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JAPA

STOPPING POWER DEPENDENCE of D_{max} VALUES for BIOLOGICAL TARGETS

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Abstract: In this study, the relationship between stopping power and d_{max} values in the interaction of electrons with brain, breast and eye tissues is discussed. Stopping power values were obtained by using Roothaan-Hartree-Fock electronic charge densities, while d_{max} values obtained with Monte Carlo based computer code Electron Gamma Shower (EGSnrc). A linear relationship between stopping power and d_{max} values has been observed; and a function was obtained that connects the d_{max} values to the stopping power values by the curve fitting method. Thus, d_{max} values can be obtained easily from stopping power values for various energy values.

BİYOLOJİK HEDEFLER İÇİN D_{max} DEĞERLERİNİN DURDURMA GÜCÜNE BAĞIMLILIĞI

Anahtar Kelimeler
Doz,
Durdurma Gücü,
Elektron,
EGSnrc,
Biyolojik Dokular

Özet: In this study, the relationship between stopping power and d_{max} values in the interaction of electrons with brain, breast and eye tissues is discussed. Stopping power values were obtained by using Roothaan-Hartree-Fock electronic charge densities, while d_{max} values obtained with Monte Carlo based computer code Electron Gamma Shower (EGSnrc). A linear relationship between stopping power and d_{max} values has been observed; and a function was obtained that connects the d_{max} values to the stopping power values by the curve fitting method. Thus, d_{max} values can be obtained easily from stopping power values for various energy values.

1. Introduction

The beginning of the studies on the interaction of charged particles with matter was the investigation of atoms and nuclei with cathode rays [1]. The stopping power, defined as the energy lost per unit length of an energetic particle in a given material, has been studied extensively in areas such as nuclear fission and nuclear physics studies, technological applications of ion cultivation, material analysis and radiation oncology. Especially in areas such as radiation biology and radiotherapy, where the target material is determined as biological material, it is necessary to know the energy transferred to the target and the distance traveled by the incident particles. Most of the radiation dose calculation methods involve the Monte Carlo method (MC), which simulates particle interactions, taking into account the randomness of the problem [2]. Electron Gamma Shower (EGSnrc), one of the applications mentioned simulation code, is more preferred in medical applications. EGSnrc simulates the interaction of photons and electrons in matter in the range of 10 KeV to 50 MeV [3].

Stopping power and absorbed dose quantities are interrelated concepts. While the stopping power is expressed as the energy lost per unit length of the particle, the absorbed dose is defined as the energy transferred to the unit mass by the incoming particle. The maximum depth (d_{max}) that the beam can travel along the axis and the percent deep dose curves (PDD) in which the dose values associated with this depth are expressed are two important quantities used in the literature to express the absorbed dose values. In the literature, there are many different studies in which stopping power values are obtained depending on the energy and d_{max} values are obtained depending on the energy [4-7]. The differences in modeling parameters such as method, material and incoming particle type in these studies appear as inadequacies in explaining the relationship between stopping power and dose values. A new form of expression, in which the stopping power and dose values obtained by modeling under the same conditions can be put forward together, has been put forward by us [8]. Thus, a statement has been put forward that the d_{max} value of a material with known stopping power value or the stopping power value of a material with known d_{max} value can be known.

In this study, it was aimed to obtain the stopping power and dose values for electrons interacting with the biological tissue. Brain, breast and eye tissues were considered as targets. The stopping power values were calculated using the procedure developed by us [9], while the dose values were obtained using the EGSnrc code. In our previous work, we investigated the relationship between stopping power and dose for muscle and skin [8]. In this work, these relationship has been investigated for eye, brain and breast tissues since considering the use of electrons alone in tumors near the surface of photon beams in deeper tissues [10, 11]. Thus, it is aimed to obtain information about a larger number of biological tissues and to evaluate the effect of tissues close to the surface on the results. The energy range of electrons has been determined as 1-20 MeV.

2. Materials and Method

2.1. Absorbed Dose Calculations with EGSnrc

Absorbed dose calculations were obtained using EGSnrc code in the energy range of 1-20 MeV for eye, breast and brain tissues. Since these tissues are not in the library of the EGSnrc code, texture information has been created using the "egs-gui" sub-package program. Mono-energetic electron beams were arranged to hit the target 100 cm above the cylinder axis (SSD=100cm). The energy at which the electrons are assumed to be completely stopped is set to 10 keV. The number of simulated particles was determined as 107 electrons. In the 'Geometry' section, the geometry of the target is modeled as a cylinder with a radius of 5 cm and a height of 15 cm. Since it is known that electrons will transfer their energy at close distances to the surface, the first 5 cm was adjusted to be 50 slices of 0.1 cm in order to take more precise measurements [12]. The next 10 cm was adjusted to have 10 slices of 1 cm.

2.2. Analytical Calculations:

a) Stopping Power- CSDA Range values

In this work; brain, breast and eye tissues were considered as targets in the calculations. Table 1 contains the material compositions of these tissues, which were taken from literature [13, 14]. To calculate stopping power and range values, the effective charge and effective mean excitation energies of the target were taken into account by using Roothan-Hartree-Fock (RHF) electronic charge densities. For incoming electrons, stopping power of the target can be calculated by considering electronic and radiative energy losses. However, in this study, only collision stopping power is considered in stopping power calculations. This is because the radiative stopping power does not contribute to the absorbed dose values. Range values, which are the distance the charged particles take until they stop in matter, were calculated with the Continuous Slowing Down Approximation (CSDA) [15]. Calculation details can be found in our previous work [8].

Table 1 Material composition of brain, breast and eye tissues.

Element	Fraction by weight		
	Brain	Breast	Eye
H	0.107	0.106	0.096
C	0.145	0.332	0.195
N	0.022	0.030	0.057
O	0.712	0.527	0.646
Na	0.002	0.001	0.001
P	0.004	0.001	0.001
S	0.002	0.002	0.003
CI	0.003	0.001	0.001
K	0.003		

b) Linear regression analysis

Linear regression is an approach to model the linear relationship between a normally distributed, a certain amount of data collected, a numerical dependent variable called Y and one or more independent variables expressed as X [16]. In this part of the study, the relationship between d_{max} values obtained with the EGSnrc code and stopping power values calculated by using RHF electronic charge densities was investigated. Simple linear regression analysis was used to reveal the relationship between these two parameters.

3. Results and Discussions

The absorbed dose values are expressed depending on the depth in the target [17-19]. The maximum dose depth (d_{max}) is the distance from the surface of the maximum dose depth that the beam can travel along its axis. By fixing the d_{max} to the 100, other dose distances are expressed percentage depth dose (PDD). The PDD curves obtained for the brain, breast and eye tissues are shown in Figs. 1-3, respectively.

From Figs.1-3, it is seen that the peak values in the deep dose curves shift deeper distances as the energy increases. Considering the deep dose profile of the electrons in the central axis, it is seen that a sudden decrease follows the plateau region [6,20,21]. Thus, the treatment of tumors with critical organs behind them becomes possible. In addition, as the energy increases, this sudden decrease leaves its place to an expanding plateau. As a result, it can be said that the skin dose will increase and the maximum dose will be drawn to the surface [11,22,23].

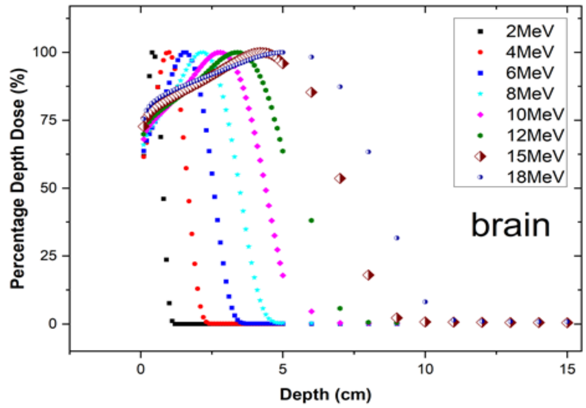

Figure 1. Percentage depth doses (PDD) for brain tissue

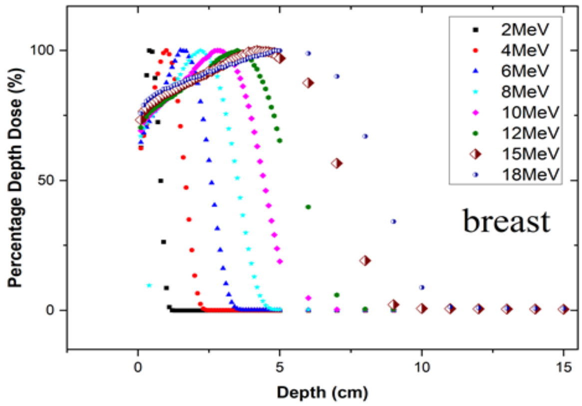

Figure 2. Percentage depth doses (PDD) for breast tissue

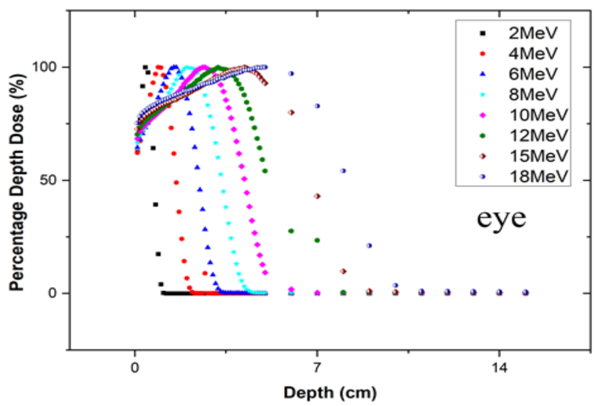

Figure 3. Percentage depth doses (PDD) for eye tissue

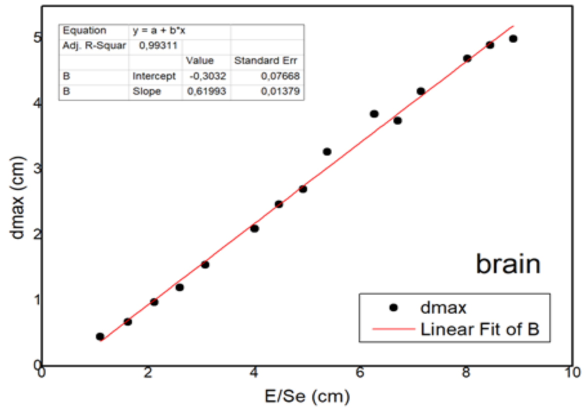

Figure 4. Relationship between Stopping power and maximum dose depth for brain tissue

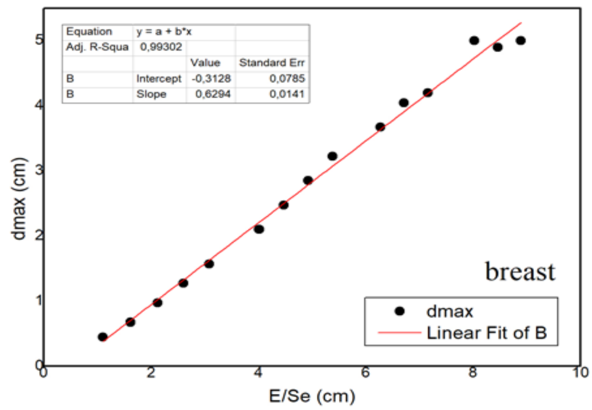

Figure 5. Relationship between Stopping power and maximum dose depth for breast tissue

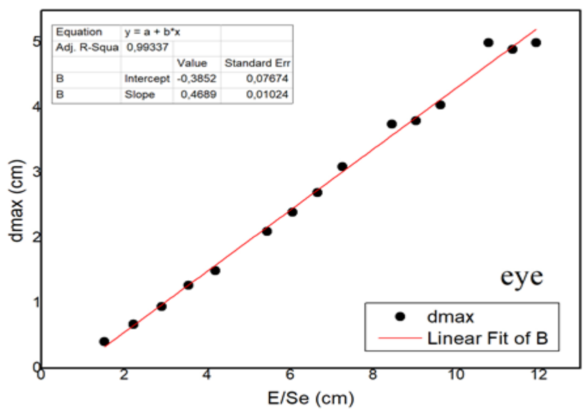

Figure 6. Relationship between Stopping power and maximum dose depth for eye tissue

Figures 3-5 show the relationship between stopping power and d_{max} values for electrons incident on the brain, eye and brain. In these graphs, the y axis represents the maximum dose depth and the x axis represents the E/Se (energy/stopping power) value. The x-axis has been designated as E/Se both to ensure the unit compatibility between the axes and to evaluate the data on a single parameter. Simple linear regression analysis was performed for these data to obtain the functional dependence of d_{max} values to the stopping power values.

4. Conclusions

In this work, the relationship between stopping power and d_{max} values has been determined for brain, breast and eye tissues. RHF approach has been used while obtaining the stopping power values. Since this approach takes into account the shell structures of atoms, it provides the most accurate approximation results.

Dose values were obtained with the MC code EGSnrc, which is frequently preferred in radiotherapy calculations. The deep dose profiles we obtained are compatible with the characteristic curves of the electrons. In order to observe the effect of tissue differences on the d_{max} value, tissues both close to the surface and at deeper distances from the surface were considered. However, due to the modeling under the same conditions, there is no effect on the d_{max} value of different tissues. Considering their location in the body in radiotherapy planning, there will be differences.

In our calculations, R^2 values are close to 1 which is important to show the model's success [24]. In this work, a connection was established between these 2 parameters, which are separately related to energy. As a result, this study is important in terms of revealing the linearly dependence between them.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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