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Effect of Calculation Grid Size on Plan Calculation for Anisotropic Analytical Algorithm and Acuros XB Algorithm in lung Stereotactic Body Radiotherapy

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Abstract: Background: The study aimed to determine the dose differences between Acuros XB (AXB) and Anisotropic Analytical Algorithm (AAA) in stereotactic body radiotherapy (SBRT) treatment for lung cancer and to investigate the dose-related effect of dose calculation grid size (CGS).
Methods. SBRT treatment was planned produced from the CT scan data of 15 patients suffering from stage I lung cancer, Clinically acceptable treatment plans with AAA were recalculated using AXB with the same monitor units (MU) and identical multileaf collimator (MLC) settings, using 1-mm and 2-mm and 3-mm CGS in the two algorithms to investigate their dosimetric affect. The Dose to planning target volumes (PTV) and organs at risk (OARs) between the two algorithms were compared. AAA and AXB algorithms with 6 MV flattening filter free (FFF) rays in Varian Trubeam STx.
Results: The dose to PTV predicted when AAA 1-mm CGS plans and AAA 2-mm and 3-mm CGS plans were compared, 2.73±1.62 % difference was observed; When AXB 1-mm CGS plans and AXB 2-mm and 3-mm CGS plans were compared, 1.36±1.21 % difference was found. No significant difference was found between plans with AAA 1-mm CGS and plans with AXB 1-mm CGS ($p>0.05$). On the other hand, there was a significant difference between plans with AAA 2, 3-mm and plans with AXB 2, 3-mm CGS ($p<0.05$).
Conclusion: As a result of the study, it was seen that the dose prediction for AXB algorithm are more stable results than the AAA in different intensity body regions, AXB principally predicts lower dose to PTV compared to AAA and the CGS contributes to the relative dose difference between the two algorithms. For SBRT, 1-mm CGS should be selected for calculation accuracy.

Keywords: Anisotropic analytical algorithm, acuros XB, calculation grid size.

1 Introduction

In advanced techniques in radiotherapy such as intensity modulated radiotherapy (IMRT) and volumetric modulated arc radiotherapy (VMAT), sharp dose drops can be achieved after the tumor volume, desired high doses are given to target volumes determined using different imaging techniques. In stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT), it is essential to give prescribed doses to target volumes with geometric uncertainty under the millimeter. In SRS/SBRT, high doses are administered in a small number of fractions. In these treatments, accuracy can be achieved using accurate calculation of the use of algorithm. In the treatment planning system of Eclipse 15.5 (Varian Medical Systems, Palo Alto, CA), the anisotropic analytical algorithm (AAA) is commonly used for dose calculation [1][2][3][4][5].

Recently, in the dosimetric study performed by many investigators, it has been reported that AAA calculated the calculated dose significantly inaccurate [6],[7]. Particularly, it has been observed that in the transition from tissue to air, dose is incorrectly calculated near two mediums. Varian (Varian Medical Systems, Palo Alto, CA) has introduced a new dose calculation algorithm called Acuros XB (AXB), a computational algorithm for clinical use.
AXB uses a sophisticated technique to solve the Linear Boltzmann Transport Equation (LBTE), and it provides the correct approach for calculating patient dose from heterogeneous sources entirely of lung, bone, air, and different density implants. LBTE describes the macroscopic behavior of the radiation beam in its environment [3-8].

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There are many studies in the literature that dosimetrically compared the AAA and AXB algorithms [8][9]. The dose difference between the two algorithms results from parameters such as energy of the incoming beam, field size, and electron density of the medium. However, studies have reported that the calculation grid size (CGS) is associated with dose changes. The difference between AAA and AXB due to different uses is not known to affect SBRT treatments, and this effect requires further investigation [8]. The dosimetric effect of AXB in the SBRT plan for lung cancer has little information on this. With advancing technological facilities, manufacturers of linear accelerator devices offer both flattened (FF) and unflattened (FFF) beams together. SBRT treatments can be applied to patients in a shorter time because of increasing dose rate due to FFF beams [10][11].

2 Materials and Methods

Eclipse Treatment Planning System

Eclipse TPS 15.5 (Varian, Palo Alto, California, USA) is designed to make 3DCRT, IMRT, VMAT, SRS/SBRT, and electron schemes. In the Eclipse treatment planning system in our clinic, pencil beam convolution and analytical anisotropic algorithm (AAA) are performed with dose volume optimization, plan geometry optimization, progressive resolution optimization, multi-resolution dose optimization (MRDC), and Acuros XB (AXB) dose calculation algorithms.

Analytical Anisotropic Algorithm (AAA)

The AAA dose calculation model is a 3D pencil beam and convolution superposition algorithm consisting of separate models for electrons emitted from primary photons, scattered photons, and beam modulators (primary collimator, beam straightening filter, and wedge filter).[10] The functional forms that form the
basic physical quantities initiate a process by adding device properties to the account. This often leads to a noticeable reduction in the computation required for
such algorithms. Tissue heterogeneities are anisotropically accounted for using photon scattering kernels in multiple lateral directions in a 3D neighborhood. The final dose distribution is formed by superimposing the photon- and electron-initiated process.

Acuros XB Algorithm

The AXB algorithm was developed for two strategic needs such as accuracy and speed in external photon beam treatment planning. AXB uses a sophisticated technique to solve the LBTE and fully exploits heterogeneity in patient mortality from lung, bone, air, and non-biological implants. Instead of Boltzman Transport Equation, which describes the macroscopic behavior of radiation particles?
LBTE, its linear form, assumes that the particles in the environment interact with each other and the external magnetic field.[2-4]There are two solution approaches that try to explain LBTE. One of them is the Monte Carlo method, which does not clearly solve the commonly known LBTE and produces indirect solutions for LBTE. Second one is solving LBTE using numerical methods. The source model of the AXB algorithm used in the Eclipse TPS uses the existing AAA source model. In this model; primary photons, out-of-focus photons, contaminant electrons, and photons scattered from the wedge. The AXB algorithm uses knowledge of the mass concentration obtained in the CT images of each voxel for dose calculation. The calculation difference between the AAA and AXB algorithms depends on the beam energy, field size, and material density.

CT scanning and contouring of organs at risk (OARs)

Scanning was acquired at a 3 mm slice thickness for both 3D and 4DCT. CT images were then transferred to Eclipse treatment planning system. For patients with conventional enhanced scanning, gross tumor volume (GTV) was contoured by an experienced radiation oncologist under the CT pulmonary windows, and the planning target volume (PTV) was acquired according to the tumor motion under fluoroscopic examination with the aid of a simulator. For patients with 4DCT scanning, GTV accounting for tumor motion on all 10 phases of the 4DCT were contoured in the same way. These 10 phases of the GTV were then combined to form the internal target volume (ITV). To account for set-up uncertainties and potential baseline tumor shift, PTV was expanded with a uniform 5 mm margin from ITV [11].

Varian TrueBeam STx Linear Accelerators

Varian TrueBeam STx is a radiotherapy device using 3D Conformal, IMRT, IGRT, VMAT, stereotactic radiosurgery (SRS), and stereotactic body radiotherapy
(SBRT). This linear accelerator is designed as a digital linear accelerator with 6 MV, 10 MV, 15 MV flattening filters (FF) and 6 MV and 10 MV flattening filter-free (FFF) beams. The dose range of filtered beams is 100-600 MU/min, 400-1400 MU/min for unfiltered 6 MV FFF beams, and 400–2400 MU/min for 10 MV FFF. The maximum area dimensions used for active MLC with minimum 0.5×0.5 cm and maximum 40×40 cm area dimensions are 22×40 cm.
15 patients has recruited with lung cancer who were treated and their CT data was used. Treatment plans were generated using the volumetric modulated arc (VMAT) SBRT planning method have been used two partial Arc angles with 6 MV FFF
beams. For each patient, six treatment planning were done using AAA and AXB algorithms using 1-mm ,2-mm and 3-mm calculation grid (CGS), respectively.

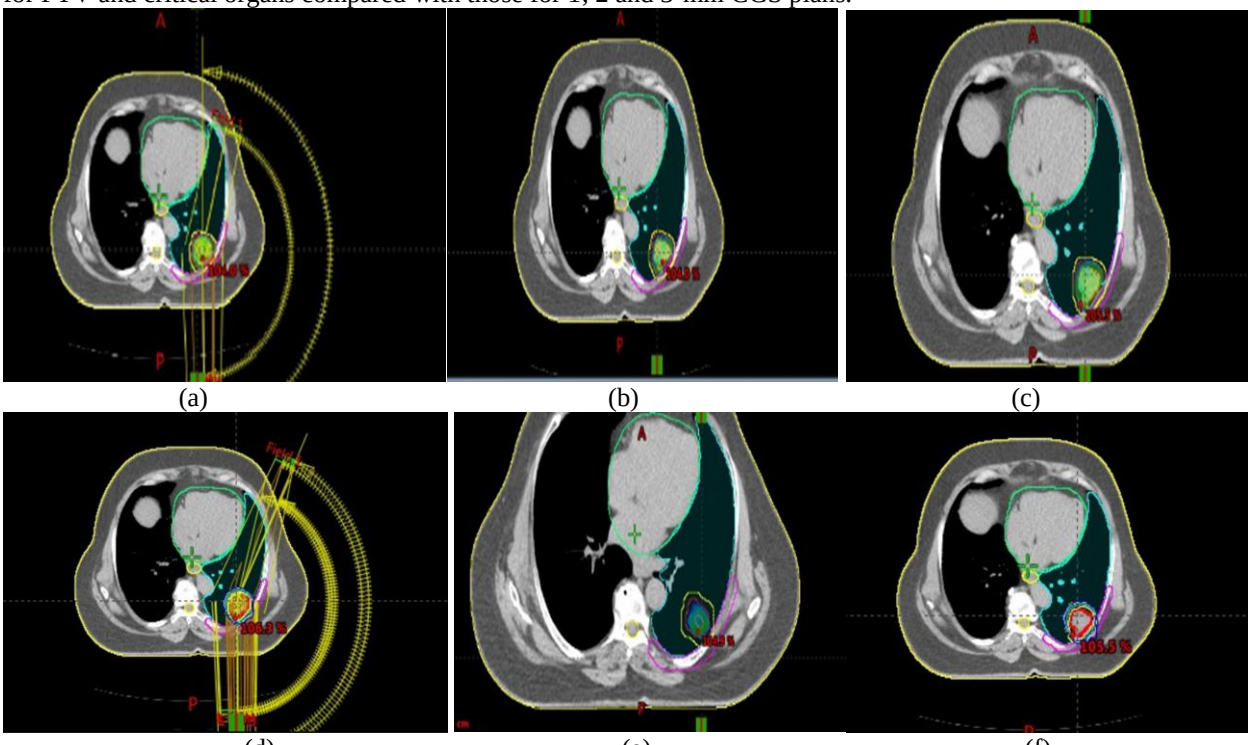
Results

The dosimetric results of our plans for SBRT planning for liver disease are shown in (Table 1). In Table 1, doses of PTV minimum, maximal, and Dmean, spinal
cord maximal dose, ipsilateral lung V5, V10, V20, and Dmean doses, bilateral kidney Dmean and small intestine Dmax doses were calculated for two AAA and AXB algorithms.

Table 1: Dose volume tables of PTV and critical organs calculated for grid size of 1, 2 and 3 mm with AAA and AXB algorithms.

Structure	Unite	AAA 3-mm	AXB 3-mm	AAA 2-mm	AXB 2-mm	AAA 1-mm	AXB 1-mm
PTV	D_{max}	55.5±6.4	54.3±2.6	55.3±6.7	54.5±2.7	56.2±6.1	54.4±2.5
	D_{mean}	47.2±5.1	46.5±3.4	47.5±5.4	46.2±3.2	48.4±5.6	46.4±3.3
	D_{min}	44.6±6.3	44.2±2.7	44.1±6.2	44.3±2.6	44.8±6.4	44.4±2.8
Spinel Cord	D_{max}	8.1±2,9	7.8±2.3	8.2±3.2	7.4±2.6	8.2±3.2	7.4±2.6
	D_{mean}	2.4±1.2	2.2±0.3	2.3±1.3	2.4±0.5	1.7±0.5	1.6±0.3
Esophagus	D_{max}	9.5±3.1	9.1±2.8	9.8±3.2	9.2±2.8	10.3±3.5	9.7±2.8
	D_{mean}	2.4±0.8	2.1±0.7	2.4±0.8	2.1±0.7	2.5±0.9	2.1±0.7
Ipsilateral lung	V5(%)	25.5±6.4	24.5±6.8	25.5±6.4	24.5±6.5	26.5±6.8	24.5±6.6
	V10(%)	15.1±5.5	15.0±4.4	15.1±5.5	15.0±4.2	15.1±5.5	15.0±4.3
	V20(%)	8.8±4.8	8.0±3.7	8.2±4.8	8.0±3.4	8.2±4.8	8.0±3.6
	D_{mean}(Gy)	6.5±1.2	6.3±1.1	6.5±1.2	6.3±1.1	6.5±1.2	6.3±1.2
contralateral	V5(%)	1.1±0.6	0.8±0.5	1.1±0.6	0.7±0.4	1.1±0.6	0.7±0.5
	D_{mean} (Gy)	0.9±0.5	1.0±0.4	0.9±0.5	1.1±0.3	0.9±0.5	1.1±0.4
Heart	D_{max}	16.0±9.6	15.8±9.1	16.1±9.6	15.8±9.3	16.1±9.6	15.8±9.3
	D_{mean} (Gy)	2.4±1.3	2.3±1.2	2.4±1.3	2.3±1.2	2.4±1.3	2.3±1.2

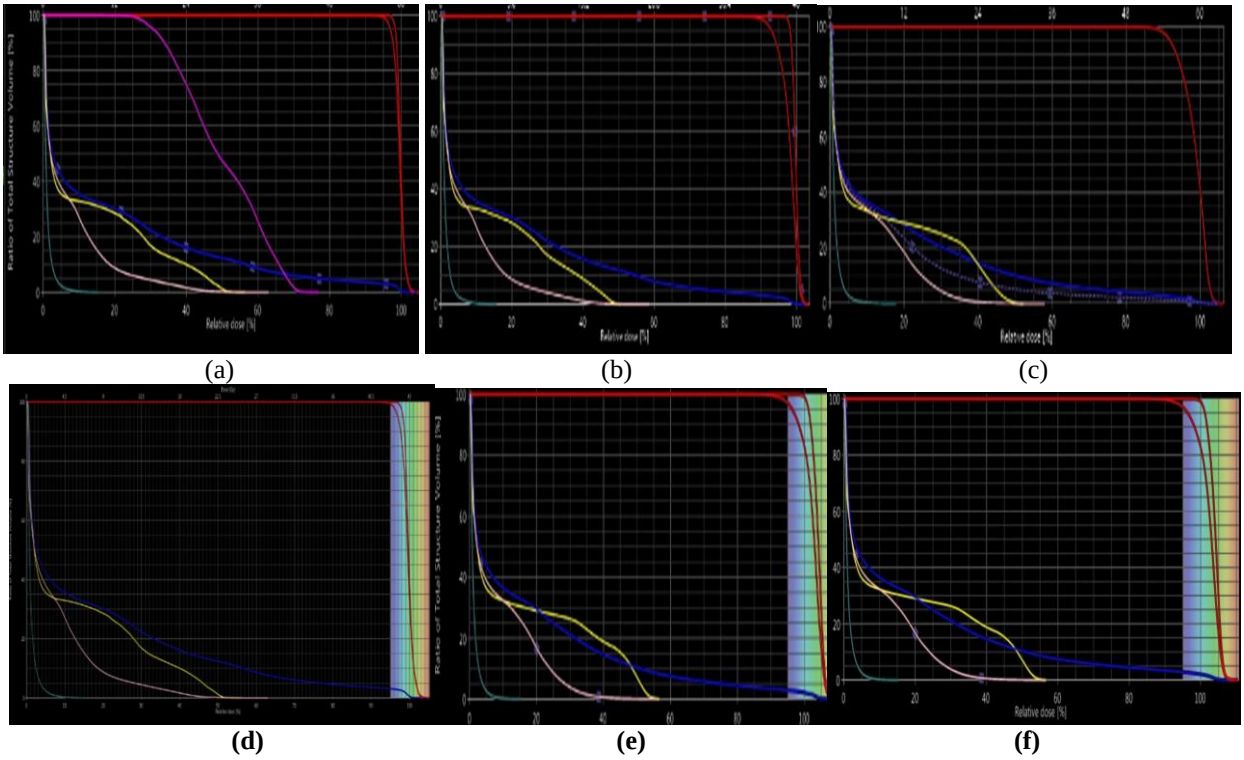
Figures (1) showThe dose distribution of SBRT treatment planning samples calculated using 1-mm ,2-mm and 3 mm CGS for both algorithms (AAA and AXB) is shown in Figures 2. a, b, c, d,e and f show the dose volume histograms for PTV and critical organs compared with those for 1, 2 and 3-mm CGS plans.



(a) (b) (c)

(d) (e) (f)

Fig.1: (a), (b), (c) are AAA isodose distribution for 1-mm, 2-mm and 3-mm CGS, (d), (e) and (f) are Isodose distribution for AXB 1-mm, 2-mm and 3-mm CGS respectively.



(a) (b) (c)

(d) (e) (f)

Fig.2 (a), (b), (c) are AAA Dose volume histograms for 1-mm, 2-mm and 3-mm, CGS (d), (e) and (f) are Dose volume histograms for AXB 1-mm, 2-mm and 3-mm CGS respectively.

In the case of spinal cord, the AXB algorithm predicted a higher dose than the AAA algorithm. The dose change on the spinal cord was statistically significant ($p<0.05$). However, the ipsilateral lung V5 and V10 are statistically higher in the AAA algorithm than in the AXB algorithm.

The dose to PTV predicted when AAA 1-mm CGS plans and AAA 2-mm and 3-mm CGS plans were compared, 2.73±1.62 % difference was observed; When AXB 1-mm CGS plans and AXB 2-mm and 3-mm CGS plans were compared, 1.36±1.21 % difference was found. No significant difference was found between plans with AAA 1-mm CGS and plans with AXB 1-mm CGS ($p>0.05$). There was a significant difference between PTV minimum doses of 1-mm, 2-mm CGS and 3-mm CGS AAA ($p<0.05$), whereas AXB plan with 1-mm, 2-mm and AXB plans with 3-mm CGS showed close results ($p>0.05$). Considering the Dmax and Dmean doses for the heart, AAA and AXB with 1, 2 and 3-mm CGS were not significantly associated with all plans ($p>0.05$). This is due to the fact that the AXB algorithm does not provide enough information about out-of-field side doses.

In the case of Dmean doses of ipsilateral lung doses, there was a significant difference between AAA plans with 1 mm CGS and 2, 3-mm CGS ($p<0.05$). Likewise, differences between AXB plans with 2, 3 mm CGS were significant ($p<0.05$). No significant results were found between AAA With 1 mm CGS and AXB plans with 1 mm CGS ($p>0.05$).

3 Discussions

In stage I, II patients with NSCLC, using the 6-MV rays, AXB and AAA were compared with each other to obtain a slightly higher mean dose with the AXB algorithm in lung tissue.[8] Fogliata et al. in their study supports our study, in which our computed ipsilateral lung dose was calculated to be 114 cGy with 2.5 mm AAA versus 196 cGy with 2.5 mm AXB. In this study, there is a significant difference between AAA and AXB plans for 2.5-mm CGS ($p<0.05$). In their study, Kan et al.[13] found that AXB had a 1% higher dose than AAA for air trapping-included nasopharyngeal carcinoma treatment plans using IMRT and RapidArc techniques. The difference between AAA and AXB is interesting as CGS has also contributed to the correct dose calculation. CGS is associated with the estimate and calculation accuracy. Kan et al. [13] showed a significant improvement in dose accuracy of AXB with 1-mm CGS. The smaller grid resolution reduces the average effect and results in a better sampling of the structure voxels. They showed that the dose difference in PTV was greater between the two algorithms in 2.5-mm CGS for 6×FFF and 10×FFF beams. In addition, Kan et al.[13] suggests that 1-mm CGS should be chosen for stereotactic plans, especially for low density tissue regions contained by PTV instead of 2.5–mm CGS. Chung et al. [14] and Mittauer et al.[15] showed that CGS was effective on dose

estimation for head and neck treatments. Ong et al. [16] demonstrated that 1-mm CGS accounts for a more accurate dose compared to AAA calculations with 2.5-mm CGS. So, it is found that there were 3.6% difference between AAA 1-mm CGS plans and AAA 2.5-mm CGS plans, whereas AXB 1-mm CGS plans and AXB 2.5-mm CGS plans had 1.2% difference. Regarding the PTV minimum doses, it was seen that there was a 5% difference between AAA plans with 1-mm CGS and AXB plans with 1-mm CGS. This may be the reason for the preference of the AXB algorithm to reduce the PTV dose during treatment planning. The effect of the dose difference between the two algorithms will be another area of interest for us. Our other work will focus on the difference between the two algorithms for different energy stages, focusing on the lung SBRT where small areas and air spaces are located.

4 Conclusions

SBRT treat high doses in a small number of fractions, So the accuracy of calculation related to the accuracy of these types of treatments, it is necessary to ensure the dose response in the critical regions of the algorithm used. The dose prediction for AXB algorithm are more stable results than the AAA in different intensity body regions, specifically in low density tissue as lung cancer AXB principally predicts lower dose to PTV compared to AAA and the CGS contributes to the relative dose difference between the two algorithms. For SBRT, 1-mm CGS should be selected for calculation accuracy.

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