Introduction

External beam radiation therapy (EBRT) is one of the most commonly used methods for cancer treatment in which ionizing radiation is used in an attempt to kill the malignant tumor cells and slow down their growths. It is essential that the prescribed dose be delivered to the tumor with high accuracy. This is because under-dosage may not kill all the cancer cells and over-dosage can harm the surrounding healthy tissue more than necessary, which could lead to unwanted side effects.

During EBRT treatment, the photon beam passes through different tissue densities within the patient’s body before it reaches the target. Therefore, beam characteristics along a heterogeneous path will be different and dose calculation algorithms must incorporate heterogeneity corrections.\[1,2\] American Association of Physicists in Medicine, Task Group 65 (AAPM, TG 65) recognized that properly accounting for tissue heterogeneity “is an essential component of dose optimization and the objective analysis of clinical results, especially with the advent of 3D precision conformal radiotherapy and the extension of IMRT treatments to structures that have not been irradiated before”.\[2\]

Previous studies on the effects of low density inhomogeneities on dose calculations were mostly focused on within lung equivalent materials or near lung/tissue interface or at selected depths beyond the low density heterogeneity interface. The purpose of this study was to investigate the ability of Pencil Beam Convolution (PBC) algorithm and Anisotropic Analytical Algorithm (AAA) to calculate the dose in deep-seated water equivalent tissue beyond high density heterogeneity interface. The data computed by AAA and PBC were compared against the measurements.

Materials and Methods

This study was done in a scenario assuming that tumor is located 20 cm deep inside the human body and 6 MV photon beam travels through soft tissue followed by lung, soft tissue, and rib/bone before reaching the tumor. The dose calculations were performed in the Eclipse treatment planning system (TPS), version 8.6.15 (Varian Medical Systems, Palo Alto, CA).

Depth dose calculations

The phantom A (30 × 30 cm², 20 cm deep) and phantom B (30 × 30 cm², 30 cm deep) were created as 3D CT...
structure sets in the Eclipse TPS. Each phantom was defined as the body structure (CT number = 0) in order to calculate the dose. Before the dose computation, rectangular slabs (30 × 30 cm²) of solid water (density = 1.0 g/cm³), Poly Vinyl Chloride (PVC) (density = 1.6 g/cm³), and Styrofoam (density = 1.2 × 10⁻³ g/cm³) were scanned using GE Light Speed CT Scanner and their CT numbers were confirmed equivalent to water, bone, and air, respectively. The phantoms’ layers consisting of solid water, Styrofoam and PVC were assigned with CT numbers of 0, -990 and +1200, respectively. All dose calculations in this study utilized 6 MV photon beam of Varian Trilogy linear accelerator (Varian Medical Systems, Palo Alto, CA) and source to surface distance (SSD) was set to 100 cm [Figure 1]. Furthermore, the dose for 100 Monitor Units (MUs) was calculated by AAA and PBC and 2.5 mm calculation grid size was used for all cases.

First, depth doses at an interval of 1 cm along the central axis of homogeneous medium (phantom A) were calculated for field size 10 × 10 cm². Second, for heterogeneous media (phantom B), dose calculations were done for 5 × 5, 10 × 10, and 20 × 20 cm² field sizes. Three points (P1, P2, and P3) were identified as points of interest in the water region and these points are labeled in Figure 1. The reason for selecting these three points was to investigate if the discrepancies between the measured and calculated doses were consistent at all selected measurement points in phantom B. The AAA’s values had better agreement with the measurements at all three points of interest (P1, P2, and P3) than that of PBC, and this was true for all three test field sizes. However, at the given point of interest, the discrepancy between calculated (AAA and PBC) and measured doses was dependent on the field size. For example, at P1, the percent dose differences increased from 1.5 to 5.3 for AAA and from 3.7 to 6.7 for PBC as the field size increased from 5 × 5 cm² to 20 × 20 cm². This trend of increased percent dose difference as a function of field size was observed at P2 and P3 as well [Table 1 and Figure 3]. The three measurement points receive lateral scatter from the PVC and solid water materials placed above them and there is a lateral scatter loss in the air region too. Thus, improper beam modeling within algorithms while accounting scatter contribution to the measurement points may have contributed to these dose discrepancies.

For a given field size, both algorithms exhibited maximum (AAA: Range, 1.5-5.3% and PBC: Range, 3.7-6.7%) and minimum (AAA: Range, 0.1-3.6%) and

\[
\text{Dose}_{\text{Depth } X} = \left( \frac{100}{R_{\text{avg}@1.5\text{cm}}} \right) \times R_{\text{avg}@\text{Depth } X} \quad (1)
\]

where, Depth X is a depth at X cm along the central axis of the phantom.

All measured doses were normalized to known dose at the dmax of 1.5 cm, and the measured percent depth doses were compared against the calculated percent depth doses (AAA and PBC).

**Results**

The benchmark test for the cylindrical ionization chamber using the central axis percent depth dose comparison in homogenous medium is shown in the Figure 2. The agreement between the measured and calculated (AAA and PBC) doses was obtained within ± 1%. This test confirmed that the cylindrical ionization chamber could be used for measurements in inhomogeneous phantom B.

Table 1 shows the percent depth dose data and the percent difference between the measured and calculated data for selected measurement points in phantom B. The AAA’s values had better agreement with the measurements at all three points of interest (P1, P2, and P3) than that of PBC, and this was true for all three test field sizes. However, at the given point of interest, the discrepancy between calculated (AAA and PBC) and measured doses was dependent on the field size. For example, at P1, the percent dose differences increased from 1.5 to 5.3 for AAA and from 3.7 to 6.7 for PBC as the field size increased from 5 × 5 cm² to 20 × 20 cm². This trend of increased percent dose difference as a function of field size was observed at P2 and P3 as well [Table 1 and Figure 3]. The three measurement points receive lateral scatter from the PVC and solid water materials placed above them and there is a lateral scatter loss in the air region too. Thus, improper beam modeling within algorithms while accounting scatter contribution to the measurement points may have contributed to these dose discrepancies.
Table 1: The measured and calculated (Anisotropic analytical algorithm and Pencil beam convolution) central axis percent depth doses at P1, P2, and P3 beyond high density heterogeneity interface for field sizes 5 × 5, 10 × 10, and 20 × 20 cm² (top to bottom) are compared. P1, P2, and P3 are points of interest at depths of 21, 22, and 23 cm, respectively in phantom B [Figure 1]. The measured as well as calculated doses were normalized to the dose of maximum (dmax) reading obtained at 1.5 cm depth. (6 MV photon beam, 100 cm source to surface distance to the surface of phantom)

| Field size | Measurement | AAA | PBC |
|------------|-------------|-----|-----|
| 5 × 5 cm²  | 35.6        | 36.1| 1.5 | 36.9| 3.7 |
| P1         |             |     |     |     |     |
| P2         | 33.7        | 33.9| 0.6 | 34.6| 2.7 |
| P3         | 31.8        | 31.9| 0.3 | 32.5| 2.2 |
| Field size | 10 × 10 cm² | 38.7| 40.0| 1.9 | 40.8| 5.4 |
| P1         | 37.0        | 37.6| 1.6 | 38.4| 3.8 |
| P2         | 35.2        | 35.5| 0.9 | 36.3| 3.1 |
| P3         | 42.0        | 44.2| 5.3 | 44.8| 6.7 |
| Field size | 20 × 20 cm² | 39.8| 41.6| 4.8 | 42.6| 6.3 |
| P1         | 38.1        | 39.5| 3.7 | 40.3| 5.8 |
| P2         |             |     |     |     |     |
| P3         |             |     |     |     |     |

AAA = Anisotropic analytical algorithm, PBC = Pencil beam convolution algorithm

PBC: Range, 1.9-5.7%) dose discrepancies at P1 and P3, respectively. The dose discrepancies were more pronounced as the measurement point was closer to the high-density heterogeneity interface [Figure 3]. As the photon beam is hardened when it traverses high density medium (PVC), the removal of low energy photons from the photon beam causes increased number of ionizations in the PVC, and this phenomenon leads to increase in the depth dose downstream. Thus, higher dose overestimation at P1 was probably due to improper modeling of the altered primary beam attenuation and scatter contribution to water-equivalent material beyond high-density medium.

Discussions

Dose calculations for EBRT present challenges especially when photon beam travels through tissues with different densities such as lung, soft tissue, and bony anatomy. The accurate modeling of primary beam attenuation and lateral scatter due to presence of different media heterogeneities along the beam path is essential to prevent from dose overestimation or underestimation.

The results from phantom A indicated that PBC and AAA could predict the doses in good agreement with the measurements in homogenous medium where heterogeneity correction is not necessary. However, results from phantom B showed the limited accuracy of PBC and AAA in heterogeneous media and similar observations were reported by other authors.²⁻⁸ Moreover, PBC and AAA have different approach of beam modeling to account the heterogeneities, and brief descriptions of both algorithms are presented below. For complete understanding on PBC and AAA, readers are advised to refer to papers authored by Carrasco et al.⁷ and Van Esch et al.⁸

The PBC involves the calculation of dose distribution in infinitesimally narrow pencil beams (directed along a ray line from the beam source),¹⁰ and dose deposition kernels or pencil kernels are derived from measured water data.¹¹⁻¹² The corrections to each pencil beam are obtained by a correction factor to account for differences in attenuation.¹³⁻¹⁴ The heterogeneity correction (modified Batho method) in PBC algorithm takes the position of the inhomogeneity with respect to the point of calculation into account.¹³ However, the dose from the adjacent pencil beams is not considered in each calculation, which can lead to errors in determination of dose in tissues that are within areas of large inhomogeneity. The effect is a heterogeneity correction only in the beam path direction, but not in lateral direction.¹³⁻¹⁴ The beams in AAA include separately modeled contributions from different photon sources.¹³⁻¹⁵ The total energy deposited by each beam is obtained by the convolution of the separately modeled contributions of different photon sources and final dose is calculated by the superposition of the contributions from the beams.¹³ The tissue heterogeneity in AAA is handled by radiologic scaling of primary photons and photon scatter kernel scaling in lateral directions according to local electron density.¹⁵

Although we were unable to make direct comparisons of our findings against previous studies on AAA and PBC due to variability in experimental set ups and difference in phantom geometries, it is relevant to mention the work of Gray et al.¹² who investigated the accuracy of AAA...
and PBC in heterogeneous media. Gray et al.\textsuperscript{12} reported that results from AAA were better than those calculated by the PBC but dose overestimation greater than 2.5% could still result when using AAA to calculate the dose beyond a large air gap. Robinson et al.\textsuperscript{13} investigated the dose on the central beam axis at a vertical depth of 3 cm below the proximal surface of the heterogeneity layer of 2-10 cm air gap. Robinson reported that the AAA algorithm tends to overestimate dose beyond low density heterogeneities. This overestimation is shown to be, on average, 3% at distances less than 10 cm and up to 7% at distances greater than 10 cm. Van Esch et al.\textsuperscript{1} confirmed these results as his group investigated the depth dose within a phantom consisting of 5 cm solid water, 15 cm cork, then 10 cm solid water for a variety of field sizes $3 \times 3$ cm to $20 \times 20$ cm$^2$. Their results showed that the AAA overestimated the dose by up to 7% beyond the cork slab. The error in the AAA and PBC doses calculated beyond bony material may also occur in other clinical situations such as when the treatment beam passes through low density material (e.g., polyurethane foam) in the immobilization device prior to entering the patient and then finally reaching the tumor situated next to the bone. The errors (up to 5.3% for AAA and up to 6.7% for PBC) found in this study could potentially increase as suggested by the results in studies of Robinson et al.\textsuperscript{13} and Gray et al.\textsuperscript{12} that dose discrepancies beyond air gaps are also dependent on the size of the air gaps. Future work involves the measurements to investigate how different thickness of Styrofoam (air-equivalent material) as well as PVC tile (bone-equivalent material) would affect the dose estimation by AAA and PBC at the selected points of interest.

**Conclusions**

The ability of AAA and PBC to account for heterogeneities was investigated using five-layer heterogeneous phantom that had combination of low and high density materials. The results of AAA had better agreement with the measurements at selected depths in this study. The dose overestimation by AAA (up to 5.3%) and by PBC (up to 6.7%) was found to be higher nearby the high-density heterogeneity interface, and the dose discrepancies were more pronounced for larger field sizes. The finding of this study suggests that the AAA is more accurate than PBC for dose calculations in treating the target seated beyond high-density heterogeneity interface at deeper depths.

**Acknowledgment**

The author would like to thank Kevin Rogers at Arizona Center for Cancer Care for his support during the course of this project.

**References**

1. Fraassa B. Quality assurance for clinical radiotherapy treatment planning. AAPM Report No. 62; Task Group No. 53, 1998.
2. Papanikolaou N, Battista J, Mackie T, Kappas C, Boyer A. Tissue inhomogeneity corrections for megavoltage photon beams. AAPM Report No 85; Task Group No. 65, 2004.
3. Robinson D. Inhomogeneity correction and the analytic anisotropic algorithm. J Appl Clin Med Phys 2008;9:112-22.
4. Wong T, Metcalfe P, Kron T, Emeleus T. Radiotherapy x-ray dose distribution beyond air cavities. Australas Phys Eng Sci Med 1992;15:138-46.
5. Plessis F, Willemsse C, Lotter M, Goedhals L. Comparison of the Batho, ETAR and Monte Carlo dose calculation methods in CT based patient models. Med Phys 2001;28:582-9.
6. Ding W, Johnston P, Wong T, Bubb I. Investigation of photon beam models in heterogeneous media of modern radiotherapy. Australas Phys Eng Sci Med 2004;27:39-48.
7. Carrasco P, Jornet N, Duch M, Weber L, Ginjaume M, Eudaldo T, et al. Comparison of dose calculation algorithms in phantoms with lung equivalent heterogeneities under conditions of lateral electronic disequilibrium. Med Phys 2004;31:2899-911.
8. Van Esch A, Tillikainen L, Pyykonen J, Tenhunen M, Helminen H, Siljamäki S, et al. Testing of the analytical anisotropic algorithm for photon dose calculation. Med Phys 2006;33:4130-48.
9. Breitman K, Rathee S, Newcomb C, Murray B, Robinson D, Field C, et al. Experimental validation of the eclipse AAA Algorithm. J Appl Clin Med Phys 2007;2:76-92.
10. Storchi P, Van Battum L, Woudstra E. Calculation of a pencil beam kernel from measured photon beam data. Phys Med Biol 1999;44:2917-28.
11. Mohan R, Chui C, Lidofsky L. Differential pencil beam dose...
computation model for photons. Med Phys 1986;13:64-73.
12. Gray A, Oliver L, Johnson P. The accuracy of the pencil beam convolution and anisotropic analytical algorithms in predicting the dose effects due to the attenuation from immobilization devices and large air gaps. Med Phys 2009;36:3181-91.
13. Hurkmans C, Knoos T, Nilsson P, Svahn-Tapper G, Danielsson H. Limitations of a Pencil Beam approach to photon dose calculations in the head and neck region. Radiother Oncol 1995;37:74-80.
14. Sontag M, Cunningham J. Corrections to absorbed dose calculations for tissue inhomogeneities. Med Phys 1977;4:431-6.
15. Storchi P, Woudstra E. Calculation of the absorbed dose distribution due to irregularly shaped photon beams using pencil beam kernels derived from basic beam data. Phys Med Biol 1996;41:637-56.

How to cite this article: Rana SB. Dose prediction accuracy of anisotropic analytical algorithm and pencil beam convolution algorithm beyond high density heterogeneity interface. South Asian J Cancer 2013;2:26-30.

Source of Support: Nil. Conflict of Interest: None declared.

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