EVALUATION OF LATERAL STRAGGLING IN SRIM2012 AND GEANT4 FOR PROTON THERAPY

AVALIAÇÃO DO DESVIO LATERAL EM SRIM2012 E GEANT4 PARA PROTONTERAPIA

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Abstract: The modality of radiotherapy with protons shows promising results compared to conventional treatment with photons. There are softwares, such as GEANT4 and SRIM, which allow simulations of passages of heavy particles through matter, thus making it possible to obtain useful results for specific studies in this area. Its importance comes from its relative simplicity of use mainly due to the high cost of hadron accelerators. The analysis of the parameters calculated by simulations and their levels of uncertainty in the region of the Bragg peak will be essential to future development stages of treatment plans with proton beam. This work presents some simulations about the trend of increase in mean lateral deviation (in the Bragg peak...
region) with increasing energy of the incident beam.

**Keywords:** Proton therapy. Simulations. SRIM2012. GEANT4.

**Resumo:** A modalidade de radioterapia com prótons vem trazendo resultados promissores comparados ao tratamento convencional por fótons. Há softwares, como o SRIM2012 e GEANT4, que permitem simulações de passagem de partículas pesadas pela matéria, tornando possível a obtenção de resultados úteis para estudos específicos nessa área. Sua importância vem de sua simplicidade de uso frente ao alto custo dos aceleradores de hídrôns. A análise dos parâmetros calculados por simulações e seus níveis de incerteza na região do pico de Bragg será essencial para o futuro aprimoramento de planos de tratamento em protonterapia. Este trabalho apresenta a tendência do aumento do desvio lateral com o aumento inicial do feixe na região de máximo alcance dos prótons(pico de Bragg).


1. **INTRODUCTION**

The new form of radiotherapy with proton beam has brought quite promising and superior results when compared to conventional treatment which uses photons (KOZAK et al. 2007; NICHOLS et al. 2012; ROMBI et al. 2012), especially for sparing critical structures adjacent to the tumor, as in the case of eyes, brain and spinal canal due to the fact that it has no exit dose. With improved treatments, there is a high quality of life expectancy, increasing for patients in general.

By means of simulations in SRIM2012 and GEANT4, there is the possibility of analyzing heavy particles passing through matter (AGOSTINELLI et al., 2003), for example, in a phantom composed of specific densities materials, close to the actual human structures. Data outputs as transmitted ions are then generated, maximum range in the target, lateral deviation and energy of the ion. Based on this new technology, one can do simulations and look forward to increasingly effective and precise treatments allied with tomography images, which is currently extensively studied due to the difficulty of knowing the not homogeneous protons pathways (PAGANETTI, 2012). There are formalisms that covering three times the value of the standard deviation, can predict the mean path of protons with an uncertainty of 0.6
mm in a homogeneous water cube (PENFOLD, 2010). So stands the need for simulations with Monte Carlo method to be carried out in order to improve the image reconstruction algorithms, since having better knowledge and control of processes that involve distortions of the most likely path of protons (MLP), would affect the density, thus the image quality.

The high cost of proton accelerators is certainly a limiting factor of the wide availability of this new kind of treatment. The protons accelerator, in general, is more robust, since linear accelerators currently used in radiotherapy, with photons and electrons do not have an electric field strong enough to accelerate heavy beams and occupy a suitable physical space for hospital use. This is one of the most important reasons to study by means of simulations before purchasing or designing a prototype. One day, it might be possible to make simulations accurate and efficient enough to be used simultaneously with treatment (PERL et al., 2012).

2. OBJECTIVES

2.1 General objective

- Evaluation of lateral deviation in the interaction of proton beams for energies of 63, 65, 70, 75, 80, 85, 90, 95 and 98 MeV with a phantom of the male pelvic region and with a water block, through simulations with the computational codes SRIM2012 and GEANT 4, respectively.

2.2 Specific objectives

- Evaluate the variable straggling (lateral deviation) for the set of a thousand protons in each beam energy level for SRIM.
- Evaluate the variable straggling (lateral deviation) for the set of a twenty thousand protons in each beam energy level for GEANT4.
- Relate beam energy and uncertainty in the lateral deviation in the Bragg peak
region.

3. METHOD

3.1 SRIM

Firstly, the target is modeled using layers as SRIM2012 works. This software contains a library of elements that simulate human tissues and biological structures. We chose to model the pelvic region of a male individual to observe the behavior of the proton beam in a possible treatment for prostate cancer with beams from 63 to 98 MeV. The final structure of the phantom has a depth of approximately 11.5 cm, and takes into account the passage of the beam in a sequence of layers of different densities and thicknesses, such as skin, adipose tissue, muscle tissue, bone, prostate, and air, as shown in Figure 1. Having the target set, it was possible for each of the energies of the proton beam (63-98 MeV), to perform the process of irradiation of the target by a set of 1000 protons sent one by one. Being the choice of energies purposeful to cover the entire region of the prostate in a possible composition beam, and, for each process, one image was generated representing the number of protons interacting with the environment and its maximum reach.
3.2 GEANT

An algorithm that contains a water block with a silicon detector there through in the horizontal plane is used. Beams with twenty thousand protons for each energy previously chosen are sent and the detector returns the value of the lateral deviation of each proton. The scheme is illustrated in Figure 2.

![Figure 2. Water block traversed by a proton beam. Source: The author.](image-url)
4. PROTON-MATTER INTERACTION

A proton beam passing through the phantom, will interact with electrons and atomic nuclei via Coulomb force, and collisions with these nuclei are also possible, although unlikely. The inelastic collisions in which the proton transfer some of its kinetic energy to the electrons produce ionizations and excitations in the atoms, so the dose absorbed by tissue. For being heavier than the electron, the proton beams are scattered in smaller angles, thus maintaining a more concise aspect. In its path, this beam transfers part of its energy (E) over a certain length traversed in the medium (x) which can be calculated in the form of LET (linear energy transfer) and is expressed as a function of \(-\frac{dE}{dx}\) (Khan, 2009). It is then noted that the lower the speed, the greater the energy transfer to the region. Therefore, we can explain the dose near the peak of maximum beam range, known as the Bragg peak (Figure 3).

![Figure 3. Damage graphic for the 90 MeV beam. Source: The author.](image)

5. RESULTS

Results were then obtained from interactions of the one hundred eighty-nine thousand protons simulate (Table 1). In this study was prioritized the analysis of average lateral deviation (average straggling) of the group of particles for each energy previously specified.

The data was analyzed, and using the program STATISTICA10, the average
deviation of this behavior as a function of the different energies of the beams (Figure 4 and 5) was correlated graphically, and also presented model linearizations.

<table>
<thead>
<tr>
<th>Energy(MeV)</th>
<th>σ Water(mm)</th>
<th>σ Prostate(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>0.13509</td>
<td>0.45501</td>
</tr>
<tr>
<td>65</td>
<td>0.07547</td>
<td>0.47907</td>
</tr>
<tr>
<td>70</td>
<td>0.16130</td>
<td>0.53505</td>
</tr>
<tr>
<td>75</td>
<td>0.20449</td>
<td>0.74522</td>
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<tr>
<td>80</td>
<td>0.37203</td>
<td>0.64776</td>
</tr>
<tr>
<td>85</td>
<td>0.15277</td>
<td>0.71651</td>
</tr>
<tr>
<td>90</td>
<td>0.37013</td>
<td>0.93441</td>
</tr>
<tr>
<td>95</td>
<td>0.71945</td>
<td>0.78996</td>
</tr>
<tr>
<td>98</td>
<td>0.69115</td>
<td>0.92147</td>
</tr>
</tbody>
</table>

Table 1. Standard Deviation. Source: The author.

5.1 SRIM data:

\[
\sigma (\text{mm}) = -0,3258 + 0,01270 \times E \text{ (MeV)} \quad (1)
\]
Figure 4. Graph representing the standard deviation as a function of beam energy for the prostate treatment simulation.

5.2 GEANT4 data:

\[ \sigma (\text{mm}) = -0.9803 + 0.0162 \times E (\text{MeV}) \]  \hspace{1cm} (2)
6. DISCUSSION

There have been several simulations and assessment of the uncertainties in the average lateral deviation for each specified energy. As can be seen in Figures 4 and 5, the mean lateral deviation tends to be higher with increasing beam energy as well as in papers (MA, 2007) and (GARCIA-MOLINA, 2012), which corroborate this proposition also with experimental data. It was also presented in this study a linearization of variables that relates the energy (MeV) and mean lateral deviation, showing a correlation level in approximately 92%. In Figures 6 and 7 we can observe the increase in deviation:

*Figure 5. Graph representing the standard deviation as a function of beam energy for the water block simulation.*
Some of these uncertainties are epistemic, as pointed out by Pia (PIA et al., 2010), regarding the differences in modeling approaches, validations, experimental parameters, and the most significant, modeling multiple scattering in beam line.

Therefore it can be noted that the Bragg peak has significant lateral uncertainties that must be taken into account when setting an assessment of a composition of beams for treatment via proton therapy.

Figure 6. Lateral deviation and maximum range for proton beam of 65 MeV

Figure 7. Lateral deviation and maximum range for proton beam of 95 MeV
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