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Original Article

Comparison of CCC and ETAR dose calculation algorithms in pituitary adenoma radiation treatment planning; Monte Carlo evaluation

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Abstract

Aims: To verify the accuracy of two common absorbed dose calculation algorithms in comparison to Monte Carlo (MC) simulation for the planning of the pituitary adenoma radiation treatment.

Materials and methods: After validation of Linac's head modelling by MC in water phantom, it was verified in Rando phantom as a heterogeneous medium for pituitary gland irradiation. Then, equivalent tissue-air ratio (ETAR) and collapsed cone convolution (CCC) algorithms were compared for a conventional three small non-coplanar field technique. This technique uses 30 degree physical wedge and 18 MV photon beams.

Results: Dose distribution findings showed significant difference between ETAR and CCC of delivered dose in pituitary irradiation. The differences between MC and dose calculation algorithms were 6.40 ± 3.44% for CCC and 10.36 ± 4.37% for ETAR. None of the algorithms could predict actual dose in air cavity areas in comparison to the MC method.

Conclusions: Difference between calculation and true dose value affects radiation treatment outcome and normal tissue complication probability. It is of prime concern to select appropriate treatment planning system according to our clinical situation. It is further emphasised that MC can be the method of choice for clinical dose calculation algorithms verification.

Keywords: CCC; dose calculation algorithm; ETAR; Monte Carlo simulation; treatment planning system

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 aim, a good understanding is needed from the dose distribution in irradiated tissue and most importantly, experimental verification of dose distribution. During the actual radiation treatment planning in clinics, dose distribution is calculated by treatment planning systems (TPS).

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Any deviation between calculated dose distribution and true value would lead to change in patient's dose that would have an important effect on the quality and effectiveness of the radiotherapy treatment.

Some methods of dose calculation algorithms are not enough accurate in term of dose calculation due to electron disequilibrium at radiation small field boundaries or at the inhomogeneities interfaces.[2–5] It is 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 has found the necessary potential for dose calculation. But, due to the time consuming process of the full MC calculations and some of the limitations in speed of computers,[11] it is still impossible to use full MC in routine clinical calculations for heavy traffic radiotherapy departments. However, it is still the most powerful technique for verification of other calculation algorithms in TPS's engines.[12–14]

In the present work, we compared two dose calculation algorithms employed in CorePLAN TPS for the special clinical case of pituitary adenoma. The algorithms are equivalent tissue-air ratio (ETAR) and collapsed cone convolution (CCC) which are routinely used in TPS of our radiotherapy departments. The project divided in to two parts: (1) Validation of MC model in homogeneous and heterogeneous volumes and, (2) 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, it was used for pituitary gland irradiation in Rando (human-like) phantom.

MATERIALS AND METHODS

MC simulations

The EGSnrc[15] user code BEAMnrc[16] was used to model an 18 MV beam from a Varian 2100C/D (Varian Medical Systems, Palo Alto, CA, USA). The Linac was modelled with different component modules (CM). Table 1 shows components and their materials. The schematic geometries of the CMs are shown in Figure 1. The 3D image was created by EGS_WINDOWS[17] program.

Table 1. Used CMs for Linac modelling in BEAMnrc code

Linac component	CM	Material
Target	SLABS	Tungsten (W) and copper (Cu)
Primary collimator	CONESTAK	Tungsten (W)
Flattening filter	FLATFIL	Tantalum (Ta) and iron (Fe)
Ion chamber	CHAMBER	Kapton
Mirror	MIRROR	Mylar
Jaws	JAWS	Tungsten (W)
Wedge	PYRAMIDS	Steel

Abbreviation: CM, component modules.

The incident electron beam was modelled by ISOURC = 19 module. This source is a circular beam with 2D Gaussian distribution of particles. ECUT and PCUT parameters which are used to define the global electron and photon cutoff energies were set to 0.7 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 minimise the simulation time.

Phase Space data were created for open $10 \times 10\,cm^2$ photon beam and the percentage 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 $30 \times 30 \times 30\,cm^3$ water phantom using DOSXYZnrc code.[18]

The method introduced by Sheikh-Bagheri and Rogers[19] were used to drive the best estimates for the energy and FWHM of the incident electron beam. For comparison between calculations and measurements, all curves were normalised to the center of each dose profile and for the PDD curve to the depth of maximum dose. This procedure is suggested by Pemler et al.[20] for MC calculated dose distributions of single electron fields. Differences between the calculated and measured curves of dose profiles were explained in terms of dose difference and distance to agreement (DTA) in millimetre (mm) for the low and high dose gradient areas, respectively.

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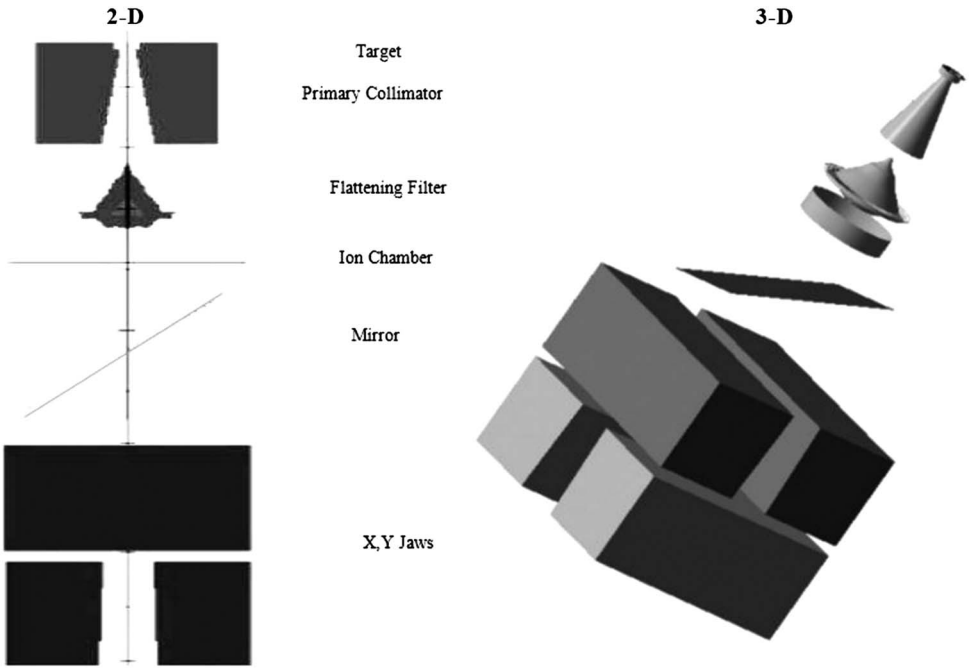

Figure 1. Schematic geometry of modelled Linac. 2D view created by BEAMnrc and 3D view created by EGS_WINDOWS.

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

Radiation treatment planning

The study was done on the Rando phantom as well as on a real clinical case CT images. Initially, the dose distribution in pituitary gland was calculated by means of ETAR implemented in CorePLAN (Seoul C&J Inc., www.coreplan.com) treatment planning software for radiotherapy. The two other dose algorithms were CCC and MC programs (BEAMnrc and DOSXYZnrc codes). The dose calculation algorithms were compared for two lateral parallel opposed and one fronto-occipital 45° oblique $3 \times 3\,cm^2$ 18 MV photon fields employing 30° physical wedges. Figure 2 shows the plan for Rando phantom and the patient.

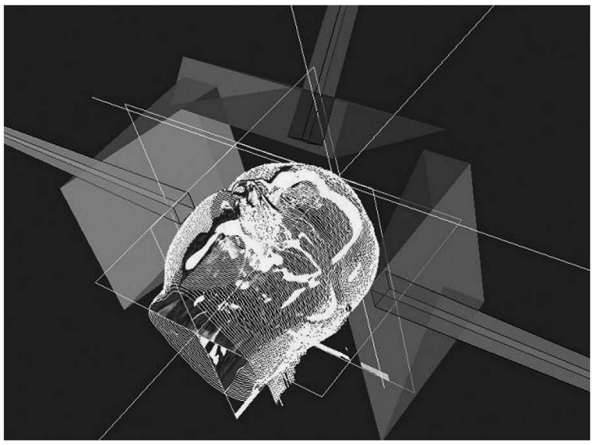

Figure 2. The axonometric image of treatment plan for Rando phantom and patient shows three non-coplanar 18 MV photon beams (two lateral parallel opposed and one fronto-occipital fields).

Dose distributions

In MC simulation, dose distributions were calculated with DOSXYZnrc and the results of MC were cross validated by film dosimetry. For this purpose, both two radiographic (Kodak EDR2) and radiochromic (Gafchromic EBT2) films were used to obtain planar dose distributions in Rando phantom study. All films scanned with Microtek 9800XL scanner. Gafchromic EBT2 films scanned 24 hours after irradiation.[21] As the pituitary gland is placed in third level of Rando phantom (see Figure 3),[22,23] dose distributions were obtained for the surfaces between

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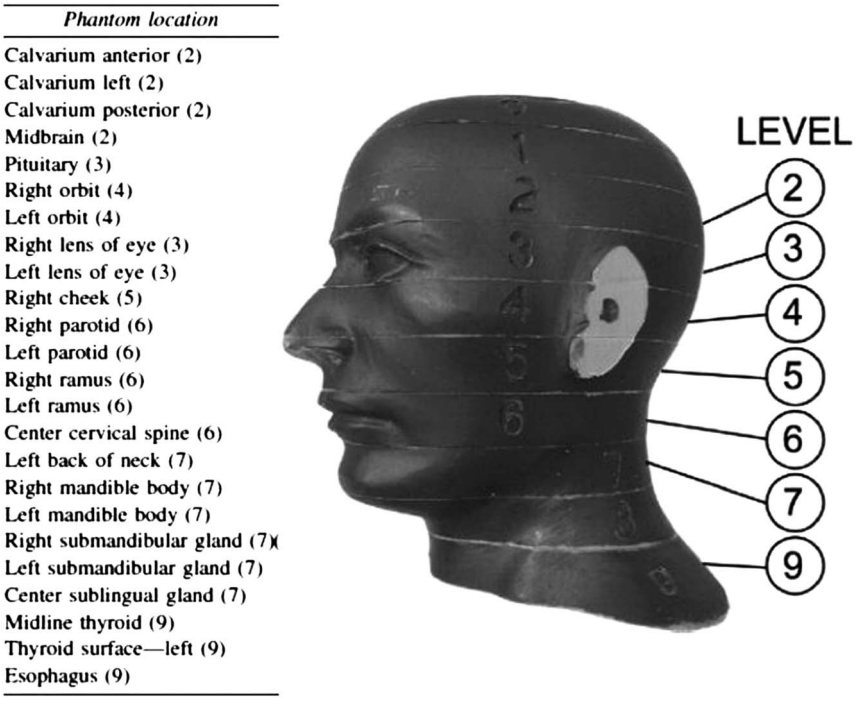

Figure 3. Rando phantom. The pituitary gland is in third level.[22,23]

levels 2 and 3, 3 and 4, and finally 4 and 5. All measurements were repeated three times.

RESULTS

Validation of MC

For validation of MC simulation, results were tuned against measurements in water phantom and finally, the incident electron beam with energy of 18.2 MeV and 1.5 mm FWHM showed the best match with measurements. Figure 4 shows PDD and dose profile for above mentioned energy and FWHM. For PDD curve; dose difference was below 1%, and for dose profile; dose difference and DTA were $0.97 \pm 0.65\%$ and 1.71 ± 1.08 mm for open field and $1.23 \pm 1.09\%$ and 1.79 ± 0.96 mm for wedged field, respectively.

Evaluation of MC simulation in Rando phantom

Simulated Linac head was evaluated against EBT2 and EDR2 film dosimetry in heterogeneous Rando phantom for the pituitary critical region where it is impossible to do in vivo dosimetry. This part of the study was performed to estimate the accuracy and compatibility of modelling within a heterogeneous mimicking human head phantom.

Overall, the mean difference between MC and film measurements were $4.93 \pm 0.87\%$ for all of the levels. The differences were $4.62 \pm 1.37\%$ for EBT2 and $5.03 \pm 0.49\%$ for EDR2 film dosimeters. Also, we found 1.2% difference between EBT2 and EDR2 results.

Results of the patient study

The final purpose of this study was evaluation of ETAR and CCC dose calculation algorithms in small size complex radiation wedged fields. The MC simulation was used as the gold standard to be compared with the various algorithms. Figure 5 shows the results of the radiation treatment planning using MC method, ETAR and CCC dose calculation algorithms.

The average dose calculation differences between MC and proposed algorithms (CCC

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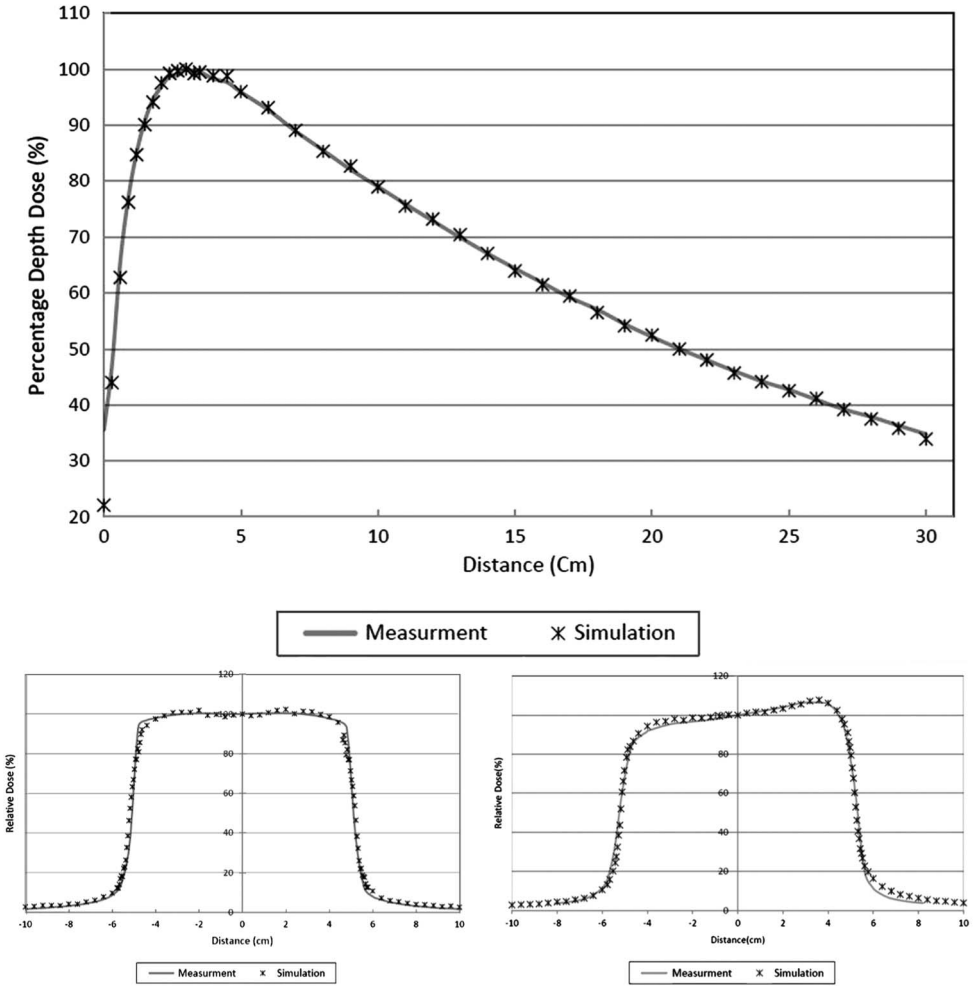

Figure 4. Percentage depth dose (PDD) and dose profiles for open field and 30° wedged field for E = 18.2 MeV and full width at half maximum (FWHM) = 1.5 mm in water phantom.

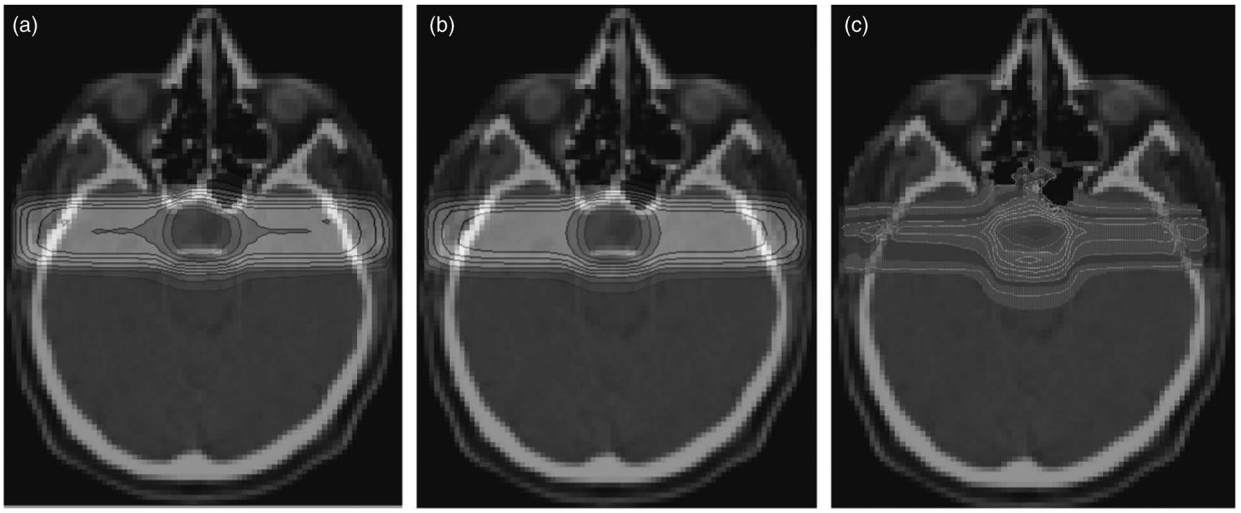

Figure 5. The plans of three diffferent methods of dose calculation are compared: (a) collapsed cone convolution (CCC), (b) equivalent tissue-air ratio (ETAR) and (c) Monte Carlo simulation. The planning was performed on the patient CT data after voxelisation.

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and ETAR) were 6.40 ± 3.44% (3.8–10.3%) and 10.36 ± 4.37% (5.5–13.9%), respectively.

DISCUSSION

Dose calculation algorithms in TPS have an important role in radiation treatment outcome. Any inaccuracy in predicting dose distribution in target volume can also change the patient quality of life. So, it is important to find the suitable algorithm for dose calculation customised to the departmental demands and irradiation fields. 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 with MC simulation and experimental film dosimetry results. The study was done on the Rando phantom and a real clinically diagnosed case of pituitary adenoma.

Results of simulated head in water phantom showed that the best match between simulated results and measurement data will appear when The optimum energy and FWHM of incident electron beam is obtained to be 18.2 MeV and 1.5 mm, respectively, those are well in the range of other researchers in previous MC studies.[19,24–26]

There are several recommendations for evaluate the accuracy of dose calculations in various areas with high or low dose gradients.[27–32] Our results for open and wedged fields in water phantom were in agreement with the values recommended by Venselaar et al.[27] for dose profiles. The differences between measured and simulated results were also <2% that is situated well within the recommended level in related studies for PDD curves.[12,19,27,33]

Evaluations in Rando phantom study showed 4.93 ± 0.87% for all of the EBT2 and EDR2 levels in comparison to the MC simulation. This difference was <7% of the discrepancy reported by Brualla et al.[34] and was more than Dobler et al.[35] results which reported 3% difference between MC and film dosimetry in heterogeneous medium. There would be two reasons for this difference; the first one can be the gaps between the different levels of Rando phantom which is created after placing the film between them. The gap is larger for EDR2 film because of its cover thickness. The gap affects the dose distribution on the film, while its effect is not existed during MC calculation.

The second reason may arise from the different electron densities on the various tissues interface region. In high density tissues such as bone the number of the secondary electrons increases per photon interaction that is well considered by MC simulation power. When a film is placed between the levels of the phantom, because the film density is equal to the soft tissue density, this may lead to a lower dose impartation to the cavity that finally causes disagreement between MC and film dosimetry.

Film dosimeters have uncertainties pertinent to several factors such as non-uniform thickness of the sensitive layer, temperature effects, scanner uncertainty and its warm up effect.[36–38] There was 1.2% difference between EBT2 and EDR2 films. EDR2 films are light sensitive and are cut in a dark room and under safe light, however, it may be better to consider the effect of low level light. Also, EDR2 film processing may have remarkable effects on the readout while there is no need for processing with EBT2 films.

Present findings showed about 6.4% difference for CCC algorithm and about 10.3% for ETAR algorithm in comparison to MC simulation. Chow et al.[39] evaluated the anisotropic analytical algorithm 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 cm^2 field size. Polednik et al.[40] in a comparison between pencil beam and collapsed cone algorithms in an anthropomorphic phantom, reported that there is about 6% difference between collapsed cone algorithm calculations and measurements. Our results are

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close to their findings and also Calvo et al.[41] results which reported about 5.6% differences for CCC in comparison with MC.

Figure 5 shows that MC is superior concerning dose absorption within a non-homogenous volume, especially, in the bone–fat (brain tissue) interface. There is pronounced change in dose distribution after skull that can effectively modify the dose distribution in the pituitary adenoma and the difference is larger for ETAR method. In fact, the 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 and/or tissue interfaces which there is an imbalance in electron equilibrium, ETAR will have fault in dose calculations.[42] Also, ETAR only considers primary and scattered photons and does not consider the secondary electrons. Hence, it cannot evaluate the electron disequilibrium.[12,43–47] While, CCC models electron transport and will predict the effects of electron disequilibrium in heterogeneous interfaces.[48] Our results showed that CCC algorithm as a model based dose calculation algorithm, have a better agreement with MC simulation in pituitary radiation treatment and the results of this study confirms the previous studies.[49–54]

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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Conflicts of Interest

None.

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