ORIGINAL ARTICLE

IMPACT OF DENTAL IMPLANTS ON DOSE CALCULATION ACCURACY: A COMPARISON OF ACUROS XB AND ANISOTROPIC ANALYTICAL ALGORITHM IN HEAD AND NECK RADIOTHERAPY

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PJR July - September 2026; 36(3): 183-189

ABSTRACT

PURPOSE: To compare the dosimetric performance of the Acuros XB (AXB) and Anisotropic Analytical Algorithm (AAA) dose calculation algorithms in head and neck cancer patients with metallic dental implants undergoing VMAT radiotherapy. **METHODS:** A retrospective dosimetric study was conducted on fifteen head and neck squamous cell carcinoma patients with metallic denture implants. For each patient, two VMAT plans were generated in Eclipse Treatment Planning System using identical beam arrangements and optimization objectives, with dose calculations performed separately using AAA and AXB algorithms. Dosimetric parameters including PTV maximum dose, minimum dose, D95%, and doses to organs at risk (brainstem, spinal cord, optic chiasm, and parotid glands) were evaluated and compared. Statistical analysis was performed using SPSS with a significance level of $p < 0.05$. **RESULTS:** AXB demonstrated higher PTV maximum dose estimates (110.0% vs 108.56%) and lower PTV minimum dose estimates (77.25% vs 81.27%) compared with AAA. PTV D95% was slightly lower with AXB (96.37% vs 97.50%), suggesting a more conservative assessment of target coverage. For organs at risk, AXB predicted higher doses to the optic chiasm (26.47 Gy vs 24.46 Gy), brainstem (35.87 Gy vs 33.39 Gy), spinal cord (34.70 Gy vs 31.59 Gy), and parotid glands (25.70 Gy vs 25.35 Gy). These findings indicate that AAA may underestimate dose in regions affected by metallic implants and tissue heterogeneities. **CONCLUSION:** Acuros XB provides more realistic dose calculations in the presence of metallic dental implants by accurately accounting for tissue heterogeneity and high-density materials. Its improved modelling capability may enhance treatment plan evaluation and support safer dose delivery in head and neck radiotherapy.

Keywords: Acuros XB, Anisotropic Analytical Algorithm, Head and Neck Cancer, Dental Implants, VMAT, Dose Calculation, Radiotherapy Planning.

AAA - Anisotropic Analytical Algorithm, AXB - Acuros XB, VMAT - Volumetric Modulated Arc Therapy, PTV - Planning Target Volume, OAR - Organ at Risk, TCP - Tumor Control Probability, NTCP - Normal Tissue Complication Probability

Introduction

Head and neck cancers present significant treatment challenges because tumors are often located in close proximity to critical organs and radiosensitive structure.

Head and neck cancers represent a diverse group of malignancies arising from the oral cavity, pharynx, larynx, and associated anatomical structures. Radio-

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Submitted 18 July 2026, Accepted 30 August 2026

therapy plays a crucial role in the management of these cancers, either as a definitive treatment modality or in combination with surgery and chemotherapy. Due to the complex anatomy of the head and neck region and the close proximity of tumors to critical organs at risk (OARs), accurate dose delivery is essential to achieve optimal tumor control while minimizing radiation-induced toxicity.[1]

However, if the patients have metallic dental implants, such as dentures, then it is likely to influence on calculations of radiation dose. The metal produces scattering and alterations in the mode of passage of radiation through tissues, causing probable errors in the treatment plan. Proper and safe treatment requires accurate measurements in regards to dosage. That is where Treatment Planning Systems (TPS) steps in. TPS utilizes certain algorithms to predict how radiation will act in the body. Some of the popular algorithms are the Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB). Although both are used to help in the radiotherapy planning, they vary with regard to how they compute dose, specifically around metal and different tissue types.[2]

The accuracy of dose calculation in such challenging situations largely depends on the treatment planning algorithm employed. The Anisotropic Analytical Algorithm (AAA) is a widely used convolution-superposition algorithm that estimates dose distribution by modeling photon interactions within heterogeneous media. Although AAA has demonstrated satisfactory performance in many clinical applications, its ability to accurately predict dose near high-density materials remains limited. In contrast, Acuros XB (AXB) is an advanced deterministic algorithm based on the solution of the Linear Boltzmann Transport Equation (LBTE), allowing more accurate modeling of material composition and radiation transport in heterogeneous environments.[3-4] Several studies have reported improved agreement between AXB and Monte Carlo calculations compared with AAA, particularly in regions containing significant density variations. Enhanced dosimetric accuracy has been observed for treatments involving air cavities, bone interfaces, and metallic implants. Nevertheless, limited data are available regarding the comparative performance of AAA and AXB in head and neck cancer patients with metallic dental implants. Furthermore, few studies have simultaneously evaluated target volume coverage and organ-at-risk dose estimation under these clinically relevant conditions.[5]

Therefore, the aim of this study was to compare the dosimetric performance of Acuros XB and the Anisotropic Analytical Algorithm in VMAT treatment plans for head and neck cancer patients with metallic denture implants. Dosimetric parameters related to target coverage and organ-at-risk protection were analyzed to determine the potential clinical impact of algorithm selection in the presence of metal-induced heterogeneities.[6]

Methodology

This work compared the dosimetric of two treatment planning algorithms named Acuros XB (AXB) and Anisotropic Analytical Algorithm (AAA) in patients with head and neck cancer disease with metallic denture implants. The methodology was developed to obtain homogeneous and reliable evaluation results for all patient cases using standardized imaging, planning, and evaluation methods.[7,8]

Patient Selection and Imaging

- Fifteen confirmed head and neck squamous cell carcinoma patients with metallic denture implants were drawn from Shaukat Khanum Memorial Cancer Hospital records.
- CT simulation was performed using a 16-slice scanner with 5 mm slice thickness.
- Patients were immobilized in a supine position using thermoplastic head, neck, and shoulder masks to ensure consistent positioning.

Contouring and Planning

- Target volumes (GTV, CTV, PTV) were delineated using CT-MRI fusion.
- Organs at risk (OARs) such as the brainstem, spinal cord, optic chiasm, and parotid glands were outlined.
- To realize images of the quality and contour accuracy near the implants, the methods of metal artifact reduction were used.

Treatment Planning

All treatment plans were generated using the Eclipse Treatment Planning System (Version 18.1, Varian Medical Systems, Palo Alto, CA, USA). For each patient, two VMAT plans were created using identical beam arran-

gements, optimization objectives, and dose constraints. One plan was calculated using the Anisotropic Analytical Algorithm (AAA) and the other using the Acuros XB (AXB Version 18.1) algorithm.

Treatment plans were generated using 6 MV photon beams delivered through a dual-arc VMAT technique. Dose calculations were performed with a 2.5 mm dose calculation grid size. For AXB calculations, the Dose-to-Medium (Dm) reporting mode was utilized to achieve more accurate dose estimation in heterogeneous tissues and high-density materials.

A Simultaneous Integrated Boost (SIB) technique was employed, delivering 60 Gy to PTV60 and 50 Gy to PTV50 in 30 fractions. Optimization objectives prioritized adequate target volume coverage while minimizing radiation exposure to organs at risk (OARs), including the spinal cord, brainstem, optic chiasm, and parotid glands. Both AAA and AXB plans were optimized under identical planning conditions to ensure a fair dosimetric comparison.

Results

The dosimetric outcomes of this study reveal consistent differences between the AAA and Acuros XB algorithms across key target and organ-at-risk parameters. While both algorithms produced clinically acceptable plans, Acuros XB demonstrated improved accuracy in modelling complex anatomical regions, particularly near metallic denture implants. The following table summarizes the average values of key dosimetric parameters, highlighting how each algorithm performed in estimating maximum and minimum target doses, PTV coverage, and doses to critical structures such as the optic chiasm, brainstem, spinal cord, and parotid glands.[9-14]

These differences underscore the importance of selecting an appropriate algorithm for accurate dose delivery in head and neck cancer cases involving high-density materials. As it is clearly shown in the following table, Acuros XB allows a more conservative and physically accurate dose estimation, particularly in areas compromised by metallic artifacts and tissue heterogeneities.

Parameter	AAA (Mean Value)	AXB (Mean Value)	Key Observations
PTV Max Dose (%)	108.56	110.00	AXB estimates higher maximum dose, capturing hotspots near dense implants.
PTV Min Dose (%)	81.27	77.25	AXB shows lower minimum dose, reflecting conservative dose in cold regions.
PTV D95 (%)	97.50	96.37	AAA overestimates target coverage slightly; AXB offers realistic estimation.
Optic Chiasm Dose (Gy)	24.46	26.47	AXB estimates higher dose, likely more accurate near skull base and cavities.
Brainstem Dose (Gy)	33.39	35.87	AXB shows higher dose, which may avoid underestimated toxicity risks.
Spinal Cord Dose (Gy)	31.59	34.70	AXB's estimate is safer; avoids breaching critical tolerance by revealing true dose.
Parotid Glands Mean Dose (Gy)	25.35	25.70	Slightly higher in AXB; reflects better modelling of dose spread near soft tissues.

Target Volume Delineation

Contouring was performed by a multidisciplinary team including radiation oncologists, radiologists, and medical physicists. The Gross tumor Volume (GTV) included the primary tumor and involved lymph nodes, as visualized on imaging and clinical assessment. The Clinical Target Volume (CTV) encompassed the GTV plus regions at risk of microscopic spread, including adjacent tissues and nodal levels depending on tumor site and stage. A

DOSIMETRIC PARAMETERS								
	Patient no.	PTV 3D Max (%)	PTV 3D Min (%)	PTV D95 (%)	Optic Chasim (Gy)	Brain Stem (Gy)	Spinal Cord (Gy)	Parotids mean (Gy)
AAA	1	108.7	88.1	99.1	–	20	27	19.1
AAA	2	110	83	99.2	–	29.1	38.34	44.1
AAA	3	111.1	70.8	99	52.34	47.93	9.75	12.32
AAA	4	106.2	86.2	98.8	1.37	26	31.23	17.75
AAA	5	110.4	81.5	97.9	–	10.57	32.74	38.22
AAA	6	109.5	84.5	98.6	2.9	38.85	37.94	36.17
AAA	7	106.3	70.6	90.6	25.65	27.5	22.44	14.66
AAA	8	106.7	86	97.7	0.53	9.89	10.43	4.79
AAA	9	110.2	63	95.4	7.48	36.56	36.76	25.7
AAA	10	106	85.6	98.2	2.47	32.16	40.65	24.78
AAA	11	110.1	86	95.8	5.45	25.14	29.5	22.95
AAA	12	107.3	89.5	98.6	48.75	50.18	37.22	31.16
AAA	13	109.5	68	96.3	21.38	45.48	39.87	38.06
AAA	14	107.8	84.5	98.7	–	48.3	44.4	27
AAA	15	108.6	91.7	98.6	53.75	53.16	35.65	23.45

Dosimetry Parameters of Anisotropic Analytical Algorithm (AAA)

margin of 5-10 mm (edited manually where appropriate) was added to form the Planning Target Volume (PTV) to account for setup variability and internal organ motion.

Overview of Dosimetric Parameters Analysed

The following tables show the comparison for both the methods used in the research data.

DOSIMETRIC PARAMETERS								
	Patient no.	PTV 3D Max (%)	PTV 3D Min (%)	PTV D95 (%)	Optic Chasim (Gy)	Brain Stem (Gy)	Spinal Cord (Gy)	Parotids mean (Gy)
Acuros	1	107.4	85.5	96.4	–	24.8	29.27	20.06
Acuros	2	106.8	84.7	97.3	1.62	23.13	35.02	37.18
Acuros	3	111.6	70.6	98.8	52.14	47.37	9.7	11
Acuros	4	111.9	54.4	91.2	–	25	30.3	22.5
Acuros	5	111.1	75.5	96.5	–	11.09	32.65	38.61
Acuros	6	111.3	82.7	96.9	2.1	39.8	39.5	34
Acuros	7	110.5	69.7	95.2	48.66	53.98	44.41	27.3
Acuros	8	110.2	81.7	95.3	–	28.86	30.35	13.59
Acuros	9	111.3	85.2	99.6	3.7	35.05	36.7	23.3
Acuros	10	110.1	84.7	97.1	2.18	33.74	43.03	25.48
Acuros	11	112.5	78.4	98.4	3.6	27.38	30	24.83
Acuros	12	106.3	81	95.1	44.14	50.18	35.58	30.65
Acuros	13	110.9	55.9	95.1	27.73	40.56	46	28
Acuros	14	109.8	82.7	97.5	22.8	44.9	43.06	25.37
Acuros	15	108.3	86	95.1	53.94	52.27	35	23.67

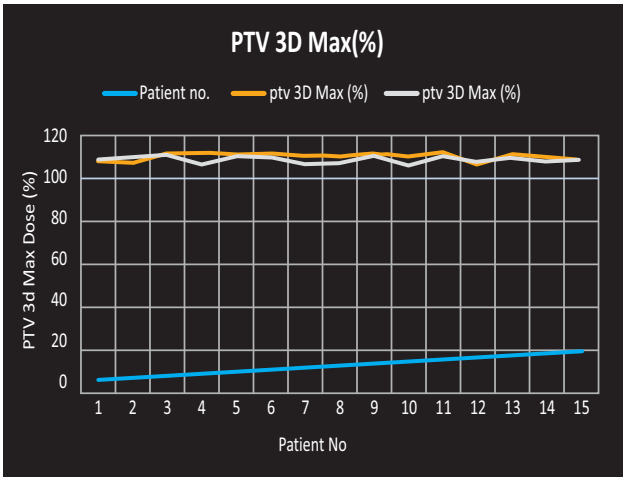
Dosimetry Parameters of Acuros

Parameter	AAA Mean	AXB Mean	p-value
PTV Max Dose (%)	108.56	110.00	0.033
PTV Min Dose (%)	81.27	77.25	0.173
PTV D95 (%)	97.50	96.37	0.178
Optic Chiasm Dose (Gy)	24.46	26.47	0.498
Brainstem Dose (Gy)	33.39	35.87	0.291
Spinal Cord Dose (Gy)	31.59	34.70	0.134
Parotid Mean Dose (Gy)	25.35	25.70	0.807

Statistical analysis demonstrated a significant difference between AAA and AXB for PTV maximum dose, with AXB predicting higher maximum dose values than AAA (110.00% vs 108.56%, p = 0.033). No statistically significant differences were observed for PTV minimum dose (p = 0.173), PTV D95% (p = 0.178), optic chiasm dose (p = 0.498), brainstem dose (p = 0.291), spinal cord dose (p = 0.134), or parotid mean dose (p = 0.807). Although several dosimetric parameters were consistently higher with AXB, these differences did not reach statistical significance within the present patient cohort.

PTV 3D Max

AXB-generated plans gave the PTV a slightly higher maximum dose (110%),, whereas AAA-calculated plans gave it a lower maximum dose (108.56%). Because AAA uses a simpler method of photon transport, it tends to underestimate high-dose locations within AXB, particularly those around metallic implants. This indicates improved demarcation of these areas. To more realistically introduce dosage escalation into extremely high-density zones and more precisely account for complicated tissue and material heterogeneities, AXB employs a deterministic approach based on the Linear Boltzmann Transport Equation (LBTE).



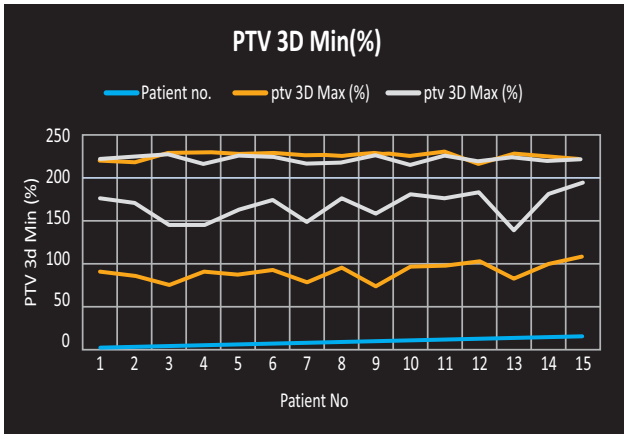
PTV 3D Min

PTV 3D Min

Contrary to the maximum dose, the minimum PTV dose was lower with AXB (77.247 Gy) than with AAA (81.267 Gy), reflecting AXB's increased spatial resolution of low dose regions and cold spots. This may result in more conservative but realistic assessments of PTV coverage, especially in patients with significant implant-related artifacts that disrupt uniform dose distribution.

Comparison of Anisotropic Analytical and Acuros Algorithms

When planning radiation therapy, especially for complex areas like the head and neck, the accuracy of your dose



PTV 3D Min

calculations is crucial. Two commonly used algorithms are the Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB). Let's break down how they differ and why it matters.

Feature	AAA	Acuros XB (AXB)
Type	Model-based convolution-Superposition	Grid-based Boltzmann Transport Equation (LBTE) solve
Medium Modeling	Assumes all tissues are water with varying densities	Explicitly models different materials (bone, air, metal,etc.)
Hetero-geneity Handling	Approximate	Highly accurate

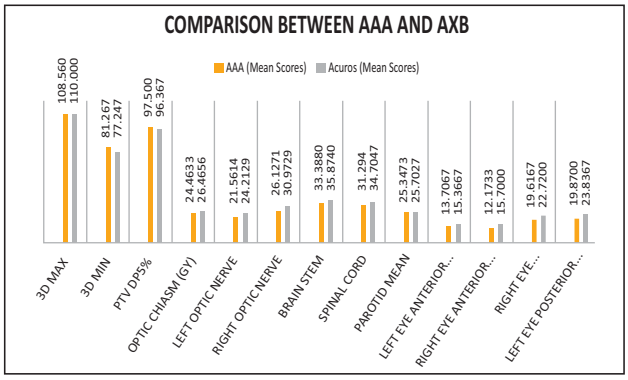
Algorithmic Basis

Calculation Accuracy

Context	AAA	AXB
Homogeneous tissue	Good	Excellent
Heterogeneous tissue (e.g., bone, air cavities)	Less accurate; may overestimate dose	More accurate; accounts for scatter, attenuation
High-Z materials (implants)	Limited accuracy	Superior modeling

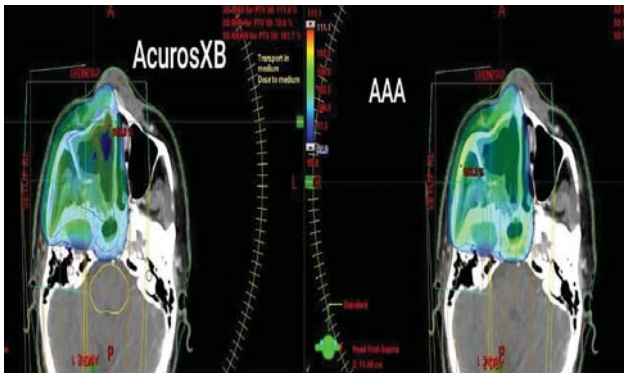
Calculation Accuracy

Comparison Between AAA and AXB



Comparison between AAA and AXB

Figure displays axial CT images comparing dose distributions calculated using Acuros XB (left) and AAA (right). The PTV is well covered in both, but Acuros shows a slightly broader high-dose region (red), likely due to its better modeling of tissue heterogeneities and implant scattering.



Axial Slice Comparison

Discussion

The present study compared the dosimetric performance of the Acuros XB (AXB) and Anisotropic Analytical Algorithm (AAA) in head and neck cancer patients with metallic denture implants treated using VMAT. The results demonstrated noticeable differences between the two algorithms, particularly in regions affected by tissue heterogeneities and high-density dental materials. AXB consistently predicted higher maximum doses and lower minimum doses within the target volumes while also estimating slightly higher doses to several organs at risk (OARs), including the brainstem, spinal cord, optic chiasm, and parotid glands.

These findings can be attributed to the fundamental differences in the dose calculation methodologies employed by the two algorithms. AAA is based on a convolution-superposition approach and approximates tissue heterogeneities using density scaling. While this approach performs adequately in relatively homogeneous media, it has limitations in accurately modeling photon scatter and electron transport near interfaces involving high-density materials such as dental implants. In contrast, AXB solves the Linear Boltzmann Transport Equation (LBTE), allowing explicit modeling of different materials and improved characterization of radiation interactions in heterogeneous environments. Consequently, AXB is capable of providing a more realistic

representation of dose perturbations, backscatter effects, and attenuation caused by metallic structures. The superiority of AXB in heterogeneous conditions has been reported in several previous investigations. Bush et al. demonstrated that AXB showed closer agreement with Monte Carlo simulations than AAA, particularly in regions containing low-density and high-density heterogeneities. Similarly, Seniwal et al. reported improved dosimetric accuracy of AXB compared with AAA when benchmarked against Monte Carlo calculations. Since Monte Carlo methods are widely regarded as the gold standard for radiation dose calculation, the closer agreement of AXB with Monte Carlo data supports the reliability of the present findings. Although direct Monte Carlo validation was not performed in this study, the observed trends are consistent with published literature.

From a clinical perspective, accurate dose calculation is particularly important in head and neck radiotherapy because target volumes are often located in close proximity to critical organs. Underestimation of dose to OARs may increase the risk of radiation-induced toxicity, whereas overestimation of target coverage may lead to an inaccurate assessment of treatment quality. The higher OAR doses predicted by AXB in this study suggest that AAA may underestimate the actual dose delivered to critical structures in the presence of metallic implants. Therefore, AXB may provide a safer basis for treatment plan evaluation and optimization, particularly when stringent dose constraints are required.

The differences observed in PTV dose metrics may also have implications for tumor control. The slightly lower PTV D95% and minimum dose values reported by AXB indicate a more conservative assessment of target coverage. Although these differences were relatively small, accurate identification of potential cold spots is important because inadequate dose delivery to portions of the tumor volume may adversely affect local tumor control probability (TCP). By more accurately accounting for dose perturbations around metallic implants, AXB may help clinicians identify areas requiring plan modification and thereby improve treatment effectiveness. Overall, the results of this study support the growing body of evidence favoring the use of Acuros XB for radiotherapy planning in anatomically complex regions. The improved handling of tissue heterogeneities and metallic implants makes AXB a valuable tool for enhancing the accuracy, safety, and reliability of treatment planning in head and neck cancer patients.

Limitations

Several limitations of this study should be acknowledged. First, the sample size was relatively small, consisting of only fifteen patients, which may limit the generalizability of the findings. Second, the study was conducted at a single institution and therefore may not fully represent variations in clinical practice across different centers. Third, although AXB has been extensively validated against Monte Carlo methods in previous studies, direct Monte Carlo verification was not performed in the present investigation. Finally, the retrospective nature of the study may introduce inherent selection biases. Future studies involving larger patient cohorts, multi-institutional datasets, and direct Monte Carlo validation are warranted to further establish the clinical advantages of AXB in patients with metallic dental implants.

Conclusion

This study compared the dosimetric performance of the Acuros XB (AXB) and Anisotropic Analytical Algorithm (AAA) in head and neck cancer patients with metallic denture implants undergoing VMAT treatment. The results demonstrated that AXB provides a more realistic representation of dose distribution in the presence of high-density dental materials and tissue heterogeneities. Compared with AAA, AXB predicted higher maximum doses, lower minimum doses, and slightly increased doses to several critical organs, indicating improved modeling of scatter, attenuation, and backscatter effects around metallic structures.

The observed differences suggest that AAA may underestimate dose in anatomically complex regions, potentially affecting the accuracy of target coverage and organ-at-risk assessment. By solving the Linear Boltzmann Transport Equation and explicitly accounting for material composition, AXB offers enhanced dosimetric accuracy and greater confidence in treatment plan evaluation.

Based on these findings, Acuros XB should be considered the preferred dose calculation algorithm for head and neck radiotherapy patients with metallic dental implants, particularly when accurate dose estimation near critical structures is required. Further studies

involving larger patient populations and Monte Carlo validation are recommended to confirm the clinical significance of these dosimetric differences and their potential impact on treatment outcomes.

FUTURE DIRECTIONS: Future investigations should include larger multicenter cohorts and direct Monte Carlo validation to further quantify dose differences near dental implants. The impact of these dosimetric variations on tumor control probability (TCP), normal tissue complication probability (NTCP), and long-term clinical outcomes should also be explored.

ETHICAL CONSIDERATIONS: This retrospective study was conducted using anonymized treatment planning data obtained from previously treated patients. Patient confidentiality was maintained throughout the study, and no identifiable patient information was included in the analysis.

CONFLICT OF INTEREST: The authors declare that they have no conflicts of interest related to this work.

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