AI-Driven Approaches for Radiation Dose Prediction in Computed Tomography Scans

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Abstract

Optimizing radiation doses for computed tomography (CT) scans is essential to ensure patient safety by minimizing potential health risks associated with ionizing radiation exposure. The necessity arises from the key role of CT scans in disease diagnosis and monitoring, balanced against the inherent radiation hazards they pose. To address this need, an innovative project is underway, proposing the application of Artificial Intelligence (AI) models to predict ionizing radiation doses within CT scans, effectively refining radiological practices and minimizing associated risks. The project aims to enhance healthcare quality by aligning doses with Diagnostic Reference Levels (DRLs) in Portugal. The approach employed is personalized, adapting imaging protocols based on individual patient attributes, following the ALARA (As Low as Reasonably Achievable) principle, aimed at achieving the minimal radiation exposure necessary for diagnosis without compromising accuracy. By leveraging technology, the project empowers healthcare professionals with efficient data analysis, facilitating precise diagnoses and effective treatments. This initiative contributes to compliance with radiological protection guidelines, contributing to Portugal's commitment to radiological protection, while healthcare professionals diligently adhere to medical protocols. These collaborative actions prioritize patient welfare and improve healthcare safety by mitigating the risks of ionizing radiation and promoting a technologically advanced healthcare environment.

1 Introduction

Radiology exams play a crucial role in the diagnosis and monitoring of diseases, but they also expose patients to ionizing radiation, which can pose health risks if not properly controlled. In Portugal, medical radiological exposures constitute the main source of artificial ionizing radiation exposure for citizens, making it essential to ensure radiological protection of patients during CT scans. To this end, strict guidelines and regulations have been adopted, including [3], [4], [6] and [7], which emphasize the importance of protecting patients from ionizing radiation in medical radiological exposures.

When it comes to the application of Medical Physics in Portugal, especially in CT scans for diagnosing and monitoring diseases, it is regulated by international regulations and national legislation. Organizations such as the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA) and the European Commission establish fundamental guidelines for radiological protection and the safety of ionizing radiation equipment [11][12]. Portuguese legislation establishes a comprehensive legal framework for radiological protection in Portugal, with specific ordinances detailing technical standards and requirements. This regulatory framework guarantees the safety, efficacy and quality of radiological procedures, protecting workers, patients and the public from the risks associated with exposure to ionizing radiation [1].

The proposed project aims to apply Artificial Intelligence (AI) models to predict the dose of ionizing radiation to which patients are exposed during CT scans, providing relevant information to improve radiological practices and minimize the risks associated with CT scans. With this project, the goal is to compare the performance of various models (decision trees, neural networks, support vector machines, random forest, etc.) in dose prediction, considering that currently the dose is determined manually by healthcare professionals or automatically by the equipment during CT scans [5]. Therefore, this project can be of great utility in validating the radiation dose that is defined to be administered to the patient.

By predicting the radiation dose, this project can significantly contribute to the improvement of the quality of healthcare services provided to patients in Portugal, optimizing radiation doses and ensuring they are within the DRLs. This allows for the adaptation of imaging protocols to each patient, considering factors such as age, weight, and medical history. This personalized approach ensures that patients receive the lowest possible radiation dose without compromising the quality of image diagnosis, following the ALARA principle [10].

Additionally, it provides healthcare professionals with greater efficiency in data analysis and interpretation, resulting in more accurate diagnoses and more effective treatments. Thus, the project represents a significant technological advancement in the healthcare field in Portugal, transforming how healthcare professionals deal with the evaluation of data related to ionizing radiation dose in CT scans.

The structure of the paper is composed in section 2 by an overview of the proposal that will be implemented. Section 3 presents some of the fundamental dosimetry quantities that might be used in the project, which are essential for establishing radiological protection principles and systems for both external and internal exposure of biological tissues to radiation. In section 4, it is presented the conclusions of the proposal and, lastly, the main references used to prepare the article are provided.

2 Approach

This study aims to develop a strategy for predicting ionizing radiation doses in CT scans by applying AI models. At an early stage, models such as Support Vector Machines (SVM), Random Forest, Artificial Neural Networks and Decision Trees will be explored, bearing in mind that a selection of models will subsequently be made based on their ability to handle complex medical data and make accurate predictions in the context of the project.

The strategy will be based on a large set of data from CT scans (examination example shown in Figure 1) stored in the Picture Archiving and Communication System (PACS) from a Portuguese hospital [2][8]. To ensure compliance with the General Data Protection Regulation (GDPR), an anonymization procedure will be applied during a pre-processing stage of the data, selecting those features that might allow patients to be identified, with the purpose of guaranteeing patient protection and safety in all circumstances.

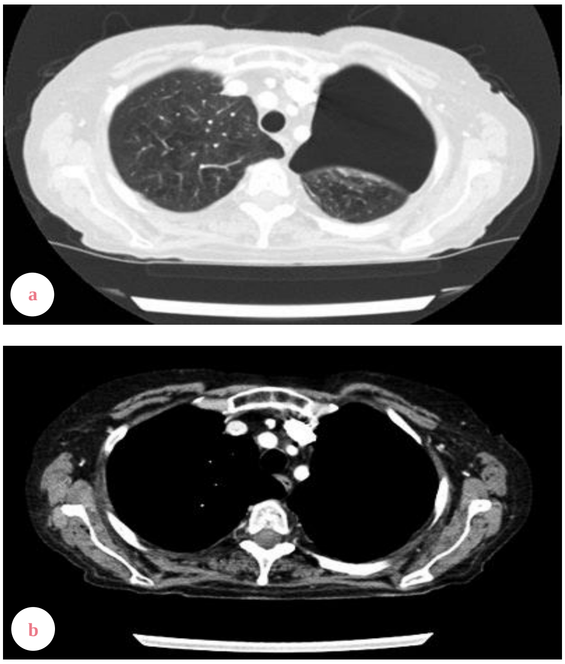

Figure 1: Chest CT: lung window (a) and soft tissue window (b) [13].

As a first approach to dose prediction, features such as age, weight, and medical history, along with imaging parameters, will be used to estimate the radiation dose that would be delivered during the scan, also analyzing the relationship between different features, as well as avoiding redundancy of information in features that present the same information, to allow the recognition of patterns in patient medical information.

Once trained with a vast set of known data, these models will be able to accurately estimate radiation doses for new CT scans, helping to optimize imaging protocols, personalize patient care and minimize risks associated with exposure to ionizing radiation. The most appropriate models will be selected later, considering the specific objectives of the study and the clinical context (Figure 2).

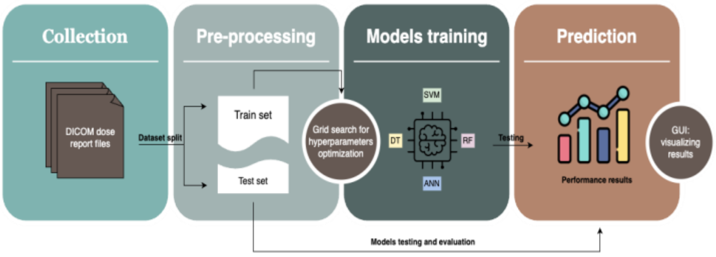

Figure 2: System approach overview.

In a conclusive phase, the theoretical values of several fundamental quantities in the field of Medical Physics are calculated to complement the prediction value of the models (see Section 3), which are finally compared with the previously defined DRLs.

DRLs are predetermined values used to assess radiation dose in radiological examinations, like CT scans. They optimize procedures, ensuring diagnostic quality while keeping patient exposure within acceptable limits. DRLs are crucial for radioprotection, monitoring and controlling radiation dose to minimize risks.

In the context of CT, DRLs are established based on protocols considering aspects such as technique, body region, and patient age. Standardization improves diagnoses and reduces dose variability across hospitals. Continuous monitoring, comparing dose data with established values, ensures compliance and patient safety.

By applying these AI models, the project seeks to provide healthcare professionals with a reliable tool for estimating radiation doses in CT scans. This enables them to optimize imaging protocols, personalize patient care, and minimize the potential health risks associated with ionizing radiation exposure.

3 Dosimetric Quantities for Radiation Measurement and Dose Assessment

Dosimetric physical quantities are essential for establishing principles and systems of radiological protection in both external and internal exposure of biological tissues to radiation [9]. External radiation fields can be described solely by physical quantities, while internal fields depend on biokinetic, anatomical, and physiological parameters, making them extremely difficult to estimate.

Kinetic Energy Released per unit Mass (*Kerma*) is defined as the average energy transferred ($E_{T,R}$) by neutral particles (photons and neutrons) to charged particles (electrons and protons) in the medium, per unit mass (m). The SI unit of *Kerma* is Gray (Gy) and is defined by equation (1).

$$K = \frac{dE_{T,R}}{dm} \tag{1}$$

Absorbed dose (*D*) is the fundamental quantity in radiological protection and is defined as the energy deposited by ionizing radiation (E) per unit mass of tissue (m). The SI unit of absorbed dose is Gray (Gy) and is defined by equation (2).

$$D = \frac{dE}{dm} \tag{2}$$

Dose equivalent (H_T) in an organ or tissue T corresponds to the average absorbed dose in that tissue or organ ($D_{T,R}$) deposited by radiation R, which is defined by the type and energy of the interacting radiation and W_R corresponds to the radiation weighting factors that have been stipulated based on the relative biological effectiveness (RBE) of the various radiations. It is calculated using equation (3), and its SI unit is Sievert (Sv).

$$H_T = \sum W_R D_{T,R} \tag{3}$$

Effective dose (*E*) is defined as the weighted sum of equivalent doses in different tissues (equation (4)), where W_T is the tissue weighting factor, and $\sum W_T = 1$. This parameter considers the different radiosensitivity of each exposed tissue or organ, with tissues having higher radiosensitivity associated with higher values of W_T. Its SI unit is Sievert (Sv).

$$E = \sum_T W_T H_T = \sum_T W_T \sum_R W_R D_{T,R} \tag{4}$$

The values of W_T were initially established in 1977 by the ICRP and revised in 1990 to consider the fatality of different neoplasms and hereditary effects. Based on various epidemiological studies, they were revised again, resulting in changes that apply to all age groups and both genders. It is worth noting that over the years, there has been a decrease in W_T values, indicating a decrease in the radiosensitivity associated with different tissues. Consequently, the radiation hazard to biological tissues has been reduced.

4 Conclusions

This study intends to achieve several objectives related to importing, processing and analyzing data from CT images. By developing models for predicting the appropriate radiation dose, identifying potential adverse effects of radiation exposure, analyzing the factors that influence the dose received by patients and validating diagnostic reference levels, the aim is to ensure adherence to the principles of justification, optimization and limitation of radiation dose.

By achieving these results, the project will contribute to the radiological protection of patients, improving the quality of imaging exams and maximizing clinical benefits, ensuring that each patient receives the appropriate radiation dose and minimizing the associated risks.

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