Tomography) head 7, PET-CT 18. All those ordering these should take into consideration these values, & especially decide on clinical impact of the investigation.

Large equivalent dose, given at a time, causes acute damage in the form of skin redness, hair loss, radiation burns, or acute radiation syndrome. The dose threshold for acute radiation syndrome is about 1 Sv (1000 mSv). Risk is much low if the radiation dose is low and/or it is delivered over a long period of time (low dose rate). Over longer periods there is a greater likelihood of repairing the damage. The risk of cancer in the long term is still there and is proportional to the radiation dose.

Prenatal exposure to ionizing radiation may induce brain damage in foetus. This occurs if an acute dose exceeding 100 mSv between weeks 8-15 of pregnancy and 200 mSv between weeks 16-25 of pregnancy is received. Human studies have shown no effects before week 8 weeks or after week 25 of pregnancy from radiation to fetal brain development.^[1]

Risk reduction strategies: Rationale use & reduced exposure

Rationale use demands using radio-imaging only when definitely indicated. Decreasing unnecessary diagnostic radiation and still obtaining diagnostic images is an art, and needs to be perfected and practiced by all. Imaging modality correct selection is the responsibility of the ordering physician. CT is inferior to Magnetic Resonance Imaging (MRI) as it does not detect as many abnormalities as MRI. MRI detects the subtle changes in detail. CT involves ionizing radiation, while MRI does not. Therefore appropriate decisions should be made. Other clinical dictum is to not to order radio-imaging if report not likely to affect management.

Reducing radiation exposure is multi-faceted. CT contributes for 24% of all radiation exposure and uses almost half of manmade radiation.^[2] Hence in CT scans the scanning range should be limited to only the area pinpointed clinically. Multiphase scanning should only be judiciously used when necessary. Advances in technology are a boon. The latest CT scanners provide images with greater detail, with multi-planar and reconstruction in 3-dimensions of the acquired data.

Diagnostic imaging, especially CT scanning should be done with least exposure to radiation. Radiologist should tailor the examination for individual paediatric patients, using the least parameters of exposure. In some instances, it is possible to reduce the radiation dose by half, even for adults in whom CT is done, without changing the diagnostic efficacy of the study and for proper diagnosis within the radiologist's abilities.^[2]

Dual-energy x-ray absorptiometry (DEXA) measures body tissue composition, and is a useful technique for monitoring long-term nutritional progress. Quantitative measures of the attenuation of two x-ray beams is used for deriving tissue density values

including lean body mass, fat mass, and bone density. These measurements are compared with standard models used for bone and soft tissue, and they are used to calculate bone mineral content, lean body mass, and fat mass. Although typical effective dose (mSv) with DEXA is only 0.001 mSv, radiation exposure as compared to no radiation exposure of Ultrasonography needs consideration. Ultrasonography is safe, widely available, and accurate, and has significant potential for widespread clinical application.

Quantitative ultrasound (QUS) is a useful technique with potential to replace DEXA scans for osteoporosis. It has been used for peripheral bone sites (most commonly the calcaneus) with accuracy comparable to DEXA scans.^[3] It is interesting to note that more than 50% of fractures occur in individuals with low bone mass rather than Bone Mineral Density (BMD) osteoporosis. Research is on to redefine the disease as a fracture risk rather than a specific BMD. QUS provides bone mass measurements by calculations from the attenuation of the signal as it passes through bone or with from the time it takes to traverse the bone length. It is unclear whether Ultrasonography provides information about properties of bone other than quality/mass. However, this is a useful advantage of the technique.^[4]

It has been usefully demonstrated that quantification of muscle wasting in intensive care patients by a limited bedside ultrasound examination predicts total body composition. The reliability of this, both intra & inter operator, is excellent.^[5,6]

Radiation therapy

Malignant cells can be killed by using high doses of radiation. The incidence of cancers and side-effects of its treatment are a cause of concern. Any improvements to radiotherapy, even small improvements, will benefit a great many people.

Radiotherapy is administered to more than half of all cancer patients.^[7] Radiotherapy forms part of treatment in 40% of those cancer patients considered cured. Early cancers curable with radiation therapy alone are of Skin (squamous and basal cell types); Prostate; Lung (non-small cell types); Cervix; & Head & neck. Lymphomas of Hodgkin's and low-grade Non-Hodgkin's types also curable if radiotherapy is given early.

Radiation is used therapeutically on the basis of its ionizing effects. All tissue in its path is damaged; however, cancer cells are particularly susceptible. The likely mechanism of this is defects in cancer cells ability to repair sub-lethal DNA and other damage.^[8] The sensitivity of normal cells is not very different from the malignant cells. Hence the need of localized radiation therapy. Therapeutic radiation can be delivered as *teletherapy* or *brachytherapy*. *Teletherapy* uses radiation generated at a distance as focussed beams and targeted at the tumor within the patient. *Brachytherapy* uses sources of radiation which are encapsulated and implanted directly into or adjacent to tumor tissues. The most commonly used is *Teletherapy*.

Adverse delayed effects of ionizing radiation is more in children, hence the need of advanced technology. A major advance for children is the application of conformal irradiation. This is most commonly applied as intensity-modulated radiation therapy. The technique utilised is sparing the normal tissue by conforming the radiation volume to the shape of the tumor, thereby enabling delivery of higher doses to the tumor with lower exposure of normal tissue adjacent to the tumor or in the path of the radiation beam. A recent randomized clinical trial of stereotactic conformal radiotherapy (SCRT) compared with conventional radiotherapy (ConvRT) evaluating clinically meaningful end points has reported encouraging results. In this young patients with residual and/or progressive benign or low-grade brain tumors requiring radiotherapy for long-term tumor control were studied. It has concluded that SCRT compared with ConvRT achieves better neurocognitive and neuroendocrine functional outcomes over 5 years without compromising survival.^[9]

Radiation therapy acute toxicities can be alleviated by giving gap in the treatment. Chronic toxicities are more serious. Second solid tumors in or adjacent to the radiation fields can develop. This risk of radiation appears to be highest for survivors of childhood cancers.^[7] Studies are required for a threshold dose of therapeutic radiation below which second cancers risk is decreased are required.

Planning, policies, practice & public health aspects are equally important. All national cancer control plans or programs should have radiotherapy as important component. Overall clinical outcomes of radiotherapy are optimized when radiotherapy services function along with effective prevention, early detection programs, and quality surgery. Radiotherapy access is lacking for 82% of the world's population living in the developing world. Of all the available equipment allocated to this part of the world is a miniscule 32%. Every 400–600 new radiotherapy patients diagnosed per year require a radiotherapy machine.^[10] Next after equipment is the importance of trained workers. Radiotherapy requires a high level of technical expertise. Qualified and competent teams of clinicians, medical physicists, and radiation technologists are necessary for a safe and effective service provision. With multidisciplinary collaboration & commitment we should be able to deliver radiotherapy services to all in need.

Radiation emergencies

Occupational or medical over-exposure of a person can occur accidentally in isolation or a major catastrophe can occur when an accident involving peaceful use of nuclear energy or a terrorist activity or a war weapon. Emergency life-support along with decontamination is needed. Decontamination should be done immediately to be effective. The ABCDE reduction approach components should be used in emergency as indicated.

Absorption from skin or gastrointestinal tract (GIT) - decontamination involves cleaning a contaminated wound and

that due to ingestion can be dealt with by performing gastric lavage, or cathartics. Administration of antacids containing alginate is useful as this reduces absorption in the GIT.

Blocking therapy/treatment is based on scientific logic. Potassium iodine or other stable iodine-containing compounds administration when internal contamination with radioactive iodine is known should be used early to be effective. The stable non-radioactive iodine effectively blocks the thyroid. Its effectiveness decreases rapidly as time passes after the contamination.

Chelation therapy should be used for trans-uranic elements (americium and plutonium) internal contamination. Calcium di-ethylene tri-amine penta-acetic acid is recommended.

Dilution therapy is useful in cases of contamination with tritium (radioactive hydrogen as water).

Elimination from the GIT in the feces of radioactive cesium or thallium is done with prussian blue. It is approved by the FDA.^[2]

Non-ionizing radiation

Radiowaves & micro-waves are used primarily in TV broadcasting, tele-communications including mobile phones, & radar for air/sea navigational aids. Ultra-Violet radiation from sun needs special consideration especially for our troops.

Radiowaves

Mobile phone use is ubiquitous. With increasing use the EM fields produced by mobile phones use needs consideration.

Short-term effects: Non-ionizing radiation is the part of the EM spectrum which does not have sufficient energy to cause ionization. The frequencies which mobile phones use is low, and most of this energy is absorbed by the skin and other superficial tissues. The rise in temperature in the brain or any other organs of the body is negligible. The effects of radiofrequency fields on brain electrical activity, cognitive function, sleep, heart rate and blood pressure has been investigated by a number of studies in volunteers. Till date, there is no consistent evidence of adverse health effects if exposure to radiofrequency fields is at levels below those causing tissue heating. Further, research has not been able to provide support for a causal relationship between exposure to EM fields and self-reported symptoms, or "EM hypersensitivity".^[11]

Long-term effects: Epidemiological research studying potential long-term risks from radiofrequency exposure has been mostly towards brain tumours and mobile phone use. The largest study till date has been Interphone, carried out retrospectively as case-control study on adults, and coordinated by the International Agency for Research on Cancer (IARC). Design was to determine whether there are links between use of mobile

phones and head and neck cancers in adults. Based largely on these data, IARC has classified radiofrequency EM fields as *possibly* carcinogenic to humans (Group 2B), a category used when a causal association is considered credible, but when chance/bias/confounding cannot be ruled out with reasonable confidence.^[12]

Microwaves

Microwave energy is not a cause of concern. It can be absorbed by the body. It produces heat in exposed tissues. Risk of heat damage is in those organs which have a poor blood supply and temperature control, e.g. the eyes, or temperature-sensitive tissue like the testes. However, the thermal damage would occur only from long exposures to very high power levels, well above those measured around microwave ovens or towers.^[13]

UV radiation

The UV region is of the wavelength 100–400 nanometer (nm) range and is classified in three bands:

- *UVC* (100–280 nm)- Effectively blocked by the earth's atmosphere
- *UVB* (280–315 nm)- Forms a small component of ambient UV radiation. However it is much more potent biologically. This is responsible for most of the sunburning activity of the natural sunlight. Its usefulness is in Vitamin D synthesis in skin.
- *UVA* (315–400 nm)- The dominant waveband found at the earth's surface. As compared to UVB, this is less active biologically.

Skin cancer incidence rise over the past decades is strongly related to increasingly popular outdoor activities and recreational exposure. Overexposure to sun light causes harmful effects on the skin, eye and immune system. Protection is provided by shade, clothing, and hats. Parts of the body that remain exposed like the face and hands should be protected with sunscreens.^[14]

Troops and UV protection

Intense unfiltered sunshine is found at high altitudes and in arid tropical and subtropical zones. UV levels increase with altitude, and the rate is 10–12% for every 1000 metres increase in altitude.^[15] The sunrays are more direct in the tropics as compared to the temperate zones, and therefore produce their effect with greater intensity. The rays at high altitude are unfiltered of its short ultra-violet portion and hence cause the deleterious effects.

The following strategies are useful:

- Limit exposure in the mid-day sun: The sun's UV rays are the strongest between 10 a. m. and 4 pm. During this time, to the extent possible, exposure to the sun should be limited.
- Use shade wisely: when UV rays are the most intense.
- Wear protective clothing: A hat with a wide brim offers good protection for eyes, ears, face, and the back of neck from the sun. Tightly woven and loose-fitting clothes are additional protection from the sun.

- Eyes protection: Sun-glasses that provide 99-100% UV-A and UV-B protection are very useful in reducing eye damage from exposure.

Conclusion

Prudent prevention is perfect professionalism. Science & technology progress should be for the betterment of mankind, and all efforts should be made to prevent any untoward effects. Heightened professionalism needed for efficacy and safety with protection to prevent harmful effects. Effective investigations & interventions in medical settings are done based on best evidence. Similarly, safety measures need to be continuously practiced with precision & perfection. The key points of review are summarised as:

“Scientific advances & sophisticated applications,
Methodical cure & meticulous care,
Multidisciplinary collaboration & meritorious commitment,
Maximum effects & minimum side-effects,
Boosting prevention and best protection, and
Vital & vigorous efforts for children & paediatric patients
vulnerability.”

Key Messages

- Children & paediatric patients vulnerability justifies special attention.
- Radiological investigation: clinical impact assessment by clinicians, and individual tailoring by radiologist.
- Multidisciplinary collaboration & commitment required for radiotherapy services
- Radiation emergencies require life-support, decontamination as and ABCDE reduction approach as indicated.
- UV radiation overexposure protection.

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Compliance with ethics guidelines

This article is based on published research papers, reports and medical literature, and does not contain any study with human participants or animals performed by the author.

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Conflicts of interest

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