Difference between etar and ccc in calculation of dose

Abstract

Aims: According to the limitations of TPS’s dose calculation algorithms, it is important to verify their calculations and to find the amount of differences of their results with actual delivered dose in the patient body for all of radiation situations to find the best and accurate algorithm to choose for use in routine radiation treatment planning.

Materials and Methods: After validation of simulated Linac’s head in water phantom as a homogeneous medium, the modeled head verified in Rando phantom as a heterogeneous medium for pituitary gland area irradiation. In the second part, ETAR and CCC algorithms were compared for 2 lateral parallel opposed and one oblique (45 degree) fields (3×3 cm2) irradiations at 18 MV using 30º physical wedge.

Results: Our results showed that there are significant difference between ETAR and CCC in calculation of delivered dose in pituitary irradiation. Also, none of the algorithms can predict actual dose in air cavity areas, except Monte Carlo method.

Conclusions: As differences between algorithms may have effects on quality of treatment, it is important to evaluate algorithms to choose the best one for use in clinical situations. MC method is a great evaluation tool for comparison of clinical dose calculation algorithms.

Keywords: Treatment planning system, Dose calculation algorithm, Monte Carlo simulation, ETAR, CCC

Introduction

The main objective of radiation therapy is to deliver the maximum possible dose to the target tumor with minimum dose to the normal surrounding tissues [1]. To achieve this, a good understanding of the dose distribution in irradiated tissue and most importantly, experimental verification of this distribution is needed. During the actual radiation treatment planning in clinics, dose distribution calculated by treatment planning systems (TPS). Any deviation in these calculated distribution would lead to difference in patient's delivered dose and would have an important effect on quality and effectiveness of the radiotherapy treatment.

Most of dose calculation algorithms in TPS's are inaccurate in radiation disequilibrium conditions such as near tissue inhomogeneity like near air cavities and bone-soft tissue interfaces for small and complex radiation fields [2-5]. Therefore, it is important to validate this dose calculations. Common validation is performed by comparisons with measured data which their reliability depends on measurement situations and instruments and several other aspects. So, there are some limitations in this kind of validation such as the fact that it is impossible to verify the dose calculations in some parts of patient's body for example in brain irradiation.

Currently, it is well known that the Monte Carlo (MC) is the most accurate method for dose calculation [6-10] and with the advancement of computer technology, dose calculation algorithms based on the MC method have the potential to be used to calculate the delivered dose in radiotherapy clinics. But, due to the time consuming process of the full MC calculations and some of the limitations in speed of computers in clinics [11], it is still impossible to use full MC in routine clinical calculations. However, it is most powerful technic to verification of TPS's dose calculations [12-14].

According to mentioned limitation of TPS's dose calculation algorithms, it is important to verify their calculations. There are several studies on MC validation of common dose calculation algorithms in homogeneous medium and simple and also complex radiation fields [15-22], but because of the several complex situations in clinical irradiations, it is important to find the amount of differences of dose calculation algorithms results with actual delivered dose in the patient body for all of these situations to find the best and accurate algorithm to choose for use in radiation treatment planning process.

In this article, we compared two dose calculation algorithms of CorePLAN TPS for computed tomography (CT) images of a patient with pituitary adenoma. The algorithms were equivalent tissue-air ratio (ETAR) and collapsed cone convolution (CCC) which are routinely used in radiation treatment planning. The project divided in to two parts: validation of MC model in homogeneous and heterogeneous medium, and comparison of ETAR and CCC algorithms with MC as a gold standard. After validation of simulated head of the medical linear accelerator (Linac) in water phantom as a homogeneous medium, the modeled head verified in Rando phantom as a heterogeneous medium for pituitary gland area irradiation. In the second part, ETAR and CCC algorithms were compared to MC simulation for planned pituitary radiation same as one in Rando phantom.

Materials and Methods

1. *Monte Carlo Simulations*

The EGSnrc [23] user code BEAMnrc [24] was used to model an 18 MV beam from a Varian 2100C/D (Varian Medical Systems, Palo Alto, CA). The Linac was modelled with different component modules (CM). Table-1 shows these components and their materials. The schematic geometry showing the CMs are shown in figure-1. The 3D image created by EGS_WINDOWS [25] program.

In this study, ISOURC== 19 was used for modelling the incident electron beam. This source is a circular beam with 2-D Gaussian distribution of particles. ECUT and PCUT parameters which used to define the global electron and photon cutoff energy, were set to 0. 7 MeV and 0. 01 MeV. Also, Electron Range Rejection with ESAVE value of 0. 7 MeV in the target and ESAVE-GLOBAL= 2 MeV and Directional Bremsstrahlung Splitting with NBRSL= 750 were used to minimize the simulation time.

Phase Space data were created for open 10 ×10 cm2 photon beam and the percent depth dose (PDD) and profiles of measured and simulated data were used for verification of the beam energy and full width at half maximum (FWHM) of the incident electron beam in 30 × 30 × 30 cm3 water phantom using DOSXYZnrc code [26].

To drive best estimates for the energy and FWHM of the incident electron beam, the method which introduced by Sheikh-Bagheri and Rogers [27] were used. For comparison between calculations and measurements, all curves were normalized to the center of the field for dose profiles and the depth of dose maximum for the PDD curves. This procedure is suggested by Pemler et al. [28] for MC calculated dose distributions of single electron fields. Differences between the calculated and measured curves for dose profiles, were compared in terms of dose difference (DD) in the low dose gradient areas, and distance to agreement (DTA) in millimeter (mm), in the high dose gradient.

For both of Rando phantom and patient studies, CT images of phantom and the patient were used by CTcreate program to make *. egsphant file for irradiation by ISOURC= 8 in DOSXYZnrc code.

0. *Radiation Treatment Planning*

The study was done for Rando phantom and one clinical case CT images originally calculated with equivalent tissue-air ratio algorithm (ETAR) by CorePLAN treatment planning system for pituitary gland radiotherapy. Two other dose algorithms were used: collapsed cone convolution (CCC) and Monte Carlo program, BEAMnrc and DOSXYZnrc codes. The dose calculation algorithms were compared for 2 lateral parallel opposed and one oblique (45 degree) fields (3×3 cm2) irradiations at 18 MV using 30º physical wedges. Figure 2 shows designed radiation plan for Rando phantom and patient CT images.

0. *Dose Distributions*

In Monte Carlo simulation, dose distributions were calculated with DOSXYZnrc that were used as a benchmark and in Rando phantom study, radiographic (Kodak EDR2) and radiochromic (Gafchromic EBT2) films used to obtain planar dose distributions. All films scanned with Microtek 9800XL scanner. Gafchromic EBT2 films scanned 24 h after irradiation [29]. As the pituitary gland is placed in level 3 in Rando phantom (see figure 3), dose calculations and measurements were compared for the delivered dose in surfaces between layers (2, 3), (3, 4) and (4, 5), in terms of 2D isodose curves. All measurements were repeated three times.

Results

1. *Validation of Monte Carlo*

For validation of Monte Carlo simulation, results were compared with measurements in water phantom and 18. 2 MeV and 1. 5 mm for energy and FWHM of the incident electron beam shows the best match with measurements. Figure 4 shows PDD and dose profile for mentioned energy and FWHM. For PDD curve, dose difference was below 1% and for dose profile, DD and DTA were 0. 97% ± 0. 65 and 1. 71 mm ± 1. 08 for open field and 1. 23% ± 1. 09 and 1. 79mm ± 0. 96 for wedged field.

0. *Evaluation of Monte Carlo simulation in Rando phantom*

Simulated Linac were evaluated by comparison with EBT2 and EDR2 film dosimetry in Rando phantom as a heterogeneous medium for pituitary radiation treatment dose calculations. This part of the study performed to make sure that simulated Linac have an acceptable performance in a heterogeneous medium similar to the patient body, where measurement of the delivered dose is impossible.

Totally, differences between Monte Carlo and film measurements were 4. 93% ±0. 87 for all of the layers. These differences were 4. 62% ± 1. 37 for EBT2 films and 5. 03% ± 0. 49 for EDR2 film dosimetry. Also, there were 1. 2% difference between EBT2 and EDR2 results.

0. *Patient study results*

The final purpose of this study was evaluation of ETAR and CCC dose calculation algorithms in almost small size complex radiation wedged fields. To achieve this, Monte Carlo simulation used as a gold standard to compare these algorithms. Figure 5 shows results of the radiation treatment planning using Monte Carlo method, ETAR and CCC dose calculation algorithms.

The differences between Monte Carlo and dose calculation algorithms were 6. 40% ± 3. 44 (range: 3. 8% to 10. 3%) for CCC and 10. 36% ± 4. 37 (range: 5. 5% to 13. 9%) for ETAR.

Discussion

Dose calculation algorithms in treatment planning systems have an important role in radiation oncology departments. Any inaccuracy in predicting dose distribution in patients body will change the quality of the treatment. So, it is important to find the suitable algorithm for dose calculations in radiation therapy process. New algorithms which commonly used in TPSs, beside of their improvements in calculation, may have appreciable inaccuracies in some clinical situations such as small fields, electron disequilibrium and interfaces between different densities [7].

In this study, the differences between CCC and ETAR algorithms were compared to MC simulation results which considered as a gold standard. The study was done for a patient case with pituitary adenoma. To achieve this, the project divided in to two parts. The first step was validation of modelled

Linac head in water and Rando phantom as homogeneous and heterogeneous medium.

Results of simulated head in water phantom showed that the best match between simulated results and measurement data will appear when energy and FWHM of incident electron beam was set to 18. 2 MeV and 1. 5 mm, respectively. These amounts were in the range of their resulted amounts in previous MC studies [27, 30-32].

There are several recommendations for evaluate the accuracy of dose calculations in various areas with high or low dose gradient[33-38]. Our results for open and wedged fields in water phantom were in agreement with recommended amounts by Venselaar et al.[33] for dose profiles and also differences between measured and simulated results were under 2 percent recommended in previous studies for PDD curves[12, 27, 33, 39].

Evaluations in Rando phantom study showed 4. 93% ±0. 87 for all of the EBT2 and EDR2 layers in comparison with MC simulation. This difference was little than 7% discrepancy reported by Brualla et al.[40] and was more than Dobler et al.[16] results which reported 3% difference between MC and film dosimetry in heterogeneous medium. There would be two reasons for this difference. The first one is the gaps between Rando phantom layers which made by placing the film between them. These gaps are larger for EDR2 films because of the thickness of their cover. While, in MC simulation these distances would not considered in calculations.

The second one is the fact that in high density tissues such as bone, as the number of the scattered secondary electrons increases, delivered dose will decrease and this will considered in MC calculations. Because this method considers all of the interactions occur in that tissue and calculates the delivered dose in it. But in film dosimetry, film density is equal to the soft tissue density and bone scatter electrons will cause an increment in delivered dose in the film and this may lead to a disagreement between MC and film dosimetry.

Film dosimetry have uncertainties pertinent to several factors such as nonuniform thickness of the sensitive layer, temperature effects, scanner uncertainty and its warm up effect[41-43]. There was 1. 2% difference between EBT2 and EDR2 films. EDR2 films are light sensitive and were cut in a dark room; However, this low light may have effects on measurements. Also, EDR2 film processing have remarkable effects on the results while there is no need to process the EBT2 films.

Final results showed about 6. 4% difference for CCC algorithm and about 10. 3% for ETAR algorithm in comparison to MC simulation. Chow et al.[44] evaluated the anisotropic analytical algorithm (AAA) and CCC in heterogeneous phantom for tangential photon beam. They showed that the mean dose differences between MC and CCC was about 4. 6% for 15 MV photon beam with 7×7 cm2 field size.

Polednik et al. [17] in comparison between pencil beam (PB) and collapsed cone (CC) algorithms in an anthropomorphic phantom, reported that there is about 6% difference between CC algorithm calculations and measurements. Our results are close to their findings and also Calvo et al. [19] results which reported about 5. 6% differences for CCC in comparison with MC.

Figure 5 shows that none of the algorithms could predict the actual dose in air cavity except MC. This difference is larger for ETAR. This is due to this fact that ETAR algorithm uses the ratio of two tissue-air ratio (TAR) for inhomogeneity correction and in definition, TAR is ratio of absorbed dose in a given depth in absorbent material to the same depth in a small air region in electron equilibrium situation. Therefore, this algorithm assumes that there is electron equilibrium in all points. So, in bone-air interfaces which there in no electron equilibrium, ETAR will have fault in dose calculations [45]. Also, ETAR only considers primary and scattered photons and doesn't consider the secondary electrons. Hence, it can't evaluate the electron disequilibrium [12, 46-50]. While, CCC models electron transport and will predict the effects of electron disequilibrium in heterogeneous interfaces [51]. Our results showed that CCC algorithm as a model based dose calculation algorithm, have a better agreement with MC simulation and the results of this study confirms the previous studies [15, 52-56].

In conclusion, as differences between algorithms may have effects on quality of treatment, it is important to evaluate algorithms to choose the best one for use in clinical situations. MC method is a great evaluation tool for comparison of clinical dose calculation algorithms.

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