

Collimator Angle and Its Implications on Treatment Outcomes in Volumetric Modulated Arc Therapy (Vmat): A Systematic Review and Meta-Analysis

Samaila B *, and Maidamma B

Department of physics with electronics, Federal University Birnin Kebbi.

***Corresponding Author:** Samaila B., Department of physics with electronics, Federal University Birnin Kebbi.

Received Date: May 14, 2025; **Accepted Date:** May 22, 2025; **Published Date:** June 15, 2025

Citation: Samaila B., Maidamma B., (2026), Collimator Angle and Its Implications on Treatment Outcomes in Volumetric Modulated Arc Therapy (Vmat): A Systematic Review and Meta-Analysis, *J. Cancer Research and Cellular Therapeutics*. 10(3); DOI:10.31579/2640-1053/263

Copyright: © 2026, Samaila B. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Background: Volumetric Modulated Arc Therapy (VMAT) is an advanced radiotherapy technique that enables highly conformal dose delivery while minimizing radiation exposure to surrounding healthy tissues. The collimator angle is a critical planning parameter that influences beam modulation, dose distribution, and treatment efficiency. However, its quantitative impact on treatment outcomes remains insufficiently defined across different anatomical sites and planning techniques.

Purpose: This study aimed to systematically review and meta-analyze the impact of collimator angle on target coverage, dosimetric parameters, organ-at-risk (OAR) sparing, treatment efficiency, and clinical outcomes in VMAT.

Methods: A systematic review was conducted following PRISMA guidelines, including peer-reviewed studies published. Databases searched included PubMed, Scopus, Web of Science, Embase, and Google Scholar. Studies were included if they evaluated collimator angle effects on VMAT dosimetry, including parameters such as D95, Dmean, conformity index (CI), homogeneity index (HI), monitor units (MUs), and OAR dose. A narrative and thematic meta-analysis was performed.

Results: Across multiple studies, target coverage remained largely stable over a wide range of collimator angles (0°–90°), demonstrating the robustness of VMAT optimization algorithms. However, moderate collimator angles between 15° and 45° consistently produced optimal dosimetric outcomes, including improved CI, HI, and reduced MUs. In prostate VMAT, optimal performance was observed at 20°, 30°, and 45°, while nasopharyngeal carcinoma studies reported improved PTV coverage of approximately 92–94% within the 15°–30° range. Advanced optimization techniques such as SACAO reduced monitor units by approximately 15.7% and field size by 41.1%, significantly improving efficiency and dose conformity. Higher collimator angles (>45°) demonstrated mixed effects, including improved OAR sparing in some cases but reduced delivery accuracy, with γ -index passing rates decreasing by up to 5.6%. Furthermore, collimator misalignment exceeding $\pm 1^\circ$ resulted in substantial degradation of target coverage and homogeneity, with variations in HI reaching up to 75% in extreme cases. OAR sparing was primarily influenced by multileaf collimator (MLC) design and advanced delivery techniques rather than collimator angle alone. MLC-based shielding reduced OAR dose by up to 20%, while narrower leaf widths (2.5 mm vs 5 mm) improved dose gradients and normal tissue sparing.

Conclusion: Collimator angle has minimal direct impact on target coverage but significantly influences plan quality, efficiency, and treatment robustness. Moderate angles (15°–45°) provide optimal dosimetric performance, while advanced optimization techniques are particularly beneficial in complex cases. Accurate delivery and strict quality assurance are essential, as mechanical errors greater than $\pm 1^\circ$ can negate dosimetric advantages. Collimator angle should therefore be integrated into a comprehensive, patient-specific VMAT planning strategy.

Keywords: collimator angle; VMAT; volumetric modulated arc therapy; dosimetric analysis; treatment outcomes; organ-at-risk sparing; cancer therapy

Introduction

Volumetric Modulated Arc Therapy (VMAT) is a radiotherapy technique that delivers radiation in a continuous arc while simultaneously modulating the intensity of the radiation beam. It offers several advantages over other techniques. Firstly, VMAT allows for rapid treatment delivery, minimizing the time patients spend on the treatment table. Secondly, it provides better sparing of organs-at-risk (OARs), reducing the radiation dose to healthy tissues surrounding the tumor. Thirdly, VMAT offers improved target coverage, ensuring that the tumor receives the prescribed dose while minimizing the dose to surrounding healthy tissues. Lastly, VMAT has shown to be robust and reproducible, providing consistent treatment outcomes. These advantages have been demonstrated in various studies, including those by Zhang et al. (2023), Hunte et al. (2022), Chen et al. (2020) and Zhang et al. (2022). Volumetric Modulated Arc Therapy (VMAT) is a modern technique used in radiotherapy that offers superior conformity, efficiency, and reproducibility in the treatment of various cancers. It involves delivering radiation in an arc-shaped trajectory while simultaneously modulating the intensity of the radiation beam. VMAT has several advantages over traditional techniques such as Three-Dimensional Conformal Radiotherapy (3DCRT). It has been shown to improve dosimetric measures and treatment outcomes in prostate, cervical carcinoma, and head and neck cancer patients. VMAT has also been found to reduce the mean dose to critical organs such as the bladder and bowel bag in rectal cancer patients, resulting in lower complication probabilities. Additionally, VMAT has been associated with lower radiation doses to the remaining kidney and better coverage of the planning target volume (PTV) in whole abdominal irradiation for Wilms tumor treatment. Overall, VMAT offers improved treatment precision, reduced toxicity, and better treatment outcomes compared to traditional radiotherapy techniques. The collimator angle plays a crucial role in VMAT planning. Different collimator angles can affect various dosimetric parameters such as target coverage, conformity index (CI), homogeneity index (HI), gradient index (GI), and monitor units (MUs) (Hashir, et al., 2023; Rose et al., 2023; Jiuling et al., 2022; Wuji et al., 2021). Optimal collimator angles have been found to improve dose conformity, homogeneity, and MUs (Lauren et al., 2021). In nasopharynx carcinoma, collimator angles between 15°-30° have shown better target coverage and reduced MUs. A novel algorithm of sub-arc collimator angle optimization (SACAO) has been developed to improve dosimetric quality and treatment delivery efficiency in single-isocenter coplanar VMAT stereotactic radiosurgery (SRS) for multiple metastases. For whole-brain radiotherapy with hippocampus and inner ear sparing, increasing the collimator angle towards 90° has shown significant improvements in plan quality, including better CI, HI, and reduced doses to organs-at-risk. However, collimator angle optimization may have limited benefit in reducing island blocking in single-isocenter multiple-target (SIMT) SRS plans. Understanding the impact of collimator angle on treatment outcomes is important in radiation therapy. Different collimator angles can affect the surface dose, dose conformity, homogeneity, and dose to organs at risk (OARs) (Jeong-Ho et al., 2022; Hashir et al., 2022; Jiuling et al., 2022;

Yong et al., 2017). Studies have shown that the surface dose increases as the collimator angle increases, and the length of the tumor also affects the surface dose. Optimal collimator angles have been found to improve dose conformity, homogeneity, and treatment efficiency. Additionally, collimator angle optimization can lead to better target dose distribution and sparing of OARs. The choice of collimator angle can impact dosimetric parameters such as target coverage, CI, HI, GI, and MUs. Therefore, understanding the impact of collimator angle is crucial for optimizing treatment plans and achieving better treatment outcomes in radiation therapy. The optimal collimator angle in radiation therapy has been a topic of controversy. Several studies have investigated the impact of collimator angle on treatment plan quality and organ-at-risk sparing. Battinelli et al. found that optimizing the collimator angle can reduce the exposed area between lesions in non-isocentric treatments, leading to more efficient treatment and potential time savings (Cecilia et al., 2021). Sun et al. demonstrated that increasing the intersection angle between collimator angles in dual-arc VMAT plans for whole-brain radiotherapy can improve plan quality, including conformity and homogeneity indices, as well as reduce monitor units and dose to organs-at-risk (Wuji et al., 2021). Saeed et al. concluded that different collimator angles have minimal impact on target coverage and dose to organs-at-risk in prostate carcinoma patients, suggesting the need for solid decision-making regarding collimator angles (Hashir et al., 2023). Mancosu et al. highlighted the significance of collimator angle rotation in optimizing dose distribution for vertebral metastases, with leaf travel parallel to the spinal cord primary orientation yielding the best plans (Pietro et al., 2010). Andersen et al. recommended maintaining collimator angles within 15-30 degrees based on various dosimetric parameters and quality assurance results (Andersen et al., 2016). The main objective of the paper is to systematically evaluate the available literature on the impact of collimator angle on treatment outcomes in VMAT. To assess the influence of collimator angle on dose distribution to the target and critical organs and to identify the optimal collimator angle for various treatment scenarios and potential recommendations for clinical practice.

Material and Method

Study Design and Search Strategy

This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to conduct a systematic review on the impact of collimator angles on treatment outcomes in Volumetric Modulated Arc Therapy (VMAT). A comprehensive literature search was performed in major databases, including PubMed, Scopus, Web of Science, Embase, and Google Scholar, from their inception to January 2025. The search terms included: "Collimator angle, Volumetric Modulated Arc Therapy" OR "VMAT, Treatment outcomes, Dosimetric impact and Radiotherapy planning. Boolean operators (AND, OR) were applied to refine search queries and retrieve relevant studies. Additional hand-searching of the reference lists of included articles was conducted to ensure comprehensive coverage.

Inclusion and exclusion Criteria

Criteria	Inclusion	Exclusion
Study Type	Peer-reviewed articles.	Reviews, case reports, editorials, conference abstracts.
	Studies with quantitative analyses on collimator angles in VMAT.	Studies using treatment modalities other than VMAT (e.g., IMRT, 3D-CRT).
Language	English-language studies.	Non-English language studies.
Tumor Sites	Studies on various tumor sites (e.g., head and neck, prostate, lung, etc.).	Studies not specifying tumor site or focusing on non-cancerous conditions.
Outcome Measures	Studies reporting dosimetric parameters, including PTV coverage, OAR sparing, homogeneity index, etc.	Studies without specific or relevant dosimetric outcomes related to collimator angles.
Collimator Angle Focus	Studies analyzing or comparing the impact of different collimator angles in VMAT.	Studies not addressing collimator angle configuration.
Publication Year	Published between January 2000 and January 2025.	Outside the specified date range.
Population	Studies involving human patients or anthropomorphic phantom models.	Preclinical studies using animals or computational-only models without patient validation.

Data extraction and Synthesis

Data extraction was performed using a standardized form that comprised of Title, Objective, Methods Used, Results, Conclusions, Contributions, Practical Implications and References. Any discrepancies in data extraction were resolved through discussion and consensus among the reviewers. A narrative synthesis approach was employed to summarize and interpret the findings from the selected studies (Samaila et al., 2024; Samaila et al., 2025).

Ethical Considerations

This review exclusively involved the narrative analysis of published data, and therefore, ethical approval was not required.

Results and Discussion

Numerous studies have explored the impact of collimator angles on dose distribution to target volumes and critical organs. Findings indicate that the optimal collimator angle varies significantly depending on the specific treatment site and technique. In prostate cancer patients, collimator angles of 20°, 30°, and 45° have demonstrated superior dose conformity, homogeneity, and monitor unit (MU) efficiency. For nasopharyngeal carcinoma, collimator angles within the 15° to 30° range have been shown to enhance target coverage while reducing MU usage. In the context of stereotactic body radiotherapy (SBRT) for non-small cell lung cancer, MLC positional errors, including collimator angle deviations, can significantly impact dose distribution, with VMAT being more susceptible than IMRT. For single-isocenter coplanar VMAT stereotactic radiosurgery of multiple brain metastases, a novel algorithm known as Sub-Arc Collimator Angle Optimization (SACAO) has been shown to improve dosimetric quality and treatment delivery efficiency. The selection of collimator angles in VMAT should be carefully evaluated for each treatment scenario to optimize plan quality, target coverage, and treatment efficiency.

Impact of collimator angle on Target Coverage

The studies summarized in Table 1 collectively demonstrate that collimator angle has a limited influence on baseline target coverage but plays a significant role in optimizing overall plan quality in volumetric modulated arc therapy (VMAT). In prostate cancer planning, both Saeed

et al. (2023) and Isa et al. (2014) consistently reported that planning target volume (PTV) coverage remains largely unchanged across a wide range of collimator angles (0°–90°). This finding suggests that modern inverse planning algorithms are sufficiently robust to maintain clinically acceptable coverage regardless of collimator orientation. However, while coverage remains stable, key dosimetric parameters such as conformity index (CI), homogeneity index (HI), and monitor units (MUs) are sensitive to angle selection, indicating that collimator angle primarily influences plan quality refinement rather than fundamental dose delivery. A consistent trend across multiple studies and anatomical sites is that moderate non-zero collimator angles, typically within the range of 15° to 45°, provide the most favorable dosimetric outcomes. Saeed et al. (2023) identified optimal plan performance at 20°–45°, while Isa et al. (2014) reported improved conformity and homogeneity at 45°. Similarly, Thomas et al. (2023) demonstrated that angles between 15° and 30° achieved superior PTV coverage and reduced monitor units in nasopharyngeal carcinoma, whereas very low angles (5°–10°) resulted in poorer coverage. These improvements are likely attributable to enhanced multileaf collimator (MLC) modulation and reduced tongue-and-groove effects, which enable more effective dose shaping. Consequently, moderate collimator angles appear to provide an optimal balance between dosimetric quality and delivery efficiency and may serve as a practical default in routine VMAT planning. Despite these advantages, important trade-offs related to deliverability, mechanical accuracy, and case complexity must be considered. Kim et al. (2015) reported a negative correlation between collimator angle and gamma index passing rates, suggesting that higher angles may compromise delivery accuracy. Furthermore, Puchades-Puchades et al. (2015) demonstrated that collimator angle misalignment exceeding $\pm 1^\circ$ can significantly degrade target coverage and homogeneity, particularly for large PTVs, highlighting the importance of rigorous quality assurance and precise mechanical calibration. In complex clinical scenarios, such as craniospinal irradiation and stereotactic radiosurgery, collimator angle assumes a more critical role. Li et al. (2015) showed that non-zero angles eliminate dose gaps at field junctions, while Battinelli et al. (2021) demonstrated that sub-arc collimator angle optimization significantly improves plan quality and efficiency. These findings underscore the need for individualized, context-specific collimator angle selection that balances dosimetric benefits with delivery feasibility.

Title	Objective	Methods Used	Results	Conclusions	Contributions	Practical Implications	References
<i>The Effect of Varying Collimator Angles on VMAT Planning of Prostate Cancer</i>	To investigate how different collimator angles affect VMAT plan quality for prostate cancer	VMAT plans optimized with 1.5 arcs at collimator angles of 0°, 10°, 20°, 30°, 45°, 90°; dose calculated with AAA (Anisotropic Analytical Algorithm)	Found optimal performance (conformity, homogeneity, MUs) at 20°, 30°, 45°. Target coverage and OAR doses were not significantly different across angles.	Optimal collimator angles (20°–45°) improve plan quality; choice of angle is important for conformity/homogeneity	Clarifies which angles yield best trade-off among plan metrics	Guides clinical medical physicists in collimator angle selection	Saeed et al., (2023)
<i>Dosimetric Dependence on the Collimator Angle in Prostate VMAT</i>	To quantify dose-volume changes (PTV and OARs) in prostate VMAT as a function of collimator angle	Single-arc VMAT plans on a phantom at collimator angles 0°, 15°, 30°, 45°, 60°, 75°, 90°; dose-volume analyses for PTV and OARs (bladder, rectum, femoral heads)	No large differences in PTV coverage across angles. The 45° angle gave a higher conformity index (~0.53) and lower homogeneity index (~0.064). Some angles (75°, 90°) favored OAR sparing.	Clinical physicists can use collimator angle tuning to optimize plan quality without compromising coverage	Provides systematic data linking collimator angle and plan metrics for prostate VMAT	Supports more evidence-based angle selection in VMAT planning	Isa et al., 2014
<i>A Dosimetric Study on the Impact of Collimator Angles in Nasopharyngeal Carcinoma (NPC) Using VMAT</i>	To determine the best collimator angle for NPC VMAT planning using Monte Carlo algorithm	Retrospective study of 29 NPC patients; dual-arc VMAT in Monaco TPS using Monte Carlo, evaluating angles 0°–45° (in steps)	Collimator angles between 15°–30° gave better PTV coverage (~92–94%) and significantly reduced monitor units. Very low angles (5°–10°) had poor	Collimator angles in the 15–30° range are optimal for NPC VMAT in this setting	Adds specific guidance for head-and-neck cancer planning	Helps clinical teams select angle to balance tumor coverage and efficiency	Thomas et al. (2023)

			coverage; 45° produced highest MUs.				
<i>The Importance of Collimator Angle Error in VMAT</i>	To assess how errors in setting collimator angle (mis-calibration) affect dosimetry	Simulated collimator errors ($\pm 0.5^\circ$, $\pm 1^\circ$, $\pm 1.5^\circ$) on VMAT plans for different PTVs (prostate, head & neck, etc.); recalculated dose; compared DVHs and HI	For large PTVs (e.g., prostate), errors $> \pm 1^\circ$ caused large loss of PTV coverage; homogeneity index relative variation up to 75% in worst case.	Collimator misalignment can severely degrade plan quality, especially for large targets	Emphasizes need for strict QA of collimator calibration	Suggests using isocenter near PTV center to reduce sensitivity	Puchades-Puchades et al., 2015
<i>Sub-Arc Collimator Angle Optimization (SACAO) for Multiple Brain Metastases in VMAT SRS</i>	To improve plan quality (CI, HI, gradient) and efficiency (MU, field size) for VMAT SRS of multiple brain mets via optimized sub-arcs	Developed and applied an automated SACAO algorithm based on heatmaps of MLC blocking index; compared SACAO plans vs fixed-collimator full-arc plans	SACAO improved CI, HI, gradient index, and reduced MU by ~15.7%, field size by ~41.1%. Also better sparing of normal brain, brainstem, eyes.	Introduces a practical, automated method for choosing collimator angles sub-arc by sub-arc to boost plan quality and efficiency	Strong contribution in algorithmic planning for SRS	Suggests that using SACAO can reduce delivery time and improve sparing for multi-target SRS	Battinelli et al., 2021
<i>Collimator Rotation in VMAT for Craniospinal Irradiation (CSI)</i>	To assess how rotating the collimator influences dose uniformity and beam overlap in multi-isocenter VMAT for CSI	VMAT plans with two isocenters, testing collimator angles of 0° , 30° , 45° for upper and lower arcs; phantom and patient DVH; experimental validation with film and ion-chamber	No significant differences in HI and CI among some angles, but plans with 45° collimator required more MUs and segments; importantly, non-zero angle ($\geq 5^\circ$) eliminated a 1 mm low-dose	Rotating the collimator off 0° (e.g., 45°) helps avoid dose gaps at beam junctions without compromising coverage	Offers practical evidence for junction management in multi-isocenter VMAT	Suggests that using non-zero collimator angles improves plan robustness in craniospinal VMAT	Li, et al. 2015

			gap at the junction.				
<i>Effect of Collimator Angle on Dosimetric Verification of VMAT (Head & Neck)</i>	To evaluate how collimator angle influences the accuracy of dose delivery (γ -index) in QA	For 10 head-and-neck patients, generated VMAT plans at collimator angles from 0° to 45° (in 5° increments), verified with 2D ion chamber array (MatriXX) and γ -index (2%/2 mm, 3%/3 mm)	γ -index passing rates showed a negative correlation with collimator angle: higher angles tended to yield lower passing rates (i.e., less accurate delivery). Maximum per-patient differences up to ~5.6%.	Accuracy of VMAT delivery (via QA) depends on collimator angle	Warns planners about potential trade-offs between plan quality and deliverability for higher collimator angles	Important for clinical physicists: when using high collimator angles, must check QA to ensure acceptable delivery	Kim et al. 2015

Table 1: Impact of collimator angle on Target Coverage.

Organ at risk (OAR) sparing

The studies presented in Table 3 demonstrate that advanced collimation techniques, particularly the use of multileaf collimators (MLCs), play a crucial role in reducing radiation dose to organs at risk (OARs) across a range of clinical applications. In breast cancer radiotherapy, significant reductions in mean dose to critical structures such as the heart, left anterior descending artery (LAD), and lungs were achieved through MLC-based shielding (Mahani et al., 2023). Similarly, MLC-shielded fields have been shown to reduce out-of-field doses compared to conventional cerrobend blocks, indicating improved protection of healthy tissues during treatment (Momeni, 2023). These findings highlight the importance of precise beam shaping in minimizing unintended radiation exposure while maintaining effective target irradiation. Beyond the presence of MLCs, their configuration and integration with advanced treatment techniques further enhance OAR sparing. Narrower MLC leaf widths have been associated with improved conformity and steeper dose gradients, resulting in superior normal tissue sparing, particularly in stereotactic irradiation for brain metastases (Ohira et al., 2021). Additionally, technique-driven innovations such as 90° angled collimated dynamic IMRT (A-IMRT) demonstrated improved OAR protection

compared to conventional IMRT, although volumetric modulated arc therapy (VMAT) remained superior overall in terms of conformity and sparing (Serarslan et al., 2023). Furthermore, dynamic trajectory radiotherapy (DTRT), which incorporates coordinated motion of the gantry, couch, and collimator, achieved substantial improvements in OAR sparing in head and neck cancers compared to VMAT (Bertholet et al., 2022). These findings suggest that both hardware characteristics and delivery techniques are critical determinants of optimal organ protection. Optimization strategies involving collimator orientation and beam geometry also contribute to achieving a balance between target coverage and OAR sparing. While variations in collimator angle alone may not significantly influence OAR dose in certain cases, such as prostate VMAT (Saeed et al., 2023), more advanced approaches can yield meaningful improvements. For example, the split X-jaw technique has been shown to enhance target coverage while simultaneously reducing dose to surrounding normal tissues (Sarma et al., 2023). Collectively, the evidence indicates that effective OAR sparing is achieved through a combination of appropriate collimator design, optimized beam modulation, and advanced planning strategies. These findings underscore the need for individualized, technique-specific planning approaches to maximize the therapeutic ratio in modern radiotherapy.

Title of the paper	Objective	Methods Used	Results	Conclusions	Contributions	Practical Implications	Ref
The Efficacy of Multi-Leaf Collimator in the Reduction of Cardiac	To evaluate the effect of multi-leaf collimators on the protection of sensitive organs in patients with	Evaluation of protective effect of multi-leaf collimator (MLC) Comparison of dosimetric results for tumor and	MLC coverage leads to significant reduction in mean dose of OARs.	MLC can effectively reduce cardiac and coronary artery dose in left-sided breast	Evaluation of the protective effect of multi-leaf collimator (MLC) in left breast cancer radiotherapy.	Multi-leaf collimator (MLC) can effectively reduce cardiac and coronary artery dose in	Mahani et al., 2023

<u>and</u> <u>Coronary</u> <u>Artery</u> <u>Dose in</u> <u>Left-Sided</u> <u>Breast</u> <u>Cancer</u> <u>Radiothera</u> <u>py</u>	left breast cancer, including the left anterior descending artery (LAD) and the left lung.	organs at risk (OARs)	Better protection of LAD, heart, and lungs achieved with MLC shielding.	cancer radiotherapy. Better protection of LAD, heart, and lungs can be achieved with MLC.	Reduction in mean dose and volume received by organs at risk (OARs).	left-sided breast cancer radiotherapy. MLC can provide better protection for sensitive organs at risk.	
<u>Ninety-</u> <u>degree</u> <u>angled</u> <u>collimator:</u> <u>a</u> <u>dosimetric</u> <u>study</u> <u>related to</u> <u>dynamic</u> <u>intensity-</u> <u>modulated</u> <u>radiotherap</u> <u>y in</u> <u>patients</u> <u>with</u> <u>endometria</u> <u>l carcinoma</u>	Develop a new IMRT technique named 90° angled collimated dynamic IMRT (A-IMRT) planning to ensure that the dose constraints of the organs at risk (OARs) were not exceeded while increasing the prescription dose to the planning target volume (PTV) from 45 to 50.	Conventional dynamic IMRT (C-IMRT) with collimator angle of 0° at all gantry angles 90° angled collimated dynamic IMRT (A-IMRT) with collimator angle of 90° at specific gantry angles (110°, 180°, 215°, and 285°) Volumetric modulated arc therapy (VMAT)	A new dynamic IMRT technique called 90° angled collimated dynamic IMRT (A-IMRT) planning was developed. A-IMRT protected organs at risk (OARs) better than conventional dynamic IMRT (C-IMRT).	VMAT achieved superior organ at risk (OAR) protection and conformity compared to A-IMRT and C-IMRT. OARs are better protected with 90° angled collimated dynamic IMRT technique.	Development of a new dynamic IMRT technique called 90° angled collimated dynamic IMRT (A-IMRT) planning. Comparison of A-IMRT with conventional dynamic IMRT (C-IMRT) and volumetric modulated arc therapy (VMAT) techniques.	The 90° angled collimated dynamic IMRT technique can protect organs at risk better than conventional IMRT. VMAT achieved superior organ at risk protection compared to A-IMRT and C-IMRT.	Serarslan et al., 2023
<u>The Effect</u> <u>of Varying</u> <u>Collimator</u> <u>Angles on</u> <u>VMAT</u> <u>planning of</u> <u>Prostate</u> <u>Cancer</u>	The paper focuses on dose-volume evaluation in the planning target volume (PTV) and organs-at-risk (OARs) in prostate carcinoma patients.	VMAT plans were optimized with different collimator angles (0°, 10°, 20°, 30°, 45°, 90°) Dosimetric analysis was performed using Anisotropic Analytical Algorithm (AAA) Version 15.6.04	Optimal collimator angles for VMAT planning are 20°, 30°, and 45°. Target coverage and dose to organs at risk are not significantly affected.	Optimal collimator angles are necessary for better conformity and homogeneity. Target coverage and dose to organs at risk are not significantly affected by collimator angles.	Investigated the effect of varying collimator angles on VMAT planning for prostate cancer. Analyzed dose-volume evaluation in planning target volume and organs-at-risk	Clinical medical physicists should consider the collimator angle for treatment planning. Optimal collimator angles can improve conformity and homogeneity in VMAT planning.	Saeed et al., 2023

<u>Organ-at-risk sparing with dynamic trajectory radiotherapy for head and neck cancer: comparison with volumetric arc therapy on a publicly available library of cases</u>	To Compare the performance of DTRT and VMAT for common head and neck (HN) cancer cases on a C-arm linac with high accuracy.	Dynamic trajectory radiotherapy (DTRT) with collimator rotation Volumetric modulated arc therapy (VMAT) for comparison	DTRT plans showed similar target coverage compared to VMAT. DTRT resulted in substantial sparing of organs-at-risk (OARs) compared to VMAT.	DTRT showed substantial improvement in OAR sparing for HN cancer radiotherapy compared to VMAT. Plans were deliverable on standard linacs with good agreement between calculated and measured dose.	The paper establishes dynamic trajectory radiotherapy (DTRT) as a viable treatment option for head and neck cancer. DTRT plans showed substantial organ-at-risk (OAR) sparing compared to volumetric modulated arc therapy (VMAT).	Substantial improvement in OAR sparing for HN cancer radiotherapy using DTRT compared to VMAT. Plans are deliverable on standard linacs and can be applied to similar cases in future clinical studies.	Bertholet,et al., 2022
<u>Impact of Multileaf Collimator Width on Dose Distribution in HyperArc Fractionated Stereotactic Irradiation for Multiple (-) Brain Metastases.</u>	To evaluate <u>Impact of Multileaf Collimator Width on Dose Distribution in HyperArc Fractionated Stereotactic Irradiation for Multiple (-) Brain Metastases.</u>	Two types of multileaf collimators (MLC) were used: high definition (HD) MLC (2.5 mm) and Millennium (ML) MLC (5 mm). Dosimetric parameters between the planning target volume (PTV) and organs at risk (OARs) were compared.	HyperArc plans with narrower MLC had higher conformity and steeper dose gradient. Narrower MLC resulted in better normal tissue sparing.	Narrower multileaf collimator (MLC) provides higher conformity, steeper dose gradient, and better normal tissue sparing. High definition (HD) MLC (2.5 mm) is more effective than Millennium (ML) MLC (5 mm).	The paper assesses the impact of multileaf collimator (MLC) width on dose distributions in HyperArc fractionated stereotactic irradiation for multiple brain metastases. The narrower MLC provided higher conformity, steeper dose gradient, and better normal tissue sparing.	Narrower multileaf collimator (MLC) improves conformity, dose gradient, and tissue sparing. HyperArc fractionated stereotactic irradiation with narrower MLC is beneficial for multiple brain metastases.	Ohira et al., 2021
<u>The Estimation of Radiation Dose to Out-of-Field Points of Organs at Risk in Block and MLC Shielded Fields in Lung Cancer</u>	measured and compare the healthy organs absorbed dose outside the cerrobend block and MLC shielded field and showed that the use of MLC to shield the lung cancer treatment field reduces the out-of-field OARs dose compared	Computed Tomography (CT) imaging of a heterogeneous Thorax phantom Conformal Treatment planning on the Prowess Panther Treatment Planning System (TPS)	Out-of-field dose in MLC-shielded fields is significantly lower than in block-shielded fields. Healthy organs absorbed doses were significantly lower than dosimetry results.	MLC shielding reduces out-of-field OAR dose compared to cerrobend block. Reduction is greater at 18 MV photon beam but not statistically significant.	Comparison of absorbed dose to out-of-field organs in block and MLC shielded fields Reduction of out-of-field organ dose with MLC shielding in lung cancer radiation therapy	The use of MLC shielding reduces out-of-field organ dose in lung cancer radiation therapy. The reduction in dose is greater with 18 MV photon beam.	Momeni., 2023

<u>Radiation Therapy</u>	to cerrobending block.						
<u>Impact of split X-jaw technique on target volume coverage and organ at risk sparing in prostate cancer: a comparative dosimetric study</u>	To use a split X-jaw planning technique was used for volumetric-modulated arc radiotherapy (VMAT) for PTVs requiring a field size larger than 18 cm in the Xjaw position in the Varian Trilogy linear accelerator.	Open, limited, and split X-jaw planning techniques were used. Computed tomography data sets from 15 prostate cancer patients were used.	Split X-jaw technique improves target dose coverage in prostate cancer patients. Split technique delivers lower dose to organs at risk.	Split X-jaw technique improves target dose coverage in prostate cancer patients. Split technique delivers lower dose to organs at risk.	The paper investigates the impact of the split X-jaw technique on target volume coverage and organ at risk sparing in prostate cancer patients. The study concludes that the split X-jaw technique improves plan quality in terms of target dose coverage for PTVs requiring a field size larger than 15 cm in the X-jaw direction.	The split X-jaw technique improves target dose coverage in prostate cancer patients. The split technique delivers a lower dose to organs at risk.	Sarma et al., 2023
<u>Dosimetric impact of different multileaf collimators on cardiac and left anterior descending coronary artery dose reduction.</u>	To evaluate Dosimetric impact of different multileaf collimators on cardiac and left anterior descending coronary artery dose reduction	Three techniques were used to create treatment plans for patients. Two different multileaf collimators (MLCs) with different leaf widths were used.	Covered LAD plan 1 (CL1) reduced lung, cardiac, and LAD doses. CL1 plans decreased mean heart dose from 6.2 Gy to 5.4 Gy.	CL1 plans reduce OAR dose without compromising target coverage. Proper implementation of MLC can decrease side effects of RT.	Evaluation of the impact of different multileaf collimators (MLCs) on shielding organ at risks (OARs), especially the left anterior descending coronary artery (LAD), in patients with left breast cancer. Comparison of dosimetric parameters of the heart, LAD, and ipsilateral lung for different MLC plans.	The use of specific multileaf collimators can reduce the dose to organs at risk in left breast cancer patients undergoing radiotherapy. Implementing proper MLC techniques can decrease side effects of radiotherapy.	Mahani,et al., 2023

Table 3: organ at risks.**Impact of collimator angle on Clinical outcomes**

The reviewed literature in table 4 demonstrates that collimator angle optimization has a measurable and clinically relevant impact on treatment quality in VMAT and SRS planning, with the degree of influence varying across anatomical sites and planning techniques. In prostate VMAT

planning, Saeed et al. (2023) reported that while target coverage and organ-at-risk (OAR) doses remained largely unchanged, optimal angles between 20° and 45° significantly enhanced dose conformity and homogeneity, emphasizing that collimator settings primarily refine dose distribution rather than altering overall plan safety. In cases involving multiple brain metastases, the influence of collimator angle selection

becomes more pronounced. Shen et al. (2022) showed that the Sub-Arc Collimator Angle Optimization (SACAO) algorithm greatly improved conformity, homogeneity, and gradient indices while reducing monitor units and field size by more than 40%, thereby improving treatment efficiency. Supporting this, Battinelli et al. (2021) demonstrated that dynamic collimator trajectories outperform fixed angles, achieving exposed-area reductions of up to 71%, which can substantially improve lesion selectivity and reduce unnecessary normal-tissue irradiation. Other studies presented more nuanced perspectives based on planning context and disease site. Pudsey et al. (2021) found that collimator angle optimization and jaw tracking provided limited clinical benefit in single-isocenter, multiple-target SRS, suggesting that geometric complexity can overshadow the effects of angle adjustment. In whole-brain radiotherapy with hippocampal and cochlear sparing, Sun et al. (2021) reported that

increasing the angular separation between dual-arc collimator configurations improved plan quality and reduced monitor units, highlighting angle selection as a modifiable parameter for complex sparing scenarios. For locally advanced nasopharyngeal carcinoma, Kim et al. (2017) found that angles of 20°–30° produced the best conformity and homogeneity indices, although higher angles were associated with increased optic-apparatus dose, demonstrating the need for balanced optimization. Foundational contributions by Zhang et al. (2010) and Kim et al. (2015) further showed that personalized and dynamically optimized collimator strategies can enhance dosimetric performance while improving quality-assurance γ -index outcomes. Collectively, these studies establish that collimator angle optimization is integral to maximizing plan conformity, improving treatment efficiency, minimizing unnecessary exposure, and strengthening overall VMAT plan quality.

Paper title	Objective	Method	Result	Conclusion	Contribution	Ref
The Effect of Varying Collimator Angles on VMAT planning of Prostate Cancer	To assess the effect of different Angle	Dosimetric analysis was performed using Anisotropic Analytical Algorithm (AAA) Version 15.6.04	VMAT plans were optimized with different collimator angles (0°, 10°, 20°, 30°, 45°, 90°). Optimal collimator angles for VMAT planning were achieved at 20°, 30°, and 45°.	Target coverage and dose to organs at risk are not significantly affected.	Clinical medical physicists should consider the collimator angle for treatment planning. Optimal collimator angles can improve conformity and homogeneity in VMAT planning.	Saeed al., 2023
Sub-arc collimator angle optimization based on the conformity index heatmap for VMAT planning of multiple brain metastases SRS treatments	The SACAO method could be superior in improving the CI, HI, and GI of the targets as well as normal tissue sparing for multiple brain metastases SRS and has the potential of increasing treatment efficiency in terms of field size and MU.	SACAO method improves dosimetric quality and treatment efficiency for multiple brain metastases SRS. SACAO reduces field size and monitoring units by 41.11%.	The SACAO method improved conformity index, homogeneity index, and gradient index. SACAO reduced field size and monitoring units by 41.11%.	Sub-arc collimator angle optimization (SACAO) algorithm Calculation of multi-leaf collimator (MLC) conformity index (MCI)	Investigated impact of collimator angle optimization in VMAT SRS for multiple brain metastases Developed a novel algorithm for sub-arc collimator angle optimization (SACAO)	Shen, al., 2022

Technical Note: Collimator angle optimization for multiple brain metastases in dynamic conformal arc treatment planning.	-	Collimator angle optimization reduces exposed area between brain metastases in treatment planning. Dynamic collimator trajectories are more effective than fixed trajectories in reducing exposed area.	Plans with optimized dynamic collimator trajectories showed a reduction in exposed area between lesions ranging from 21.7% to 71.3%. Beam-wise reductions in exposed area ranged from 5.83% to over 90%.	An algorithm that estimates the quality of an arc by considering the target projections onto the plane perpendicular to the central axis of the arc beam. The algorithm can generate two outputs: the fixed optimal collimator angle over all the control points, or the optimal collimator angle trajectory through all the control points considering the rotation speed of the collimator.	Development of an algorithm for optimizing collimator angle orientation in brain metastases treatment planning. Comparison of plans with optimized fixed collimator angles and optimized dynamic collimator trajectories.	Battinelli,et al., 2021
The use of collimator angle optimization and jaw tracking for VMAT-based single-isocenter multiple-target stereotactic radiosurgery for up to six targets in the Varian Eclipse treatment planning system.	In this article, the authors investigated the effect on plan quality and delivery, of reducing island blocking through collimator angle optimization (CAO), and the effect of jaw tracking in this context was also investigated.	Collimator angle optimization (CAO) has limited benefit in VMAT SIMT SRS. Jaw tracking in SIMT SRS plans has minimal clinical benefits.	Collimator angle optimization (CAO) has limited benefit in VMAT SIMT SRS. Jaw tracking in SIMT SRS plans has minimal clinical benefits.	Collimator angle optimization (CAO) algorithm Jaw tracking in single-isocenter multiple-target (SIMT) stereotactic radiotherapy (SRS) plans	Investigated the effect of reducing island blocking through collimator angle optimization (CAO) Assessed the effect of jaw tracking on plan quality and delivery	Pudsey,et al., 2021

Optimization of collimator angles in dual-arc volumetric modulated arc therapy planning for whole-brain radiotherapy with hippocampus and inner ear sparing.	In this article, a dual-arc volumetric modulated arc therapy (VMAT) plan for whole-brain radiotherapy with hippocampus and inner ear sparing (HIS-WBRT) was generated for 13 small-cell lung cancer patients.	The collimator angle in dual-arc VMAT planning significantly affects plan quality. Increasing the intersection angle between collimator settings improves dose distributions and reduces monitor units.	Increasing the collimator angle ($\Delta\theta$) towards 90° improves plan quality. The effect of $\theta 1/\theta 2$ combinations on plan quality is insignificant.	Retrospective analysis of 13 small-cell lung cancer patients. Generation of dual-arc VMAT plans with different collimator angles	Optimization of collimator angles in dual-arc VMAT plans for HIS-WBRT. Evaluation of plan quality and QA for different collimator settings.	Sun, et al., 2021
Effect of collimator angles on the dosimetric results of volumetric modulated arc therapy planning for patients with a locally-advanced nasopharyngeal carcinoma	The effect of collimator angle on the dosimetric results of VMAT plans for patients with a locally-advanced nasopharyngeal carcinoma (LA-NPC) was evaluated and the mean doses had positive correlations and the CI had a weak positive correlation with the irradiated volume.	Increasing collimator angles in VMAT plans for LA-NPC patients increases absorbed doses to the optic apparatus. The best values for conformity index and homogeneity index were achieved at specific collimator angles.	Increasing collimator angles in VMAT plans increased absorbed doses to the optic apparatus. The best conformity index (CI) was achieved at collimator angles of 20° and 30° .	VMAT treatment planning sets were generated with different collimator angles. Dosimetric parameters such as target coverage and dose conformity were analyzed.	Evaluated the effect of collimator angle on dosimetric results of VMAT plans for LA-NPC patients. Analyzed dosimetric parameters such as target coverage, OAR, and dose conformity	Kim,et al., 2017
Collimator angle optimization method for volumetric-modulated arc therapy plan	In this article, a collimator angle optimization method for a volumetric-modulated arc therapy plan is proposed to dynamically optimize the angle according to the patient-specific target region information, so the manual participation degree and the degree of dependence of the plan quality on the	The method can dynamically optimize the collimator angle for volumetric-modulated arc therapy plans. The personalized optimization method improves plan quality and	The method can dynamically optimize the collimator angle according to the patient-specific target region information. The resulting dosimetric improvement can avoid	Three-dimensional reconstruction of target region using patient-specific information. Segmented optimization of complete arc based on collimator angles and conformal indexes	The paper proposes a collimator angle optimization method for volumetric-modulated arc therapy plans. The method dynamically optimizes the collimator angle based on patient-specific target	Zhang,et al., 2010

	artificial experience are reduced.	clinical efficacy.	unnecessary tumor control rate decline and normal tissue damages and improve the efficacy of clinical radiotherapy.		region information.	
Effect of the Collimator Angle on Dosimetric Verification of Volumetric Modulated Arc Therapy	In this article, the effect of the collimator angle on the results of dosimetric verification of volumetric modulated arc therapy (VMAT) plans for head and neck patients was studied.	Results of patient-specific QA for VMAT plans depend on collimator angle. Collimator angles of VMAT plans for head and neck cancer patients range between 15-25 degrees.	The collimator angle has a negative correlation with the γ -index passing rates. The accuracy of the delivered dose depends on the collimator angle.	VMAT plans with different collimator angles were generated for head and neck patients. Dosimetric verification was performed using a 2-dimensional ion chamber array.	Studied the effect of collimator angle on dosimetric verification of VMAT plans for head and neck patients. Found negative correlation between collimator angle and γ -index passing rates.	Kim et al., 2015
SU-G-BRC-04: Collimator Angle Optimization in Volumetric Modulated Arc Therapy	It can be concluded that collimator angles should be maintained within 15-30 deg.	Collimator angles should be maintained within 15-30 degrees. CI, HI, NTCP, and gamma passing index support this conclusion.	Collimator angles between 15-30 deg showed superior results in terms of NTCP for OAR. CI, HI, and gamma passing rates were not correlated with collimator angle.	Two sites (prostate and head and neck) were investigated. 10 plans were created with varying collimator angles from 0-90 deg.	Investigated the impact of collimator angle on plan quality and organ at risk sparing in VMAT. Concluded that collimator angles should be maintained within 15-30 degrees	Andersen et al., 2016

Table 4: Impact on Clinical outcomes.

Potential factors influencing the impact of collimator angle

The influence of collimator angle on radiotherapy planning is shaped by several interrelated factors, including anatomical site, treatment modality, and the range of angular rotation applied during optimization. Each of these factors plays a critical role in determining how effectively the collimator orientation contributes to improving dose conformity, sparing organs at risk, and enhancing overall treatment efficiency. Understanding these parameters is essential for ensuring that collimator adjustments are not used generically but tailored to the specific clinical scenario. This tailored approach ensures that treatment plans achieve adequate tumor coverage while minimizing unintended dose to surrounding tissues. One of the most important determinants is the treatment site, as different anatomical regions respond differently to changes in collimator orientation. Prostate cancer planning, for example, has shown limited

sensitivity to collimator angle variations, with negligible differences in conformity and homogeneity across multiple angles, suggesting that the relatively simple geometry of the target reduces the influence of angular adjustments (Kim et al., 2024; Saeed et al., 2023). Conversely, brain metastases present a more complex dosimetric environment, where optimized collimator angles have been shown to significantly improve OAR sparing and inter-lesion dose separation due to the irregular and spatially separated targets involved (Shen et al., 2022). These findings emphasize that anatomical complexity and target geometry strongly dictate the potential benefits of collimator optimization. The treatment technique further modulates the importance of collimator angle selection. In conventional VMAT, specific collimator angles have been shown to enhance dose distribution by aligning more effectively with the MLC leaf motion and the geometry of the target volume. However, more advanced techniques such as hybrid VMAT (HVMAT) introduce additional

flexibility that allows for a wider range of acceptable angles without significantly compromising plan quality, owing to the technique's ability to incorporate static-field components that support dose shaping (Kim et al., 2024; Saeed et al., 2023). Additionally, the range of collimator rotation itself plays a crucial role. Research indicates that intermediate angles—typically around 20°, 30°, and 45°—produce superior dosimetric outcomes by balancing leaf travel efficiency and beam modulation, whereas very small or extreme angles can lead to suboptimal distributions, including elevated surface doses in small-target scenarios (Saeed et al., 2023; Kim et al., 2022). These combined findings show that while collimator angle adjustments hold significant potential for improving treatment efficacy, their actual impact is highly dependent on treatment site, planning technique, and selected angle range.

Implications of Collimator Angle in VMAT: Comparisons of literature findings

The collective body of evidence demonstrates that collimator angle selection in VMAT significantly influences dose distribution, although the magnitude of its impact varies by anatomical site, treatment geometry, and planning strategy. Several studies, including Yoo et al. (2014) and Jeong et al. (2014), reported that modest angles—typically around 15°—can enhance dose conformity and improve target coverage in prostate VMAT, reflected in metrics such as increased D95 and improved planning target volume (PTV) dose uniformity. For more complex scenarios, such as whole-brain radiotherapy, Niemierko et al. (2013) found that dual-arc configurations using orthogonal or near-orthogonal collimator angles (e.g., 350°/80°) produced superior dosimetric performance. These variations highlight that optimal collimator settings depend heavily on patient anatomy and the spatial characteristics of the target structures. In contrast, studies such as Xing et al. (2016) showed limited or no dosimetric improvement when adjusting collimator angles for multi-target SRS, suggesting that in highly conformal high-dose treatments, arc geometry and MLC modulation may play a more dominant role than the angle itself. The literature also reveals a critical balance between dose distribution and treatment delivery efficiency. Dynamic collimator rotation approaches (DC-VMAT) have been investigated as a means of improving efficiency by adjusting the angle throughout gantry rotation. Niemiec et al. (2016) demonstrated reductions in treatment time with DC-VMAT compared with static-angle VMAT (SC-VMAT). However, not all findings support routine adoption of dynamic approaches. Zhang et al. (2023) reported that in single-isocenter multitarget SRS, DC-VMAT provided limited clinical benefit and introduced additional mechanical complexity that could outweigh its efficiency advantages. Similarly, algorithm-based collimator angle optimization (CAO), explored by Wang et al. (2020), shows potential for automating angle selection and improving plan quality, but its effectiveness is highly dependent on case complexity and the relative weighting of planning objectives. Together, these findings indicate that while angle optimization and dynamic strategies can improve workflow and potentially enhance precision, they must be applied judiciously and tailored to the clinical scenario. Another recurring theme in the literature is the impact of collimator angle on sparing organs at risk. Yoo et al. (2014) observed that certain angle combinations in double-arc VMAT led to reduced rectal doses in prostate cancer treatments, illustrating how beam orientation influences the interplay between MLC projection and organ geometry. Thomas et al. (2023) further supported the trend that angles between 15° and 30° often strike an effective balance between target coverage and OAR protection across several anatomical sites.

However, some investigations—such as Xing et al. (2016) in multitarget SRS—found negligible differences in OAR dose with varying angles, reinforcing that the benefits of angle selection are not universal and depend strongly on spatial complexity. Advancements such as dynamic collimator adjustment, as explored by Zhang et al. (2016) and supported by work from Sun et al. (2021), suggest that real-time modulation of angle could further optimize both OAR sparing and delivery efficiency. Nonetheless, widespread clinical integration requires additional validation due to challenges related to treatment verification, mechanical reliability, and integration into existing planning workflows. Overall, current evidence supports collimator angle optimization as an important but context-dependent component of VMAT planning that warrants continued investigation.

Meta-Analysis of Key findings

Meta-analysis of the Impact of Collimator Angle on Target Coverage

The synthesis of studies in Table 5 indicates that collimator angle has a limited direct influence on baseline target coverage in volumetric modulated arc therapy (VMAT), but plays a significant role in optimizing plan quality, efficiency, and robustness. Across prostate cancer studies, target coverage remained largely unchanged over a wide range of collimator angles (0°–90°), demonstrating the robustness of modern VMAT optimization algorithms (Isa et al., 2014; Saeed et al., 2023). Despite this stability, important differences were observed in plan quality metrics such as conformity index (CI), homogeneity index (HI), and monitor units (MUs), suggesting that collimator angle primarily functions as an optimization parameter rather than a determinant of target dose adequacy. This distinction is clinically relevant, as improved conformity and homogeneity contribute to better dose shaping and reduced irradiation of surrounding normal tissues. A consistent and well-supported finding across the included studies is the superiority of moderate non-zero collimator angles, typically within the range of 15°–45°. Multiple investigations demonstrated that this range yields improved conformity, homogeneity, and treatment efficiency. For instance, optimal plan performance was reported at 20°–45° in prostate VMAT (Saeed et al., 2023), while 45° produced the best conformity and homogeneity indices in phantom-based analyses (Isa et al., 2014). Similarly, in nasopharyngeal carcinoma, angles between 15° and 30° achieved superior target coverage and reduced monitor units, whereas very low angles (5°–10°) resulted in suboptimal coverage (Thomas et al., 2023). These findings suggest that moderate collimator rotation enhances multileaf collimator (MLC) modulation and reduces geometric inefficiencies, such as tongue-and-groove effects, thereby improving dose distribution without compromising coverage. The impact of collimator angle is further influenced by anatomical complexity and treatment technique. In relatively simple geometries, such as prostate VMAT, angle selection primarily refines plan quality. However, in more complex scenarios, including craniospinal irradiation and stereotactic radiosurgery (SRS) for multiple brain metastases, collimator angle becomes a more critical planning variable. For example, non-zero collimator angles eliminated dose gaps at field junctions in craniospinal irradiation, thereby improving treatment robustness (Li et al., 2015). In addition, sub-arc collimator angle optimization (SACAO) significantly enhanced conformity, homogeneity, gradient index, and normal tissue sparing, while reducing monitor units and field size in multi-target SRS (Battinelli et al., 2021). These findings indicate that the clinical importance of collimator angle increases with treatment complexity and modulation demands. Another important dimension highlighted by the meta-analysis is the influence of collimator

angle on treatment deliverability and mechanical accuracy. Higher collimator angles have been associated with reduced gamma index passing rates, indicating potential discrepancies between planned and delivered dose distributions (Kim et al., 2015). More critically, collimator angle misalignment exceeding $\pm 1^\circ$ has been shown to significantly degrade target coverage and homogeneity, particularly for large planning target volumes, with substantial variations in dosimetric indices (Puchades-Puchades et al., 2015). These findings emphasize that the benefits of optimal angle selection are contingent upon precise mechanical calibration and rigorous quality assurance, as inaccuracies in collimator positioning can negate dosimetric advantages. Overall, the

evidence supports a hierarchical interpretation in which collimator angle has a modest direct effect on target coverage but a substantial indirect effect on plan quality, robustness, and clinical reliability. Moderate angles (15° – 45°) consistently provide the best balance between dosimetric performance and efficiency, while advanced or automated optimization strategies are particularly beneficial in complex cases. Importantly, the clinical gains associated with collimator angle optimization depend on accurate delivery and quality assurance. Therefore, collimator angle should be considered as part of an integrated treatment planning strategy rather than an isolated parameter, with selection tailored to anatomical complexity, treatment technique, and machine performance.

Theme	Key Findings	Consensus Level	Evidence Strength	Supporting Studies
Target Coverage Stability	Minimal variation in PTV coverage across most angles in standard VMAT	High	Moderate–Strong	Saeed et al. (2023), Isa et al. (2014), Li et al. (2015)
Optimal Angle Range (15° – 45°)	Moderate angles improve conformity, homogeneity, and efficiency	High	Strong	Saeed et al. (2023), Isa et al. (2014), Thomas et al. (2023)
Low Angles ($\approx 0^\circ$ – 10°)	May reduce coverage and plan quality in some sites	Moderate	Moderate	Thomas et al. (2023)
High Angles ($>45^\circ$ – 90°)	Mixed effects: possible OAR sparing but reduced QA performance	Moderate	Moderate	Isa et al. (2014), Kim et al. (2015)
Monitor Units & Efficiency	Moderate angles reduce MUs; some high angles increase complexity	Moderate	Moderate	Thomas et al. (2023), Battinelli et al. (2021), Li et al. (2015)
OAR Sparing	No consistent universal trend; depends on geometry	Low–Moderate	Limited–Moderate	Isa et al. (2014), Battinelli et al. (2021)
Deliverability / QA	Higher angles may reduce gamma passing rates	Moderate	Moderate	Kim et al. (2015)
Collimator Angle Error	Misalignment $>\pm 1^\circ$ significantly degrades coverage and HI	High	Strong	Puchades-Puchades et al. (2015)
Complex Cases (SRS, CSI)	Angle optimization significantly improves plan quality and robustness	High	Strong	Battinelli et al. (2021), Li et al. (2015)

Table 5: Meta-analysis of the Impact of Collimator Angle on Target Coverage.

Meta-Analysis results Summary for Organ-at-Risk (OAR) Sparing

The meta-analysis presented in Table 6 demonstrates that organ-at-risk (OAR) sparing in modern radiotherapy is predominantly influenced by multileaf collimator (MLC) utilization and advanced treatment delivery techniques, with additional contributions from geometric and planning optimizations. Across multiple studies, MLC-based approaches consistently achieved significant reductions in dose to critical structures such as the heart, lungs, and left anterior descending artery compared to conventional shielding methods (Mahani et al., 2023; Momeni, 2023). Furthermore, improvements in hardware design, particularly the use of narrower MLC leaf widths, were associated with enhanced dose conformity, steeper gradients, and superior normal tissue sparing (Ohira et al., 2021). Advanced delivery techniques, including volumetric

modulated arc therapy (VMAT) and dynamic trajectory radiotherapy (DTRT), further strengthened OAR protection, with DTRT showing notable improvements over VMAT in complex head and neck cases (Bertholet et al., 2022; Serarslan et al., 2023). While collimator angle variation alone appears to have a limited and context-dependent impact on OAR dose (Saeed et al., 2023), more sophisticated planning strategies such as split X-jaw techniques and dynamic beam modulation provide meaningful enhancements in both OAR sparing and target coverage (Sarma et al., 2023). Overall, the evidence supports a multifactorial approach in which optimal OAR protection is achieved through the combined use of advanced MLC design, innovative delivery techniques, and individualized treatment planning strategies.

Theme	Pooled Findings	Consistency of Evidence	Strength of Evidence	Key Supporting Studies	Clinical Interpretation
MLC-based OAR Dose Reduction	MLC significantly reduces dose to critical organs (heart, LAD, lungs, out-of-field tissues) compared to conventional shielding	High	Strong	Mahani et al. (2023); Momeni (2023)	MLC should be standard for OAR protection in modern radiotherapy
Effect of MLC Leaf Width	Narrower MLC (e.g., 2.5 mm) improves conformity, dose gradient, and normal tissue sparing	High	Strong	Ohira et al. (2021)	Use high-definition MLC where available for better sparing, especially in SRS
Advanced Techniques (VMAT, DTRT, A-IMRT)	Advanced delivery techniques improve OAR sparing compared to conventional IMRT; VMAT and DTRT show superior performance	High	Strong	Serarslan et al. (2023); Bertholet et al. (2022)	Prefer VMAT/DTRT for complex cases requiring enhanced sparing
Collimator Geometry Optimization	Collimator angle and beam geometry have modest but context-dependent effects on OAR dose	Moderate	Moderate	Saeed et al. (2023); Serarslan et al. (2023)	Angle optimization should be used as a refinement, not primary strategy
Technique-based Optimization (Split X-jaw, Dynamic Motion)	Advanced planning techniques improve both OAR sparing and target coverage	Moderate–High	Moderate–Strong	Sarma et al. (2023); Bertholet et al. (2022)	Incorporate geometric/trajectory-based optimization in large or complex targets
Comparison with Conventional Shielding	MLC shielding is superior to traditional blocks in reducing unintended dose	High	Strong	Momeni (2023)	Replace block shielding with MLC-based approaches in clinical practice
Overall Determinant of OAR Sparing	OAR sparing is multifactorial: depends on MLC design, technique, and planning strategy	High	Strong	All studies	Combine hardware + technique optimization for best outcomes

Table 6: Meta-Analysis results Summary for Organ-at-Risk (OAR) Sparing.

Meta-Analysis Summary Results for the Impact of Collimator Angle on Clinical Outcomes

The meta-analysis summarized in Table 7 demonstrates that collimator angle optimization influences clinical outcomes primarily through improvements in plan quality, treatment efficiency, and normal tissue protection rather than direct enhancement of target coverage. A consistent finding across multiple studies is that moderate collimator angles, typically within the range of 15°–45°, provide optimal dosimetric performance, resulting in improved conformity index (CI), homogeneity index (HI), and, in some cases, reduced normal tissue complication probability (NTCP) (Andersen et al., 2016; Kim et al., 2017; Saeed et al., 2023). Importantly, target coverage remains largely unchanged across varying collimator angles, indicating that collimator angle serves as a refinement parameter rather than a primary determinant of dose delivery. These improvements in dosimetric quality are clinically relevant, as enhanced conformity and homogeneity are associated with better tumor control and reduced radiation-induced toxicity, thereby improving the

overall therapeutic ratio. Furthermore, the analysis highlights the growing importance of advanced and automated collimator angle optimization strategies, particularly in complex treatment scenarios such as multiple brain metastases and whole-brain radiotherapy. Techniques such as sub-arc collimator angle optimization (SACAO) and dynamic trajectory optimization have demonstrated substantial improvements in plan quality, including reductions in monitor units and unnecessary irradiation of normal tissue (Battinelli et al., 2021; Shen et al., 2022). However, the benefits of collimator angle optimization are not universal, as some studies report limited impact in specific treatment configurations, such as single-isocenter multiple-target stereotactic radiosurgery (Pudsey et al., 2021). Additionally, higher collimator angles may introduce trade-offs, including increased dose to sensitive structures and reduced delivery accuracy, as reflected by lower gamma index passing rates (Kim et al., 2015; Kim et al., 2017). Overall, these findings suggest that while collimator angle optimization can enhance clinical outcomes, its effectiveness is context-dependent and should be integrated with other planning strategies to achieve optimal and clinically reliable results.

Domain	Pooled Findings	Consistency	Strength of Evidence	Key Studies	Clinical Impact
Optimal Angle Range	Angles between 15°–45° consistently improve CI, HI, and overall plan quality	High	Strong	Saeed et al. (2023); Andersen et al. (2016); Kim et al. (2017)	Recommended default range for improved dosimetric outcomes
Target Coverage	Minimal or no significant change in target coverage across angles	High	Strong	Saeed et al. (2023); Kim et al. (2017)	Angle mainly refines plan quality rather than coverage
Plan Quality (CI, HI, GI)	Moderate angles and optimization techniques improve conformity, homogeneity, and gradient index	High	Strong	Shen et al. (2022); Battinelli et al. (2021); Sun et al. (2021)	Enhances dose shaping and treatment precision
Treatment Efficiency	Significant reductions in monitor units (up to ~41%) and field size with optimized angles	Moderate–High	Strong	Shen et al. (2022); Sun et al. (2021)	Improves delivery time and machine efficiency
Advanced Optimization Techniques	Dynamic and algorithm-based optimization (SACAO, CAO) outperform fixed-angle approaches	High	Strong	Zhang et al. (2010); Battinelli et al. (2021); Shen et al. (2022)	Supports automation and patient-specific planning
OAR Dose / NTCP	Moderate angles reduce NTCP; higher angles may increase dose to sensitive structures	Moderate	Moderate–Strong	Andersen et al. (2016); Kim et al. (2017)	Requires balance between tumor control and toxicity
Deliverability / QA	Higher angles may reduce gamma passing rates and delivery accuracy	Moderate	Moderate	Kim et al. (2015)	QA verification critical at higher angles
Technique Dependency	Some techniques (e.g., SIMT SRS) show limited benefit from angle optimization	Moderate	Moderate	Pudsey et al. (2021)	Angle optimization not universally beneficial
Complex Case Sensitivity	Greater benefit in multi-target SRS and whole-brain radiotherapy cases	High	Strong	Battinelli et al. (2021); Sun et al. (2021)	Critical in complex geometries

Table 7: Meta-Analysis Summary Table: Impact of Collimator Angle on Clinical Outcomes.

Conclusion

This systematic review and meta-analysis provide strong evidence that collimator angle plays a secondary yet clinically significant role in VMAT planning, primarily influencing plan quality, efficiency, and treatment robustness rather than directly affecting baseline target coverage. Across multiple studies, target coverage remained consistently stable over a wide angular range (0°–90°), highlighting the robustness of modern inverse planning algorithms. However, optimal dosimetric performance was consistently achieved within moderate collimator angles of 15°–45°, with specific optimal values of 20°, 30°, and 45° identified in prostate cancer planning, and 15°–30° in nasopharyngeal carcinoma, achieving PTV coverage levels of approximately 92–94%. The analysis demonstrates that collimator angle optimization significantly enhances key plan quality metrics, including conformity index (CI), homogeneity index (HI), and monitor unit (MU) efficiency. Advanced optimization strategies, such as Sub-Arc Collimator Angle Optimization (SACAO), further improved treatment quality by reducing monitor units by approximately 15.7% and field size by 41.1%, while enhancing dose conformity and normal tissue sparing. These improvements are particularly pronounced in complex treatment scenarios, such as stereotactic radiosurgery (SRS) for multiple brain metastases and craniospinal irradiation, where optimized collimator angles eliminate dose gaps and improve treatment robustness. Despite

these benefits, the findings highlight important trade-offs related to treatment deliverability and mechanical accuracy. Higher collimator angles (>45°) were associated with decreased γ -index passing rates, with reductions of up to 5.6%, indicating potential discrepancies between planned and delivered dose distributions. More critically, collimator misalignment exceeding $\pm 1^\circ$ was shown to significantly degrade target coverage and homogeneity, with variations in HI reaching up to 75%, particularly for large planning target volumes. These results underscore the necessity of rigorous quality assurance protocols and precise mechanical calibration to ensure safe and effective treatment delivery. In terms of organ-at-risk (OAR) sparing, the analysis confirms that collimator angle alone is not the primary determinant. Instead, OAR dose reduction is predominantly influenced by multileaf collimator (MLC) design, leaf width, and advanced delivery techniques. MLC-based approaches achieved dose reductions of up to 20% in critical structures such as the heart and lungs, while narrower MLC leaf widths (e.g., 2.5 mm) provided superior dose gradients and normal tissue sparing compared to wider leaves (5 mm). Additionally, advanced techniques such as VMAT, dynamic trajectory radiotherapy (DTRT), and split X-jaw planning further enhanced OAR protection and treatment efficiency. Overall, this study establishes that collimator angle should be considered as part of a multifactorial, patient-specific optimization strategy in VMAT planning. Moderate angles (15°–45°) are recommended as a practical

default for most clinical scenarios, while advanced and automated optimization techniques should be employed for complex cases. Future research should focus on large-scale clinical trials and the development of standardized, automated collimator angle optimization protocols to further improve treatment precision, efficiency, and long-term clinical outcomes.

References

- Andersen, A., Johnson, C., Bartlett, G., & Das, I. (2016). SU-G-BRC-04: Collimator angle optimization in volumetric modulated arc therapy. *Medical Physics*, 43(6, Part 24), 3627.
- Battinelli, C., Fredriksson, A., & Eriksson, K. (2021). Collimator angle optimization for multiple brain metastases in dynamic conformal arc treatment planning. *Medical Physics*, 48(9), 5414–5422.
- Bertholet, J., Mackeprang, P. H., Mueller, S., Guyer, G., Loebner, H. A., et al. (2022). Organ-at-risk sparing with dynamic trajectory radiotherapy for head and neck cancer: Comparison with volumetric arc therapy on a publicly available library of cases. *Radiation Oncology*, 17(1), 122.
- Chen, M. J., Leao, C. R., Simoes, R. C. P., Belletti, F. S., Figueiredo, M. L. S., et al. (2020). Kidney-sparing whole abdominal irradiation in Wilms tumor: Potential advantages of VMAT technique. *Pediatric Blood & Cancer*, 67(5), e28223.
- Hunte, S. O., Clark, C. H., Zyuzikov, N., & Nisbet, A. (2022). Volumetric modulated arc therapy (VMAT): A review of clinical outcomes—what is the clinical evidence for the most effective implementation? *The British Journal of Radiology*, 95(1136), 20201289.
- Isa, M., Rehman, J., Afzal, M., & Chow, J. C. (2014). Dosimetric dependence on the collimator angle in prostate volumetric modulated arc therapy. *International Journal of Cancer Therapy and Oncology*, 2(4), 20419.
- Jeong-Ho, K., Min-Cheol, J., & Man-Seok, H. (2022). A study on the change in surface dose caused by electromagnetic radiation according to the angle of the collimator. *Journal of Magnetism*, 27(4), 480–484.
- Kim, M., Kim, B., Choi, E., Shin, Y. S., Park, S. G., et al. (2024). Analyzing collimator rotation angle influence on half-beam VMAT outcomes for prostate cancer: A comparative approach using statistical and machine-learning methods. [Journal information not provided].
- Kim, Y. H., Park, D., Park, H. R., Kim, W. T., Kim, D. H., et al. (2017). Effect of collimator angles on the dosimetric results of volumetric modulated arc therapy planning for patients with a locally advanced nasopharyngeal carcinoma. *Journal of the Korean Physical Society*, 70(5), 539–544.
- Kim, Y. H., Park, H. R., Kim, W. T., Kim, D. W., Ki, Y., Lee, J., ... & Nam, J. H. (2015). Effect of the collimator angle on dosimetric verification of volumetric modulated arc therapy. *Journal of the Korean Physical Society*, 67(1), 243–247.
- Li, M. H., Huang, S. F., Chang, C. C., Lin, J. C., & Tsai, J. T. (2018). Variations in dosimetric distribution and plan complexity with collimator angles in hypofractionated volumetric arc radiotherapy for treating prostate cancer. *Journal of Applied Clinical Medical Physics*, 19(2), 93–102.
- Li, Q., Gu, W., Mu, J., Yin, W., Gao, M., Mo, J., & Pei, H. (2015). Collimator rotation in volumetric modulated arc therapy for craniospinal irradiation and the dose distribution in the beam junction region. *Radiation Oncology*, 10(1), 235.
- Mahani, L., Kazemzadeh, A., Saeb, M., Kianinia, M., & Akhavan, A. (2023). Dosimetric impact of different multileaf collimators on cardiac and left anterior descending coronary artery dose reduction. *Journal of Cancer Research and Therapeutics*, 19(3), 633–638.
- Mahani, L., Kazemzadeh, A., Saeb, M., Kianinia, M., & Akhavan, A. (2023). The efficacy of multi-leaf collimator in the reduction of cardiac and coronary artery dose in left-sided breast cancer radiotherapy. *Advanced Biomedical Research*, 12(1), 89.
- Momeni, N. S., Afraydoon, S., Hamzian, N., Nikfarjam, A., Vakili, G. M., Abdollahi, D. S., ... & Heidari, A. (2023). The estimation of radiation dose to out-of-field points of organs at risk in block and MLC shielded fields in lung cancer radiation therapy. [Journal information not provided].
- Ohira, S., Ueda, Y., Kanayama, N., Isono, M., Inui, S., et al. (2021). Impact of multileaf collimator width on dose distribution in HyperArc fractionated stereotactic irradiation for multiple brain metastases. *Anticancer Research*, 41(6), 3153–3159.
- Pietro, M., Luca, C., Antonella, F., Lattuada, P., Giacomo, R., et al. (2010). Collimator angle influence on dose distribution optimization for vertebral metastases using VMAT. *Medical Physics*.
- Puchades-Puchades, V., Serna-Berná, A., Mata-Colodro, F., Ramos-Amores, D., & Alcaraz-Baños, M. (2015). The importance of collimator angle error in volumetric-modulated arc therapy. *Journal of Radiotherapy in Practice*, 14(3), 323–330.
- Pudsey, L. M., Cutajar, D., Wallace, A., Saba, A., Schmidt, L., et al. (2021). The use of collimator angle optimization and jaw tracking for VMAT-based single-isocenter multiple-target stereotactic radiosurgery for up to six targets in the Varian Eclipse treatment planning system. *Journal of Applied Clinical Medical Physics*, 22(9), 171–182.
- Saeed, H., Sadiqullah, S., Manzoor, H., Ahmad, H. K. N., Shafiq, S., Ahmed, Q., Basit, A., & Ur Rehman, A. (2023). The effect of varying collimator angles on VMAT planning of prostate cancer. *Pakistan Journal of Medical & Health Sciences*, 17(4), 145.
- Sarma, G., Nath, J., Goswami, S., Goswami, P., Sharma, S. B., et al. (2023). Impact of split X-jaw technique on target volume coverage and organ at risk sparing in prostate cancer: A comparative dosimetric study. *Journal of Radiotherapy in Practice*, 22, e41.
- Serarslan, A., Daştan, Y., Aksu, T., Yıldız, R. E., Gürsel, B., et al. (2023). Ninety-degree angled collimator: A dosimetric study related to dynamic intensity-modulated radiotherapy in patients with endometrial carcinoma. *BMC Cancer*, 23(1), 515.
- Shen, J., Dai, Z., Yu, J., Yuan, Q., Kang, K., et al. (2022). Sub-arc collimator angle optimization based on the conformity index heatmap for VMAT planning of multiple brain metastases SRS treatments. *Frontiers in Oncology*, 12, 987971.
- Sun, W., Chen, K., Li, Y., Xia, W., Dong, L., et al. (2021). Optimization of collimator angles in dual-arc volumetric modulated arc therapy planning for whole-brain radiotherapy

- with hippocampus and inner ear sparing. *Scientific Reports*, 11(1), 19035.
25. Samaila, B., Tijjani, A.M., Abdul-Azeez, M.A., and O.W. Olasoji, O.W. (2025). Effect of Exposure to Ionizing Radiation on Reproductive System. *Jour of Clin Cas Rep, Med Imag and Heal Sci* 11 (4)
 26. Samaila, B., Tijjani, A.M., Abdul-Azeez M.A., and Olasoji, O.W. (2024), Implications of Ionizing Radiation Exposure to Patients' Mental Health During Diagnosis and Treatment: A Systematic Review, *J. Cancer Research and Cellular Therapeutics*, 8(3);
 27. Thomas, R., Nair, S. S., Sharan, K., Nagesh, J., & Hussain, S. (2023). A dosimetric study on the impact of collimator angles in nasopharynx carcinoma using VMAT planning. *Indian Journal of Science and Technology*, 16(11), 823–828.
 28. Wang, Y., Li, X., Zhang, Y., Qin, S., Song, L., & Wu, Q. (2020). Collimator angle optimization and jaw tracking for VMAT-based single-isocenter SRS. *Radiation Oncology Journal*, 35(4), 232–240.
 29. Xing, Y., Li, X., Qin, S., Song, L., Li, T., & Wu, Q. (2016). Collimator angle optimization and jaw tracking for SRS. *Radiation Oncology Journal*, 31(6), 473–482.
 30. Yoo, J. H., Park, S. Y., Kim, J. H., Kim, D. H., Kang, E. B., et al. (2014). Dose distribution effect related with collimator angle in VMAT of prostate cancer. *Radiation Oncology Journal*, 29(1), 1–7.
 31. Yong, H. K., Park, D., Park, H. R., Kim, W. T., Kim, D. H., Bae, J. S., ... & Ki, Y. (2017). Effect of collimator angles in VMAT for nasopharyngeal carcinoma. *Journal of the Korean Physical Society*.
 32. Zhang, P., Happersett, L., Yang, Y., Yamada, Y., Mageras, G., et al. (2010). Optimization of collimator trajectory in volumetric modulated arc therapy: Development and evaluation for paraspinal SBRT. *International Journal of Radiation Oncology, Biology, Physics*, 77(2), 591–599.
 33. Zhang, X., Li, X., Liu, J., Xu, X., & Li, H. (2023). Collimator optimization and jaw tracking for SRS in Eclipse. *Radiation Oncology Journal*, 38(1), 1–8.
 34. Zhang, Z., Li, D., Peng, F., Tan, Z., Yang, P., et al. (2022). Evaluation of hybrid VMAT advantages considering setup errors via SGRT. *Frontiers in Oncology*, 12, 907181.
 35. Zhang, Z., Yu, S., Peng, F., Tan, Z., Zhang, L., et al. (2023). Advantages and robustness of partial VMAT with prone position for rectal cancer. *Radiation Oncology*, 18(1), 102.
 36. Zhang, Y., Li, X., Qin, S., Song, L., Li, T., & Wu, Q. (2016). VMAT optimization with dynamic collimator rotation. *Radiation Oncology Journal*, 31(3), 225–232.



This work is licensed under Creative Commons Attribution 4.0 License

To Submit Your Article Click Here:

Submit Manuscript

DOI:10.31579/2640-1053/263

Ready to submit your research? Choose Auctores and benefit from:

- fast, convenient online submission
- rigorous peer review by experienced research in your field
- rapid publication on acceptance
- authors retain copyrights
- unique DOI for all articles
- immediate, unrestricted online access

At Auctores, research is always in progress.

Learn more <https://www.auctoresonline.org/journals/cancer-research-and-cellular-therapeutics>