Factors influencing the electron dose calculation in Eclipse eMC

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Abstract. This study aims to evaluate the factors influencing electron dose calculation in Eclipse electron Monte Carlo (eMC) on virtual phantoms. Each parameter of accuracy, calculation grid size, random number generator seed, number of particle histories, smoothing method and smoothing level in Eclipse eMC was varied while other parameters were fixed in default value. Gamma analysis was used to evaluate dose distribution accuracy. The reference dose distributions were set as the best option values. The 1% accuracy, 1 mm calculation grid size, 2100000000 random generator seed number, 0 number of particle histories, 3D Gaussian smoothing method and strong smoothing level with 2%/2mm criteria were defined as the best option values. The 6 and 18 MeV energy, the sizes of 6x6 cm² and 10x10 cm² applicator were used. The overall results showed the gamma passing rate higher than 90% except when higher accuracy than 2%, 5 mm calculation grid size, no smoothing/low smoothing level and changed the number of particle histories other than 0 were applied. This study shows that the accuracy, calculation grid size, smoothing method, smoothing level and number of particle histories parameters are significantly impact to dose distribution and the first two factors are also affect to calculation time.

1. Introduction

Electron beam therapy are external beam radiotherapy used for the treatment of superficial tumors and sparing deeper normal tissue because electron beam contributes a high surface dose and rapid dose fall off beyond the tumor. Although superficial tumors can be treated with the low energy photon beams, electron therapy has been recommended to treat superficial tumors because electron beam has the advantages in high and uniform dose in the target volume and in minimizing dose to deeper tissues [1]. The Eclipse eMC is a dose calculation algorithm in treatment planning system (Varian Medical Systems, Palo Alto, CA). The eMC is the fast Monte Carlo based on standard EGS4 Monte Carlo methods. In Eclipse, eMC provides several parameters that user can select for suitable dose calculation: accuracy, calculation grid size, random number generator seed, number of particle histories, smoothing method and smoothing level. The variation in values of Eclipse’s parameters were used to find the optimal value of each parameter for various clinical situations such as in case of high gradient area, the finer calculation grid size should be used. The main factors that affect to dose calculation accuracy are accuracy, calculation grid size, smoothing method and smoothing level, which result in dose distribution, monitor unit calculation and calculation time. Accuracy is defined as the average statistical uncertainty in all voxel of dose greater than 50% of the maximum dose value within the body contour. This option is not used if the value of the Maximum number of particle history parameter is other than 0 [2]. Calculation grid size is defined as resolution in dose calculation.
that controls grid size in the transversal plane; X and Y dicom axes. For Z dicom axis, the grid size is fixed to the slice spacing from CT image. Smoothing method is used to reduce noise of the Monte Carlo calculations due to the random nature of the simulation process that will need to be used the smoothing [2]. The smoothing level is defined as the standard deviation of smoothing. Random generator seed number is the random number sequence used in the particle generator or starting point of each simulation. Number of particle histories is the maximum number of particles to be transported in a calculation. Calculation stops when the set number of particles has been transported, even if accuracy is not reached. When set this value in 0 means that this option is not used, the Accuracy option is used instead [2]. The calculation will continue until specified accuracy is achieved [3]. The different situations such as heterogeneity material, irregular surface, extend source to surface distance are possible to affect in electron dose calculation accuracy. Consequently, the selection of appropriate parameters must be carefully selected as well as appropriate calculation time. So, it should be understand and known the impact of each parameter in treatment planning system. In order to select the appropriate parameters to achieve the effective treatment, this study can be implemented for this purpose. Therefore, the purpose of this study was to determine the appropriate parameters of Eclipse eMC in various situations such as heterogeneity material, irregular surface, extended source to surface distance.

2. Materials and methods

2.1. The virtual water phantom creation
Before create the plans, the virtual water phantom with the size of 30x30x30 cm$^3$ were created in Eclipse treatment planning system (Version 11.0.31). This phantom is homogenous that Hounsfield unit was set as water (HU = 0).

2.2. The treatment planning in homogeneous phantom
The energies that used in the experiment were 6 and 18 MeV which are represented the low and high energy, respectively. The applicator sizes in this study were 6x6 cm$^2$ and 10x10 cm$^2$ as the most commonly used in clinic. The calculations were performed in both 100 and 110 cm SSD. Eclipse eMC has several parameters that user can select for dose calculation. Each parameter was varied, while other parameters were fixed in the best option values as shown in following

- **Accuracy**
  Vary: 1%, 2%, 3%, 5% and 8%
  Best option: 1%
- **Calculation grid size**
  Vary: 1 mm, 1.5 mm, 2 mm, 2.5 mm, and 5 mm
  Best option: 1 mm
- **Random generator seed number**
  Vary: 1, 1000000, 39916801, 2100000000
  Best option: 2100000000
- **Number of particle histories**
  Vary: 0, 1, 100, 10000
  Best option: 0
- **Smoothing method**
  Vary: No smoothing, 2D Median, 3D Gaussian
  Best option: 3D Gaussian
- **Smoothing level**
  Vary: 1-Low, 2-Medium, 3-Strong
  Best option: 3-Strong

2.3. The treatment planning in inhomogeneous phantom
The inhomogeneous phantoms in this study with the size of 30x30x30 cm³ are shown in Figure 1 (zoom in for interesting area) for (a) the high-density material like bone, (b) the low-density material like air, (c) the protrusion shape surface like nose and (d) the depression shape surface like ear canal or surgical defect. The inhomogeneous materials were 1 cm thickness and 1 cm depth below the surface. The protrusion and depression shape were 2 cm in length.

Figure 1. The zoom-in inhomogeneous phantoms for (a) the high-density material like bone (b) the low-density material like air (c) the protrusion shape surface like nose and (d) the depression shape surface like ear canal or surgical defect.

2.4. Dosimetric evaluation of each parameter
The parameters that affect to dose accuracy and calculation time were studied in extended source to surface distance, heterogeneity material, and irregular surface. Gamma analysis was used to evaluate dose distribution accuracy that overlays between evaluated dose distribution and reference dose distribution. The reference dose distributions were set as the best option values. There are 1% accuracy, 1 mm calculation grid size, 2100000000 random generator seed number, 0 number of particle histories, 3D Gaussian smoothing method and strong smoothing level. The gamma analysis of 2%/2mm criteria with percentage passing rate more than 90% were used to evaluate the plans.

3. Results and discussion
3.1. Gamma passing rate
Each parameter evaluated by the gamma passing rate with 2%/2mm criteria. The dose distribution between the reference parameter plan (the best option values) and varied parameter plans were compared. The results were average from both energies and both applicator sizes.

3.1.1. Accuracy
The gamma passing rate was significantly reduced at high value accuracy of 3%, 5% and 8% as displayed in Figure 2, however, using 2% accuracy presented the same dose distribution as the best option value 1% accuracy in all situations that consistent with the study of Chamberland et al. [4] who evaluated the accuracy of the electron eMC dose calculation algorithm and compared its performance against an electron pencil beam algorithm by varied accuracy between 1% and 2% in different inhomogeneous solid phantoms. However, as protrusion and depression clinical situations from our study are possible to calculated with 8% accuracy, they still presented the high gamma passing rate

Data compared with 1% accuracy

Figure 2. The percent gamma passing rate on different accuracy variation in various situations.
3.1.2. Calculation grid size
When the calculation grid size increases, the gamma passing rate reduces, especially for 5 mm calculation grid size as shown in Figure 3. The lower calculation grids were not significantly increase gamma passing rate but the calculation time increased in lower calculation grid size as shown in Table 1. The air inhomogeneity was more effect on dose distribution difference than bone inhomogeneity insertion. The calculation grid size was strongly affected to protrusion and depression irregular shape surface even 1.5 mm calculation grid size due to the low resolution in high gradient region.

![Data compared with 1 mm calculation grid size](image)

**Figure 3.** The percent gamma passing rate on different calculation grid size variation in various situations.

3.1.3. Smoothing method
In case of smoothing method variation, we found that it impacted to dose distribution when the smoothing method was not applied as consistent with the study of Popple et al. [5] who evaluated the performance of a commercial electron dose calculation software (Macro Monte Carlo algorithm) using a standard verification data set by varying parameters in various situation. They also founded that the number of points violating criteria are sharply reduced when using the others smoothing method because smoothing reduces the number of points violating the different criterion in the high-dose, low-gradient regions, but increases the number violating the criteria in the high-gradient region. The results showed that 2D Median smoothing method was a lot of better than no smoothing applied, however, it was not enough for air heterogeneity and irregular shape surface as shown in Figure 4.

![Data compared with 3D gaussian smoothing method](image)

**Figure 4.** The percent gamma passing rate on different smoothing method variation in various situations.
3.1.4. **Smoothing level**
When medium smoothing level was selected, the same dose distribution compared with using the best option level (strong) was presented except in air heterogeneity material and irregular shape surface. The low smoothing level should not be applied in all situations as displayed the results in Figure 5.

![Data compared with 3-strong smoothing level](image)

**Figure 5.** The percent gamma passing rate on different smoothing level variation in various situations.

3.1.5. **Random generator number**
The change in random generator seed number was not affected to the dose distribution, the results showed almost 100% gamma passing rate in both energies and all situations that presented the same results as Pemler et al. [6] who investigated the influence of the seed of the random generator using different values of the random generator seed in the range 1 and 500000000 and then they founded that whether a seed number is even or odd, no systematic impact on the result.

3.1.6. **Number of particle histories**
In case that the number of particle histories other than 0 was selected, the results of dose distribution was suddenly wrong represented by very low gamma passing rate in all situations. As the recommended by Popple et al. [5], the number of particle histories must be set to zero to ensure that the desired statistical precision was attained.

3.2. **Calculation time**
Table 1 shows the average calculation time from all situations, energies and applicator sizes in each parameter. The calculation time of 1% accuracy spent more than 3 times higher than 2% accuracy that presented the good results in gamma passing rate. It is because when the number of particle histories increases, the calculation time will increase. Therefore the 2% accuracy is the good option in terms of the small difference in dose distribution and less calculation time. For the calculation grid size, the calculation time of 1.0 mm calculation grid size spent more than 100 times higher than 5.0 mm calculation grid size. however, 5.0 mm calculation grid size presented the low gamma passing rate. The 2.5 mm calculation grid size that presented the optimal for gamma passing rate can reduce 20 times lesser in calculation time than 1.0 mm calculation grid size. For all other parameters, the variation situations were not significantly depended on the calculation time.
Table 1. The average calculation time from all situations, energies and applicator sizes in each parameter.

| Parameters          | Variation/Calculation time (min) |
|---------------------|----------------------------------|
| Accuracy            | 1%  | 2%  | 3%  | 5%  | 8%  |
| Calculation time    | 1.74 | 0.49 | 0.27 | 0.19 | 0.17 |
| Cal. grid size      | 1.0 mm | 1.5 mm | 2.0 mm | 2.5 mm | 5.0 mm |
| Calculation time    | 9.82 | 2.34 | 0.89 | 0.48 | 0.08 |
| Smoothing method    | No smoothing | 2D-Median | 3D-Gaussian |
| Calculation time    | 0.48 | 0.52 | 0.49 |
| Smoothing level     | 1-Low | 2-Medium | 3-Strong |
| Calculation time    | 0.48 | 0.49 | 0.49 |
| Random generator number | 1 | 1 000 000 | 399 168 012 | 100 000 000 |
| Calculation time    | 0.49 | 0.48 | 0.45 | 0.49 |
| Number of particle histories | 0 | 1 | 100 | 10 000 |
| Calculation time    | 0.45 | 0.15 | 0.13 | 0.13 |

4. Conclusion
This study shows that the accuracy, calculation grid size, smoothing method, smoothing level and number of particle histories parameters are significantly impact to dose distribution and the first two factors are also affect to calculation time. The optimal parameters on average in all situations are 2% accuracy, 2.5 mm calculation grid size, 2D or 3D smoothing method, medium or strong smoothing level, any random generator number and 0 number of particle histories.

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