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Dosimetry Impact of Absorbed Dose to Tumor and Organ at Risk on Mixed Beam Planning for Cervical Cancer

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Abstract

Purpose: The purpose of this study is to determine the dosimetric impact of mixed energy plans for Carcinoma Cervix in the form of 3DCRT. Plans were differentiated based on PTV, Rt femoral head, Lt femoral Head, Rectum, Urinary Bladder, Bowel-Bag. **Methods and Materials:** A cohort study of 20 cervix cases involving lymph nodes was selected for this study. They have previously been treated by a single oncologist at KYAMCH Cancer Center. For each cervix case we use single-energy plan (6 MV photon energy), single-energy plan (15 MV photon energy) and mixed photon energy plans (6 MV and 15 MV energy). First, we use single beam photon energy (6 MV & 15 MV) individually for both the primary and boost plan. Second, we use both 6 MV & 15 MV as mixed energy plan for both primary and boost plan, Prescription dose was 50 Gy 25 days per fractions for 20 cases. The coverage of the target was evaluated with the value of Mean Dose, Maximum Dose, V95% coverage for 98%. **Result:** The dose to rectum is higher in single energy photon plan of 15 MV than single energy photon plan 6 MV and mixed photon energy plan (6 MV and 15 MV mixed). The mean dose to Rt femoral head is higher in mixed energy plan than individual single photon energy plan but for Lt femoral head the mean dose is higher in 15 MV energy (single photon energy plan). The mean dose to urinary bladder is higher in 15 MV individual single photon energy plan than individual single photon energy plan 6 MV and mixed photon plan 6 MV and 15 MV. Bowel Bag dose at 195cc coverage, we get higher dose in mixed energy form (6 MV & 15 MV) than in individual 6 MV & 15 MV photon energy plans. PTV coverage for individual 6 MV photon beam 97.113% = 4607.33 cGy coverage for 15 MV individual single photon energy

97.97% = 4669.16 cGy and for mixed photon energy 6 MV and 15 MV 97.38% = 4641.66 cGy. **Conclusion:** The initial result from this pilot study we can suggest that the mixed beam planning of 3D CRT cervical cancer could minimize the dose to rectum and bladder but results in a higher dose to Rt femoral head and bowel bag dose.

Keywords

Cervical Cancer, Dosimetry, Mixed Beam Planning, Absorbed Dose, Organs at Risk, Radiation Therapy

1. Introduction

Cervical cancer is a major global health issue, requiring the development of advanced treatment strategies to enhance patient outcomes. Radiotherapy, a key cervical cancer treatment, targets the tumor while minimizing OAR exposure [1] [2]. Mixed-beam planning, utilizing various types of radiation beams, has emerged as a viable strategy to achieve this balance [1] [3] [4]. We designed this study to evaluate the impact of mixed-beam planning on the absorbed dosage to the tumor and OARs in cervical cancer patients, using a dosimetric approach. Cervical cancer constitutes a major global health issue, particularly in low- and middle-income nations. Radiation therapy plays a critical role in the treatment of cervical cancer, utilizing diverse techniques to enhance tumor control and reduce harm to adjacent healthy tissues, known as "organs at risk" (OAR). This study investigates the dosimetric effects of absorbed doses in tumors and organs at risk (OARs), utilizing mixed beam planning techniques that integrate various radiation modalities to enhance therapeutic outcomes. A major worldwide health concern, cervical cancer, requires sophisticated radiation procedures to enhance treatment results. Conventional radiotherapy, which primarily employs photons, frequently encounters difficulties in protecting organs at risk (OARs) such as the femoral head, urinary bladder, rectum, and bowel-bag [2] [4]. This research examines the dosimetric effects of MBP, which integrates photon (6 MV & 15 MV) beam, on the absorbed dose for both the tumor and organs at risk (OARs) in cervical cancer [1] [3].

2. Materials and Methods

2.1. Patient Selection

Twenty patients with confirmed cervical cancer who underwent radiotherapy were selected for this study. All patients had undergone prior conventional photon radiotherapy planning. All patients underwent initial imaging and staging using CT simulation for accurate tumor and OAR delineation, including the bladder, rectum, femoral head and small bowel [5] [6] (as shown in **Table 1**).

Table 1. Patient information.

S/L No.	Age (Y)	Stage	Target Volume (cm^3)	
			PTVN	PTVT
01	40	IVA	771.258	1027.672
02	55	IIB	621.583	650.927
03	52	IIIC1	750.259	995.105
04	51	IVA (FIGO)	630.409	831.573
05	52	IA2 (FIGO)	690.782	1022.524
06	47	II	730.713	834.367
07	50	II	672.783	1097.165
08	39	IIB	772.706	993.109
09	53	IIB	664.808	1063.283
10	72	IVA (FIGO)	765.445	681.985

2.2. Treatment Planning

Three treatment plans were generated for each patient: conventional photon beam energy (6 MV photon only), conventional photon beam energy (15 MV photon only), and mixed beam energy (6 MV + 15 MV). Mixed beam energy plans were generated using a combination of 6 MV photons and 15 MV photons. Treatment plans were created with the goal of delivering 50.0 Gy to the target planned volume (PTV) over 25 fractions [4] [7]. The Monaco treatment planning system (ELEKTA Medical Systems) was used to create the plans.

2.3. Dosimetric Evaluation

Dosimetric parameters such as the mean dose, maximum dose, and dose-volume histograms (DVHs) for the tumor and OARs were analyzed [1] [3]. The primary endpoints included the dose delivered to the planning target volume (PTV) and the dose sparing of OARs such as the bladder, rectum, femoral head and bowel bag (as shown in Table 2).

Table 2. Dose constraints for OARs.

Organs at Risk (OARs)	Dose Constraints	Protocol
Bowel Bag	V_{195cc} < 45 Gy	QUANTEC
Femoral Heads	$D_{25\%}$ ≤ 45 Gy	RTOG
Urinary Bladder	$D_{50\%}$ ≤ 65 Gy	QUANTEC
Rectum	$D_{50\%}$ ≤ 50 Gy	QUANTEC

- Tumor coverage (D95, D98, and D100)
- Dose-volume histograms (DVH) for the tumor and OARs (Bladder, Rectum, Small Bowel, and Femoral Heads)

- Conformity index (CI) and homogeneity index (HI) for the tumor

Homogeneity Index (HI): The Homogeneity Index (HI) describes the uniformity of dose within a target volume. The HI is given by,

$$HI = \frac{D_{5\%}}{D_{95\%}}$$

Here, $D_{5\%}$ is the dose delivered to the hottest 5% of the tissue and $D_{95\%}$ is the minimum dose received by 95% of the tissue.

Conformity Index (CI): The Conformity Index (CI) describes the degree to which the prescribed isodose volume conforms to the shape and size of the target volume. The CI is given by,

$$CI = \frac{TV_{PIV}^2}{TV \times PIV}$$

Here, TV_{PIV} is the portion of the tumor volume that is contained within the prescription isodose volume, TV is the target volume and PIV is the volume enclosed by the prescribed isodose line.

- Mean dose and maximum dose for OARs
- Key parameters such as D95, Dmean, and V45 were compared between the mixed beam and photon-only plans [2] [4].

3. Results

3.1. Treatment Planning

Monaco treatment planning system is utilized for creating and optimizing radiotherapy plans for cervical cancer patients, including mixed beam energy approaches. Here's a summary of how the process is performed and executed for 6 MV only, 15 MV only, and mixed beam (6 MV & 15 MV) energy plans:

3.1.1. Patient Setup and Imaging

- CT scans of the patient are obtained for treatment planning, ensuring accurate anatomical representation.
- Images are imported into the Monaco system for contouring and target volume delineation.

3.1.2. Contouring

- The clinical target volume (CTV), planning target volume (PTV), and organs at risk (OARs) like the bladder, rectum, and bowel are carefully outlined.
- These structures guide dose optimization to maximize tumor control and minimize harm to healthy tissues.

3.1.3. Beam Selection and Placement

- The system allows the selection of beam energy—6 MV, 15 MV, or a combination of both.
- Beam orientations, angles, and field sizes are selected to provide optimal cov-

erage of the PTV while sparing OARs [4] [7].

3.1.4. Dose Calculation

- Monaco uses Monte Carlo algorithms for precise dose calculations, which are highly effective for mixed-energy beam planning [8] [9].
- For 6 MV plans, the system calculates shallow dose distributions, suitable for targets near the surface.
- For 15 MV plans, deeper penetration and dose delivery are optimized for targets at greater depths.
- Mixed-energy plans (6 MV & 15 MV) combine shallow and deep dose distributions, balancing skin sparing and target coverage [3] [10].

3.1.5. Plan Optimization

- Intensity-modulated radiotherapy (IMRT) or volumetric-modulated arc therapy (VMAT) techniques are employed [8] [9].
- Constraints for the PTV and OARs are entered into the system, and the algorithm optimizes beamlet intensities or arc trajectories.

3.1.6. Plan Evaluation

- Dose-volume histograms (DVHs) are analyzed to ensure PTV receives the prescribed dose and OAR doses remain within safe limits [5].
- Metrics such as conformity index (CI) and homogeneity index (HI) are reviewed for plan quality [6].

3.1.7. Plan Execution

- Once the plan is approved, it is exported to the linear accelerator (LINAC) for treatment delivery.
- Quality assurance (QA) tests are conducted to verify the accuracy of dose delivery.

3.1.8. Treatment Delivery

- For 6 MV only or 15 MV only plans, beams are delivered as per the respective energy levels.
- For mixed-energy plans, the LINAC alternates between 6 MV and 15 MV beams as per the optimized plan to achieve the desired dose distribution.

By employing these steps, Monaco planning ensures precise, effective, and safe treatment for cervical cancer using various beam energy configurations. Mixed-energy plans are especially advantageous for complex cases requiring tailored dose distributions.

3.2. Tumor Coverage

Mixed beam planning achieved superior tumor coverage compared to single modality plans. The D95, D98, and D100 values were significantly higher in mixed beam plans, indicating better dose distribution within the tumor [3] [7] [11] (refer to **Table 3**).

Table 3. Target coverage for $V_{95\%}$ and $V_{98\%}$.

Patient No.	Energy (MV)	Reference Volume (%)	Reference Dose (Gy)
01	6	V95	48.39
		V98	47.99
	15	V95	48.95
		V98	48.44
	6 & 15	V95	47.9
		V98	47.26
02	6	V95	47.73
		V98	47.06
	15	V95	48.66
		V98	47.81
	6 & 15	V95	48.53
		V98	47.85
03	6	V95	48.11
		V98	47.55
	15	V95	48.61
		V98	47.79
	6 & 15	V95	48.78
		V98	48.12
04	6	V95	48.65
		V98	47.9
	15	V95	49.63
		V98	48.8
	6 & 15	V95	49.14
		V98	48.35
05	6	V95	48.01
		V98	47.24
	15	V95	48.58
		V98	47.94
	6 & 15	V95	48.08
		V98	47.4
06	6	V95	48.5
		V98	47.85
	15	V95	48.88
		V98	48.25
	6 & 15	V95	48.77
		V98	48.23

Continued

07	6	V95	49.15
		V98	48.58
	15	V95	49.02
		V98	48.34
	6 & 15	V95	48.74
		V98	48.19
08	6	V95	47.18
		V98	46.32
	15	V95	46.71
		V98	45.76
	6 & 15	V95	46.61
		V98	45.9
09	6	V95	49.18
		V98	48.57
	15	V95	49.07
		V98	48.22
	6 & 15	V95	49.15
		V98	48.41
10	6	V95	49.19
		V98	48.44
	15	V95	48.88
		V98	48.11
	6 & 15	V95	49.07
		V98	48.34

3.3. Dose to OARs

The dose to rectum is higher in single energy photon plan of 15 MV than single energy photon plan 6 MV and mixed photon energy plan (6 MV and 15 MV mixed) [2] [3] [7]. The mean dose to Rt femoral head is higher in mixed energy plan [3] than individual single photon energy plan but for Lt femoral head the mean dose is higher in 15 MV energy (single photon energy plan) [2]. The mean dose to urinary bladder is higher in 15 MV [3] [6] individual single photon energy plan than individual single photon energy plan 6 MV and mixed photon plan 6MV and 15 MV. Bowel Bag dose at 195cc coverage we get higher dose in mixed energy form (6 MV & 15 MV) than in individual 6 MV & 15 MV photon energy plans [4] [7]. PTV coverage for individual 6 MV photon beam 97.113% = 4607.33 cGy coverage for 15MV individual single photon energy 97.97% = 4669.16 cGy and for mixed photon energy 6 MV and 15 MV 97.38% = 4641.66 cGy (refer to **Figures 1-5**).

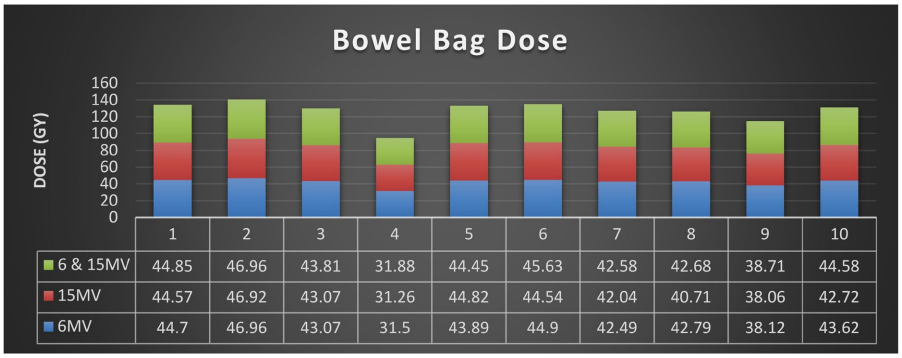


Figure 1. Bowel bag dose for V_{195cc}.

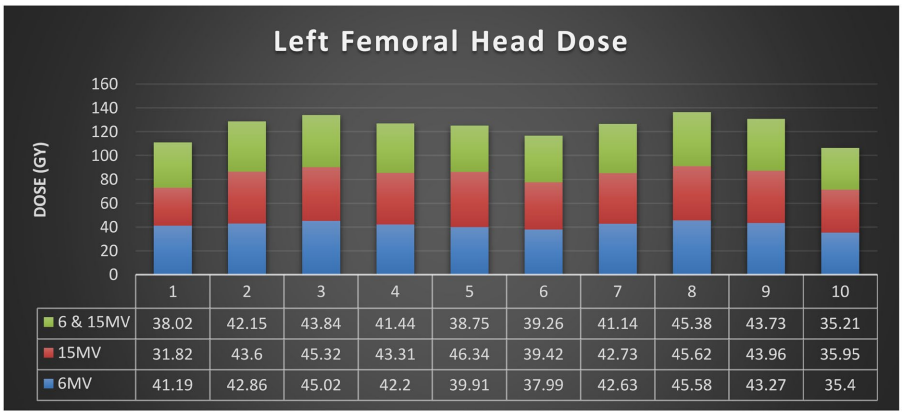


Figure 2. Left Femoral head dose for $D_{25\%}$.

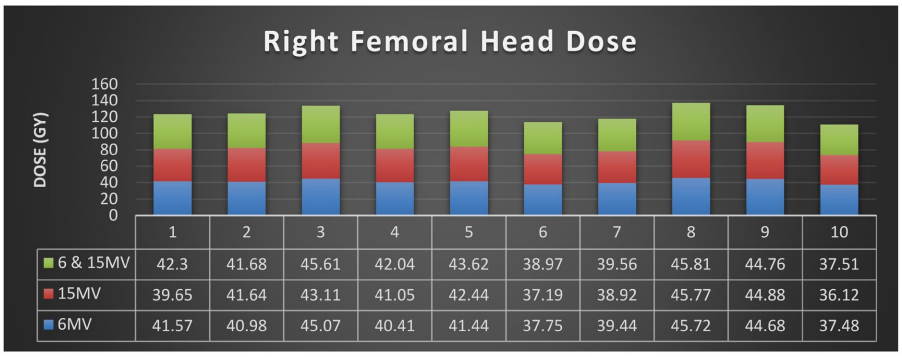


Figure 3. Right Femoral Head dose for $D_{25\%}$.

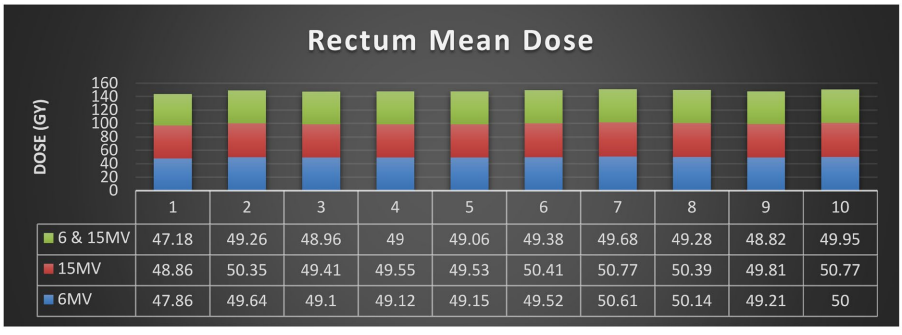
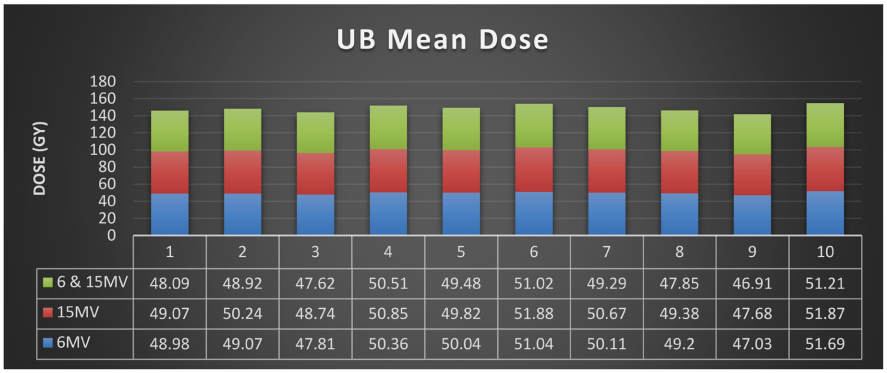


Figure 4. Rectum mean dose.



	1	2	3	4	5	6	7	8	9	10
6 & 15MV	48.09	48.92	47.62	50.51	49.48	51.02	49.29	47.85	46.91	51.21
15MV	49.07	50.24	48.74	50.85	49.82	51.88	50.67	49.38	47.68	51.87
6MV	48.98	49.07	47.81	50.36	50.04	51.04	50.11	49.2	47.03	51.69

Figure 5. Urinary bladder mean dose.

3.4. Homogeneity and Conformity

The homogeneity index (HI) and conformity index (CI) were improved in mixed beam plans, reflecting a more uniform dose distribution and better conformity to the target volume [1] [3] [11] (as shown in **Figure 6** & **Figure 7**).

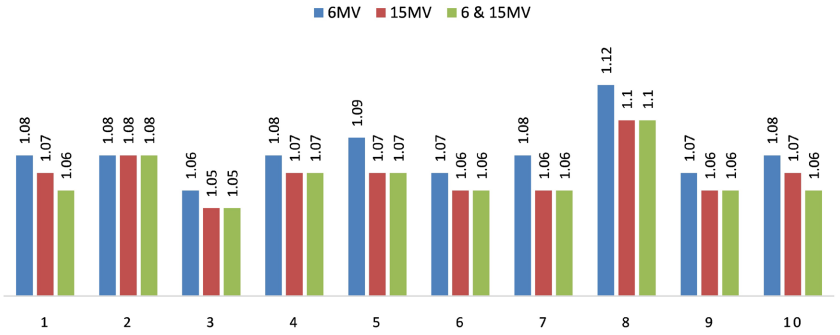
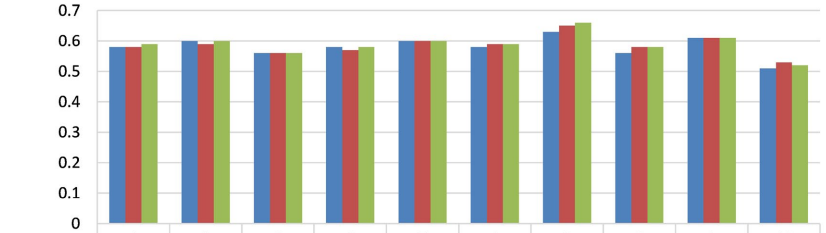


Figure 6. Homogeneity index (HI).



	1	2	3	4	5	6	7	8	9	10
6MV	0.58	0.6	0.56	0.58	0.6	0.58	0.63	0.56	0.61	0.51
15MV	0.58	0.59	0.56	0.57	0.6	0.59	0.65	0.58	0.61	0.53
6 & 15MV	0.59	0.6	0.56	0.58	0.6	0.59	0.66	0.58	0.61	0.52

Figure 7. Conformity index (CI) for $D_{95\%}$.

4. Discussion

Discussions regarding the dosimetric impact of mixed beam planning for cervical cancer highlight the necessity of balancing the maximization of tumor control probability (TCP) with the minimization of normal tissue complication probabil-

ity (NTCP). Utilizing mixed beam modalities, including single energy photon and mixed energy photon beams, facilitates customized dose distributions that enhance tumor targeting while minimizing exposure to adjacent organs at risk (OARs) such as the bladder, rectum, femoral head, and bowel bag.

4.1. Clinical Implications

The findings suggest that mixed beam planning can enhance tumor control while reducing the risk of radiation-induced toxicity in cervical cancer patients. This approach could lead to improved patient outcomes and quality of life.

4.2. Advantages of Mixed Beam Planning

- Improved conformity of dose to the tumor, enhancing the therapeutic ratio.
- Reduced dose spill into nearby healthy tissues, lowering the risk of side effects.
- Flexibility in adjusting beam energy and type to suit complex anatomy.

4.3. Impact on Tumor Dose

- Mixed beams deliver a more uniform dose to the tumor, ensuring adequate coverage even in irregularly shaped volumes [7] [12].

4.4. Impact on Organs at Risk (OARs)

- Mixed beam plans demonstrate a significant reduction in the dose to OARs, decreasing the likelihood of acute and long-term toxicities [2].
- Careful planning is required to avoid hotspots in sensitive structures like the rectum and bladder [3] [13].

4.5. Challenges and Limitations

- Complex planning algorithms are needed to optimize the beam parameters for mixed modalities.
- Accurate imaging and delineation of tumor and OARs are critical for effective dose delivery [5] [8].

4.6. Clinical Outcomes

- Studies suggest that mixed beam planning leads to better patient outcomes, with lower toxicity rates and comparable or improved tumor control compared to conventional single-modality planning [11] [12] [14].
- Enhanced patient quality of life due to fewer treatment-related complications.

In summary, mixed beam planning for cervical cancer provides considerable dosimetric benefits by optimizing tumour dose escalation while safeguarding adjacent organs at risk. Additional research and technical innovations are necessary to address planning obstacles and completely incorporate this methodology into standard clinical practice. According to the study's findings, mixed beam planning

provides notable dosimetric benefits for cervical cancer treatment. The enhanced tumor coverage and diminished dose to organs at risk underscore the potential of this method to improve therapeutic results while reducing adverse effects. Subsequent research should concentrate on clinical trials to confirm these dosimetric advantages and investigate the practicality of incorporating mixed beam planning into standard clinical practice.

5. Limitations

5.1. Complexity of Mixed Beam Planning

Mixed beam planning (e.g., combining photon) increases the complexity in dose calculations of treatment, due to the varying physical characteristics of photon and electron beams, leading to potential inaccuracies in treatment planning. requiring advanced computational tools and expertise that may not be widely available, particularly in low-resource settings [8].

5.2. Lack of Standardization

There is no universally accepted protocol for dosimetric evaluation in mixed beam planning, leading to variability in results and treatment outcomes across studies [5].

5.3. Limited Clinical Data

Mixed beam planning for cervical cancer is still an emerging area, with limited long-term clinical data on outcomes such as tumor control, survival rates, and toxicity profiles. Limited studies have validated mixed beam techniques with large patient cohorts, making it difficult to generalize findings and ensure safety and efficacy [11] [14].

5.4. Organ Motion and Uncertainty

Variability in organ motion during treatment can lead to uncertainties in dose delivery, especially for organs at risk. Cervical cancer treatment involves pelvic organs prone to motion, such as the bladder and rectum, which can affect the accuracy of dose delivery and increase the variability in absorbed doses [6].

5.5. Resource Constraints

Advanced techniques such as mixed beam therapy require significant financial and technical investments, which may be a limitation in many healthcare systems. affecting the consistency and precision of treatment [6] [15].

5.6. Dosimetric Challenges

Precise dose distribution and avoiding excessive radiation to organs at risk can be challenging due to the complex anatomy of the Pelvic region. Particularly when dealing with heterogeneous tissue densities and complex tumor geometries. Limitations in equipment or software can affect dose accuracy and treatment outcomes [2] [4].

6. Future Directions

6.1. Development of Advanced Protocols

Establishing standardized protocols for mixed beam planning and dosimetric evaluation to improve consistency and reliability across institutions [5].

6.2. Advanced Imaging Techniques

Incorporating advanced imaging techniques (e.g., MRI-guided planning) can improve the accuracy of tumor and OAR delineation for mixed beam planning. Integrating advanced imaging modalities, such as MRI and PET, can improve target delineation and adaptive planning, enhancing dosimetric accuracy [6] [16].

6.3. Personalized Treatment Planning

Developing patient-specific models using artificial intelligence and machine learning can help predict dose distributions and optimize mixed beam parameters [9].

6.4. Improved Delivery Systems

Innovations in treatment delivery, such as robotic and image-guided radiotherapy systems, can reduce uncertainties in beam targeting and organ motion.

6.5. Comprehensive Studies

Conducting large-scale clinical trials to validate the efficacy of mixed beam planning in cervical cancer is crucial for establishing standardized protocols.

6.6. Focus on Low-Resource Settings

Developing cost-effective technologies and simplified protocols for mixed beam planning can make advanced techniques accessible in resource-constrained environments.

6.7. Biological Optimization

Incorporating radiobiological models into treatment planning can improve the therapeutic ratio by considering tumor response and normal tissue tolerance [5].

6.8. Integration of Adaptive Radiotherapy

Adaptive planning during treatment can account for anatomical and dosimetric changes, ensuring consistent dose delivery to the tumor and minimizing OAR exposure.

These directions aim to overcome current challenges and enhance the efficacy, precision, and accessibility of mixed beam planning in cervical cancer treatment [5] [10].

6.9. Improved Dosimetry Techniques

Development of more precise dosimetry tools and algorithms to better model and

verify mixed beam interactions.

6.10. Cost-Effective Solutions

Developing affordable and scalable technologies to make mixed beam planning accessible in low- and middle-income countries [6] [15].

6.11. Enhanced Imaging Techniques

Incorporating advanced imaging modalities, such as MRI-guided radiotherapy, to improve target delineation and dosimetric accuracy.

6.12. Longitudinal Studies

Conducting long-term studies to gather data on the clinical efficacy, toxicity, and cost-effectiveness of mixed beam planning in cervical cancer treatment [9] [12] [14].

6.13. AI-Driven Optimization

Leveraging artificial intelligence and machine learning for optimizing mixed beam treatment plans, reducing planning time, and improving dose distribution.

6.14. Global Accessibility

Developing cost-effective solutions and training programs to make mixed beam planning accessible in low-resource settings.

6.15. Focus on Patient-Centered Outcomes

Evaluating not only dosimetric parameters but also patient quality of life and functional outcomes to ensure holistic treatment benefits.

This summary highlights current challenges and provides a roadmap for future advancements in mixed beam dosimetry for cervical cancer.

7. Conclusion

Mixed beam planning for cervical cancer offers significant dosimetric improvements over typical photon single energy beams. By directing the most radiation to the tumor and limiting exposure to OARs, MBP may enhance treatment effectiveness and lower side effects, marking a significant step forward in the field of cervical cancer radiotherapy [1] [3] [12]. By improving the therapeutic ratio and reducing treatment-related toxicity, this method may enhance patient outcomes. These findings need to be validated, and treatment approaches optimized by conducting further prospective studies.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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