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Radiation Dose Reduction Strategies: Investigate Techniques and Technologies Aimed at Reducing Radiation Exposure to Patients and Healthcare Workers during Diagnostic Imaging

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Abstract

Accurate disease diagnosis and better patient care are crucial, and medical imaging has shown to be incredibly helpful throughout the entire process. In preventative medicine, curative care, and palliative care, its application is essential at all levels of healthcare. However, because ionizing radiation is linked to cancer risk, its usage in medical imaging should adhere to safety guidelines and be optimized as a result. In addition to exploring methods and tools targeted at lowering radiation exposure to patients and medical personnel during diagnostic imaging, this project intends to address the problem of radiation dose optimization in diagnostic radiology.

Keywords*:* radiation, dose, investigate, healthcare, imaging.

Introduction

Accurate disease diagnosis and better patient care are crucial, and medical imaging has shown to be incredibly helpful throughout the entire process. In preventative medicine, curative care, and palliative care, its application is essential at all levels of healthcare. Over the past fifty years, there has been a technological revolution in the medical field that has increased the amount of ionizing radiation used by X-ray equipment. This transition has been gradual, moving from analogue to digital detectors and platforms, from single slice to multidetector-row computed tomography (CT), from fluoroscopy to sophisticated, complex angiography systems, and from intraoral dental machines to comprehensive, cone beam CT technologies [1].

Modern medical imaging X-rays are widely available, and as patient demand has grown, so many other clinical specialists including interventional cardiologists, orthopedic surgeons, gastroenterologists, dentists, anesthesiologists, urologists, etc.—are using them outside of the traditional radiology department [1].

Utilization has increased exponentially as a result of the widespread availability and advancement of medical radiological imaging technologies. There is currently insufficient evidence to support a cancer risk associated with radiation exposures lower than 100 mSv. Optimizing patient dosage is necessary [1].

Nonetheless, because ionizing radiation is linked to an increased risk of cancer, its use in medical imaging must adhere to safety regulations and be optimized. Optimizing medical exposure for diagnostic and interventional purposes means "...keeping the exposure of patients to the minimum necessary to achieve the required diagnostic or interventional objective," according to the International Atomic Energy Agency's (IAEA) Radiation Protection and Safety in Medical Uses of Ionizing Radiation, Safety Standards Series No. SSG-46 [2].

Everyone agrees that ionizing radiation has carcinogenic properties. The observation of a higher incidence of carcinoma in populations that have survived nuclear attacks or in uranium miners exposed to radiation at work forms the basis for a large portion of this agreement. The radiation dose from imaging modalities is minimal in comparison to the exposures listed above. For example, annual background radiation exposure in the United States is approximately 3 mSv on average; radiation exposure from a chest X-ray is approximately 0.1 mSv, and radiation exposure from a whole-body computerized tomography (CT) scan is approximately 10 mSv. This is one of the reasons why doctors typically underestimate the risks of radiation exposure when using radiologic imaging procedures [3].

This page aims to provide an explanation of radiation quantification, the biological impact of radiation, the hazards that arise from radiation exposure for healthcare workers, and some suggestions and advice for different medical specialties [4].

An energy form that moves is called radiation. It falls into one of two groups: ionizing or non-ionizing kind. Electromatterless electromagnetic radiation and particle radiation are two other categories under which ionizing radiation can be categorized [4].

Wave-like energy packets, called photons, are what make up electromagnetic radiations. Radon and beta radiation are basic types of electromagnetic radiation. A particle beam, which might be neutral or charged, is known as particulate radiation. Strong energy allows electromagnetic radiations to readily enter bodily tissues. Diagnostic uses are the primary applications of ionizing radiation [4].

Aim Of Study

This study aims to investigate methods and technology targeted at lowering radiation exposure to patients and healthcare personnel during diagnostic imaging, as well as to address the topic of radiation dose optimization in diagnostic radiology.

Literature Review

Radiation dosimetry

Radiation oncology has a lengthy history with the dosimetry of ionizing radiation. The phrase is currently used to refer to the process of determining a customized dose distribution that will be given to cancer patients during radiotherapy treatment planning, or the measurement and quantification of the effects of ionizing radiation. Utilizing the unit gray (Gy, named for Louis Harold Gray), the absorbed dosage is measured as energy per mass ($J\ kg^{-1}$). When it comes to interpreting absorbed dose readings, the conversion of this absorbed dose to biological consequences will only be taken into account. Biological effective dose (BED) is a measure of the predictable effects of radiotherapy. Equivalent dose and effective dose are two words of importance in radiation protection [5].

Effect of ionizing radiation and radiation risk

Less than a microsecond after the impact, cells exposed to ionizing radiation experience a stress reaction. This reaction is brought on by the interaction of ionizing radiation with biological material, which can interact directly or indirectly with cellular macromolecules including DNA, proteins, and lipids to create reactive oxygen species (ROS) and cause damage. All cellular organelles are affected by this process, which can also change their molecular mechanisms. Consequently, the quiescent phenotype changes to a pro-inflammatory one due to endothelial activation [6].

Endothelial dysfunction can result from prolonged and/or repetitive exposure, which can deplete the endothelium's normal protective action. In other words, this diseased condition can be understood as a maladaptive reaction to pathogenic stimuli and denotes an endothelium that is unable to carry out its typical physiological tasks. Consequently, the afflicted endothelium site experiences edema, inflammation, and issues with blood hemostasis in addition to worsening of the vascular tone. Given the endothelium's pivotal role in integrating vascular risk, a number of pathogenic disorders, including atherosclerosis, can arise from the convergence of pathogenic signals, including ionizing radiation. Heart disease brought on by radiation is caused by atherosclerosis, which causes vascular damage [7].

For the purposes of this review, "low dose" is generally understood to mean a dose of 0.1 Gy or less. In this review, the words "moderate dose" and "high dose" refer to dosages that fall between 0.1 Gy and 2 Gy and equal or exceed 2 Gy, respectively. High doses of ionizing radiation have been demonstrated to cause cardiovascular illnesses in cancer therapy patients and survivors of atomic bombs [8].

Because medical imaging provides such important phenotypic information on the patient's clinical status, it has become an essential healthcare resource due to its significant benefits in accuracy, definitiveness, and versatility. Nowadays, a wide range of disorders are treated with medical imaging, which is seen to be crucial for both adult and pediatric healthcare [9].

Definition of optimization of patient dose for medical imaging

The goal and method by which the danger of an imaging procedure—in this case, radiation exposure—is weighed against its benefits is known as optimization. This technique is essentially derived from the reason behind the procedure being carried out. Radiation exposure in medical imaging is done specifically with the intention of securely gathering relevant data regarding a target indication of interest for precise and accurate patient care management [10].

Images should reflect the patient's condition more so than the specifics of the imaging method in order to meet this goal. The precise diagnostic information required from the test should guide the choice of imaging equipment or technique used in the examination. Due to the difficulties in objectively and individually assessing the clinical outcome or the additional value of the imaging process, this goal is extremely challenging to accomplish in practice [10].

Activities related to clinical care are typically varied, complex, and compounded. They involve different offerings in terms of technology, each with different technical specifications. This landscape's heterogeneity results in less-than-ideal and inconsistent picture quality and dosage, which makes it impossible to meet the procedure's stated objective of "safely obtaining useful information relevant to a target indication of interest for accurate and precise management of patient care” [11].

Consequently, there is a chance that subpar imaging will fall short of the original goal. An assurance that the imaging procedure's objective is met should come from optimization. This involves taking into account the risk—known as radiation risk—related to applying the ionizing radiation utilized in the procedure. The most crucial thing to remember is that clinical risk is the possibility that imaging will not accomplish its primary goal of producing the intended benefit. Both of these risks—clinical and radiological—are combined in comprehensive optimization into a single overall risk estimate, or index, inside an indication-informed procedure [10].

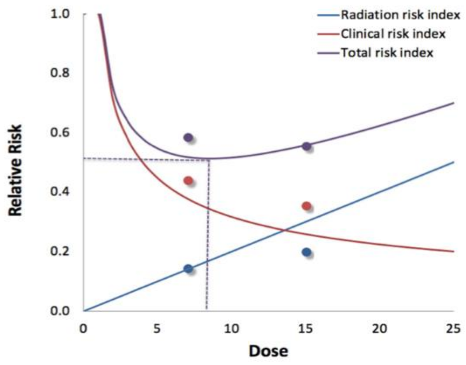

Figure 1 overall patient risk including radiation risk and clinical risk as a function of dose [10].

Quantities necessary to achieve optimization

Dependent and independent quantities are involved in the imaging optimization process. Dependencies are arranged in two layers. The first layer is made up of the fundamental imaging factors, like mA and kV, which are independently variable in a continuous or sparse parameter space. The second layer of dependencies is formed by dosimetric values like CTDI and DLP, which are impacted by changing these parameters [10].

Optimization of imaging is done in terms of one or more independent or dependent factors combined. Certain characteristics, like slice-thickness, are related to the processing of the acquisition, like rotation time, or geometry, like field of view; other parameters, like the dosimetric values of CTDI and DAP, are related to the radiation output of the imaging system. Since they are frequently associated with patient dose, the latter are frequently referred to as “dose" [10].

Tools for achieving and managing optimization

Tools that are both practical and capable are needed for the optimization process to be successful. These include the integration of relevant metrics, the stratification of data according to different criteria, and analytics tools (software) for managing and analyzing the data in order to extract optimized dose ranges. Figure 2 provides a schematic representation of the parts and the procedure. The graphic shows how clinical data informs image quality and dose metrology, and how analytical, empirical, or machine learning methods determine their interdependence to maximize patient benefit [10].

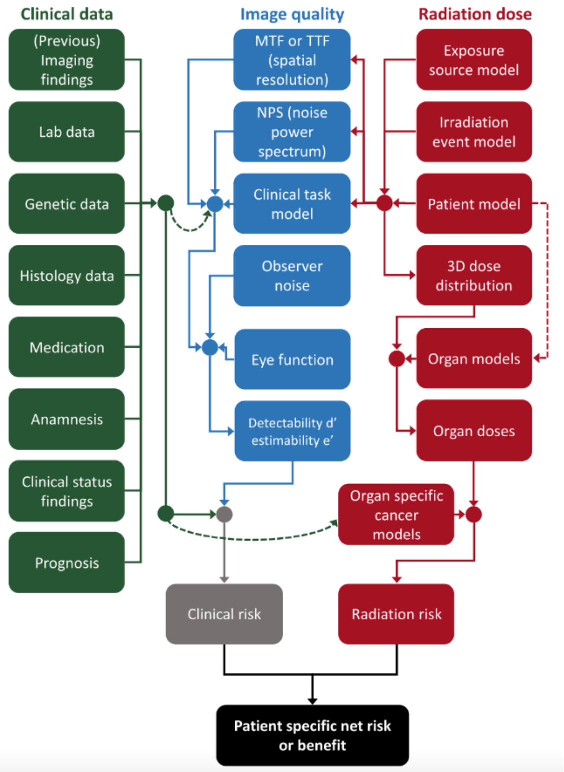

Figure 2 Comprehensive risk modeling data flow in clinical parameters, image quality, and radiation dose characterization for imaging optimization [10].

Automatic Exposure Control (AEC)

In order to maintain image quality despite significant X-ray attenuation, automatic exposure control, or AEC, is frequently used to modulate tube current. It raises tube current in big patients as well as in particularly attenuating portions of a given patient. Numerous variables, including the kind of AEC software, the direction of scout imaging, arm placement, and patient centering, affect the radiation dose that AEC calculates. When optimizing, image quality and radiation dose should be evaluated since decreasing radiation dose can lead to increased image noise and a decline in therapeutic value [12].

This is done by stopping the exposure as soon as the ionization chambers of the AEC device register the specified dose level. Traditionally, AEC devices were calibrated to maintain optical density (OD) at a target value when used in conjunction with film-screen detectors. This allowed the film reader to confidently analyze the image. Because digital image detectors, like computed radiography (CR) photostimulable powder phosphors, have a larger dynamic range than film and are not contrast (OD) limited, a wider variety of metrics can be taken into account while calibrating the AEC equipment [13].

Iterative reconstruction algorithms

We are able to swiftly and effectively rebuild images based on an analytical equation thanks to traditional FBP-based analytic approaches that have been around for more than 40 years. As opposed to this, iteratively reducing an objective function in accordance with predetermined convergency criteria is how IR algorithms reconstruct images. The procedure is necessary in order to minimize discrepancies between the forward projected data, which is derived from the latest estimate of the imaged item, and the obtained projection data (forward projecting is the mathematical process of obtaining CT projection data of an object). In addition to modeling the CT system, x-ray attenuation and detection procedure, and regulations requiring a smooth final image while preserving anatomic lines and boundaries, the objective function can also (Fig 3) [13].

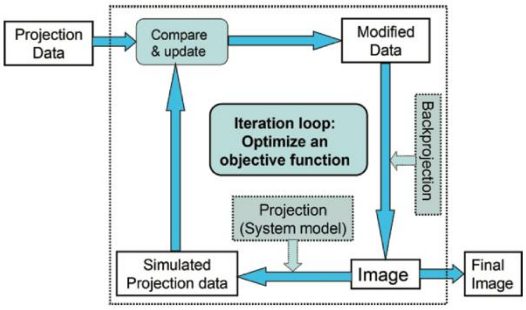

Figure 3 Schematic summarizes a generalized approach for an iterative reconstruction algorithm [13].

IR algorithms have several advantages. Firstly, they make it possible to model the X-ray source and detector, which can enhance the precision and spatial resolution of the reconstruction. Secondly, the algorithm can easily take into account photon statistics, which makes it possible to give higher weight to lower-noise projections and lower weight to higher-noise projections. This reduces artifacts and increases dose efficiency. Third, picture noise can be reduced by IR algorithms while maintaining the clarity of anatomic borders because they make generalized assumptions about physical objects, such as the fact that things normally change smoothly except at edges. Lastly, when data are not gathered in an axial or helical route, for example, IR algorithms may easily accommodate unconventional scanning geometries [13].

Cone Beam Computed Tomography

Despite their increasing compactness, CT machines are still somewhat large, costly, and expose patients to substantial radiation doses. A device called an extraoral imaging scanner, made especially for head and neck imaging, is used in CBCT to provide three-dimensional images of the maxillofacial skeleton. It uses a device that may resemble a traditional panoramic radiography equipment in terms of size. Cone beam machines use x-rays to cover the head surface that has to be studied in the shape of a huge cone; a 2-dimensional (2D) planar detector is used in place of a linear array of detectors as in CT [15].

Cone beam imaging requires less rotation than CT imaging; instead of illuminating a tiny slice, it irradiates a large volume area, therefore one rotation is sufficient to provide all the information needed to rebuild the ROI. With minimal x-ray exposure, this method gives medical professionals access to 2D reconstructions in all planes and 3D reconstructions [15].

Cone Beam Computed Tomography Image Formation

Acquisition and reconstruction are the first two main steps in the production of a picture, and image display comes next.8,9 Certain machines need that data be transmitted from one processing computer (workstation) for reconstruction to another acquisition computer in order to make data handling easier. Reconstructing cone beam data is often done on Windows-based systems [15].

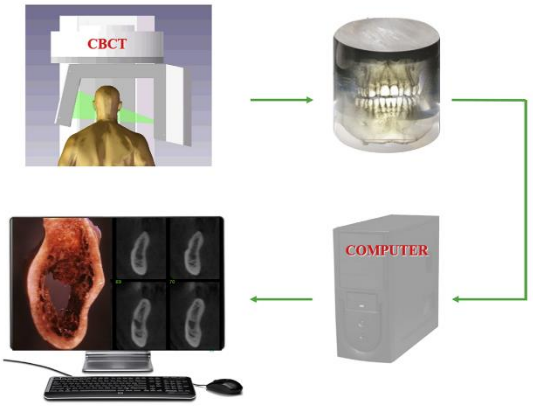

Figure 4 CBCT image formation [15].

Dose Tracking and Monitoring

For the purpose of protecting each patient, it is helpful to keep track of their radiological procedures since it gives clinical information that can prevent the need for additional radiological exams on that particular patient. A 100% dosage reduction is achieved by avoiding a second examination, even in cases where the dose from the prior examination is not taken into consideration. Since the patient serves as their own benchmark or reference for comparison while taking into account the clinical indication and body part, individual dose tracking improves follow-up evaluation [16].

Prior years' optimization strategies relied on comparing a facility's average dose values—such as its computed tomography dose index (CTDI)/dose-length product (DLP)—with diagnostic reference level (DRL) values. We consider the DRL value to be the standard value. DRL is not applicable to a single patient and contains a variety of body weights [16].

Comparing a facility's average dose values—such as its computed tomography dose index (CTDI)/dose-length product (DLP)—with diagnostic reference level (DRL) values has been the foundation of optimization approaches in the past years. As a standard value, the DRL value is accepted. Because DRL is not valid for a single patient and has a mixed body weight [16].

Role of the Hospital Facility

Hospital management's primary responsibility is to reduce radiation exposure. Using shielding techniques at the architectural level is one way to make it happen. Every hospital should evaluate the radiation exposure of its employees and give them updates on a regular basis. Additionally, dosimeters should be mandatory for every worker who is anticipated to receive more than 10% of the applicable dose level. Employing personnel with the skills and training necessary to guarantee the creation of high-quality pictures at the right patient dosages will reduce the likelihood of repeat procedures. The operating manual for the equipment should always be accessible, and it should be used in accordance with its instructions [17].

Radiation exposure should be optimized in relation to the functionality of the imaging system. Here, the ideal dosage should neither be too high nor too low in order to preserve the caliber of the imaging research. By gathering and evaluating radiation dose data and comparing it to achievable doses and diagnostic reference values, facilities can use these as instruments for quality improvement [17].

Radiation exposure and safety

Time, distance, and shielding are the three factors that determine radiation exposure. In order to be protected, one must decrease the duration of exposure, get closer to the source, and use appropriate shielding [18].

Shielding techniques are used not just on a personal level—that is, when wearing personal protective equipment—but also when building new hospitals. PPE consists of gloves, scrub hats, lead aprons, protective eyewear, and thyroid collars. Adjusting PPE to achieve adequate fitting and subsequent radiation protection requires consideration of body physique differences [17].

Lead aprons

Owing to its high density and high atomic number, lead may effectively suppress some types of radiation. X-rays and gamma rays are the main radiation types that it effectively blocks. Wearers are shielded from secondary or scatter radiation by using it as an apron, thyroid collar shield, gonadal shield, and other secondary barriers [18].

Radiation protection for patient

Equally vital is the patient's protection from radiation. In kids and teens, it's advised to safeguard the thyroid, breast, and gonads. To screen the gonads from primary beam radiation exposure, a lead apron should be worn; additionally, the patient should have a lead collar to cover their neck and thorax, shielding their breast and thyroid [18].

Pediatric Dose Reduction

Why We Must Reduce Radiation Dose?

Due to their fast cell division, children and young adults are more susceptible to the stochastic effects of ionizing radiation. In addition, compared to adults, children and young adults have comparatively longer remaining life spans, which allows for more time for possible radiation impacts to manifest. Furthermore, children's smaller bodies mean that they receive higher effective doses if specific pediatric CT protocols are not used [19].

Newer generation CT scanners

Dual-energy CT (DECT) has just been incorporated into routine clinical CT scanners, marking a significant advancement in CT technology. All of the main CT scanner manufacturers now provide clinical scanners that can photograph things with two X-ray energy spectra thanks to this innovative technology, which has received FDA approval. Two main forms of "spectral" CT are DECT and photon-counting, energy-discriminating (PCED) CT, where novel diagnostic information can be obtained due to the distinctive, energy-dependent attenuating properties of materials [20].

The development of novel contrast agents intended especially for these cutting-edge diagnostic imaging modalities will be crucial to realizing the potential of clinical spectral CT. The DECT and upcoming spectral CT scanner generations offer the capacity to not only identify a specific reporter element, like iodine [4], but also to differentiate between various reporter elements when the body is given multiple contrast agents with various reporter elements either simultaneously or almost simultaneously [20].

Conclusion

While lowering radiation exposure is the purpose of these tactics, it's crucial to remember that the ultimate objective is always to weigh the advantages of the diagnostic data acquired against the risks of radiation exposure. To achieve the best possible dosage reduction while preserving diagnostic accuracy, these tactics should be put into practice in collaboration with medical physicists, radiologists, and other healthcare specialists.

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