Original Article

Dosimetric Accuracy Comparison between ACUROSE XB, AAA and PBC Dose Calculation Algorithms in EclipseTM TPS Using a Heterogeneous Phantom

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Received: 25 July 2019
Accepted: 11 October 2019
DOI: 10.1039/x0xx00000x
http://FBT.tums.ac.ir

Keywords:
Acuros XB Algorithm;
Heterogeneous Tissues;
Treatment Planning System;
Dose Calculations.

Abstract

Purpose: The aim of this study is to compare the accuracy of different algorithms in EclipseTM Treatment Planning System (TPS) using a heterogeneous phantom.

Materials and Methods: The method is based on the International Atomic Energy Agency's TEC-DOC 1583 report. The chest phantom of CIRS, PTW30010 ionization chamber and an electrometer (PTW, Freiburg) were used for the measurements.

Three ACUROSE XB (AXB), Analytical Anisotropic Algorithm (AAA) and Pencil Beam Convolution (PBC) dose calculation algorithms available in Eclipse TM TPS were considered in this study.

Results: Based on the measurements, the maximum differences between calculated dose by TPS and measured dose in TEC-DOC 1583 tests were 2.5%, 8.6% and 16.1% for the AXB, AAA and PBC algorithms in heterogeneous media, respectively.

Conclusion: The Acuros XB algorithm has superior accuracy to predict the dose distribution in the heterogeneous tissues such as lung compared to AAA and PBC algorithms.

1. Introduction

Using an accurate algorithm in the Treatment Planning System (TPS) to calculate dose distribution has a crucial role to deliver prescribed dose to the target tissue and minimize extra dose to the organ at risks [1, 2].

A good separation between healthy tissues and target tissue decreases the errors in the treatment [3]. According to the clinical dose curves, the overall radiometric accuracy of the dose should be less than 5% [4]. The difference between dose calculations in water and heterogeneous media is a main problem in designing the dose calculation algorithms [5, 6]. Although the incoherent effect on the initial photon is generally predicted, the dispersed radiation dose is often purely approximated. Most heterogeneous tissue modification algorithms are used for a homogeneous texture of simple geometries. Several authors have reported these errors [5, 7, 8].

Over the years, researchers such as Westermann *et al*. (1984) [9], Rosenow (1987) [10], and Wittkamper *et al*. (1987) [11] have shown that the presence of imbalances in areas of low density such as the lungs can lead to changes in water dose data of more than 30%. Dose calculation algorithm in TPS can be broadly categorized by methods based on the correction based, model-based and solving of the Linear Boltzmann Transport Equation (LBTE) [12].

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The Anisotropic Analytical Algorithm (AAA) analytical algorithm was implemented in Eclipse for a more accurate prediction of the dose in the unauthorized environment [13]. There are some phantoms with low, moderate and high density materials to assess depth dose and dose profiles among Acuros XB (AXB), AAA and Pencil Beam Convolution (PBC) algorithms. Several previous studies have shown that LBTE solutions using the AXB algorithm and phantom experiments (assuming the presence of water or heterogeneous region) is roughly equivalent to the MC method, which is currently the most accurate method of calculating the dose [14].

There are numerous international documents on this issue, as reported by the International Atomic Energy Agency (IAEA), which advises on the exploration of the element's division, the general beam and the verification of beam data. The purpose of this study is to test the accuracy of available dose calculation algorithms in Eclipse TM TPS based on IAEA TEC-DOC 1583 protocol [15, 16].

2. Materials and Methods

2.1. Phantom

For clinical measurements, the 002LFC CIRS Phantom Thorax (CIRS lnc, Norfolk) was used. The phantom consists of the WaterTM plastic tube (electron density 1.003), the lung (relative density of electron 0.207), and the osseous part (electron density 1.506). There are ten interchangeable holes to hold the ionization chambers which is shown in Figure 1. The phantom was scanned at the hospital's imaging center using a Computed Tomography system (CT). The conversion curve of the Hansfield Unit (HU) to the electron density was obtained and imported in the TPS.

2.2. Clinical Tests

The CT images of the phantom were imported to the TPS. A series of clinical trials recommended by the IAEA TEC-DOC 1583 [15, 16] were used to examine a range of initial treatment methods used in clinical practice. The description of test cases, reference and measurement points are given in Table 1. The scheduled tests and the number of monitor/time units to deliver the desired dose were calculated.

2.3.Treatment Planning System

Three different inhomogeneity correction algorithms of the EclipseTM TPS were investigated in this study. Commissioning and audit tests of this TPS were reported previously for AAA and PBC algorithms [17]. However it is desired to test its recent algorithm, named AXB. Table 1 shows the algorithms that were used for a comparison in this study include:

(a) The AXB algorithm, which considers the behavior of beam particles (neutrons, photons, electrons, etc.) by moving and communicating with the matter [12, 18].

(b) The AAA algorithm is a measurement-based algorithm which shows the effect of variations in the path of the beam and the lenghth of the beam path [19].

(c) The PBC algorithm and its equivalent path length corrections are used to detect inconsistencies. Changes in the transmission of electrons and photons are not modeled. It worths to note that some studies mentioned that PBC algorithm is a correction-based algorithm [20].

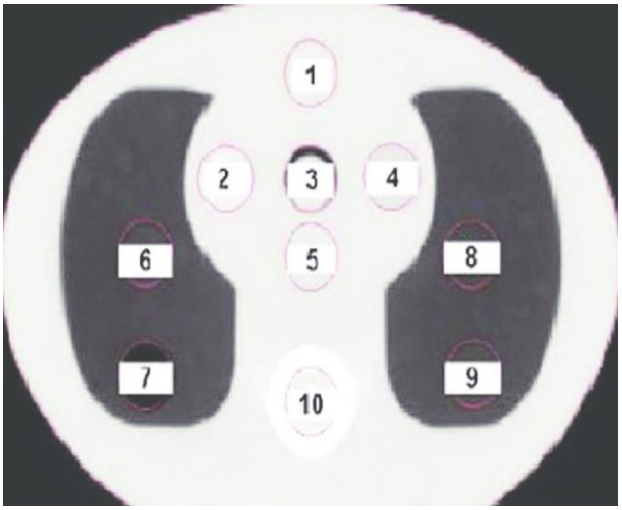

Figure 2. Position of measurement holds in CIRS phantom. Plugs number1,2,3,4 and 5 are tissue equivalent materials; plugs number 6, 7, 8, and 9 are lung substitute materials and plug number 10 is bone substitute material [21]

Table 1. TPS algorithms used in this study

TPS Vendor	Inhomogeneity Correction Algorithm	Version	Type of Accelerator	Nominal Energies (MV)
Varian ECLIPSE	Acuros XB	13	Varian Clinac 2100 C	6
	AAA	7.3.2.1		
	PBC	7.3.2.1		

2.4.Measurements

Measurements were performed using 6MV photon energy of Varian accelerator (Varian Medical Systems, Palo Alto). To mitigate randomize error, each measurement was performed 3 times. The ionization chamber type PTW30010 was used with an ionizing electrometer (PTW, Freiburg) to measure the dose. The chamber is located in the middle of the hole. The ionization chamber and electrometer have a traceable calibration from Iran's second standard dosimetry lab. Different correction factors (pressure and temperature effect, polarity and recombination effect etc.) according to the IAEA TRS 398 [22] protocol were considered in the dose measurement.

2.5.Analysis of the Results

To assess the measured (D_{meas}) and the calculated (D_{cal})values in the treatment planning systems , Equation 1 was utilized as follow :

$$Error\,[\%] = 100 \times \frac{[(D_{cal} - D_{meas})]}{D_{meas,ref}} \qquad (1)$$

Where D (meas,ref) is the measured dose value at the reference point. The test cases and their corresponding agreement criteria that were used in this particular study are listed in Table 2. The basis of our selection was based on the test cases that are checking effect of tissue heterogeneities (e.g., lung and bone).

Table 2. Description of test cases and their corresponding agreement criteria, that were used in this study

Description of Test Cases	Test Case No.	Test Purpose	Ref. Point	Meas. Point	Agreement Criteria (%)
Technique: Standard SSD 100 cm ,10×10 cm^2 field size, collimator and gantry 0°, Deliver 2 Gy to point 3	1	Confirmation of basic beam data	3	3 9 10 5	2 4 3 F1:0° 2 F2:90° 3 F3:180° 3 F4:270° 3 Σ 3
Technique: SAD with isocenter at point 5. AP field(10×15 cm^2, Gantry 0°), Left Lat field (8×15 cm^2, Gantry 90°), PA field (10×15 cm^2, Gantry 180°), Right Lat field (8×15 cm^2, Gantry 270°). Deliver 2Gy to point 5	4	Four field box	5	6 10	F1:0° 4 F2:90° 3 F3:180° 4 F4:270° 3 Σ 3 F1:0° 3 F2:90° 4 F3:180° 3 F4:270° 4 Σ 3
Technique: SAD with isocenter at point 5. Field size 10×20 cm^2 with a block 6×12 cm^2 blocking central axis. Gantry 45°. Coll 0°. Deliver 2 Gy at point 3	6	L-shaped fields with oblique incidence	3	3 7 10	3 5 5

3. Results

The results for all cases are within criteria levels when the measured point was located at homogenous part of the phantom. However, the greatest differences were seen in inhomogeneous parts of the phantom. Therefore, the resuts in the bone and lung materials are reported here. Table 3 shows the results of algorithms calculations in the heterogeneous parts.

Table 3. Difference (%) between calculated dose by an algorithm and measured dose in the cases that the points were located in the heterogeneous (as lung and bone) part of the phantom

Test Cases in Heterogeneous (as Lung) Part						
Algorithm	Case 1(point 9)		Case 4(point 6)		Case 6(point 7)	
AXB	%1.0	Pass	%2.2	Pass	%0.2	Pass
AAA	%8.9	Fail	%6.0	Fail	%5.0	Fail
PBC	%9.6	Fail	%16.1	Fail	%13.2	Fail

Test Cases in Heterogeneous (as Bone) Part						
Algorithm	Case 1 (point 10)		Case 4 (point 10)		Case 6 (point 10)	
AXB	%2.5	Pass	%2.2	Pass	%2.3	Pass
AAA	%1.1	Pass	%1.0	Pass	%0.3	Pass
PBC	%0.0	Pass	%0.7	Pass	%3.4	Pass

As it is seen, the AXB algorithm were passed all tests successfully. However, the AAA and PBC algorithms show larger deviations, especially for points located at equivalent lung material (up to 16.1%).

The test case #4 has three measurement points: (1) at the isocenter in the plastic water (point 5); (2) in equivalent lung material in the central axis of the beams (point 6); and (3) in equivalent bone materials in the central axis vertical beams (point 10). According to the table 3, at point (6), the largest deviations in the lung were obtained %2.2, %8.9, %16.1 for AXB, AAA, PBC algorithms, respectively. This deviation decreases by increasing the depth. The least deviations in the equivalent lung material were % 0.2, %5, %9.6 for AXB, AAA, and PBC algorithms, respectively. However, the results for bone material were better (in criateria agreement) for all algorithms.

The results of AXB algorithm were in good agreement with dose measurements in both equivalent lung and bone materials (Table 3), while, the AAA algoithm failed in the lung equivalent materials, with the maximum difference of 8.9% .

The greatest deviation (16.1%) in this study is regard to point #6 in the case #4 when the Gantry was 270 degree for the PBC algorithm.

4. Discussion

The accuracy of dose calculations of algorithm is one of the most important characteristic of the TPS. Therefore, understanding the limitations of the algorithm is important for the experiments. In this study, the comparison of the dose by different algorithms were performed using the TEC-DOC 1583 IAEA protocol.

There are several differences between AXB and AAA algorithms as: 1) The Acuros XB calculation grid voxel size can range from 1 to 3 mm. AAA in our TPS version supports a voxel size range between 2.5 and 5 mm.; 2) in AXB the majority of the calculation time is spent for the scattered photon and electron fluence calculations; 3) in AAA CT-curve is used to covert HU to electron density while for AXB algorithm the mass density should be assigned to each voxel based on a hard coded look up table stored in the Varian system database. The results of this study indicate that advanced dose calculation algorithms such as AAA, routinely available in EclipseTM TPS show improved accuracy compared to

the previous PBC algorithms, but significant errors still persist at the lung/soft tissue interface. While AXB algorithm recently introduced by Varian Co. iteratively solves the Linear Boltzman Transport Equation and has been demonstrated to show equivalent accuracy to Monte Carlo calculations in heterogeneous media (within about 2%).

The results of our study are consistent with the results of Muralidhar et al. [23], Vanderestraeten *et al.* [24], Asparadakis *et al.* [25] and Kavousi *et al.* [26]

5. Conclusion

The methodology described in IAEA TECDOC 1583 [16] was used to compare three different heterogeneous correction algorithms in EclipseTM TPS. The difference between the calculated and the measured dose is presented. To conclude, the AXB algorithm is suggested for more precise dose calculations in lung/soft tissue or bone/soft tissue interfaces, especially for head and neck cancer treatment.

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