Original Article

Dosimetric Impact of AAA and AXB Dose Calculation Algorithm in VMAT Treatment Planning for Rectal Tumors

Karthikeyan Srinivasan[1,2], Sureka Chandrasekaran Sekaran[1], Suresh Thangavelu[1,2], M. S. Belliappa[2]

[1]Department of Medical Physics, Bharathiyar University, Coimbatore, Tamil Nadu, [2]Department of Radiation Oncology, Aster CMI Hospital, Bengaluru, Karnataka, India

Abstract

Aim: The study aims to compare the accuracy of Anisotropic Analytical Algorithm (AAA) and acuros XB (AXB) dose calculation algorithms for radiotherapy (RT) planning of rectal tumors. **Materials and Methods:** Treatment plans from 20 patients with previously treated rectal cancer were retrospectively analyzed. All patients underwent VMAT treatment planning using the AAA algorithm in Eclipse (v15.6) system. These plans were recalculated with AXB in Eclipse (v15.6) while maintaining the original multileaf collimator fluence. Dosimetric parameters and gamma analysis (3%/3 mm and 2%/2 mm criteria) were compared between the two algorithms. A paired two-tailed *t*-test was used to statistically compare dosimetric and gamma analysis results between the AAA and AXB algorithms. **Results:** The results indicate that AAA could be potentially overestimating the dose to planning target volume (PTV). While the mean bowel dose was marginally lower in AAA plans ($P = 0.013$), doses to other organs at risk (OARs) were slightly higher, suggesting a general overestimation trend. This implies that AAA could be potentially overestimating the dose to OARs and PTV as compared to AXB. The statistical analysis of the Gamma parameters also shows a significant change. **Conclusion:** The results indicate that the dose calculation accuracy of AXB is superior to AAA for rectal cancer RT.

Keywords: Acuros XB, Anisotropic Analytical Algorithm, carcinoma rectum, Eclipse planning system

Received on: 23-08-2024 **Review completed on: 25-11-2024** **Accepted on: 12-12-2024** **Published on: 24-02-2025**

Introduction

The role of radiotherapy (RT) in the treatment of rectal cancer has been established in the last few decades. It is well known that RT can reduce local recurrence and enhance survival when used in combination with surgical resection. However, RT for rectal cancer is a complex problem because of the shape of target volumes (TV) and the need of minimizing the involvement of organs at risk (OAR) such as small bowel, bladder, and femur heads.[1] Several planning studies have demonstrated the advantages of intensity-modulated radiation therapy (IMRT) in target coverage and normal tissue sparing over three-dimensional (3D) conformal RT for rectal cancer patients.[2-4] However, a few studies reported that the prolonged delivery time per fraction may impact the delivery accuracy because of increased intra-fractional patient motion. These studies also reported that more monitor units (MU) may increase the possibility of radiation-induced secondary malignancies.[5,6]

Volumetric-modulated arc therapy (VMAT) is a technique enabling an intensity-modulated dose to be delivered during a continuous gantry rotation. VMAT involves dynamically modulating the delivery parameters such as the shape of multileaf collimator (MLC) and dose rate to achieve highly conformal dose distributions.[7,8] Some studies report that VMAT overcomes the shortages of IMRT with the improvements in treatment delivery efficiency.[9] Rapid Arc (Varian Medical Systems, Palo Alto, CA) is one of such VMAT techniques that delivers modulated radiation beams with simultaneous adjustment of MLC shape, dose rate, and gantry rotation speed.[10,11] To achieve the therapeutic advantage from rapid arc technique for the rectal cancer, it is essential to perform precise dose calculation. The American Association of Physicists in Medicine has recommended that the uncertainty in the computed dose distribution to be <2%.[12]

Address for correspondence: Dr. Sureka Chandrasekaran Sekaran, Department of Medical Physics, Bharathiar University, Coimbatore, Tamil Nadu, India.
E-mail: surekasekaran@buc.edu.in

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_147_24

How to cite this article: Srinivasan K, Sekaran SC, Thangavelu S, Belliappa MS. Dosimetric impact of AAA and AXB dose calculation algorithm in VMAT treatment planning for rectal tumors. J Med Phys 2025;50:86-92.

An important issue with rectal cancer is the involvement of air gaps. Some papers have reported that conventional dose calculation algorithms such as pencil beam convolution algorithm and Anisotropic Analytical Algorithm (AAA) cannot predict the accurate dose in the heterogeneous region including the interface between air cavities and tissues.[13-16]

Recently, a new photon dose calculation algorithm called Acuros XB (AXB) has been implemented in Eclipse TPS (Varian Medical System, Palo Alto, CA). The AXB algorithm solves deterministically the coupled system of linear Boltzmann transport equations that describes the macroscopic behavior of radiation particles as they travel through and interact with matter. Several studies have stated that the AXB provides more fast and accurate dose calculations in heterogeneous media as compared to AAA using comparisons with measurement and Monte Carlo (MC) calculations.[13-18] These studies have established that AXB indeed provides more accurate dose calculation in heterogeneous media. These results ignited a huge curiosity among the medical physics fraternity to understand the limitations of AAA in comparison with AXB in the context of VMAT.

Consequently, researchers have conducted studies in esophageal, lung, nasopharynx, prostate, cervix cases and virtual phantoms comparing the performance of AAA and AXB.[19-28] These studies revealed significant differences in the dose distribution obtained from AAA and AXB and they also reported the superior accuracy of AXB over AAA. The results from these studies imply that AAA could have inherent limitations in modeling the interaction of radiation with matter especially when encountered with complex geometry and highly heterogeneous media, which is addressed by AXB algorithm.

The purpose of this study is to compare the performance of AAA and AXB dose calculation algorithms for rectal tumors. Our assumption is that AAA algorithm would fall short in terms of accuracy in the air-soft tissue interface encountered in the rectal cases in line with the results obtained from the previous studies for other anatomic sites. Moreover, to the best of our knowledge, there are no such studies reported on rectal cancer.

Materials and Methods

A Varian TrueBeam sTx linear accelerator equipped with a High-Definition 120-leaf MLC was used in this study. The maximum field size was 22 × 40 cm². The width of the MLC at isocenter plane is 2.5 mm and 5 mm in the middle and peripheral respectively. Portal dosimetry was performed for all the cases for plan verification using the portal vision software of version AS1200, Varian Medical System, Palo Alto, CA. Varian Portal vision AS1200 detector has an active area of 40 cm × 40 cm with 1190 × 1190 pixels array and pixel width of 0.336 mm which was used for AAA and AXB plan verification.

This retrospective study analyzed the treatment plans of 20 patients with rectal cancer who had previously received RT. The rectal cases with inguinal lymph nodes and para-aortic lymph nodes were excluded from the study due to the field size limitations of HDMLC, which can treat only up to 22 cm in the craniocaudal direction with a single isocenter. The following planning process was adopted: The CT images of these previously treated patients covered a region from thorax to whole pelvis in supine position. A 16 slice positron emission tomography computed tomography (CT) scanner (GE Health care, USA) was used to obtain these CT scans. The slice thickness of the CT images was 2.5 mm and was obtained with intra venal contrast for better visualization of TV. The tumor volume and the normal structures were delineated by physician as per the recommended guidelines and planning target volume (PTV) margins of 5 mm axially and 8 mm in superior/inferior directions were added to CTV as per our hospital protocol. OARs such as bladder, bowel, and femoral heads were outlined in the CT section. The original plans for these 20 patients were done using Eclipse treatment planning system (v15.6, VARIAN, Palo Alto, USA). VMAT treatment technique was used for all patients planned with two full arcs length 359″ (179–181″) CW direction and counter clockwise direction. 6MV X-ray energy with a dose rate of 600 MU/min was used. VMAT optimization was performed with the PTV and OAR dose constraints complying with the radiation therapy oncology group (RTOG) protocol. The VMAT optimization was carried out for all patients with a 2.5 mm grid size for a dose prescription of 50.4 Gy in 28 fractions.

In the present study, these 20 VMAT plans calculated using AAA algorithm were revisited and new VMAT plans were generated with the only difference of dose calculation being AXB version 15.6 algorithm instead of AAA algorithm. Essentially, the same MLC fluence that was used in the respective AAA calculated plans was used for these new VMAT plans and subsequently the dose was recalculated with AXB as dose to medium. This approach was adopted because any changes in the original MLC fluence through re-optimization (or by any other means) would instantly invalidate the ground truth (i.e. dose distribution obtained from AAA for the original MLC fluence) and hence an exact comparison between AAA and AXB cannot be performed.

The plans were compared and evaluated based on dosimetric parameters such as PTV coverage, conformity index, Homogeneity index, TV maximum dose, mean dose, and minimum dose. The HI and CI indices were calculated using the below mentioned methods.

$$HI = \frac{D2 - D98}{Dp} \times 100$$

$$CI = \frac{\text{Volume of PTV covered by the reference dose}}{\text{Volume of PTV}}$$

Previous studies have shown that AXB gives a much better agreement with MC calculations[14] or dose measurements[26] in regions of re-buildup in soft tissue after the beam has passed through low-density tissue such as lung or air. Since the rectal cases too share a similar heterogeneity profile like lung, we

performed the gamma analysis to confirm if similar pattern of results is obtained. The gamma analysis was performed with passing rate of 3% and 3 mm as well as 2% and 2 mm for AAA and AXB for all 20 cases to validate the assumption that AXB could offer more accurate dose calculation. Detailed statistical analysis was performed using the paired two tailed *t*-test and subsequently the *P* value was determined for the dosimetric comparison and also for the gamma comparison. In the paired two tailed *t*-test, the mean difference between the paired data set (i.e. AAA and AXB) is considered as statistically significant if the $P < 0.05$. Based on the results from previous studies on the similar topic, it was assumed that a sample size of 20 would yield findings with the expected statistical significance.

Results

The dosimetric results obtained in AAA-based plans for PTV and OARs are summarized in Tables 1 and 2, respectively. Similarly, the dosimetric results obtained in AXB-based plans for PTV and OARs are summarized in Tables 3 and 4, respectively. Figure 1 shows the dose distribution for AAA and AXB plans for the same case. The gamma comparison between AAA and AXB based plans is captured in Table 5. The results of the statistical analysis for PTV, OARs and Gamma Index between AAA and AXB are captured in Tables 6-8, respectively.

Table 6 shows the statistical analysis, including *P* values and mean differences, for dosimetric parameters such as Dmax, Dmin, Dmean, D2%, D98%, D50%, V95%, V107%, CI, and HI between AAA and AXB plans. The mean differences in PTV volume between AAA and AXB plans for Dmax, Dmin, Dmean, D2%, D98%, D50%, V95%, V107%, CI, and HI were 0.623, –4.245, –0.650, –0.105, –0.662, –0.639, –1.334, 0.180, –0.088, and 0.012, respectively. Statistical analysis demonstrated significant differences between AAA and AXB plans for all evaluated PTV dosimetric parameters. Figure 2 shows the dose volume histogram (DVH) comparison for PTV for one of the cases.

Table 1: Dosimetric values obtained for planning target volume in Anisotropic Analytical Algorithm-based plans

D_{max}	D_{min}	D_{mean}	CI	HI	V95%	V107%
52.33	47.03	51.03	1.01	0.04	99.98	0
53.10	46.36	51.22	1.04	0.05	99.98	0
53.30	47.35	51.33	1.11	0.04	100.00	0
53.81	47.65	51.81	0.90	0.04	100.00	0
53.66	40.06	50.59	0.98	0.05	99.86	0
53.85	35.42	51.22	0.95	0.07	99.87	0
53.38	46.71	51.28	1.07	0.04	100.00	0
54.53	46.39	51.50	1.21	0.06	100.00	0.1
52.68	39.92	50.84	1.03	0.04	100.00	0
54.53	36.50	51.30	1.05	0.07	100.00	0.1
53.30	47.35	51.33	1.03	0.07	99.85	0.1
53.81	47.65	51.81	1.01	0.04	100.00	0
52.50	46.20	50.51	1.08	0.05	100.00	0
53.10	47.10	51.31	1.11	0.04	99.90	0
52.80	47.80	51.08	1.03	0.03	100.00	0
53.40	46.30	50.98	0.97	0.05	100.00	0.1
53.10	45.10	50.71	1.03	0.07	99.95	0
52.70	46.30	51.34	1.01	0.03	100.00	0
52.30	47.80	51.02	1.08	0.06	99.85	0
52.90	47.30	50.64	1.13	0.05	99.91	0

CI: Confidence interval, HI: Homogeneity index

Table 7 shows the statistical analysis, including *P* values and mean differences, for OAR volume between AAA and AXB plans. The mean difference in bladder volume is –0.27 cc, –0.67 cc, –0.38 cc, and –0.21 cc for the 50%, 25%, 15% volume, and mean dose, respectively. The mean difference in bowel volume was –0.18 cc for the 180 cc volume and 1.78 for the mean dose, respectively. The mean difference in femoral heads was –1.63 for the maximum dose, –0.06 for the 25% volume, and –0.03 for the 40% volume. Statistical analysis revealed no significant differences in OAR volume between AAA and AXB plans for all dosimetric parameters evaluated.

Table 8 shows the statistical analysis, including *P* values and mean differences, for gamma index comparisons between AAA and AXB plans. The mean difference in gamma analysis is 1.83 for the 3%, 3mm criterion and 4.52 for the 2%, 2 mm criterion. Statistical analysis revealed significant differences between AAA and AXB plans for both the 3%, 3 mm and 2%, 2 mm gamma criteria. Figure 3 shows the Gamma index distribution for 2% and 2 mm criterial for AAA and AXB plans.

Discussion

This study compared the dose distributions obtained by two different dose calculation algorithms (AAA and AXB) for rectal tumors. There is a mean difference of about 4 Gy in Dmin for PTV. The AAA seems to be overestimating the Dmin for PTV as compared to AXB. This difference is evident in the dose distribution [Figure 1], DVH [Figure 2] and also in the dosimetric indices [Tables 1-4]. A significant difference in CI value is observed and apparently AAA seems to be overestimating the dose to PTV. The study does not show any other significant changes in the PTV dose. The results shown in Table 6 indicate that the obtained dosimetric difference between AAA and AXB are also statistically significant. Especially, the dosimetric values obtained for PTV are substantiated by $P < 0.05$, indicating the statistical validity of the findings. The above findings indicate that AAA could be overestimating the dose to PTV. It is evident that the measured underdosage on recalculation using AXB falls in the interface between air and soft tissue. This implies that AAA may not be suitable for dose calculation involving tissue-air junctions and in general heterogeneous regions. Different studies have reported and concluded that AAA could fall short in other anatomic sites such as lung, head, and neck that share similar heterogeneity profile.[13,17]

The dosimetric analysis for OARs reveals that there are no clinically significant differences in the dosimetric values in AXB-based plans when compared to the respective

Table 2: Dosimetric values obtained for organs at risks in Anisotropic Analytical Algorithm-based plans

Bladder (Gy)				Bowel (Gy)		Femoral heads (Gy)		
50%	25%	15%	Mean	180 cc	Mean	Maximum	25%	40%
26.9	33.0	36.2	26.9	25.9	14.8	39.0	22.9	19.7
27.3	35.4	38.9	29.4	28.4	15.8	40.0	20.8	17.0
28.4	36.1	39.3	29.9	26.4	10.9	35.8	17.6	13.7
27.5	36.5	40.6	29.4	31.4	16.1	42.6	21.0	18.5
27.9	36.5	40.4	28.3	26.2	14.2	44.1	18.9	17.1
28.8	36.3	39.6	29.9	31.5	11.1	37.6	22.3	19.9
25.3	33.7	37.3	27.0	25.5	15.3	37.2	20.3	18.2
27.4	34.6	38.0	28.6	28.7	16.6	45.8	31.7	24.2
21.2	30.3	34.4	23	26.7	14.6	38.4	19.4	17.9
26	34.8	39.2	28.1	11.5	10.2	37.6	23.7	19.9
27.5	34.8	39.1	28.5	25.6	13.5	38.5	21.5	16.5
28.6	34.5	38.5	26.5	21.9	14.5	37.5	23.5	21.3
24.5	31.5	37.3	25.1	23.7	17.9	41.1	29.4	20.9
29.0	36.1	41.1	30.2	21.9	18.7	38.7	21.3	16.5
21.0	31.3	33.5	22.7	25.1	12.5	43.6	20.7	14.8
25.9	37.5	40.1	24.3	24.5	15.5	41.8	22.1	18.6
24.7	35.4	38.7	25.6	29.6	12.8	36.7	17.1	13.7
21.8	31.0	38.3	22.1	23.5	11.7	37.9	22.3	15.3
31.2	38.3	41.1	30.4	22.7	10.9	40.1	20.5	16.6
23.6	35.6	40.3	29.5	30.6	13.4	42.7	22.9	23.1

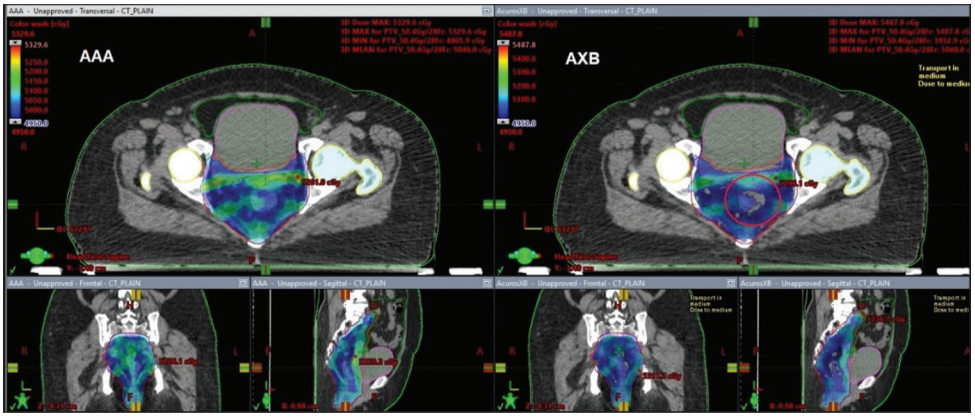

Figure 1: The dose distribution for Anisotropic Analytical Algorithm and Acuros XB plans for an example case. The red circle indicates the region of underdosage inside the target volume

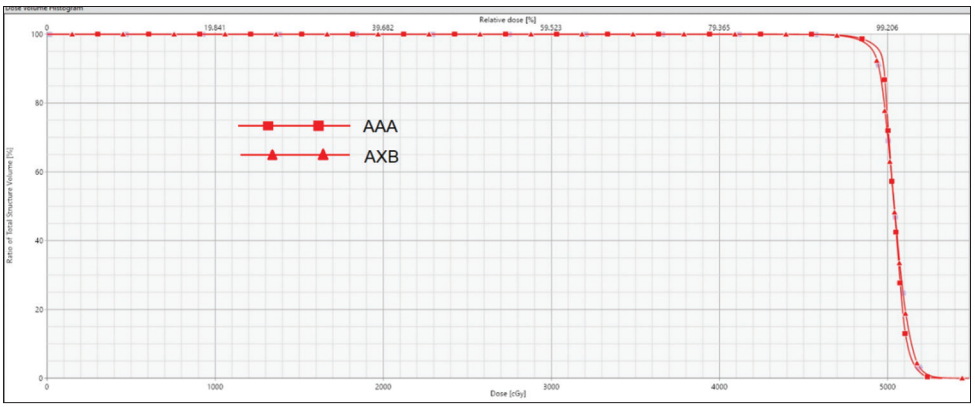

Figure 2: The dose volume histogram (DVH) comparison between Anisotropic Analytical Algorithm and Acuros XB (AXB) for PTV showing the lack of dose coverage for AXB plan after dose recalculation

Table 3: Dosimetric values obtained for planning target volume in Acuros XB -based plans

D_{max}	D_{min}	D_{mean}	CI	HI	V95%	V107%
53.41	46.46	50.95	0.97	0.05	99.70	0.2
53.38	43.98	50.75	0.94	0.05	99.50	0.1
53.61	46.55	50.84	0.99	0.05	99.70	0.2
53.50	39.25	49.47	0.92	0.08	97.80	0.1
54.35	38.76	49.97	0.82	0.07	98.60	0.3
54.52	35.11	50.66	0.84	0.06	99.00	0.3
53.88	45.11	50.94	1.01	0.05	99.20	0.1
53.87	45.35	51.04	1.06	0.06	98.07	0.2
53.66	35.24	50.60	0.84	0.08	98.30	0.2
54.30	34.83	51.05	0.98	0.08	99.40	0.2
52.80	35.21	50.85	0.98	0.05	99.30	0
55.31	38.95	50.43	0.93	0.07	98.20	0.4
54.67	37.56	50.45	1.01	0.05	97.50	0.2
53.25	39.60	50.71	0.97	0.06	98.60	0.1
53.83	43.57	49.85	0.96	0.05	99.00	0.3
54.16	38.59	50.31	1.02	0.06	98.20	0.4
53.88	39.65	50.21	1.03	0.07	98.70	0.2
52.87	45.68	50.76	0.98	0.08	97.60	0
53.19	44.35	50.12	0.89	0.05	98.30	0.3
54.10	43.58	49.89	0.93	0.05	97.80	0.2

CI: Confidence interval, HI: Homogeneity index

Table 4: Dosimetric values obtained for organs at risks in Acuros XB-based plans

Bladder (Gy)				Bowel (Gy)		Femoral heads (Gy)		
50%	25%	15%	Mean	180 cc	Mean	Maximum	25%	40%
26.2	32.3	34.7	26.3	25.7	14.5	38.1	22.5	19.3
26.7	34.8	38.4	28.8	27.9	23.2	39.3	19.5	16.5
27.7	35.4	38.7	29.3	26.3	10.6	35.2	17.1	13.4
27.5	36.4	40.6	29.5	32.6	16.8	44.0	21.3	18.7
27.1	35.7	39.6	27.5	26.4	16.3	44.2	18.3	16.5
28.1	35.7	39.0	29.2	30.8	10.7	37.4	26.1	19.5
24.5	33.0	36.7	26.4	25.0	16.7	36.6	19.8	17.8
26.6	33.9	37.4	27.8	28.3	16.2	45.1	31.1	23.5
22.7	31.5	35.4	23.8	25.8	14.3	36.0	19.9	16.9
25.5	34.2	38.7	27.5	11.0	10.0	36.3	23.2	19.4
23.5	31.1	35.1	23.8	23.5	13.5	37.3	21.3	19.5
25.8	35.2	38.2	24.1	26.7	15.8	44.3	23.6	17.5
24.6	34.9	36.8	27.3	25.3	16.1	41.3	24.1	18.1
26.3	33.5	39.3	27.8	27.8	19.3	42.1	25.6	19.1
24.9	33.1	39.8	26.5	26.1	18.6	36.1	21.3	15.1
28.3	35.3	40.1	25.1	29.3	21.2	38.5	20.9	17.2
27.9	32.8	38.5	28.1	23.2	13.5	34.3	17.9	16.9
23.6	33.8	39.6	27.5	14.0	11.8	32.1	23.1	21.3
25.4	34.1	39.5	28.5	24.0	17.9	30.6	20.8	18.6
26.3	33.2	38.3	26.3	28.0	19.6	35.3	21.3	16.8

AAA-based plans. The same is reflected in the statistical analysis [Table 7]. However, the mean dose to bowel was marginally lower ($P = 0.013$) in AAA-based plans as compared to AXB-based plans. The trend is reversed in other OAR parameters, where the dose is marginally higher in AAA

Table 5: Gamma index comparison between Anisotropic Analytical Algorithm and Acuros XB plans

AAA		AXB	
3% 3 mm	2% 2 mm	3% 3 mm	2% 2 mm
99.80	97.60	100.00	99.60
93.80	88.30	95.40	89.50
99.70	96.40	99.90	97.20
99.50	96.90	99.70	97.00
94.00	89.50	99.70	97.90
98.30	94.40	98.50	94.60
97.80	91.00	99.90	99.50
94.30	88.30	95.30	89.40
95.70	85.90	99.70	98.70
99.80	97.50	96.30	89.30
94.80	93.20	97.80	96.80
96.70	89.50	99.10	97.30
98.10	88.60	98.30	96.80
93.90	94.30	98.60	96.90
95.40	89.70	99.20	98.30
98.10	91.30	97.50	95.70
95.70	92.50	99.30	98.10
94.30	89.00	99.30	98.30
96.70	90.50	98.70	97.60
97.10	90.30	98.00	96.60

AAA: Anisotropic Analytical Algorithm, AXB: Acuros XB

Table 6: Dosimetric comparison between Anisotropic Analytical Algorithm and Acuros XB and *P* values for planning target volume

Dosimetric parameters	AAA		AXB		Mean difference	*P*
	Mean	SD	Mean	SD		
D_{max}	53.25	0.64	53.88	12.06	0.623	0.002*
D_{min}	45.11	3.84	40.87	4.13	−4.245	0.000*
D_{mean}	51.14	0.36	50.49	0.45	−0.650	0.000*
D2%	52.24	0.45	52.13	0.26	−0.105	0.000*
D98%	49.66	0.47	48.99	0.59	−0.662	0.002*
D50%	51.25	0.29	50.61	0.37	−0.639	0.000*
V95%	99.96	0.06	98.62	0.70	−1.334	0.000*
V107%	0.02	0.04	0.20	0.11	0.180	0.000*
CI	1.04	0.07	0.95	0.07	−0.088	0.000*
HI	0.05	0.01	0.06	0.01	0.012	0.060

*Statistically significant. SD: Standard deviation, CI: Confidence interval, HI: Homogeneity index, AAA: Anisotropic Analytical Algorithm, AXB: Acuros XB

plans as compared to AXB plans. This implies that AAA could be overestimating the dose to OARs as well apart from PTV. In other words, recalculating treatment plans for rectal cancer using AXB dose calculation algorithm instead of AAA produces a lower dose to the PTV, and slightly lower dose to the surrounding OARs. This is in line with the results from the literature survey, for example, for lung tumors, where AXB predicts up to 1.1 Gy less than AAA to the soft tissue in the PTV for 3D, IMRT and VMAT plans.[15] However, it is important to note that the *P* value for OARs were consistently higher than

Table 7: Dosimetric comparison between Anisotropic Analytical Algorithm and Acuros XB and *P* values for organs at risks

OAR parameters	AAA		AXB		Mean difference	*P*
	Mean	SD	Mean	SD		
Bladder (Gy)						
50%	26.2	2.8	26.0	1.6	−0.27	0.630
25%	34.7	2.2	34.0	1.4	−0.67	0.150
15%	38.6	2.1	38.2	1.7	−0.38	0.395
Mean	27.3	2.7	27.1	1.8	−0.21	0.689
Bowel (Gy)						
180 cc	25.6	4.4	25.4	5.0	−0.18	0.820
Mean	14.1	2.4	15.8	3.6	1.78	0.013*
Femoral heads (Gy)						
Maximum	39.8	2.8	38.2	4.1	−1.63	0.068
25%	22.0	3.4	21.9	3.2	−0.06	0.891
40%	18.2	2.9	18.1	4.6	−0.03	0.664

*Statistically significant. AAA: Anisotropic Analytical Algorithm, AXB: Acuros XB, OAR: Organs at risk, SD: Standard deviation

Table 8: Gamma index comparison between Anisotropic Analytical Algorithm and Acuros XB

Gamma index	AAA		Acuros		Mean difference	*P*
	Mean	SD	Mean	SD		
3% 3 mm	96.68	2.13	98.51	1.44	1.83	0.001*
2% 2 mm	91.74	3.45	96.26	3.18	4.52	0.000*

*Statistically significant. SD: Standard deviation, AAA: Anisotropic Analytical Algorithm

0.05, which implies that the study results for OARs are not statistically significant with the sample size used in the study. Hence, more experiments are needed to confirm the results for OARs. However, the regions covered under PTV or OAR would be indifferent for the dose calculation algorithms from the dosimetric point of view, and hence it is safe to assume that the results are valid for OARs as well.

The recalculation of dose for the same MLC fluence using AXB resulted in slight reduction in target coverage. However, it was still within the RTOG tolerance levels and all the prescribed objectives were met in both set of plans for all 20 cases. It is to be noted that re-optimization using AXB would have resulted in better target coverage. Since the objective of the study was to quantify the dosimetric differences between AAA and AXB, dose recalculation was performed. In some cases, we performed re-normalization of dose to match the PTV coverage between AAA and AXB plans, which marginally increased the MU (around 1.5%) with a corresponding increase in mean dose delivered to the surrounding normal tissues. This too is in agreement with a previous study on esophageal cancer.[19]

The gamma comparison [Table 5] and the statistical analysis of the same [Table 8] also show a significant change, especially for the 2% and 2 mm criteria with $P < 0.05$. The Gamma Evaluation also shows that AXB gives a better agreement with

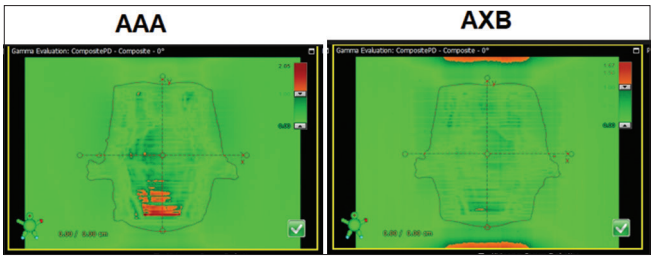

Figure 3: The Gamma analysis for 2% and 2 mm criteria for Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB) indicating the accuracy of AXB-based dose calculation over AAA-based dose calculation

the measurements. This is also evident from Figure 3. This result validates our initial assumption that AXB calculates dose more accurately than AAA algorithm and is also in agreement with the results of previous studies.[19-28]

Conclusion

The study reveals that recalculating treatment plans for rectal cancer using AXB dose calculation algorithm instead of AAA produces a lower dose to the PTV, and slightly lower dose to the surrounding OARs. The results suggest that AXB can be more suitable than AAA for dose calculation in rectal cancers and especially in cases involving tissue-air junctions in the path of the beam. While this study was performed for VMAT technique, it is reasonable to expect the same pattern of results in IMRT as well. Moreover, the results reinforce the point that AAA could have inherent limitations in modeling the interaction of radiation with matter especially when encountered with complex geometry and/or highly heterogeneous media, and hence it is recommended to use AAA with caution for the anatomic sites involving the above characteristics or preferably use AXB if available.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Czito BG, Meyer J. Radiation therapy in anal and rectal cancer. Surg Oncol Clin N Am 2013;22:525-43.
2. Guerrero Urbano MT, Henrys AJ, Adams EJ, Norman AR, Bedford JL, Harrington KJ, *et al.* Intensity-modulated radiotherapy in patients with locally advanced rectal cancer reduces volume of bowel treated to high dose levels. Int J Radiat Oncol Biol Phys 2006;65:907-16.
3. Arbea L, Ramos LI, Martínez-Monge R, Moreno M, Aristu J. Intensity-modulated radiation therapy (IMRT) versus 3D conformal radiotherapy (3DCRT) in locally advanced rectal cancer (LARC): Dosimetric comparison and clinical implications. Radiat Oncol 2010;5:17.
4. Mok H, Crane CH, Palmer MB, Briere TM, Beddar S, Delclos ME, *et al.* Intensity modulated radiation therapy (IMRT): Differences in target volumes and improvement in clinically relevant doses to small bowel in rectal carcinoma. Radiat Oncol 2011;6:63.
5. Hall EJ, Wuu CS. Radiation-induced second cancers: The impact of 3D-CRT and IMRT. Int J Radiat Oncol Biol Phys 2003;56:83-8.
6. Ruben JD, Davis S, Evans C, Jones P, Gagliardi F, Haynes M, *et al.* The effect of intensity-modulated radiotherapy on radiation-induced second

malignancies. Int J Radiat Oncol Biol Phys 2008;70:1530-6.
7. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys 2008;35:310-7.
8. Yu CX, Tang G. Intensity-modulated arc therapy: Principles, technologies and clinical implementation. Phys Med Biol 2011;56:R31-54.
9. Teoh M, Clark CH, Wood K, Whitaker S, Nisbet A. Volumetric modulated arc therapy: A review of current literature and clinical use in practice. Br J Radiol 2011;84:967-96.
10. Ling CC, Zhang P, Archambault Y, Bocanek J, Tang G, Losasso T. Commissioning and quality assurance of RapidArc radiotherapy delivery system. Int J Radiat Oncol Biol Phys 2008;72:575-81.
11. Tang G, Earl MA, Luan S, Wang C, Mohiuddin MM, Yu CX. Comparing radiation treatments using intensity-modulated beams, multiple arcs, and single arcs. Int J Radiat Oncol Biol Phys 2010;76:1554-62.
12. Papanikolaou N, Battista JJ, Boyer AL, Kappas C, Klein C, Mackie TR, *et al.* Tissue Inhomogeneity Corrections for Megavoltage Photon Beams. Report of Task Group No. 65 of the Radiation Therapy Committee of the American Association of Physicist in Medicine, AAPM; 2004.
13. Kan MW, Leung LH, Yu PK. Dosimetric impact of using the Acuros XB algorithm for intensity modulated radiation therapy and RapidArc planning in nasopharyngeal carcinomas. Int J Radiat Oncol Biol Phys 2013;85:e73-80.
14. Han T, Mikell JK, Salehpour M, Mourtada F. Dosimetric comparison of Acuros XB deterministic radiation transport method with Monte Carlo and model-based convolution methods in heterogeneous media. Med Phys 2011;38:2651-64.
15. Fogliata A, Nicolini G, Clivio A, Vanetti E, Mancosu P, Cozzi L. Dosimetric validation of the Acuros XB advanced dose calculation algorithm: Fundamental characterization in water. Phys Med Biol 2011;56:1879-904.
16. Bush K, Gagne IM, Zavgorodni S, Ansbacher W, Beckham W. Dosimetric validation of Acuros XB with Monte Carlo methods for photon dose calculations. Med Phys 2011;38:2208-21.
17. Pandu B, Khanna D, Mohandass P, Elavarasan R, Vivek TR, Jacob S, *et al.* Dosimetric comparison and plan evaluation of different dose computing algorithms for different radiotherapy techniques in head and neck tumors. Iran J Med Phys 2022;19:346-55.
18. Pandu B, Khanna D, Palanisamy M, Jacob S, Manichan S. Dosimetric impact of prescription point placement in heterogeneous medium for conformal radiotherapy dose calculation with various algorithms. J Med Phys 2024;49:400-9.
19. Padmanaban S, Warren S, Walsh A, Partridge M, Hawkins MA. Comparison of Acuros (AXB) and anisotropic analytical algorithm (AAA) for dose calculation in treatment of oesophageal cancer: Effects on modelling tumour control probability. Radiat Oncol 2014;9:286.
20. Kroon PS, Hol S, Essers M. Dosimetric accuracy and clinical quality of Acuros XB and AAA dose calculation algorithm for stereotactic and conventional lung volumetric modulated arc therapy plans. Radiat Oncol 2013;8:149.
21. Han T, Followill D, Mikell J, Repchak R, Molineu A, Howell R, *et al.* Dosimetric impact of Acuros XB deterministic radiation transport algorithm for heterogeneous dose calculation in lung cancer. Med Phys 2013;40:051710.
22. Rana S, Rogers K, Lee T, Reed D, Biggs C. Dosimetric impact of Acuros XB dose calculation algorithm in prostate cancer treatment using RapidArc. J Cancer Res Ther 2013;9:430-5.
23. Bhushan M, Yadav G, Tripathi D, Kumar L, Kishore V, Chowdhary RL, *et al.* Clinical dosimetric impact of AAA and AXB on high-density metallic implants in case of carcinoma cervix. Oncol J India 2019;3:28.
24. Srivastava RP, Basta K, De Gersem W, De Wagter C. A comparative analysis of Acuros XB and the analytical anisotropic algorithm for volumetric modulation arc therapy. Rep Pract Oncol Radiother 2021;26:481-8.
25. Ito T, Monzen H, Kubo K, Kosaka H, Yanagi Y, Sakai Y, *et al.* Dose difference between anisotropic analytical algorithm (AAA) and Acuros XB (AXB) caused by target's air content for volumetric modulated arc therapy of head and neck cancer. Rep Pract Oncol Radiother 2023;28:399-406.
26. Prasath SS, Ramesh Babu P. Dosimetric comparison between Acuros XB (AXB) and anisotropic analytical algorithm (AAA) in volumetric modulated arc therapy. Asian Pac J Cancer Prev 2023;24:1677-85.
27. Hirashima H, Nakamura M, Nakamura K, Matsuo Y, Mizowaki T. Dosimetric verification of four dose calculation algorithms for spine stereotactic body radiotherapy. J Radiat Res 2024;65:109-18.
28. Hoffmann L, Jørgensen MB, Muren LP, Petersen JB. Clinical validation of the acuros XB photon dose calculation algorithm, a grid-based Boltzmann equation solver. Acta Oncol 2012;51:376-85.