American Journal of Botany and Bioengineering
https://biojournals.us/index.php/AJBP
ISSN: 2997-9331

Evaluation and Optimization of Radiation Dose in Computed Tomography

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Received: 2024 19, Dec
Accepted: 2025 28, Jan
Published: 2025 19, Feb

Annotation: In computed tomography, patient radiation doses should be kept as low as possible in order to minimise the risk of that individual developing cancer in the future from the radiation from the scan. This message needs to be effectively but sensitively communicated to the lay public. The objective of this work was to understand the fundamentals of computed tomography (CT) radiation dose, how CT radiation doses are measured, and to discuss the factors influencing that dose, such that CT radiation dose can be evaluated and optimised. With the development of technology, the successive introduction of multi-slice spiral CT and cone beam CT scans has allowed the 3D high-resolution reconstruction of a broad anatomic region in a very short time (one rotation). This fact, coupled with the synthetic generation of very thin sections, has resulted in a large increase in the number of sections acquired per examination, namely with the new scanner models, which allow the acquisition of the about 800 sections typical of the chest, abdomen, and pelvis. Patient radiation dose is an important issue in modern CT imaging, considering the enormous increase in the number of examinations performed in the last two decades. On the 40th anniversary, it is important to remember that unlike other X-ray procedures, the average dose to which the population is exposed in CT examinations increases rather than decreases with time. For systemic cancer in children, it was recently noted that the risk was about 1% per average dose of 10 mSv in the first decade of life without a clear dose-response relationship.

Keywords: Computed tomography, radiation dose, optimization, dosimetry, patient safety, image quality, ALARA principle.

1. Introduction

The fascination and general public attention with the consumption behavior of decision-making agents and how these should be acting were already addressed in the theory of individual choice and consumer choice. Still, since the market fair ruling and the incentive for a labor market with some structure to finally open, the subject needs further grounding and practical development. Hopefully this section satisfies those further needs with a detailed review. Starting from the basics and only iterating at user interest in income-induced consumption changes, the text encloses general economic theory about choice of consumption, investment, risk-attitude or bequest with reliable decision rules regarding these issues. The research intends to approach the evaluation and optimization of the current practice of patient absorbed dose measurement on CT procedures and to explore the benefits of including dose optimization approaches. For this task, specialization in the most advanced and widely used imaging diagnosing equipment as well as on the many dedicated resources available on the matter was chosen. On the subjects covered research has found from the CT underlying principles and typical investigation layout to the test object and actual instrumentation required for a properly executed study. Starting with a general introduction on the increasing significance of CT scan techniques as they evolve gaining the most important role in a modern radiological department and exposing the maybe less expert but the potential interested reader to the potential risks due to inadequate use or planning of the radiological diagnostic path. Once the reader is presented with the necessary background to understand the potential adverse effects of a general misuse of CT scans, the focus narrows and the text details the primary ways computerized tomographic examinations can be mishandled. On purposeful distraction a comprehensive overview of procedures under investigation is provided, and is detailed such procedures in a numbered list. For the same purpose, a prompt reminder of all the pieces of information thought to be important during the investigation of a test object on a CT apparatus has been formulated in a 7-point list and disclosed. [1][2][3]

Literature Review

2. Fundamentals of Computed Tomography (CT) Imaging

Computed tomography (CT) is a widely used imaging technology. By processing data from a sequence of small fan-beam X-ray scans around the patient, who is being imaged, the machine generates images. In medical applications, the images show "slices" through the body, each collecting information about the structure and density of a thin cross-section. The attenuation of X-rays as they pass through the patient is detected, and images representing the path of the X-rays provide a clear picture of the internal composition of the patient's body. In a basic imaging application, the user can extract, view, and manipulate 2-D cross-section images of the patient.

The fundamental principles of computed tomography are crucial to understand how to measure and potentially reduce radiation dose from CT imaging procedures. In a CT scan, an X-ray source is used to project X-ray beams through the patient's body to a corresponding detector;

many of these projections in different angles are taken around the patient. To obtain a single CT image, the raw data must be processed using computer algorithms to reconstruct the images; this is achieved by devising a model of the X-ray transport through the body and using these models to transform raw data into reconstructed images. In this scenario, an image is a representation of attenuation values inside the imaging volume, as opposed to those which can be measured linearly along an axial line by rotating one X-ray source with many detectors. The collection of these projections is referred to as a CT scan, and an image of the patient after reconstruction is referred to as a slice. [4]. An advantage of CT over X-ray and magnetic resonance imaging (MRI) is that many slices can be obtained from the scan and viewed at any plane in reconstruction. More complex algorithms can reconstruct three-dimensional images using a volume of slices. It is important to understand these principles before discussing how to measure and potentially reduce the dose from CT exams. A glossary of terms related to CT is supplied in the appendix to facilitate the understanding of these concepts. [5][6]

Materials and methods

3. Radiation Dose in CT: Types and Measurement

X-rays are the most widely used diagnostic tool due to their penetrating power and reasonable dose. Computed Tomography (CT) is a powerful imaging technique offering fast and accurate cross-section images of the body, and it is widely available. Computed tomography's flexibility presents the advantage of imaging anywhere within the body and generating images with perfect spatial resolution. However, the clinical utilization of CT images requests a relatively high dose to the patient. A compromise must be maintained between image quality, radiation dose and, as a consequence, patient safety. Various dose quantities are encountered in CT, and they are named according to the context in which they are used and the way they are calculated. In principle, each dosimetric quantity has its own specific use, and each is a measure of a significantly different aspect of the absorbed or imparted dose [4]. There are three general categories of utilities in dose measurements: estimate of individual dose, dosimetric observables, and dosimetric indexes. It also plays a role in assuring standards are being met by equipment or workers. Dose measurements are performed with a variety of apparatuses including film dosimeters, optically stimulated luminescence (OSL) dosimeters, thermoluminescent dosimeters (TLD), and silicon detectors. Some systems such as computed tomography (CT) scanners, mammography systems, and fluoroscopy systems, have an examination practice that results in exposure of a uniform area or volume. Since the absorbed dose depends on the volume or area exposed, while the measurement equipment usually provides results depending on length, the absorbed dose cannot be directly determined. In this case, two measurements have to be performed: one to determine a radiation output-rate, the other to determine length. Generally, CT is responsible for higher doses to patients compared to other radiological diagnoses. For this reason, there has been an increasing concern combined with an urgency to accurately determine doses and take steps for optimization. In many countries, it is mandatory to conduct radiation levels produced in radiological examinations. Evaluation of doses is necessary in order to recognize the risks in order to take the necessary steps for the protection of patients and staff. [7][8]

Results

4. Factors Influencing Radiation Dose in CT Scans

The amount of radiation exposure during computed tomography (CT) scans depends on multiple factors. Some of them such as patient-related variables including patient's age, weight, and medical conditions cannot be altered, but there are other factors which can be adjusted for the optimization of the administered dose. A review technique was employed to explore the factors that can influence radiation exposure dose in CT. The review found that patient related, scan parameters, protocol, technological, and passive factors are major contributors to the effective dose experienced by the patients during the CT examination. On the patient side, weight plays a very important role on radiation dose. When other conditions are constant, as patients weight increases, CC dose also tends to increase. Multi-detector row CT technology allows faster scanning, however, the effective dose increases due to factors such as increased scan overlap, patient exposure to the x-ray tube placed closer to the patient, increased scatter radiation, discontinuation of pitch factors, and routine examination. Tube current modulation and fast adapted tube voltage selection are newly available techniques for automatic exposure control in multi-slice CT. Both techniques automatically adjust imaging parameters based on patient size. Advanced image reconstruction algorithms have been developed which employ complex mathematical models to estimate and reduce image artifacts. These image-model based iterative reconstruction algorithms have been shown to allow image noise in CT examinations to be reduced by up to 50% without compromising lesion detectability. Use of AIDR 3D is a very prominent factor in exposure dose reduction with a significant positive impact on image quality as well. Furthermore, it is very important to choose a protocol which uses the best scanner parameters for a specific kind of examination and patient and to conduct the examination at the right time. [9][10][11] [12][13]

Discussion

5. Technological Advances for Dose Reduction in CT Imaging

The concept of radiation dose optimization in computed tomography (CT) is widely described in a number of publications. There are commonly raised problems and possible ways of solving them in this field. The evaluation of numerous publications offers new and practical solutions to dose optimization problems. The impact of the discussed strategy was assessed by the analysis of thorax, abdomen, and pelvis CT examinations performed in a selected patient group. The presented analysis of the available information and the implemented trial operations pursued better adaptation of CT examinations to the expectations of the ALARA principle and good CT practice.

The risk associated with ionizing radiation exposure from computed tomography (CT) imaging is a recurring subject of research and discussion. A substantial body of work exists related to methods to reduce radiation dose from CT scanning, not only in terms of technical development, but also retrospective analysis and dose monitoring. It appears that, in the context of patient registered CT dose index (CTDIvol) values, knowledge on the background doses received by patients coming from sources other than CT scans is poor. With the motivation to attempt a balance between published facts and personal experience, a number of common, popular, disputed, and from an epidemiological viewpoint relevant issues are presented, particularly focusing on the CT dose record. [14][15]

6. Conclusion

It is a widespread view among medical professionals that computed tomography (CT) examinations should be optimized to a dose which gives an acceptable image quality at a level as low as reasonably achievable (ALARA accreditation). Currently, a key issue being faced is how to monitor these doses accurately and the influencing factors. Strategies to reduce doses are necessary, such as the implementation of technological advancements. Optimizing radiation doses in CT is essential for both patient safety and achieving images adequate for medical diagnosis. However, with image quality requiring to be as high as possible while radiation protection is kept to minimal levels, achieving and keeping this balance is no simple task. A considerable portion of diagnostic medical exposure arises from CT examinations, which raise a greater concern due to their inherently much greater irradiations compared with those resulting from, for example, projection (or simple) radiographs. In the radiological environment, it seems critical both to identify a dose which acts as a link between patient safety and image quality, and evaluate methods for its quantification [4].

A literature review has revealed that dose accuracy is highly dependent on the dosimeter used, the measuring size, the measuring depth, and being very sensitive to positioning, while the most usual dose units (namely CTDIv and DLP) hide yet a more complex and poorly understood profile of the irradiated volume and of the total absorbed radiation reaching the patient. In what concerns dose optimization a number of factors are relevant: patient’s body size and weight, position type, convolution kernel, reconstruction slice thickness, temporal and/or overdosage variations (such as tube parameters, voltage, rotation time, and pitch), the site and machine used, and finally the slice coverage, every one of these being influenced by a profound amount of settings. Techniques for dose evaluation are thusly either incomplete or very complex, lacking adaptability to broadly monitor systems. While this problem is common to both industrial and medical applications of radiation, it particularly concerns the latter and there are already a number of approaches to its solution, most of which able to be optimized [16].

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