DISCRIMINANT ANALYSIS OF THE TOTAL SCATTER FACTOR IN WATER PHANTOM FOR PHOTON DOSE CALCULATION USING THE ECLIPSE TREATMENT PLANNING SYSTEM

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Abstract. In this work, an extensive set of measured data was developed to verify the accuracy of a photon dose calculation algorithm for the Eclipse treatment planning system (TPS). Test cases included square fields, rectangular fields, fields having different source-to-surface distances, wedged fields, irregular fields, obliquely incident fields, asymmetrically collimated fields with wedges, multileaf collimator-shaped fields. The data set was used to validate the photon dose calculation algorithm in the Eclipse TPS. The monitor unit tests revealed that the 6 MV open square fields, rectangular fields, wedged fields, oblique incidence, source-to surface distance variation, mantle field, half beam block, and oblique incidence with wedge test cases did not meet the TG-53 criteria all the time. The results can be used also to establish standards of acceptance for the demonstration of the correct working of the TPS in regular QA-checks. The algorithm must accurately calculate dose distributions for a variety of clinical beam configurations. It was concluded that the generally stated goal of accuracy in dose delivery of within 5% cannot be met in all situations using this beam model in the Eclipse TPS. Although Eclipse is more accurate than measured reading for total scatter factor in water phantom, it is recommended to improve the accuracy of the treatment planning process, e.g. with the incorporation of the Monte Carlo calculation method to the latest version of Eclipse.

Key words: photon dose calculations, accuracy, Eclipse, radiotherapy.

INTRODUCTION

Treatment planning in cancer radiotherapy has become a complex and sophisticated process [5]. Regarding patient safety and success of therapy, its accurate and stable functioning is an issue of highest importance [4]. For these reasons, treatment planning systems (TPS) have to be commissioned by a qualified

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medical physicist then quality assurance (QA) procedures have to be implemented before the clinical routine running of a TPS. Task Group 23 of the AAPM Radiation Therapy Committee has produced a test package for verification of the accuracy of treatment planning for photon external beam therapy. The package includes measured fundamental beam data for 4 and 18 MV X-rays, and 13 test cases with measured dose values at selected points, which serve as the reference for determination of calculated dose accuracy. This document is the report of Task Group 53 of the Radiation Therapy Committee of the American Association of Physicists in Medicine. The purpose of this report is to guide and assist the clinical medical physicist in developing and implementing a comprehensive but viable program of quality assurance for modern radiotherapy treatment planning. Kent *et al*. [5] have developed other test cases as well as the methodology used in generating these test cases evolved from the TG-23 and TG-53 work. AAPM [1] developed a test package for verifying the accuracy of photon-beam dose-calculation algorithms. Data for the test cases were acquired for two beam energies from two clinical linear accelerators: a 4-MV X-ray beam from a Clinac-4 (Varian Oncology Systems, Palo Alto, CA), and an 18 MV X-ray beam from a Therac-20 (Atomic Energy of Canada, Ltd., Kanata, Ontario, Canada). Although TG-23 used 13 test cases for algorithm verification, several clinically significant situations were not included. In fact, many clinics no longer use two-dimentional treatment planning. Additionally, when treating the thoracic region, some beams have to traverse bone and then lung tissue. The differences in material composition in this region can significantly affect dose-calculation algorithms because electronic equilibrium is not established at the interfaces. The accuracy of treatment planning system (Monitor Unit calculations) was also assessed. Test cases representing 12 different clinical setups were included in the data set required to verify the accuracy of the photon dose-calculation algorithm. These setups included open square and rectangular fields, extended source to skin distances (SSDs), wedged fields, irregular fields, short SSDs, oblique incidence, including fractional depth dose curves (FDD) curves, sagittal and transversal beam dose profiles, total scatter factors, and point doses in the heterogeneous case [2]. These test cases [9] were applied to the Pinnacle treatment planning system (Philips Healthcare, The Netherlands) to verify the accuracy of the photon dose-calculation algorithm. The monitor unit tests revealed that the 18 MV open square fields, oblique incidence, oblique incidence with wedge, and mantle field test cases did not meet the TG-53 criteria but were within ±2.5% of measurements [10].

The purpose of this study is to generate a data set that could be used for evaluating photon dose-calculation algorithms used in contemporary treatment planning systems. To achieve this goal, several revisions were made to the data set described in the TG-23 project. First, the test cases pertaining to inhomogeneous media were 3D instead of 2D. Additional test cases were needed; these included oblique incidence with a wedged field, significant asymmetric half beam collimation, a mantle field, a field defined using multileaf collimators (MLCs), a

3D representation of the lung with a tissue-bone interface, and a neck phantom with a tissue-air interface. The accuracy of treatment planning system MU calculations was also assessed.10 Test cases representing 12 different clinical setups were included in the data set to verify the accuracy of the photon dose-calculation algorithm. These setups included open square and rectangular fields, extended source skin distances (SSDs), wedged fields, irregular fields, short SSDs, oblique incidence, as well as the cases described in the previous paragraph.

METHODOLOGY

PHOTON DOSE CALCULATION ALGORITHM

The photon dose-calculation algorithm evaluated in this study is the Pencil Beam Convolution (PBC) algorithm, one of the photon calculation algorithms supported in Eclipse. The set of beam model parameters used in the clinic was employed in all open field test cases. All dose calculations were performed on Eclipse Version 6.5 of the treatment planning system. A 2.5 mm dose grid was used in some of the test cases while 5 mm was used for the others because this is the grid typically used for calculations in “King Fahd” Specialist Hospital. With the exception of the oblique test cases, all test cases were calculated using the water phantom option provided in the treatment planning system.

SYSTEM SOFTWARE AND CALCULATION ALGORITHMS

Dose calculation algorithms are the most critical software components in the Computerized RTPS. These modules are responsible for the correct representation of dose in the patient. In addition, they may be linked to the monitor unit calculation. Dose calculations have evolved from simple 2D calculations, to partial 3D point kernel methods, to full 3D dose models in which the histories of the primary and scattered radiation in the volume-of-interest are considered. There are numerous dose calculation algorithms used by the computerized TPS, Pencil beam convolution method and The Monte Carlo method.

Eclipse

Eclipse is a system software in which it is possible to create the treatment plan and perform dose calculation in External Beam Planning Task. By using the patient and CT data as well as configured beam data, treatment plan can be performed Specification: The dose distribution can be calculated and evaluated in 2D and 3D. In addition, the photon dose distribution, and the treatment time (MU) can be calculated.

Dose calculation with PBC algorithm in Eclipse

The Pencil Beam Convolution algorithm is one of the photon calculations algorithms supported in Eclipse. The pencil beam kernel represents the absorbed dose distribution in the water phantom at standard source-phantom distance, resulting from a very small circular photon beam (2.5 mm diameter). Convolution is done by summing a number of pencil beams, each weighted with the field intensity, to obtain the total dose contribution.

The PBC algorithm calculates the dose distribution. Calculation of the Monitor Unit settings is based on the actual dose delivery. Moreover, the PBC algorithm deals with field accessories, field fluencies, field normalization and dose normalization.

The Pencil Beam Convolution (PBC) algorithm needs specific measured beam data for performing dose calculations. All the beam data must be measured in conditions as uniform as possible. The Beam Configuration task imports the measured beam data in the (w2CAD) file format, which is supported by most water phantom systems. PBC algorithm calculates the dose distribution with the following accuracy: For Photon fields in typical clinical setup: 2–3%, Photon beam reconstruction model: +/– 1% (rectangular fields), +/– 2% (irregular fields) and for oblique correction to within 1–2% [9].

Monitor unit verification

Current treatment planning systems may offer the option of calculating MUs, thus relating the dose distributions to the actual machine output. The methods by which the treatment planning systems relate dose distributions to machine output vary widely. For example, one commercial treatment planning system uses calibrated machine output obtained when the machine was originally commissioned as the starting point for MU calculations.

In this method, the physicist enters the measured output at a specified reference point (usually at a 10 cm depth) for a reference field size (usually 10 cm × 10 cm), and for a reference distance (for example, 100 cm SAD). Rather than normalizing the detector readings to the reading obtained under the reference conditions at the time of each set of measurements, calculations of the total scatter factor (TSF) were compared rather than the absolute number of MUs.

The TSF is defined to be the output at the dose normalization point divided by the output at a 10 cm depth for a 10 cm × 10 cm field. Using the TSF for absolute dose determination removes the daily variation of the machine output from the measured data. To test Monitor Unit calculations, the TSF in the water phantom was measured at the normalization points for each of the ten water-phantom test cases. TSFs were obtained by referencing the electrometer reading at the particular normalization point to the electrometer reading at a depth of 10 cm for a 10 cmx10 cm field at an SSD of 100 cm for each energy for 100 MU. To extract these TSFs from the commercial radiation treatment planning system, 100 MUs were prescribed for each test case, and the absolute dose was recorded and then divided by the dose for a 10 cm × 10 cm collimator setting for each energy.

RESULTS

Table 1 summarizes the results of the monitor unit testing process. The numbers in the cells are the total scatter factors for each test situation. A noteworthy trend is seen in the table. Specifically, when modifiers or blocks were applied to the beam, the treatment planning system consistently underestimated the total scatter factor.

Table 1

Calculated and measured total scatter factor in a water phantom

Test	Description	Measured	Eclipse	%E	Met criteria
Case 1	6×5×5	0.929	0.934	0.5	Yes
	6×20×20	1.062	1.069	0.7	No
	18×5×5	0.929	0.93	0.06	Yes
	18×20×20	1.058	1.059	0.1	Yes
Case 2	6×16.6×16.6 at 120 cm SSD	0.736	0.739	0.4	Yes
	18×16.6×16.6 at 120 cm SSD	0.748	0.744	–0.6	Yes
Case 3	6×5×20	0.986	0.986	0	Yes
	6×20×5	0.962	0.966	0.4	Yes
	18×5×20	0.988	0.989	0.2	Yes
	18×20×5	0.99	1	1	No
Case 4	6×6×6 w45	0.949	0.957	0.9	Yes
	6×20×20 w45	1.0776	1.05	–2.6	No
	6×15×15 w60	1.0457	1.033	–1.2	Yes
	18×6×6 w45	0.941	0.94	–0.1	Yes
	18×20×20 w45	1.072	1.07	–0.2	Yes
	18×15×15 w60	1.047	1.043	–0.3	Yes
Case 5	6×30×30 mantle	1.088	1.086	–0.1	Yes
	18×30×30 mantle	1.0767	1.096	1.8	No
Case 6	6×10×10 SSD 90 cm	0.925	0.936	1.2	No
	6×10×10 SSD 80 cm	0.943	0.954	1.2	No
Case 7	6×330	0.993	1	0.7	No
	6×305	0.907	0.928	2.4	No
	18×330	1.21	1.22	0.9	No
	18×305	1.136	1.144	0.6	No
Case 8	6×HBB	0.263	0.262	0.3	Yes
	18×HBB	0.268	0.272	1.7	No
Case 9	6×wedge oblique	0.539	0.552	2.4	No
	18×wedge oblique	0.693	0.717	3.5	No
Case 10	6×MLC	0.995	0.993	0.20	Yes

The discrepancies in monitor units for the 6 MV 20 cm × 20 cm beams also did not meet the TG-53 criterion of 0.5%. However, these criteria do not include the errors in determining the absolute dose under standard calibration conditions in their tolerance figures for the absolute dose (at the normalization point).

The criteria also do not provide for errors in determining the total scatter factor in their estimate for acceptable agreement. In addition, the errors in monitor units for one of the rectangular fields exceeded the TG-53 tolerance of 0.5%. The error in monitor units for the mantle field also exceeded the TG-53 criterion for blocked fields of 1%.

DISCUSSION

The primary causes for discrepancies between calculations and measurements could be summarized in the following: First: Deficiencies in the beam model, for small, square open fields (5 cm × 5 cm), the calculated shoulders and tails underestimated the measured data.

The underestimation resulted because parameters that described the finite source size and stray scatter from the head had to be modified so that monitor unit calculations would closely match clinical data. Thus, compromising the accuracy of calculations in the shoulders and tails was achieved. For large, square open fields (20 cm × 20 cm), calculations overestimated measurements in the tails, because the parameter that described stray scatter from the head was also modified so that monitor unit calculations would closely match clinical data. Second: Inaccuracies in modeling scatter were also evident in the effect of modifiers or blocks on the accuracy of monitor unit calculations [5]. A possible remedy to the extra focal radiation problem is to use a dual-source photon beam model.

Calculated profiles along the long axis of rectangular fields (5 cm × 20 cm or 20 cm × 5 cm) underestimated measurements in the shoulder region, while calculated profiles along the short axis overestimated measurements. These inaccuracies occurred because of the manner in which the radial distribution of the in-air fluence was modeled. Specifically, the incident photon fluence was assumed to increase linearly with the distance from the central axis until a certain boundary, beyond which the fluence was assumed to be flat. Thus, two parameters specify the incident fluence. Firstly, a cone angle, which described the rate of increase in the fluence as the off-axis distance increased; then a cone radius, which described the point at which the fluence is falling down.

Profile became flat [8] in the treatment planning system, all rectangular fields were modeled with cone angles and cone radii for the equivalent square-field size.

In commissioning this beam, the cone radius was taken to be field-size dependent to match calculation with measurement. A more realistic beam model, however, would have a cone radius independent of the field size. For the 5 cm × 20 cm field, the equivalent square is 8 cm × 8 cm. The cone radius that should have been used for this field was the one for a 20 cm × 20 cm field. Similarly, the cone radius that should have been used for the profiles acquired in the *x* direction for this setup was the cone radius for a 5 cm × 5 cm field.

Consequently, the cone radius of 7 cm, which would have been appropriate for an 8 cm × 8cm field, resulted in a cut-off of the fluence increase at too small a radius for the 20 cm width of the 5 cm × 20 cm field. The underestimation of dose in the tails may be due to inaccurate modeling of the attenuation and scatter from the block, while the underestimation of dose in the shoulders may also be due to inaccurate modeling of the fluence profile within the field. Calculations in wedged fields underestimated measurements in the tails on the side of the heel of the wedge and in the shoulder near the toe of the wedge.

These discrepancies were due to the symmetric nature of the parameters that were radially dependent such as the Gaussian height parameter, which accounts for more head scatter and modifies the calculated dose in the both tails and the cone angle, which accounts for the profile of the in-air fluence. In the case of a wedge, the relative dose profile is not radially symmetric, resulting in a compromise when selecting the cone radius and cone angle. Moreover, the beam model does not directly account for wedge-generated scatter.

One remedy to this situation is to include the wedge in the calculation volume, as in the extended phantom model. The beam model also does not address differential hardening from the wedge. Consequently, calculated depth doses tend to underestimate measurements at larger depths and overestimate measurements at smaller depths.

Calculated doses outside the field yet under MLC leaves were underestimated because interleaf leakage was not modeled. Ion chamber measurements indicate that doses to most of the calculated points are acceptable according to the TG-53 criteria. The sources of the deviations from the criteria were identified. However, the generally stated goal of dose delivery accuracy to within 5% was not met in all situations with this beam model.

Clinically, the greatest difficulty is posed by rectangular fields, where the inner region of the beam was underestimated by as much as 9.75% in some cases. In addition, the monitor unit calculations for the oblique incidence cases show deviations around 2.4%, which is considered borderline acceptable in a clinical context.

To compare calculated and measured doses, the TG-53 report [2] divided the beam into several regions, the buildup region, the inner region, the penumbra, and the outer region. The tolerances for the buildup region range from ±20% for open fields at standard SSD to ±50% for wedged fields. According to the TG-53 report, dose acceptability criteria were based on the collective expectations of the members of the task group and were not to be used as goals or requirements for any particular situation.

The present work indicated that the TG-53 dose acceptability criteria for the buildup region are too forgiving and may require adjustment. Furthermore, the buildup region might be considered as a region of a high-dose gradient and a distance criterion might be used rather than a dose criterion. A shortcoming of the TG-53 report may be in how the various regions are defined [6].

For example, the TG-53 report defines the penumbra as the region from 0.5 cm inside to 0.5 cm outside the beam/modifier edge. However, this definition does not allow for broadening of the penumbra with depth. This leads to a definition of the penumbra that may not encompass the entire high dose-gradient portion of the beam. Moreover, treatment planning system Eclipse can be much predictable using the Monte Carlo method option besides the Pencil Beam Convolution (PBC) algorithm option provided by the vendor.

CONCLUSION

We have generated a measured data set for verifying photon dose calculations for a commonly used TPS, Eclipse. In contrast to previous data sets, this set includes measured total scatter factors. Our analysis revealed that Eclipse is more accurate than measured reading for total scatter factor in water phantom. SCDFC showed that Eclipse reading is a more efficient system than TLD reading system. The effects of oblique incidence with a wedged field, asymmetric collimation with a wedged field, mantle-field irradiation, and use of MLC were also studied for different calculation grid sizes. Test cases used in the study can be used to validate the dose-calculation algorithm, accuracy of the Treatment Planning System under various situations. Although ion chamber measurements indicate that doses to most of the calculated points are acceptable according to the TG-53 criteria, it was concluded that the generally stated goal of accuracy in dose delivery of within 5% cannot be met in all situations using this beam model in the Eclipse TPS. Thus, the Eclipse TPS may require adjustment, hence some of the TG-53 criteria may need to be modified regarding build up region in heterogeneous media and it is recommended to improve the accuracy of the Treatment Planning System with the incorporation of the Monte Carlo calculation method to the latest version of Eclipse. Regarding patient safety and success of therapy, its accurate and stable functioning is an issue of highest importance for these reasons quality assurance (QA) procedures have to be implemented after the commissioning phase, and before the clinical routine running of a TPS. Quality Assurance or testing has to validate the proper functioning of the system (algorithm verification) according to the specifications and to clinical requirements.

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A detailed suite of electron depth dose calculations in water is also presented. Areas for future code develop-ment have also been explored and include the dependence of cell and detector tallies on different bremsstrahlung angular models and alternative variance reduction splitting schemes for bremsstrahlung production.Â used the experimental results of Faddegon 2-4 for 15 MeV electrons incident on lead, aluminum, and beryllium targets. The calculated integrated bremsstrahlung yields, the bremsstrahlung energy spectra, and the mean energy of the bremsstrahlung beam were compared with experi-ment.Â In Compton scattering, an incident photon undergoes a collision with an electron, usually assumed to be free and at rest (see Figure 2.1). Highly conformal photon dose distributions in various treatment sites can be achieved using different techniques of multileaf collimator-based intensity modulated radiotherapy, including static intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT). Radiotherapy using intensity modulated techniques improves the possibility to escalate the target dose and minimize doses to critical organs when compared to three-dimensional conformal radiotherapy [1â€“11].Â The total dose is calculated by superposition of pencil beam dose kernels at each point in space around the incident beam derived from Monte Carlo simulations.Â For the former technique, the mesh is limited to refinement in factors of 2 or smaller in any direction. For photon beams, the formalism includes the use of blocked elds, physical or dynamic wedges, and (static) multileaf collimation. No formalism is provided for intensity modulated radiation therapy calculations, al-though some general considerations and a review of current calculation techniques are included. For electron beams, the formalism provides for calculations at the standard and extended SSDs using either an effective SSD or an air-gap correction factor.Â The dose rate or dose per monitor unit of the userâ€™s beam under normalization con-ditions.Â This check becomes more important as the sophistication of the planning algorithm increases. Many manual methods are currently being used to deter-mine MUs. 1 VARIAN MEDICAL SYSTEMS CLINICAL PERSPECTIVES ACUROS XB Acuros XB advancd dos calculation for th Eclips tratmnt planning systm Grgory A. Failla 1, Todd Waring 1, Yvs Archambault 2, Stphn Thompson 2 1 Transpir Inc., Gig Harbor, Washington 2 Varian Mdical Systms, Palo Alto, California. 2.Â Acuros XB provids comparabl accuracy to Mont Carlo mthods in tratmnt planning for th full rang of X-ray bams producd by clinical linar acclrators, 4 MV 25 MV with xcptional calculation spd and without statistical nois.Â Acuros XB calculats th nrgy dpndnt lctron flunc using th matrial compositions of th patint, rgardlss of whthr D W or D M is slctd.Â Most of th Acuros XB calculation tim is in solving for th scattrd photon and lctron fluncis, which ar prformd only onc for all bams in th plan. There are numerous factors which can be used to calculate photon beam dose distributions. Percent Depth Dose. Percent Depth Dose is the ratio of dose at a point on the central axis (P) relative to the point of maximum dose (zmax). (1). \begin{align} PDD = \frac{D_P}{D_{z_{max}}} \end{align}. Use of PDD.Â The peak scatter factor determines the ratio of dose at zmax that is due to scatter from other parts of the beam. A special case of the PSF occurs for kilovoltage beams at zmax - which for these beams is located on the surface.Â Use of the TPR/TMR. The tissue phantom and tissue maximum ratios are used for high energy photon beams. They allow correction of monitor units/treatment time to account for change in dose at depths other than the reference used.