Project Proposal: Exploring Methods for Computing Absorbed Radiation Dose in CT Imaging

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Introduction

This project aims to investigate and describe various methodologies used to compute the absorbed dose of radiation during CT imaging. It will examine both standard clinical dose estimation techniques and advanced approaches like Monte Carlo simulations. The goal is to deepen our understanding of how radiation interacts with tissue, how the absorbed dose is calculated, and potential implications for patient safety.

Objectives

The objectives of this project are:

- Reviewing common dose estimation techniques in clinical practice
- Exploring more sophisticated dose computation methods using Monte Carlo simulations, with an emphasis on simulating organ-specific photon-tissue interactions

Dataset

Reference Dataset for Benchmarking Organ Doses Derived from Monte Carlo Simulations of CT Exams
Associated with: Hardy, Anthony J., et al. "Reference dataset for benchmarking fetal doses derived from Monte Carlo simulations of CT exams." Medical physics 48.1 (2021): 523-532.
Accessed from: https://zenodo.org/records/3959512

Tentative Methodology

Standard Dose Metrics

The project will begin by reviewing common dose metrics used in clinical settings, such as:

- Computed Tomography Dose Index (CTDI)
- Dose-Length Product (DLP)

Organ Dose Estimation

While CTDI and DLP provide useful clinical metrics, more precise methods are required for organ-specific dose calculations. The project will also explore techniques to estimate the absorbed dose for specific organs, offering a better understanding of how radiation impacts different tissues.

Monte Carlo Simulations

Monte Carlo simulations offer a more advanced, granular approach to dose calculation by simulating the interaction of X-ray photons with human tissues. Steps for this section will include:

Simulating photon interactions

We would like to simulate how X-ray photons behave as they pass through tissues, focusing on the distribution of radiation within the body during a CT scan. The simulation can be refined by focusing on a single organ to reduce computational complexity.

Potential simplification strategies for Monte Carlo simulations:

- **Photon count reduction:** Instead of simulating millions of photons, we can reduce the photon count to thousands, which will speed up computation while maintaining reasonable accuracy.
- **2D slice modeling:** Rather than simulating the full 3D anatomy, a single 2D slice of the patient's anatomy may be sufficient to estimate organ dose.
- **Monoenergetic X-ray source:** By assuming all photons have the same energy, we avoid the complexity of simulating the entire X-ray energy spectrum.
- **Dominant interaction modeling:** In soft tissues at CT energies, Compton scattering is the dominant interaction. By focusing on this, we can simplify the photon interaction model, potentially increasing the simulation speed.
- **Reduced iterations:** Reducing the number of iterations in the Monte Carlo model may lower computational cost, though some precision may be sacrificed.

Python toolboxes that we may use (preferred):

1. B Faddegon, J Ramos-Méndez, J Schümann, A McNamara, J Shin, J Perl, H Paganetti. "The TOPAS Tool for Particle Simulation, a Monte Carlo Simulation Tool for Physics, Biology and Clinical Research." Phys Med. 2020 Apr 02; 72:114-121. PMID: 32247964. PMCID: PMC7192305
2. Perl, J Shin, J Schümann, B Faddegon, H Paganetti. "TOPAS: an innovative proton Monte Carlo platform for research and clinical applications." Med Phys. 2012 Nov; 39(11):6818-37.
3. https://github.com/sebasj13/TopasGraphSim
4. https://primoproject.net/primo/
5. https://github.com/MGHPhysicsResearch/moquimc
6. https://github.com/DIDSR/PyBDC

MATLAB toolboxes that we may use:

1. Bo Qiang (2024). Monte Carlo Simulation for Photon Migration Inside Biological Tissue (https://www.mathworks.com/matlabcentral/fileexchange/8754-monte-carlo-simulation-for-photon-migration-inside-biological-tissue), MATLAB Central File Exchange. Retrieved October 21, 2024.
2. A.A. Leino, A. Pulkkinen and T. Tarvainen, ValoMC: a Monte Carlo software and MATLAB toolbox for simulating light transport in biological tissue, OSA Continuum 2, 957-972 (2019)
3. Leland Muller (2024). Toolkits for monte carlo dose simulation and visualization (https://www.mathworks.com/matlabcentral/fileexchange/68660-toolkits-for-monte-carlo-dose-simulation-and-visualization), MATLAB Central File Exchange. Retrieved October 21, 2024