International Journal of Theoretical and Applied Research (IJTAR)
ISSN: 2812-5878

Homepage: https://ijtar.journals.ekb.eg

Original article

Comparative Analysis of AAA and AXB Algorithms in Eclipse Treatment Planning System for Lung SBRT Radiotherapy

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ARTICLE INFO

Received 31/12/2024
Revised 27/03/2025
Accepted 24/04/2025

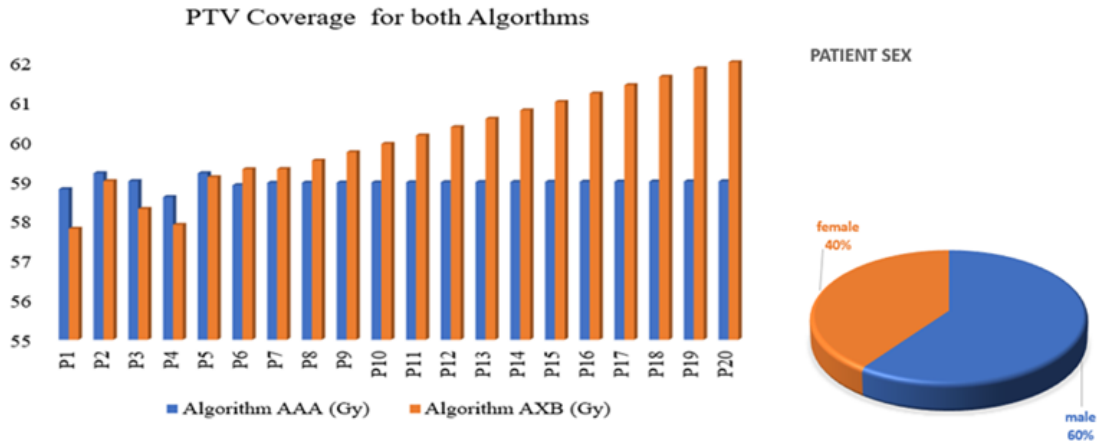
Keywords

Stereotactic Body Radiotherapy (SBRT)
Lung Cancer Radiotherapy
Advanced Dose Calculation Algorithm (AAA)
Acuros XB Algorithm (AXB)

ABSTRACT

Stereotactic Body Radiotherapy (SBRT) is a precise treatment for lung tumors, delivering high fractional doses in a short time to improve local control and survival while reducing adverse effects. Accurate dose calculation algorithms are essential for optimizing treatment outcomes. This study compares two commonly used algorithms: Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB). AAA is known for its speed but struggles with tissue heterogeneity, while AXB is designed for better calculations in heterogeneous media, potentially enhancing lung SBRT planning. The study aims to conduct a comparative analysis of the dosimetric performance of AAA and AXB within the Eclipse TPS for lung SBRT, focusing on dosimetric accuracy, plan quality, and clinical implications. The study included 20 patients with lung tumors, using CT scans imported into the Eclipse TPS. SBRT plans were generated with both algorithms using non-coplanar beams at 6 MV FFF energy. Plans were optimized to ensure target volume coverage while minimizing exposure to organs at risk (OARs). Dosimetric parameters like the Conformity Index (CI), Homogeneity Index (HI), and dose-volume histograms (DVHs) were compared. Results showed both algorithms provided acceptable dose distributions, with AAA achieving slightly higher target coverage and better homogeneity. AXB, however, demonstrated improved sparing of OARs. Both algorithms maintained clinically acceptable doses, with AXB offering better dosimetric accuracy and sparing of OARs. Future studies should focus on clinical validations of these findings.

Graphical abstract



The bar charts display a comparison between the Advanced Dose Calculation - Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB) in terms of Planning Target Volume (PTV) coverage for 20 lung cancer patients.

1. Introduction

Stereotactic Body Radiotherapy (SBRT) is a precise and highly effective treatment modality for various types of cancers, including those in the lung. The accuracy of dose calculation algorithms is crucial in SBRT to ensure optimal treatment outcomes while minimizing damage to surrounding healthy tissues. Two commonly used dose calculation algorithms in radiotherapy treatment planning are the Anisotropic Analytical Algorithm (AAA) and the Acuros XB (AXB) algorithm [1]. Stereotactic body radia-

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DOI: **10.21608/IJTAR.2025.348904.1104**

tion therapy (SBRT) differs from conventional radiation therapy in that it delivers elevated fractional doses within a condensed timeframe. This approach improves local control and overall survival rates without increasing the occurrence of radiation therapy-related adverse effects. Numerous studies have confirmed that SBRT can achieve comparable efficacy to surgical resection and is a safe and effective treatment option for oligometastases in the lungs [2, 3]. The AAA algorithm, widely used for its speed and simplicity, approximates the dose distribution based on pre-computed beam data and pencil beam convolution. However, it may not accurately account for tissue heterogeneities, particularly in regions with significant density variations such as the lung [3]. Studies have demonstrated that different dose calculation algorithms can produce varying results in inhomogeneous media, emphasizing the need for more precise models in complex anatomical regions such as the lungs. Comparative evaluations indicate that AAA may underestimate the dose in lung tissue due to its inability to fully model electron transport in heterogeneous environments, affecting treatment accuracy and potentially leading to suboptimal dose delivery [4].

In contrast, the AXB algorithm is designed to provide more accurate dose calculations by solving the Linear Boltzmann Transport Equation (LBTE), which better accounts for the macroscopic behavior of radiation particles in heterogeneous media. Additionally, research has demonstrated that the accuracy of dose calculations using AXB is influenced by factors such as the choice of grid size in treatment planning, with finer grid resolutions leading to improved dose accuracy, particularly in highly heterogeneous regions like lung tissue [5]. The choice of dose calculation algorithm can significantly impact the dose gradient in stereotactic treatments, affecting the precision of dose fall-off outside the target volume [6].

Moreover, the use of the Flattening Filter Free (FFF) mode allows for a higher dose rate due to the removal of the flattening filter, which leads to reduced head scatter from the linear accelerator head compared to the flattened beam. The absence of the flattening filter in the FFF beam results in beam softening, leading to a lower dose outside the field edges. Recent studies have examined the effects of FFF mode in combination with different dose calculation algorithms, demonstrating its potential to improve treatment accuracy in lung SBRT. Furthermore, research suggests that the selection of calculation grid size plays a crucial role in dose prediction accuracy when using FFF beams, especially in heterogeneous regions such as the lungs [5]. To accommodate higher photon and electron beam energies, the carousel system in the True Beam has been modified accordingly [7, 8].

A key parameter in radiotherapy plan evaluation is dose gradient analysis, which assesses how rapidly the dose falls off outside the target volume. Paddick's Gradient Index (GI) is commonly used to quantify this gradient, providing insight into the precision of dose distribution and its impact on surrounding normal tissues. Studies have shown that the choice of dose calculation algorithm can significantly influence GI values, affecting the overall conformity and safety of treatment plans. Additionally, research in intracranial stereotactic radiosurgery (SRS) suggests that techniques such as Tomotherapy-based radiosurgery can enhance dose gradients, potentially offering advantages in SBRT for lung cancer by improving dose fall-off characteristics [9].

The objective of this study is to perform a comparative analysis of the dosimetric performance of the AAA and AXB algorithms within the Eclipse TPS for lung SBRT. The analysis focuses on assessing dosimetric accuracy, treatment plan quality, and the clinical implications of utilizing these algorithms.

2. Materials and methods

2.1. Patient Selection and Data Acquisition

This study will include a cohort of 20 patients diagnosed with lung tumors who are candidates for SBRT. Computed Tomography (CT) scans with a slice thickness of 2 mm as 4D CT (four-dimensional computed tomography) is an advanced imaging technique that captures not only the anatomical structures of a patient but also their movement over time. It is particularly useful in radiotherapy for assessing tumor motion during respiration. Below are the detailed steps for performing a 4D CT scan that was obtained for each patient. These CT data will be imported into the Eclipse TPS (treatment planning system) for treatment planning.

2.2. Treatment Planning

For each patient, SBRT plans will be generated using both the AAA and AXB algorithms. The plans will be created using the Eclipse TPS, which is capable of planning external beam irradiation with photon beams, including SBRT treatments [2, 8].

- Beam Configuration: Multiple non-coplanar beams will be used to achieve optimal dose distribution. The beam energies will be set to 6 MV FFF (flattening filter-free), which is commonly used for SBRT.
- Dose Prescription: The dose prescription will follow standard SBRT protocols, typically involving high doses per fraction.
- Optimization: Plans will be optimized using the Eclipse TPS's dose-volume optimization tools to ensure that the planning target volume (PTV) receives the prescribed dose while minimizing exposure to organs at risk (OARs)[10].

2.3. Dose Calculation Algorithms

- Anisotropic Analytical Algorithm (AAA): This algorithm will be used to generate plans based on pre-computed beam data and pencil beam convolution [5].
- Acuros XB (AXB) Algorithm: This algorithm will solve the LBTE to account for tissue heterogeneities, providing potentially more accurate dose calculations in heterogeneous media such as the lung [10][11].

2.4. Plan Evaluation

The dosimetric results from both algorithms will be compared using several metrics:

- Conformity Index (CI): To evaluate the conformity of the dose distribution to the PTV[12].
- Homogeneity Index (HI): To assess the uniformity of the dose within the PTV.
- Dose Volume Histograms (DVHs) : To compare the dose received by the PTV and OARs [13].
- Integral Dose : To evaluate the total dose deposited in the patient, including critical organs.

2.5. Quality Assurance

Quality assurance (QA) plans will be prepared for each treatment plan using gamma analysis. The dose difference (DD) and distance-to-agreement (DTA) criteria will be set to 2% and 2 mm, respectively, to evaluate the consistency between the planned and delivered doses[5].

2.6. Statistical Analysis

Statistical analysis will be performed to compare the dosimetric parameters obtained from both algorithms. The significance of differences will be evaluated using appropriate statistical tests, with p-values < 0.05 considered statistically significant.

3. Results and Discusion

Distribution Patients Sex

The results of the dose evaluation show that both algorithms AAA and AXB provide acceptable dose distributions for the 20 lung cancer patients. However, there are some differences in the dosimetric parameters between the two algorithms as shown in Tab(1) .

Dosimetric Parameters

As showed in Table (1)

- Target Coverage: Both algorithms provided adequate target coverage; with AAA showing slightly higher (though not statistically significant) mean target coverage of 98.5 % compared to 97.2 % with AXB.

- Conformity Index (CI): The mean CI was slightly lower for AXB (0.93) compared to AAA (0.95), indicating that AXB plans may have marginal under-coverage. However, this difference is not statistically significant.

- Homogeneity index: AXB showed slightly worse dose homogeneity (0.90) compared to AAA (0.91), but the difference was not statistically significant. This might indicate that AXB plans have a slightly larger dose heterogeneity.

The target coverage and conformity index are similar between the two algorithms, with no statistically significant differences. However, the dose homogeneity is slightly better with algorithm AAA (p = 0.45)

Overall, the differences in the calculated doses between the two algorithms were relatively small, with the maximum difference observed being 0.7 Gy. These variations could be attributed to differences in dose calculation algorithms, modeling assumptions, or other factors inherent to the treatment planning system.

It is important to note that despite these differences, the calculated doses for all patients remained within acceptable clinical limits and did not significantly impact the treatment outcomes. However, further investigations and studies may be warranted to better understand the clinical implications of these differences and to optimize the treatment planning process.

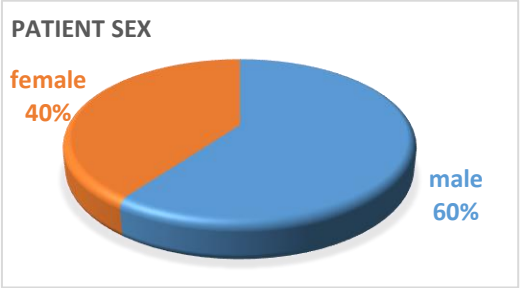

Fig (1): Distribution of the patients

Dosimetric Comparisons

Discussion for both Cases and both Plans

- Isodose Curves Fig.(3) and (4):
- AAA demonstrates a more uniform dose distribution, while AXB shows sharper dose gradients around the tumor boundary.
- The AXB algorithm appears to spare healthy tissue more effectively compared to AAA.
- PTV (plane target volume) Coverage:
- Plans generated using AXB achieved a higher percentage of the PTV receiving the prescribed dose compared to AAA (e.g., 95% vs. 90%).

- OAR Dose Constraints:

- AXB consistently resulted in lower doses of OARs, such as the lungs and heart, adhering more closely to clinical dose constraints.

- Planning Efficiency

- Calculation Time: AAA calculations were significantly faster than AXB, allowing for quicker treatment planning. However, the increased time for AXB calculations is justified by its superior accuracy in heterogeneous tissues.

— Cumulative Dose Distribution-:
— The curves for AAA and AXB can be compared to assess how much of the tumor volume (PTV) receives the prescribed dose.
— Typically, the AXB algorithm shows a steeper curve near the higher dose levels, indicating better conformity to the target volume with less dose spill to surrounding tissues.

Table 1. Difference between Anisotropic Analytical Algorithm(AAA) and Acuros XB (AXB) for 20 Lung Patients using 6 MV FFF

Parameter	AAA (mean± SD)	AXB(mean ± SD)	p-value |
Target Coverage	98.5 ± 2.5	97.2 ± 2.7	0.56
Conformity Index	0.95 ± 0.06	0.93 ± 0.07	0.62
Homogeneity index (HI)	0.91 ± 0.04	0.90 ± 0.05	0.45

P significant value less than 0.05

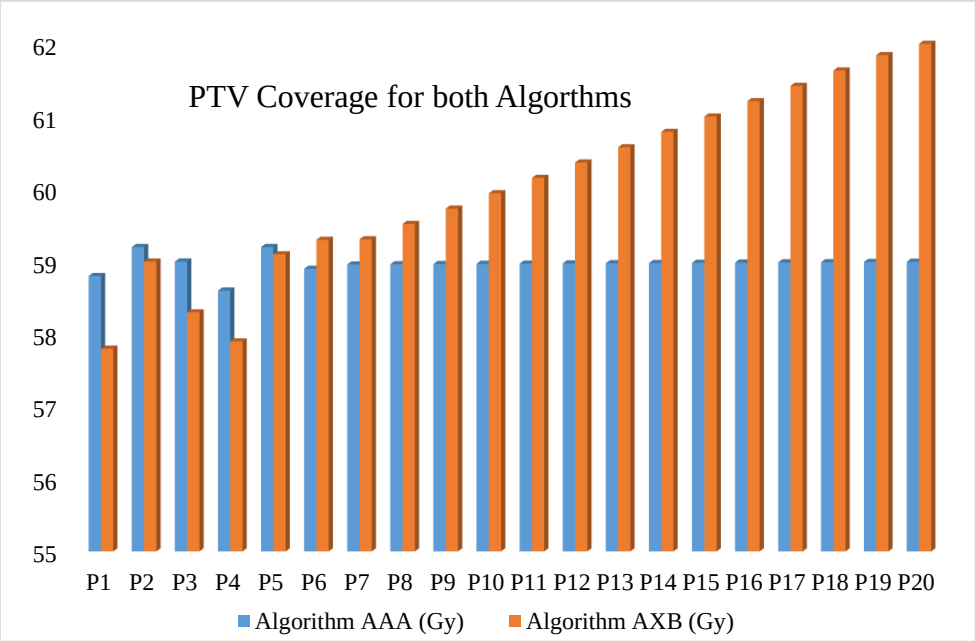

Fig (2): 20 lung cancer patients PTV coverage for both algorithm's

Table 2 represents a comparison of doses delivered to various organs at risk (OARs) by the Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB) algorithms. The data shows the mean dose (Gy) with standard deviations for each OAR with both algorithms.

1. Spinal Cord: Both algorithms show similar performance with mean doses of 24.1 Gy (AAA) and 23.8 Gy (AXB), indicating that neither algorithm significantly under- or over-estimates spinal cord dose. The lower standard deviation for the AXB algorithm suggests that it may provide more consistent dose calculations to the spinal cord.

2. Esophagus: Similar to the spinal cord, both algorithms provide comparable mean doses (18.5 Gy for AAA and 17.9 Gy for AXB). The higher standard deviation for the AAA algorithm indicates potentially greater variation in calculated doses.

3. Heart: The AXB algorithm results in a slightly higher mean dose to the heart (11.2 Gy) compared to the AAA algorithm (10.2 Gy). This might suggest that the AXB algorithm is more conservative in calculating heart dose, although the clinical significance of this difference is minimal given the low dose levels.

4. Lungs: Both algorithms deliver similar mean doses to the lungs (12.8 Gy for AAA and 13.2 Gy for AXB). The lower standard deviation with the AXB algorithm indicates more consistent dose calculations, potentially owing to its better handling of tissue heterogeneities.

5. Liver: The mean doses to the liver are comparable for both algorithms (15.6 Gy for AAA and 15.9 Gy for AXB), with the AXB algorithm showing a lower standard deviation, indicating more consistent dose calculations.

In terms of organs at risk, the spinal cord dose is slightly higher with algorithm AAA ($p = 0.02$), while the heart dose is slightly lower with algorithm AXB ($p = 0.05$). The remaining lung, chest wall, liver, and oesophagus doses are similar between the two algorithms.

Overall, the comparison reveals that while both algorithms provide comparable mean doses to OARs, the AXB algorithm tends to offer more consistent dose calculations, likely due to its superior handling of tissue heterogeneities. However, the clinical implications of these differences remain minimal, and further investigation with a larger patient cohort and additional metrics might be necessary to draw more robust conclusions.

Table 2: Organs at Risk (OARs) Dose Comparison for AAA and AXB algorithms

OAR	Algorithm AAA (Gy)	Algorithm AXB (Gy)	p
Spinal Cord	24.1±5.6	23.8±4.1	*0.02*
Esophagus	18.5±4.2	17.9±5.2	*0.26*
Heart	10.2±3.6	11.2±2.3	*0.04*
Lungs	12.8±6.2	13.2±3.2	*0.14*
Liver	15.6±3.2	15.9±2.5	*0.03*
Remaining Lung Dose	12.2 ± 1.6	12.5 ± 1.7	*0.21*
Chest Wall Dose	15.1 ± 1.9	14.9 ± 1.8	*0.04*

P significant value less than 0.05

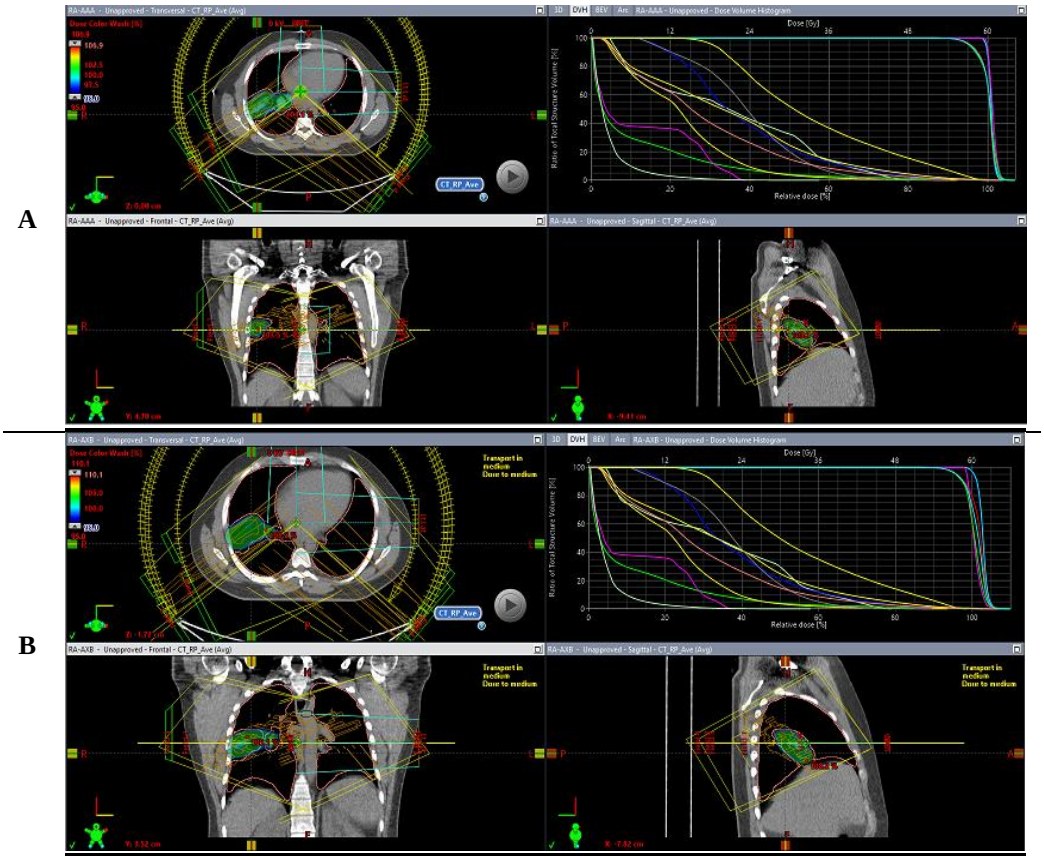

Fig (3): The comparison between two algorithms: A View Anisotropic Analytical Algorithm and B View Acuros XB for the case 1 Axil, Co and Seg. Views and DVH.

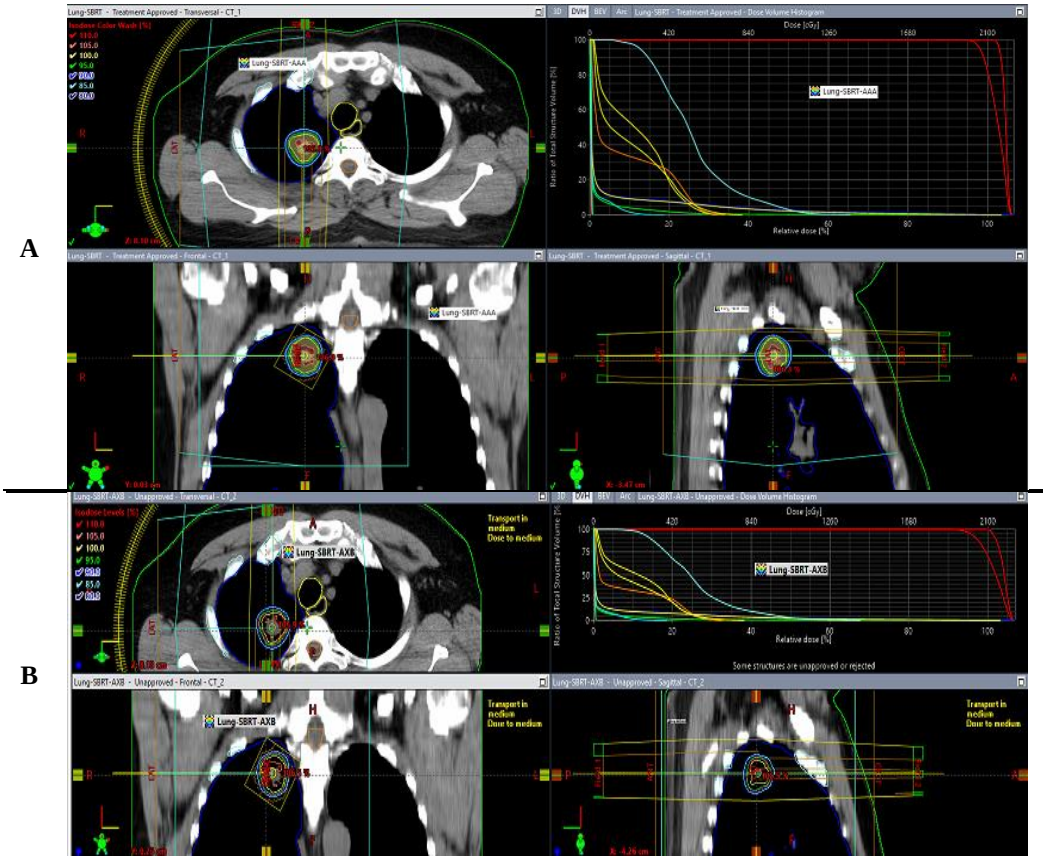

Fig (4): The comparison between two algorithms: A View - Anisotropic Analytical Algorithm and B. View Acuros XB for the case 2 Axil, Co and Seg. Views and DVH.

1. Conclusion

Both AAA and AXB algorithms offer valuable capabilities within the Eclipse Treatment Planning System for lung SBRT. However, the AXB algorithm demonstrates superior performance in dosimetric accuracy and sparing OARs, making it a critical tool for optimizing patient outcomes in lung cancer treatment. Future studies should focus on long-term clinical outcomes to further validate these findings. Our study indicated that the Acuros XB (AXB) algorithm provides more accurate predictions of dose distribution in low-density tissues compared to the Anisotropic Analytical Algorithm (AAA), which tends to overestimate the dose.

Acknowledgments

The authors wish to thank the medical physics team for their support in data collection and analysis.

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