Comparison of Intensity Modulated Radiation Therapy Dose Calculations with a PBC and AAA Algorithms in the Lung Cancer

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The pencil beam convolution (PBC) algorithms in radiation treatment planning system have been widely used to calculate the radiation dose. A new photon dose calculation algorithm, referred to as the anisotropic analytical algorithm (AAA), was released for use by the Varian medical system. The aim of this paper was to investigate the difference in dose calculation between the AAA and PBC algorithm using the intensity modulated radiation therapy (IMRT) plan for lung cancer cases that were inhomogeneous in the low density. We quantitatively analyzed the differences in dose using the eclipse planning system (Varian Medical System, Palo Alto, CA) and I'mRT matirxx (IBA, Schwarzenbruck, Germany) equipment to compare the gamma evaluation. 11 patients with lung cancer at various sites were used in this study. We also used the TLD-100 (LiF) to measure the differences in dose between the calculated dose and measured dose in the Alderson Rando phantom. The maximum, mean, minimum dose for the normal tissue did not change significantly. But the volume of the PTV covered by the 95% isodose curve was decreased by 6% in the lung due to the difference in the algorithms. The difference dose between the calculated dose by the PBC algorithms and AAA algorithms and the measured dose with TLD-100 (LiF) in the Alderson Rando phantom was −4.6% and −2.7% respectively. Based on the results of this study, the treatment plan calculated using the AAA algorithms is more accurate in lung sites with a low density when compared to the treatment plan calculated using the PBC algorithms.

Key Words: Anisotropic analytical algorithms (AAA), Pencil beam convolution (PBC), Lung cancer, Intensity modulated radiation therapy (IMRT)

INTRODUCTION

One the most important aspects of radiation therapy is the accuracy of the calculated dose. The Pencil beam convolution (PBC) algorithms have been widely used for dose calculations in the treatment planning system. More recently, the Varian Medical System (Palo Alto, CA) was released to improve the accuracy of the dose calculation for interfacial or inhomogeneous tissues regions. This system was based on a new photon dose calculation algorithm, referred to as the anisotropic analytical algorithms (AAA).[1-6] The AAA algorithms use triple-source modeling for primary photons, scattered extra-focal photons and electrons contamination scattered from the beam limiting devices for accurate photon dose calculations.[7] Several authors have reported that some errors in the calculated dose distributions resulted from poor modeling of the used algorithms.[8,9] These differences in the dose between the PBC and AAA algorithms were relatively high in lung sites that were inhomogeneous.[7-9]

Although several studies have compared the calculated and measured dose for the clinical treatment of lung cancer, the AAA algorithm has not been widely investigated in regards to dose calculations for intensity modulated radiation therapy. The aim of this study was to investigate the differences in the dose calculation between the pencil beam convolution algorithm and

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anisotropic analytical algorithm using the intensity modulated radiation therapy (IMRT) techniques in lung cancer treatment.

MATERIALS AND METHODS

To compare the dose distribution according to the algorithms, we used the Pencil Beam Convolution (version 8.6.15) and the Anisotropic Analytical Algorithm (version 8.6.15) in combination with the eclipse treatment planning system (8.6 Platform) in the Varian Medical System (Palo Alto, CA). 11 patients with lung cancer at various regions (center, center-left, center-right) were performed with intensity modulated radiation therapy (IMRT) on the PBC algorithms clinically. The doses were ranged from 180 to 200 cGy with fractionations of 20 to 25. All of the plans composed of 9 fields with 10 MV photons energy and equivalent 40 degrees (0^o, 40^o, 80^o, 120^o, 160^o, 200^o, 240^o, 280^o, and 320^o). The treatment plan calculated using the AAA algorithms was made by copying the clinical plan used for the PBC algorithm, with the exception of the calculation models. The average volume of the PTV, CTV, GTV was 618.3 cm^3, 308.7 cm^3 and 99.7 cm^3 respectively. We quantitatively analyzed the target and normal tissue near the target volume, including the trachea, esophagus, lung and PRV Spinal cord. PRV Spinal cord was extended 3 mm from the OAR Spinal cord in the superior and inferior directions. We also used the I'mRT Matrixx (IBA, Schwarzenbruck, Germany) equipment with 2D ionization chamber array to compare the dose difference in the axial plane.

TLD-100 (LiF) chips were used to compare the dose difference between the calculated dose and the measured dose. The TLD-100 (LiF) was annealed and read using a Harshaw 5500 series automatic TLD Reader (Harshaw/Bicon, Solon, Ohio, USA). The TLD-100 was placed in the lung site of the Alderson Rando anthropomorphic Phantom.

RESULTS AND DISCUSSION

Fig. 1 shows an example of the dose distributions calculated using the (a) pencil beam convolution algorithms and (b) anisotropic analytical algorithms of the commercial treatment planning system in the axial direction. From the 95% isodose line of the prescription dose (green line), the dose difference

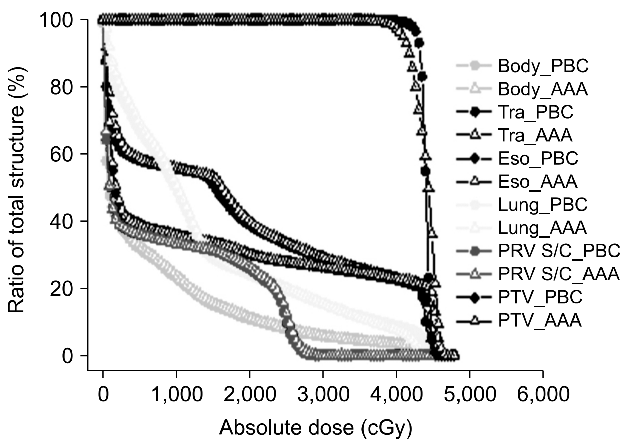

Fig. 2. The dose volume histogram analysis of the planning target volume and clinical organs, such as trachea, esophagus, lung and planning organs at risk volume of the spinal cord.

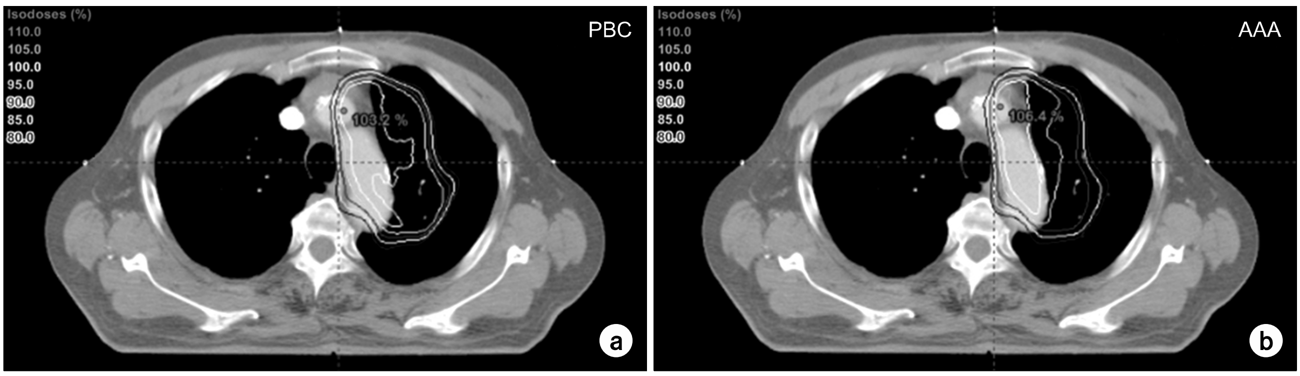

Fig. 1. Example of the dose distributions calculated using the treatment planning system in the axial plane. (a) Isodose line curve calculated using the PBC algorithms. (b) Isodose line curve calculated using the AAA algorithms.

between the two algorithms was significantly at lung sites that appeared inhomogeneous, such as regions with a low electron density. Evaluation of the dose volume histogram for the PBC and AAA calculations is shown in Fig. 2. The radiation dose at normal tissue, such as the body, trachea, esophagus, lung, and PRV spinal cord, could not be easily distinguished between PBC with AAA algorithms. However, the dose of the PTV was slightly different. If radiation dose calculations were performed using the AAA algorithm, the maximum PTV dose increased by 1.9% and minimum PTV dose decreased by 3.1%. Also, the volume of the PTV covered by the 95% isodose curve decreased by 6.0%, as shown Table 1. There was very little difference in the dose at most organs, such as the trachea mean dose, esophagus mean dose and lung mean dose, except for the maximum dose and minimum dose of the planning target volume and volumes exceeding 2,000 cGy (V_{20})

Table 1. Quantitative analysis of the dose difference analysis according to the differences in the algorithms (PBC/AAA) for the planning target volume and clinical organs, such as trachea, esophagus, lung and planning organs at risk volume of the spinal cord in the 11 patient with a lung cancer.

Structure	Parameter	PBC		AAA		AAA - PBC	
		Mean	SD	Mean	SD	Mean	SD
PTV	D_{max} (%)	106.3	1.9	108.2	2.5	1.9	1.2
	D_{min} (%)	82.7	5.8	79.5	4.5	−3.1	2.4
	D_{mean} (%)	100	0	100	0	0	0
	V_{95} (%)	98.9	0.7	93.0	2.7	−6.0	2.6
Trachea	D_{mean} (%)	57.8	13.0	58.8	12.9	0.7	0.5
	D_{mean} (cGy)	2,594.1	623.5	2,637.6	619.2	31.6	21.8
Esophagus	D_{mean} (%)	45.8	9.0	46.6	9.0	0.7	0.4
	D_{mean} (cGy)	2,058.4	492.5	2,093.3	492.4	28.6	18.1
Lung	D_{mean} (%)	30.8	6.9	31.4	6.8	0.6	0.2
	D_{mean} (cGy)	1,370.5	274.7	1,395.4	273.2	24.9	9.6
	V_5 (%)	64.9	13.0	66.4	13.0	1.5	0.6
	V_{10} (%)	55.3	12.0	56.3	11.9	1.1	0.4
	V_{20} (%)	24.3	7.7	25.3	8.2	1.0	0.8
	V_{30} (%)	13.2	4.7	13.3	4.7	0	0.2
PRV spinal cord	D_{max} (%)	56.8	16.9	56.8	17.3	0.1	0.7
	D_{max} (cGy)	2,549.8	793.1	2,552.1	812.6	2.3	32.7

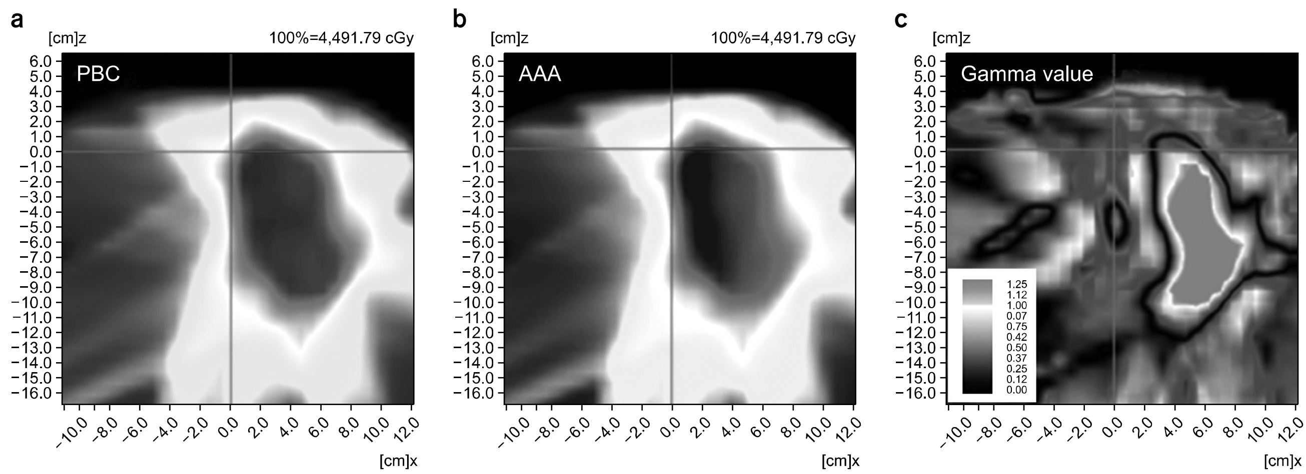

Fig. 3. Gamma evaluation of the dose distribution calculated with the PBC/AAA algorithms using the I'mRT Matrixx in the axial plane. (a) Dose distributions calculated by the PBC algorithms. (b) Dose distributions calculated by the PBC algorithms. (c) Gamma evaluations between the PBC and AAA algorithms.

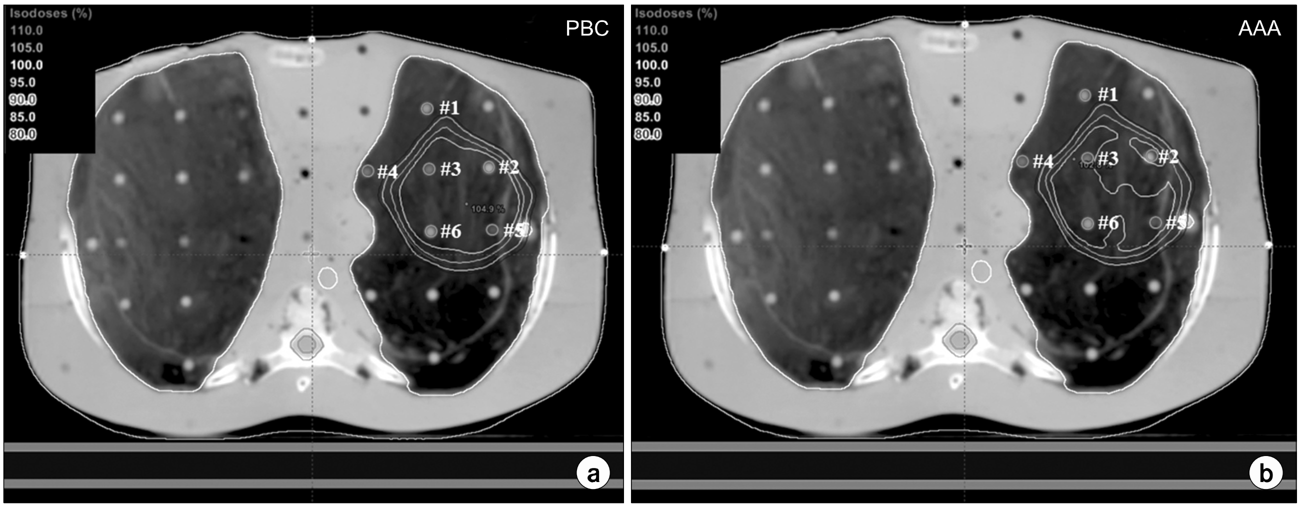

Fig. 4. Dose distributions calculated using the PBC/AAA algorithms in the Alderson Rando Phantom for dose measurements using the TLD-100 (LiF) chips. TLD-100 (LiF) chips are placed in the #1～#6. (a) Calculated by the PBC algorithms, (b) calculated by the AAA algorithms.

Position	PBC			AAA		
	Calculated (cGy)	Measured (cGy)	Difference (%)	Calculated (cGy)	Measured (cGy)	Difference (%)
#1	325	332	−2.2	336	350	−4.1
#2	504	553	−8.9	519	548	−5.4
#3	508	539	−5.8	514	541	−5.1
#4	304	324	−6.2	331	323	2.5
#5	504	524	−4.0	515	537	−4.1
#6	509	512	−0.6	516	514	0.2
Average			−4.6			−2.7

Fig. 5. Dose measurement results according to the PBC/AAA algorithms using the TLD-100 chips in the above mentioned positions (#1~#6).

(Table 1). Fig. 3 shows the results of the gamma evaluation for dose distribution calculated by the Eclipse planning system in the axial plane using the I'mRT Matrixx. The gamma index (for 3% Dose Difference and 3 mm distance to agreement (DTA)) was measured to be 94.85% and $r \leq 1$. The region of the $r > 1$ (Red color) occurred in the lung at low density with an increase in dose difference. Fig. 4 shows the dose distributions calculated using the PBC and AAA algorithms in the Alderson Rando phantom. The red circles indicate the position of the TLD-100 chips. The treatment plan used the intensity modulated radiation therapy technique on the 10MV photon at 9 fields with equivalent interval angles (40 degree). The dose comparison measurement results for the Pencil beam convolution and the anisotropic analytical algorithms using the TLD-100 chips is shown in Fig. 5. The standard deviation of the PBC and the AAA algorithms was 3.0% and 3.2%, respectively. The dose difference between the calculated dose and the measured dose for the PBC algorithms ranged from −0.6% to −8.9%. The average dose difference from the the PBC algorithms and AAA algorithms in the lung position was −4.6% and −2.7%, respectively. The dose difference between the calculated dose and measured dose of the AAA algorithms ranged from 0.2 to −5.4%.

Bragg et al.[9] examined the differences between the calculated and measured dose (%) in the semi-anthropomorphic phantom planned with pencil beam convolution algorithms and anisotropic analytical algorithms for the 3 field plan and parallel pair plan. In this previous study, the differences between the calculated and measured doses for the pencil beam convolution and the anisotropic analytical algorithms was +4.7% and −0.8% with a 3 field plan in the mid lung, respectively. In the parallel pair plan, the differences were +1.3% and +7.5%, respectively.

From our comparison experiments using the TLD-100 (LiF) chips, the treatment plan calculated using the AAA algorithms was determined to be more accurate in lung sites with a low density compared to the treatment plan calculated using the PBC algorithms.

CONCLUSION

In this study, we compared the dose difference between the pencil beam convolution and anisotropic analytical algorithm using the eclipse dose calculation, I'mRT matrix and TLD-100 chips. 11 patients with lung cancer were quantitatively analyzed for the target volume and critical organs. There was no significant difference in the maximum, mean, minimum dose for the normal tissue. However, the volume of the PTV covered by the 95% isodose line was dramatically decreased by 6% due to the differences in the algorithms. The comparison results of the PBC and AAA algorithms with the TLD-100 chips at the lung position in the Alderson Rando phantom resulted in a more accurate dose distributions calculation when the anisotropic analytical algorithms were used. Based on this result, the acceptable criteria for the treatment plan calculated using the AAA algorithm should be re-evaluated.

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폐암의 세기조절방사선치료에서 PBC 알고리즘과 AAA 알고리즘의 비교연구

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방사선치료계획장치에서 선량계산을 위해 PBC 알고리즘(pencil beam convolution)은 가장 널리 사용되고 있다. Varian (Varian Medical System, Palo Alto, CA)사는 광자의 선량 계산을 위해서 AAA 알고리즘을 새롭게 선량계산모델로 탑재하였다. 본 연구는 폐와 같은 저밀도 영역에 종양부위가 있는 환자를 대상으로 세기조절방사선치료를 시행할 경우에 PBC 알고리즘과 AAA 알고리즘으로 계산했을 때 차이를 정량적으로 알고자 하는데 목적이 있다. 두 알고리즘의 정량적 분석을 위해서 Eclipse planning system과 I'mRT matrixx (IBA, Schwarzenbruck, Germany)를 사용하였다. 또한 두 알고리즘으로 계산된 선량과 실제 측정된 선량의 차이를 확인하기 위해서 인체모형펜텀(Alderson Rando phantom)속에 TLD-100 (LiF)을 위치 시켰다. 종양부위 주위의 중요장기인 trachea, esophagus, lung, PRV spinal cord의최대선량, 평균선량, 최소선량은 알고리즘의 변화에 따라서 거의 변화가 없었으나, PTV의 V95는 PBC와 비교하여 AAA가 약 6% 감소하는 결과를 얻었다. 이러한 결과는 I'mRT matrixx를 이용하여 저밀도를 가지는 폐의 위치에서 확연하게 나타남을 확인할 수 있었다. 또한 인체모형펜텀(Alderson Rando phantom)과 TLD-100 (LiF)을 이용한 계산선량과 실제 측정치의 결과는 PBC 알고리즘은 평균 4.6%의 차이를 보였으며, AAA 알고리즘은 평균 2.7%의 차이를 보였다. 이 결과로 저밀도를 가지는 폐암에서의 세기조절방사선치료를 시행할 경우에 PBC 알고리즘보다 AAA 알고리즘이 더 유효함을 알 수 있다.

중심단어: AAA 알고리즘(anisotropic analytical algorithms), PBC 알고리즘(pencil beam convolution), Lung cancer, 세기조절방사선치료(intensity modulated radio therapy)