Comparison of 3DCRT Dose Distribution in Radiotherapy for Lung Cancer Patient by Using AAA and PBC Algorithms

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Abstract. The Pencil Beam Convolution (PBC) algorithm in radiation treatment planning system is widely used to calculate the radiation dose distribution in radiotherapy planning. A new photon dose calculation algorithm known as Anisotropic Analytical Algorithm (AAA) by Varian Medical Systems is applied to investigate the difference of dose distribution by using AAA and PBC algorithms for the lung cancer with an inhomogeneity of its low density. In the present work, radiotherapy treatment planning of 10 lung cancer patients are designed with 6 MV photon beam using three-dimensional conformal radiation therapy (3DCRT) and dose distribution was calculated by the AAA and the PBC Algorithms. The dose distribution performance is evaluated by dose profile curve along transversal slice of PTV and Dose Volume Histogram (DVH) covered by the 95% isodose of PTV. The mean dose of organ at risks did not changed significantly but the volume of the PTV covered by the 95% isodose curve was decreased by 6% with inhomogeneity due to the algorithms. The dose distribution and the accuracy in calculating the absorbed dose of the AAA algorithm of the Varian Eclipse treatment planning system is analyzed and discussed.

Introduction

In radiotherapy, maximum control of tumors with minimum of complications to the normal tissues depends on various factors especially on the accuracy of absorbed dose deliver [1] to the tumor. Since 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 [2]. In clinical data consideration lead to generally agreed recommendations on the required accuracy in clinical dosimetry for radical curative being given in ICRU report-24 (1976) for at least accuracy of $\pm 5\%$ in the delivery of absorbed dose to the target volume of the treatment tumor [3-4]. Brahme [5] also proposed a tolerance value of accuracy in dose delivery of $\pm 3.5\%$ at one standard deviation level. In radiobiology, the dose response relationship for tumor cell killing follow the sigmoidal curves at high dose which implies that the tumor control can only achieve with a very high precisional dose delivery.

In recent years, the increased sophistication of treatment techniques and delivery methods, the accuracy of highly conformal radiotherapy has improved rapidly with technological advances. This leads the demands on modern treatment techniques require better modeling of treatment beams and more sophisticated modeling in the presence of in homogeneities in order to assure the accuracy in the calculation of dose distribution. In order to achieve such accuracy, the uncertainties in all stages of the radiotherapy process, such as dosimetry, simulation and planning to the treatment delivery, must be reduced as far as possible. The introduction of increasingly complex treatment techniques

and the possibility for delivering higher doses in radiotherapy treatments has reinforced the requirement for accuracy in dose calculation algorithms. Historically, one of the most serious weaknesses in treatment planning systems has been their ability to accurately predict doses in the presence of inhomogeneities, particularly through poor consideration of electron transport [6].

Radiotherapy treatment planning is generally performed on dedicated computers using specialized treatment planning software. Dose calculation algorithms are the most critical software component in a computerized Treatment Planning System (TPS). Different algorithms are applied in different commercial treatment planning systems e.g., Elekta XiO: Clarkson, FFT Convolution, Multigrid Convolution, Superposition, Fast Superposition; for Phillips Pinnacle: Collapsed Cone Convolution, Pencil Beam and for Varian Eclipse: Anisotropic Analytical Algorithm, Pencil Beam Algorithm etc. The PBC algorithm is most common that implemented in the TPS Eclipse version 8.0.05 (Varian Medical Systems), uses experimental measurements as part of the beam configuration [7]. The study for the accuracy of recent developed AAA algorithm is compared with Eclipse's Pencil Beam Convolution (PBC) algorithm by many authors [8-11] compared Monte Carlo (MC) simulation which was considered as gold standard in dose calculation. E. Sterpin et al. [12] have studied the accuracy of AAA algorithm against MC and compared with IMRT plans in presence of inhomogeneous tissue. Bragg et al. [6] compared AAA to the PBC algorithm and was not found any significant values of quality compared to IMRT treatments plans for prostate, parotid or nasopharynx while in case accurate modeling of lateral electron transport demonstrates there found a significant increases in the volume of PTV being under dosed in IMRT non-small cell lung cancer (NSCLC) treatments plans reported. The most recent studies of AAA and PBC algorithm was studied by Antonella Bufacchi et al. [9] for prostate and lung cancer planning in combination with NTCP (Normal Tissue Complication Probability) parameters that varied by 12.8% and 4.5% respectively between the algorithms. The large variation implies that a more detail studies of AAA algorithm in case of inhomogeneous tissues is highly required. The aim of this study was to evaluate differences in dose distributions in therapy treatment plans of lung tumors calculated with pencil beam convolution (PBC) algorithm and anisotropic analytical algorithm (AAA) of the Varian Eclipse treatment planning system. Beam profile and dose volume histogram (DVH) were used to get the performance of dose distribution using both AAA and PBC algorithms.

This research work is performed with newly installed linear Accelerator (Clinac DHX, SN: 5550, Varian Medical Systems) of National Institute of Cancer Research and Hospital (NICRH), Dhaka, Bangladesh having a TPS (Varian Eclipse, platform: 10.0) provision for using AAA (version: 10.0.28) and PBC (version: 10.0.28) calculation algorithms.

Materials and Methods

The AAA is a three-dimensional (3D) pencil beam convolution/superposition algorithm that uses Monte Carlo derived kernels. Since the majority of the convolution operators appearing in the mathematical formalism can be converted into analytical expressions (which significantly reduce the computational time) the 'analytical' property was added to the algorithm name. The AAA was originally conceived by Ulmer *et al.* (Ulmer and Harder 1995, 1996) [13-14] and Kaissl *et al.* (Ulmer and Kaissl 2003) [15]. The AAA accounts for tissue heterogeneity anisotropically in the entire three-dimensional neighborhood of an interaction site using photon scatter kernels in multiple lateral directions. The final dose distribution is obtained by the superposition of photon and electron convolutions.

The pencil beam kernel (K) represents the absorbed dose distribution in the water phantom at standard SPD , resulting from a very small circular photon beam (2.5 mm diameter) and convolution. Convolution is done by summing a number of pencil beams, each weighted with the field intensity to obtain the total dose contribution. The PBC model generates the dose distribution matrix by convolution of pencil-beam kernels with a non-uniform field function; the pencil-beam kernels are derived from open-beam measurements. 10 lung cancer patients were performed with three dimensional conformal radiation therapy (3DCRT) on the AAA and PBC algorithms clinically. To compare the dose distribution according to the algorithms, we used the Anisotropic Analytical

Algorithm (version 10.0.28) and the Pencil Beam Convolution (version 10.0.28) by Eclipse treatment planning system (Platform: 10) in Varian Medical Systems.

The images of thorax region all of the lung cancer patients taken by Brilliance Big Bore CT Simulator (Philips) and all the images were imported into Eclipse TPS of LINAC (Clinac DHX, SN: 5550, Varian Medical Systems) system. The 3D patient body was made using the imported images. Gross Tumour Volume (GTV), Clinical Target Volume (CTV), Planning Target Volume (PTV) and all Organ AT Risks (OAR) e.g. heart, lung etc. were contoured by hospital oncologist in all axial images according to standard contouring protocol (Fig: 1). All treatment plans were completed by using three dimensional conformal radiation therapy technique (3DCRT).

Fig. 1. (a) shows imported CT image for TPS planning. Figure (b) shows contoured structures, GTV- pink, PTV- red, Heart – blue and Spinal cord – Cyan

A linear accelerator (Clinac DHX, SN: 5550, Varian Medical Systems) was assigned to all of the plans and five fields with different angles were used for the treatment plans with a Source to Axis Distance (SAD) of 100 cm (such as Fig: 2) with a 6 MV photon energy. Multi Leaf Collimator (MLC) were also used to make costume irregular treatment field. To get a homogeneous dose distribution different angle Enhancement Dynamic Wedges (EDW) were used in all of plan. The prescribed dose was set to 6000 cGy to the planning target volume at 200 cGy per fraction for each plan.

Fig. 2. Shows 3DCRT planning with 5 fields ($14 \times 14 \text{ cm}^2$, $14 \times 14 \text{ cm}^2$, $14 \times 14 \text{ cm}^2$, $14 \times 15 \text{ cm}^2$ and $14 \times 15.2 \text{ cm}^2$) isocentric technique

All of the treatment plans were calculated by using AAA algorithm with 2.5 mm grid size. The treatment plans were copied and recalculated again by using PBC algorithm having same grid size. Beam profile was taken by scanning along transvers direction through central axis from right to left with additional 50% distance of the respective tumor width both for AAA and PBC by using Eclipse Beam Profile tool (Fig: 3). Same procedure was applied to all the plans. All data convert to text file for comparison.

Fig. 3. Figure shows profile and point dose for a 3DCRT isocentric technique lung cancer patient treated with 5 fields for AAA.

By taking 95% isodose curve of the Planning Target Volume (PTV) and using Dose Volume Histogram (DVH) the performance of the dose distribution to the PTV and the organs at risk both for AAA and PBC algorithms were evaluated. Same procedure was applied to all the plans.

Results and Discussion

The treatment plan calculated with the AAA (105.1%) for the lung cancer patient has a lower absolute dose maximum in this transversal slice with about 10% compared to the PBC (115%) but approximately at the same location shown in Fig 4(a) and 4(b) because the AAA takes into account the lower amount of scattered radiation from the low density lung which the PBC doesn't.

Fig. 4. Isodoses for the lung cancer patient calculated with the AAA and PBC through a transversal slice at dose absolute maximum. PTV is drawn in the image and 3DCRT treatment using 5 fields.

From the 95% isodose curves, the dose difference from the two algorithms was significantly larger in the inhomogeneous lung such as the low electron density. From (Fig 5) the profiles through the tumour in the lung the PBC algorithm overestimate the absorbed dose compare to the AAA algorithm. Since the PBC overestimates the amount of scattered radiation from the low-density lung tissue therefore, the absorbed dose calculated by PBC algorithm is higher.

Fig. 5. Isodoses for the lung cancer patient calculated with the AAA and PBC through a transversal slice at dose absolute maximum. PTV is drawn in the image and 3DCRT treatment using 5 fields.

In addition, from the Table 1, it is seen that in the profiles, lung tumour dose maximum (D_{max}) by using the AAA algorithm is approximately average 10.3% lower than the PBC algorithm.

Table 1 Absolute dose maximum both for calculated AAA & PBC of lung cancer patients.

Case no	AAA(D_{max}) (%)	PBC(D_{max}) (%)	PBC(D_{max}) - AAA(D_{max}) (%)
1	105.10	115.0	9.9
2	104.50	115.2	10.7
3	106.00	113.0	7.0
4	104.00	116.0	12.0
5	103.00	115.0	12.0
6	101.00	112.0	11.0
7	105.00	115.0	10.0
8	102.00	111.0	9.0
9	107.00	116.0	9.0
10	106.00	118.0	12.0
Average	104.36%	114.6%	10.3%

The DVH shows that dose calculation by using AAA algorithm gives a lower absorbed dose to the PTV compare to the PBC (Fig 6).

Fig. 6. DVH for a lung cancer patient treated with ($14 \times 14 \text{ cm}^2$, $14 \times 14 \text{ cm}^2$, $14 \times 14 \text{ cm}^2$, $14 \times 15 \text{ cm}^2$ and $14 \times 15.2 \text{ cm}^2$) fields showing the dose distribution for PTV both for the AAA and the PBC.

The organs at risk did not changed significantly but the volume of the PTV covered by the 95% isodose curve was decreased by average 6.09% due to performance AAA of algorithm. That means, the mean dose calculated by using AAA algorithm was average 6080.3 cGy. Whilst the mean dose calculated by the PBC algorithm was average 6445.76 cGy given in Table 2.

Table 2 The AAA and PBC calculated mean dose (cGy) of the PTV from DVH covered by the 95% isodose.

Case no	AAA(PTV _{min})	PBC(PTV _{min})	PBC(PTV _{min}) - AAA(PTV _{min})	(%) decreased by AAA
1	6081.5	6447.3	365.8	6.10
2	6082.6	6446.2	363.6	6.06
3	6080.4	6448.1	367.7	6.13
4	6083.5	6448.5	365	6.08
5	6085	6449.5	364.5	6.08
6	6081	6447.5	366.5	6.11
7	6082	6446.5	364.5	6.08
8	6080	6443	363	6.05
9	6079	6442.5	363.5	6.06
10	6068	6438.5	370.5	6.18
Average	6080.3	6445.76	365.46	6.09

Conclusion

In this study, we have tried to investigate possible clinical data for dose distribution and absorbed dose in 3DCRT treatment planning for lung cancer by using PBC and AAA algorithm. The differences between the two algorithm shows a significant value of dose variation in inhomogeneity case which implies more investigation requires to conduct the verification of AAA and PBC to compare both in experimentally and MC simulation method. It could be concluded here that the dose distribution and the accuracy in calculating the absorbed dose of the AAA algorithm is better than the PBC algorithm.

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