THE TRANSPORT OF ELECTRONS IN MATTER THROUGH THE SUPERPOSITION ALGORITHM AND THEIR DOSIMETRY

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Abstract

The dose calculation of electron and photon transport in matter is critical for application like radiation therapy, where accurate dose is delivery to cancerous tissues, while spearing healthy tissues is essential. The electron transport is indirectly modeled through the convolution of kernels that represent the spread of dose from photons. The approach is less detailed compared to direct electron modeling. The algorithm typically handles secondary production from photons interaction. The electron algorithm is a fast implementation method for the calculation of the dose distribution from high-energy electron beam. The dose distribution within the body is closely related to the electron density of the tissues, which can be represented using an electron density phantom, absolute percent depth dose (PDD), dose at depth max and depth of reference

Key words: *Algorithm, electron transport, PDD, electron density.*

Përmbledhje

Llogaritja e dozës së transportit të elektroneve dhe fotoneve në materie është kritike për aplikim si terapia me rrezatim, ku doza e saktë shpërndahet në indet kancerogjene, ndërkohë që indet e shëndetshme janë të nevojshme të ruhen. Transporti i elektroneve modelohet në mënyrë indirekte përmes konvolucionit të pikësave që përfaqësojnë përhapjen e dozës nga fotonet. Qasja është më pak e detajuar në krahasim me modelimin e elektroneve të drejtpërdrejta. Algoritmi zakonisht trajton prodhimin dytësor nga ndërveprimi i fotoneve. Algoritmi i elektroneve është një metodë e shpejtë e zbatimit për llogaritjen e shpërndarjes së dozës nga tufa elektronike me energji të lartë. Shpërndarja e dozës brenda trupit është e lidhur ngushtë me densitetin elektronik të indeve, i cili përfaqësohet duke përdorur një fantomë të densitetit elektronik, duke

përdorur përqindjen e dozës së thellësisë (PDD), dozën në thellësi maksimale dhe në thellësinë e referencës.

Fjalë kyçe: *Algoritmi, transporti I elektroneve, PDD, densiteti elektronik.*

Introduction

The algorithm of superposition is part of general Monte Carlo algorithm eMC, has been incorporated into the treatment planning system as a powerful choice of dose, for dose calculation in electron radiotherapy treatment. The electron transport is indirectly modeled through the convolution of kernels that represent the spread of dose from photons. The approach is less detailed compared to direct electron transport modeling. May struggle with accuracy in heterogeneous regions, as it relies on pre-calculated kernels that may not fully account for complex tissue interactions. In radiotherapy, a "kernel" refers to a pre-calculated, spatial distribution function that describes how radiation. dose is deposited around a point source of radiation. The kernel embodies the physical processes of energy transfer from photons or electrons to the surrounding tissue. In radiotherapy, a "kernel" refers to a pre-calculated, spatial distribution function that describes how radiation dose is deposited around a point source of radiation figure 1, 3.

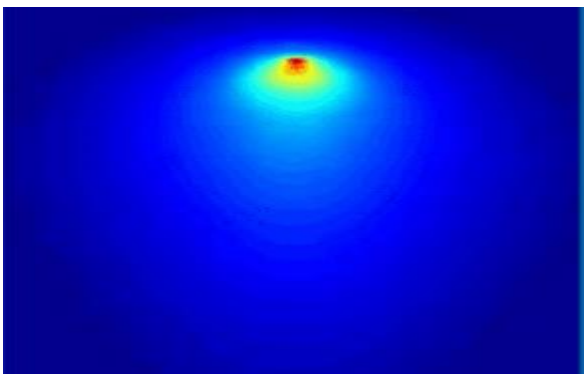


Figure 1: Dose deposited kernel

The kernel embodies the physical processes of energy transfer from photons or electrons to the surrounding tissue. In electron beam therapy or when secondary electrons are significant contributors to the dose, electron kernels help in accurately modeling the dose distribution. The superposition algorithm refines the convolution approach by considering the varying density and

composition of the tissue. The kernels are adjusted or "superposed" according to the local heterogeneities in the patient's anatomy, providing more accurate dose distributions in heterogeneous tissues. Kernels are often calculated using Monte Carlo simulations, which simulate the complex interactions of radiation with matter figure 2.

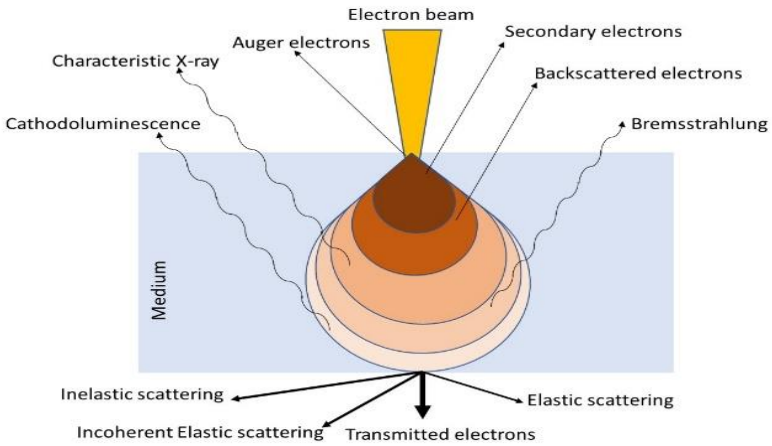


Figure 2: Interaction of electron with medium

These simulations consider all possible interactions and energy transfers, providing a highly accurate kernel.

The dose distribution within the body is closely related to the electron density of the tissues, which can be represented using an electron density phantom. An electron density phantom is a model or device that gives theroriticaly the electron density distribution of human tissues. It is used in radiotherapy planning and calibration to simulate how radiation interacts with the human body.

These phantoms often have sections with different known electron densities, corresponding to various tissue types (e.g., muscle, bone, lung). They help in calibrating imaging systems and verifying dose calculation algorithms. When photons travel through the body, their interactions (photoelectric effect, Compton scattering, pair production) are influenced by the electron density of the tissues they encounter. Higher electron density means more interactions and higher dose deposition. The calculation algorithms must account for these variations. Dose algorithms adjust the dose distribution based on the electron density information derived from imaging studies (e.g., CT scans), which provide a map of tissue electron densities.

Methodology

The eMC algorithm methods it is referred as a class stochastic algorithm widely used for simulating the behavior of mathematical system. The algorithm is capable of producing more precise results than analytical calculation, especially for systems with large number of coupled degrees of freedom, such as the transport of a beam of electrons and photons through several layers of different materials. Its application includes not only calculation of dose deposited in matter by primary and secondary particles in patients under clinical radiation treatment, but also and optimization of radiation therapy and above all accurate commissioning of treatment planning system (Knoos, 2006).

The algorithm id based on the X-ray Voxel Monte Carlo program, to provide raw calculations that involved electron and photon transport in matter. When the algorithm is used to calculate a distribution, the process starts with a single electron being generated to travel virtual space towards the patient volume according to its initial momentum. The series of interactions this electron experiences as it crosses different matter; the resulting sequence of energy losses and secondary particle. When a real radiation linac machine is used to deliver the treatment plan, every single particle will take a different path. However, after a large enough number of electron stories will be generated the calculation does not qualitatively improve the final result.

Figure show the isodose curves for a sample plan with phantom and illustrate a typical calculation result obtained after running thousand paths stories of electron travel and energy deposited in matter. If the statistical precision of the resulting dose distribution will be not satisfactory, more calculation needed to be generated in time. In practice to visually a dose distribution it is necessary to have added before dose distribution calculation; i) electron density data, ii) calibration curve of Hounsfield number vs scan scale and above all, iii) dosimetry collected data by linac machine.

During the process of calculation, we will refer the isodose distribution according on normal incidence of electron beam at an interaction point and the deposition dose at a second point figure 3 (European Society for Therapeutic Radiology and Oncology 2001).

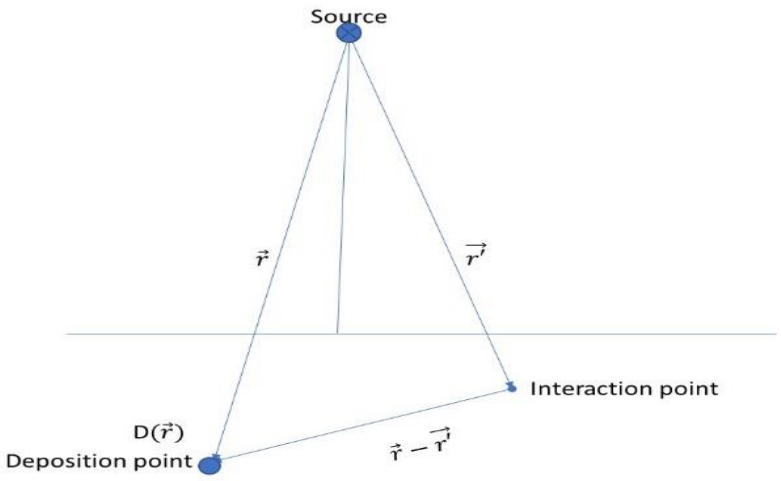


Figure 3: schematic interaction and deposition dose kernel to a matter

The dose at point $\vec{r}$ is the sum of the Total Energy Released per unit Mass (TERMA) point $T\ (\overrightarrow{r'})$ times the value of the energy deposition kernel $H(\vec{r}-\overrightarrow{r'})$ originating at point r' and evaluated at point r. The dose is prescribed by below superposition equation (Ahnsejö A. 1989):

$$D(\vec{r}) = \int T\left(\overrightarrow{r'}\right)\frac{\rho(\overrightarrow{r\prime})}{\bar{\rho}}K_{\rho}(\bar{\rho}\left|\vec{r}-\overrightarrow{r'}\right|\vec{r}-\overrightarrow{r'})d^3r' \qquad (1)$$

Where, ρ(r') is the density at the interaction site and $\vec{\rho}$ is the average density along the straight-line path between the interaction site and dose deposition site, K_{ρ} kernel density.

According to that, this is a relative statistical process, and also we needed to know the mean relative statistical uncertainty (MRSU), that is an average statistical uncertainty of the entire dose distribution and it is given by:

$$MRSU_{D\geq P} = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\frac{s_k^2}{D_k^2}} \qquad (2)$$

Where k is the grid point index, D_k is the dose deposited point k, s_k^2 is the estimated variance of the mean point k.

When the electron algorithm is used to calculate a dose distribution, particles are allowed to travel within the patient volume and a series of interaction are

logged as they cross different media. The resulting of interaction contains a sequence of energy losses, which provides information necessary to calculate the total energy deposited in arbitrary point within the patient, it may need to travel through some of surrounding regions.

The algorithm produces dose calculation results that take into account fundamentals properties of each material present in the irradiated volume, using CT number to determine mass densities and material compositions for each point int the computation grid. Traditional radiation therapy treatment system based on analytical algorithm have assumed patients to be bodies of water with relative electron densities, and calculation dose is in base of primary linac measurement. The algorithm allows to force the absorbed dose calculation to be performed assuming that the absorption point is in a volume of water, with mass density information obtained from CT number (Barret, et.al, 2009).

The measurement of the absorbed dose, under standard conditions, is performed at the reference depth z_{ref} = 10cm. It is precisely this depth that is resolved, since this is also where the electronic equilibrium is established, and pollution from secondary or primary electrons is almost zero. The equation for measuring dose in water is given as follows (International Atomic Energy Agency, 2000; American Association of Physicists in Medicine Task Group 51, 1999):

$$D_{w,Q} = M * k_{T,p} * k_S * k_{pol} * k_{elec} * N_{w,Q} \quad (3)$$

Where M (C) is the reading of the electrometer, $k_{T,p}$ correction factor of air temperature and pressure (T_0 =20$_o$C, P_0 = 101.3 kPa); k_S correction factor for the recombination of ions produced before they have been collected at the central electrode of the ionization chamber; k_{pol} correction factor for voltage polarity and k_{elec} correction factor for electrometer sensitivity. $N_{(w,Q)}$ (Gy/C) is the calibration coefficient of the ionization chamber for the absorbed dose in water.

The results obtained from the dosimetric measurements are then applied to create the model of the photon or electron beam which will be applied for therapy. Also, to create this beam model, it is necessary to know more precisely what electronic density we have during the image transport from the scanner device (Computed Tomography - CT) to the treatment plan, in which the treatment beam modeling will be performed. For this purpose, it is necessary to perform the scanning of the relevant phantom with different

electron densities, which is of the CBCT type "Cone Beam Computed Tomography - Electron Density" of the CIRS company, figure 4 (American Association of Physicist in Medicine Task Group 51, 1999).

Figure 4. Presentation of the CIRS phantom with materials of different densities

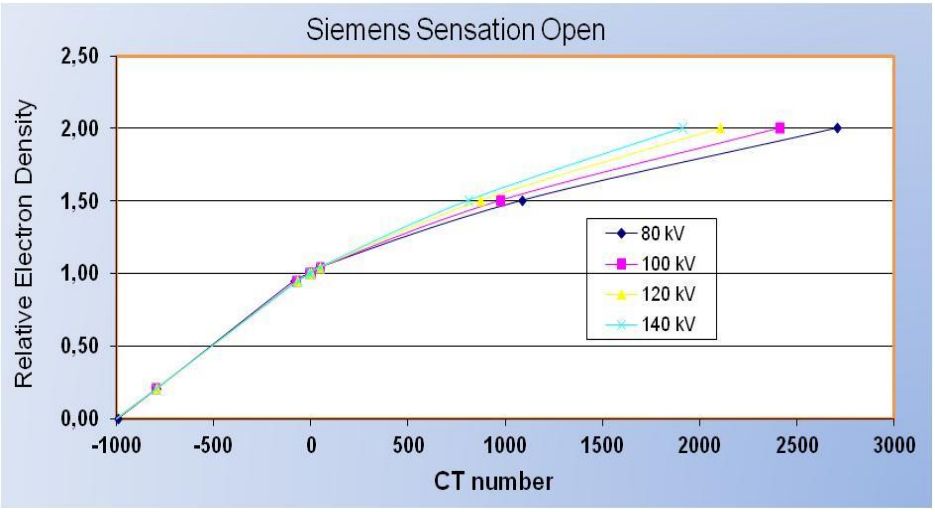
Results

• During the processing of the dosimetry measurements, it was concluded that the dose absorbed in water at depth d_{max} for electron beam with different high energy the data are as in table 1.

Table 1. Measure dose at 100 cm SSD

Energy	6 MeV	9 MeV	12 MeV	16 MeV
D_{max} (H_2O)	13 mm	21mm	28.9mm	30mm
Dose (200MU)	1.978 Gy	2.019Gy	2.018Gy	2.02Gy

- Based on these measured values, we reach the conclusion of the quality index for photon beams for energy 6 MeV, k_Q = 0.938; 9MeV - k_Q = 0.925; 12 MeV - k_Q = 00.912 and for energy 16 MeV - k_Q = 0.901,
- In accordance with these values, the LINAC apparatus is calibrated, under standard conditions for 100 MU, 100 SDD, field size 10 x 10 cm^2 a dose of 1.009 Gy for 6 MeV.
- From the scanning of the CIRS phantom, in the CT suite of the Hygeia hospital for different voltages applied for scans, it was concluded that the used voltage of 120kV gave image density close to the theoretical values with a discrepancy of the order of ± 0.8%, graph 1. as well as the relevant data in graph 1



Graph 1: Chart of densities of different materials

After receiving the dosimetric data and scanning the electron density phantom, the reference beam model for therapy applications is created. This beam model is created based on the Superposition algorithmic method.

For this purpose, they are used interspersed in the treatment plan to conform the treatment beam to the patients' treatment plan.

Due to its speed, the algorithm method is useful for batch commissioning and for calculations on homogeneous subjects. For patients who will be treated in non-homogeneous tissue areas, it is advisable to use the other Multigrid Superposition algorithm.

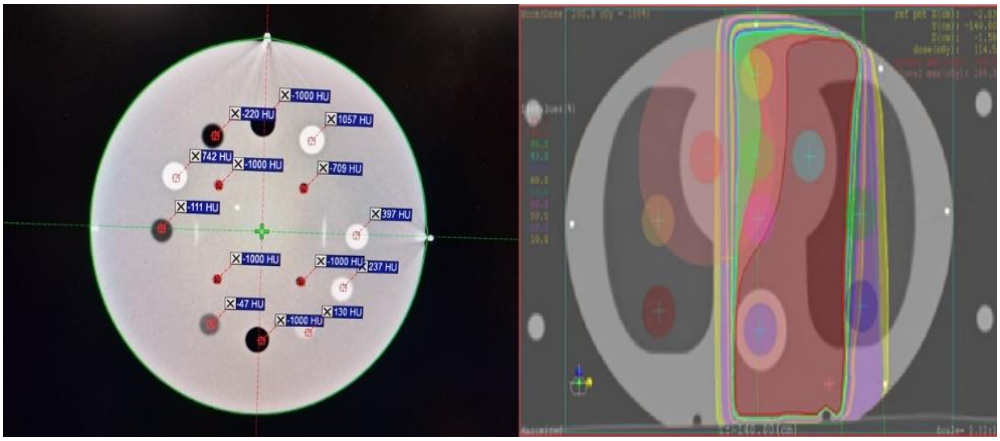


Figure 5. Presentation of the CIRS phantom which is irradiated with the reference beam and in base of HU number.

Based on the acquired data; after processing them and placing them in a treatment plan database, it was possible to create a reference electron beam for the radiotherapy center. Based on the initial data and their processing, we came to the conclusion that in our conditions the use of the Superposition algorithm meets the requirements set in the commissioning of the linac devices and is appropriate algorithm for electron treatment.

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