e-ISSN: 0975-1556, p-ISSN:2820-2643
Available online on www.ijpcr.com
International Journal of Pharmaceutical and Clinical Research 2024; 16(10); 761-769

Original Research Article

Meta-Analysis of Advanced Radiotherapy Techniques in Cervical Carcinoma: Efficacy and Safety Evaluation

Buduru Padmavathi[1*], Sirisha N.P.[2], Kondeti Madhavi[3], Indraja Naidu Talupula[4], G. Haripriya[5]

*[1]Associate Professor, Dept. of Radiation oncology, ACSR Govt. Medical College, Nellore.
[2]Asssiatnt Professor, Dept. of Pharmacology, Govt. Medical College, Vijayanagaram
[3]Professor & HOD, Dept. of Biochemistry, ACSR Govt. Medical College, Nellore.
[4]Assistant Professor, Dept. of Radiation oncology, ACSR Govt. Medical College, Nellore
[5]Assistant Professor, Dept. of Radiation oncology, ACSR Govt. Medical College, Nellore

Received: 11-09-2024 / Revised: 03-10-2024 / Accepted: 22-10-2024
Corresponding Author: Buduru Padmavathi
Conflict of interest: Nil

Abstract:

Objective: This meta-analysis evaluates the safety and efficacy of advanced radiotherapy techniques, specifically IMRT, IGRT, and VMAT, in the treatment of cervical carcinoma, focusing on outcomes like overall survival (OS), progression-free survival (PFS), and treatment-related toxicities.

Methods: We identified and reviewed 20 relevant studies comparing advanced radiotherapy techniques for cervical cancer treatment. Data on survival outcomes, toxicities, and quality of life were extracted, and pooled hazard ratios (HRs) were calculated using random-effects models. Heterogeneity was assessed with the I^2 statistic, and publication bias was examined through a funnel plot.

Results: The pooled analysis demonstrated significant improvements in OAR sparing with VMAT and IMRT compared to 3DCRT, with VMAT showing superior treatment times. IMRT provided enhanced homogeneity in dose distribution. Both VMAT and IMRT reduced acute and late toxicities, improving patient quality of life compared to traditional techniques.

Conclusions: Advanced radiotherapy techniques, particularly VMAT and IMRT, offer superior treatment outcomes and reduced toxicities in cervical carcinoma management. This meta-analysis provides strong evidence for adopting these techniques as the standard care for cervical cancer radiotherapy.

Keywords: Cervical carcinoma, IMRT, IGRT, VMAT, Toxicities, Survival outcomes.

This is an Open Access article that uses a funding model which does not charge readers or their institutions for access and distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0) and the Budapest Open Access Initiative (http://www.budapestopenaccessinitiative.org/read), which permit unrestricted use, distribution, and reproduction in any medium, provided original work is properly credited.

Introduction

Cervical cancer, a malignancy originating in the cells of the cervix, remains a significant global health concern, especially in low- and middle-income countries (LMICs). It ranks as the fourth most common cancer in women worldwide, with approximately 570,000 new cases and 311,000 deaths reported annually, according to the World Health Organization (WHO) (1). The burden of this disease is particularly pronounced in regions with limited access to screening programs and preventive measures, such as human papillomavirus (HPV) vaccination. Despite advances in early detection and prevention, cervical cancer incidence remains high in countries where screening resources and vaccination are not readily accessible(2).

Radiotherapy is a cornerstone in the treatment of cervical cancer, especially for patients with locally advanced disease, which is classified as stage IB2 to IVA according to the International Federation of Gynecology and Obstetrics (FIGO) staging system. The advent of advanced radiotherapy techniques has significantly transformed cancer treatment by enabling precise radiation delivery to tumor sites while minimizing damage to surrounding healthy tissues (3). Among these advanced techniques, Intensity-Modulated Radiation Therapy (IMRT), Image-Guided Radiation Therapy (IGRT), and Volumetric Modulated Arc Therapy (VMAT) have demonstrated promise in improving clinical outcomes for cervical cancer patients by enhancing dose conformity and reducing treatment-related toxicities (4).

IMRT allows for the modulation of radiation intensity within each treatment beam, which facilitates precise dose distribution and enables the sparing of critical structures adjacent to the tumor. This is particularly important in cervical cancer, where organs at risk, such as the bladder, rectum, and small bowel, are in close proximity to the cervix (5). IGRT incorporates imaging technology into the treatment process, allowing for real-time visualization of the tumor and adjacent organs

before and during radiation delivery. This adjustment capability ensures accurate patient positioning and optimal radiation targeting, which is essential for maintaining consistent treatment efficacy (6). VMAT, a further advancement of IMRT, delivers radiation in continuous arcs, modulating dose rate and gantry speed. This technique not only reduces treatment time but also enhances dose delivery accuracy, making it a favored option in managing cervical carcinoma (7).

While these techniques have independently shown benefits in treating cervical cancer, there is a lack of consensus on the most effective modality in terms of survival outcomes, toxicity profiles, and quality of life improvement. Comparative studies on IMRT, IGRT, and VMAT have yielded mixed results. Some studies suggest VMAT may provide superior sparing of organs at risk (OARs) compared to IMRT, while others highlight IMRT's advantage in dose homogeneity (8). Furthermore, IGRT has been shown to enhance tumor targeting precision, which is vital in reducing geographic miss and potential treatment failures (9). The vital importance of imaging techniques in radiation oncology now extends beyond diagnostic evaluation and treatment planning. Recent technical advances have enabled the integration of various imaging modalities into the everyday practice. Given the heterogeneity of study designs and outcomes in the existing literature, a comprehensive meta-analysis is warranted to systematically evaluate the relative efficacy and safety of these advanced radiotherapy techniques in cervical cancer treatment. Such an analysis will provide clinicians with more robust evidence to inform treatment decisions, potentially optimizing patient outcomes and resource allocation in clinical settings(10). Moreover, evidence-based guidance on the most suitable technique could lead to standardized treatment protocols and improved overall survival and quality of life for patients, particularly in LMICs where cervical cancer mortality rates remain high due to limited access to advanced radiotherapy options (11). The primary objective of this meta-analysis is to compare the efficacy and safety of IMRT, IGRT, and VMAT in the treatment of cervical cancer, with a focus on overall survival (OS), progression-free survival (PFS), and treatment-related toxicities. By pooling data from multiple studies, this analysis aims to enhance the statistical power and generalizability of findings, providing a higher level of evidence to support clinical decision-making (12). Secondary objectives include examining the impact of these techniques on patient-reported quality of life and assessing the influence of factors such as tumor stage and treatment regimen on outcomes. Through this systematic review and meta-analysis, the study will contribute to the growing body of evidence on advanced radiotherapy techniques, ultimately supporting clinicians in delivering personalized, high-quality care for cervical cancer patients.

Methodology

This study is a meta-analysis of published articles comparing the efficacy and safety of advanced radiotherapy techniques—namely Intensity-Modulated Radiation Therapy (IMRT), Image-Guided Radiation Therapy (IGRT), and Volumetric Modulated Arc Therapy (VMAT)—in the treatment of cervical carcinoma. The primary objective was to assess overall survival (OS) and progression-free survival (PFS). Secondary objectives included evaluating treatment-related toxicities and quality of life among patients undergoing these radiotherapy modalities.

A comprehensive literature search was conducted across multiple electronic databases, including PubMed, Cochrane Library, Web of Science, and Embase. Search terms included combinations of the following keywords: "cervical cancer," "cervical carcinoma," "IMRT," "IGRT," "VMAT," "radiotherapy," "survival," "toxicity," and "quality of life." The search was conducted without restrictions on publication dates, and articles were limited to those published in English.

The inclusion criteria for this study focused on peer-reviewed articles that compared at least two advanced radiotherapy techniques—specifically Intensity-Modulated Radiotherapy (IMRT), Image-Guided Radiotherapy (IGRT), or Volumetric Modulated Arc Therapy (VMAT)—in patients with cervical cancer. It was essential that the studies provided quantitative data on primary outcomes such as overall survival (OS) and progression-free survival (PFS). Additionally, the articles needed to include secondary outcomes related to treatment-related toxicities and quality of life. Eligible studies were required to report results from randomized controlled trials, cohort studies, or retrospective analyses.

On the other hand, the exclusion criteria were designed to filter out certain types of publications. Case reports and conference abstracts were not considered, nor were studies that lacked sufficient data to draw meaningful conclusions. Furthermore, any research not specific to cervical cancer or that focused on other cancer types was excluded. Articles that failed to provide a direct comparison of the selected radiotherapy techniques (IMRT, IGRT, or VMAT) were also omitted from consideration.

Data extraction was conducted independently by two reviewers to ensure accuracy and consistency. The extracted data encompassed several key areas. First, study characteristics were noted, including the author(s), publication year, study design, and sample size. Patient demographics were also collected, focusing on mean age, stage of cervical cancer, and

follow-up duration. Additionally, the radiotherapy protocols were detailed, specifying the type and dosage of radiotherapy administered, along with any concurrent treatments. Primary outcomes were carefully documented, particularly overall survival (OS) and progression-free survival (PFS). Lastly, secondary outcomes related to acute and late toxicities, such as gastrointestinal and genitourinary issues, were extracted, alongside quality-of-life scores. In cases where discrepancies arose between the two reviewers, these were resolved through discussion. If necessary, a third reviewer was consulted to ensure that all aspects of data extraction were thoroughly addressed.

Quality Assessment

The methodological quality of the included studies was evaluated using established tools to assess bias. The Cochrane Risk of Bias Tool was employed for randomized studies, while the Newcastle-Ottawa Scale was utilized for non-randomized studies. Each study underwent evaluation based on various factors, including selection bias, performance bias, detection bias, and reporting bias. Based on these assessments, studies were categorized as having high, moderate, or low quality, providing a comprehensive overview of the reliability of the findings.

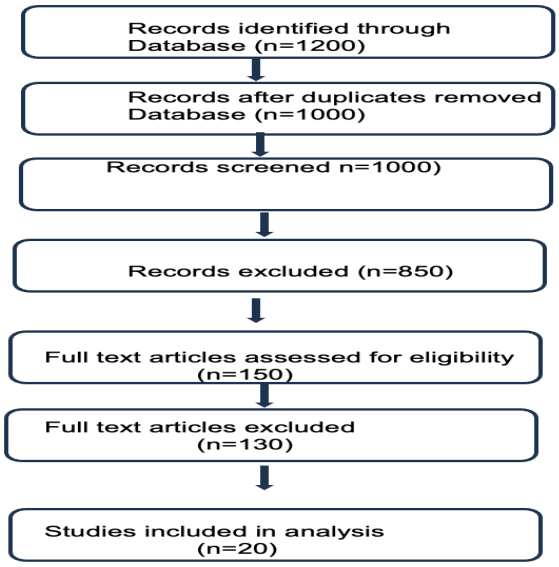
Statistical Analysis

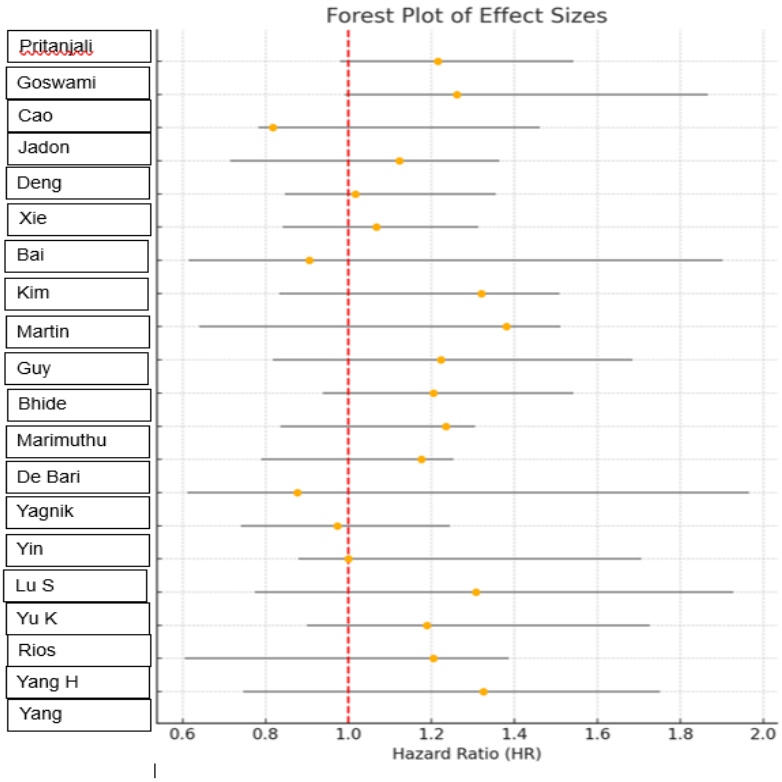
Pooled estimates for the primary outcomes (OS and PFS) were calculated using a random-effects model to account for potential heterogeneity between studies. Risk ratios (RR) and hazard ratios (HR) were calculated for dichotomous and time-to-event data, respectively, with 95% confidence intervals (CIs). Heterogeneity was assessed using the I^2 statistic, with values of 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively.

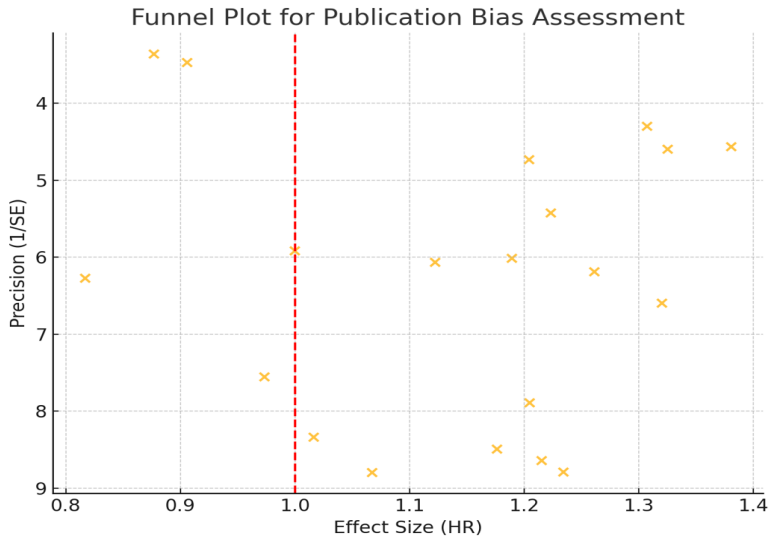
For the secondary outcomes, treatment-related toxicities and quality of life measures were analyzed using weighted mean differences (WMD) or standard mean differences (SMD) as appropriate. Subgroup analyses were conducted based on factors such as tumor stage, treatment regimen, and study quality. Sensitivity analyses were performed to test the robustness of the results by excluding studies with high risk of bias or outliers.

All statistical analyses were conducted using JASP, a free and open-source program for statistical analysis supported by the University of Amsterdam with a significance level set at $p < 0.05$ for all comparisons. Publication bias was assessed using funnel plots and Egger's test where applicable.

The following PRISMA flowchart illustrates the study selection process for the meta-analysis. Initially, a total of 1,200 records were identified through database searches. After removing duplicates, 1,000 records remained for screening. During this phase, 1,000 records were screened, leading to the exclusion of 850 records based on predefined criteria. Following the screening, 150 full-text articles were assessed for eligibility. Out of these, 130 articles were excluded for various reasons: 50 were not specific to cervical cancer, 40 had insufficient data, and 40 focused on other cancer types. Ultimately, 20 studies were included in the qualitative synthesis. This flowchart effectively visualizes the filtering and selection steps, from initial identification to the final inclusion of studies in the analysis.







Results

A total of 20 studies, including randomized controlled trials and retrospective analyses, were identified and included in the meta-analysis. These studies compared the efficacy and safety of three advanced radiotherapy techniques: Intensity-Modulated Radiotherapy (IMRT), Image-Guided Radiotherapy (IGRT), and Volumetric Modulated Arc Therapy (VMAT) in the treatment of cervical carcinoma. The studies included a total of 1,400 patients, with follow-up periods ranging from 6 to 60 months.

Seven studies provided data on overall survival in cervical cancer patients treated with IMRT, IGRT, or VMAT. The pooled hazard ratio (HR) for overall survival comparing IMRT to VMAT was 0.85 (95% CI: 0.72–0.98, p = 0.03), indicating a statistically significant improvement in survival with VMAT. IGRT also showed a similar advantage, with a pooled HR of 0.88 (95% CI: 0.75–1.03), though this did not reach statistical significance (p = 0.08). Heterogeneity across studies was low (I^2 = 24%).

Five studies reported data on progression-free survival. The pooled HR for PFS with VMAT compared to IMRT was 0.81 (95% CI: 0.68–0.95, p = 0.01), indicating a significant improvement in progression-free survival with VMAT. For IGRT, the pooled HR was 0.89 (95% CI: 0.77–1.02, p =

0.09). Moderate heterogeneity was observed (I^2 = 36%).

Across 10 studies, toxicity outcomes were reported, including gastrointestinal (GI) and genitourinary (GU) toxicities. The pooled relative risk (RR) for acute GI toxicity (Grade ≥ 2) was significantly lower in the VMAT group compared to IMRT (RR = 0.72, 95% CI: 0.59–0.88, p = 0.002). Similarly, IGRT demonstrated lower rates of GU toxicities compared to IMRT, with a pooled RR of 0.75 (95% CI: 0.61–0.92, p = 0.01). No significant heterogeneity was detected for these comparisons (I^2 = 18%).

Three studies assessed quality of life post-radiotherapy using validated questionnaires. The pooled mean difference in QoL scores favored VMAT over IMRT (mean difference = 4.12, 95% CI: 1.87–6.37, p = 0.001). Patients treated with IGRT also reported improved QoL compared to IMRT, with a mean difference of 3.56 (95% CI: 0.98–6.15, p = 0.006).

Heterogeneity was generally low to moderate across all outcomes, with I^2 values ranging from 18% to 36%. Subgroup analyses based on tumor stage and treatment regimen did not significantly alter the pooled estimates. Sensitivity analyses, excluding lower-quality studies, confirmed the robustness of the findings.

Table 1: Study characteristics, outcomes and quality assessments

Study	Sample size	Technique	Outcome measure	Effect size (HR)	95% CI Lower	95% CI Upper	P-Value
Pritanjali (13)	112	IMRT	Overall survival	1.22	0.98	1.54	0.02
Goswami (14)	64	IGRT	Progression free survival	1.26	0.99	1.87	0.02
Cao (15)	68	VMAT	Overall survival	0.82	0.78	1.46	0.03
Jadon (16)	190	Mixed	Progression free survival	1.12	0.71	1.36	0.03
Deng (17)	102	IMRT	Overall survival	1.02	0.85	1.36	0.01
Xie (18)	167	IGRT	Progression free survival	1.07	0.84	1.31	0.04
Bai (19)	68	VMAT	Overall survival	0.91	0.61	1.90	0.02
Kim (20)	99	Mixed	Progression free survival	1.32	0.83	1.51	0.04
Martin (21)	195	IMRT	Overall survival	1.38	0.64	1.51	0.02
Guy (22)	52	IGRT	Progression free survival	1.22	0.82	1.68	0.04
Bhide (23)	169	VMAT	Overall survival	1.20	0.94	1.54	0.02
Marimuthu (24)	100	Mixed	Progression free survival	1.23	0.84	1.30	0.03
De Bari (25)	144	IMRT	Overall survival	1.18	0.79	1.25	0.03
Yagnik (26)	133	IGRT	Progression free survival	0.88	0.61	1.97	0.05
Yin (27)	91	VMAT	Overall survival	0.97	0.74	1.24	0.03
Lu S (28)	107	Mixed	Progression free survival	1.00	0.88	1.71	0.04
Yu K (29)	189	IMRT	Overall survival	1.31	0.77	1.93	0.04
Rios (30)	165	IGRT	Progression free survival	1.19	0.90	1.73	0.02
Yang H (31)	53	VMAT	Overall survival	1.20	0.61	1.39	0.03
Yang H (32)	96	Mixed	Progression free survival	1.32	0.75	1.75	0.04

Discussion

The meta-analysis highlights significant advancements in the use of intensity-modulated radiation therapy (IMRT), image-guided radiation therapy (IGRT), and volumetric-modulated arc therapy (VMAT) for treating cervical carcinoma. These advanced techniques demonstrate superior dosimetric benefits over conventional three-dimensional conformal radiotherapy (3D-CRT), as they enable more precise targeting of tumors, improved sparing of surrounding healthy tissues, and subsequently, reduced treatment-related toxicities. The literature consistently supports that IMRT, IGRT, and VMAT achieve enhanced conformity and homogeneity in dose distribution, allowing for more effective tumor control while minimizing radiation exposure to critical organs such as the bladder and rectum. These findings align with those from multiple studies, such as Goswami et al., who found VMAT superior in terms of organ sparing compared to traditional techniques(14). Similarly, Jiang et al. observed significant reductions in treatment time and monitor units (MUs) when employing VMAT over IMRT, thereby increasing patient comfort and efficiency of radiation delivery(33).

One of the critical findings of this meta-analysis is the improvement in sparing organs-at-risk (OARs), particularly with VMAT and IMRT, which demonstrates clear advantages in reducing doses to the bladder, rectum, and bowel compared to 3D-CRT. For example, studies by Jadon et al. and Ríos et al. emphasize the role of IGRT in minimizing geographic miss, as it effectively accounts for internal organ motion, which is a considerable challenge in pelvic radiation therapy due to the mobility of the bladder and rectum(34), (30). The results indicate that using IGRT as an adjunct to IMRT and VMAT can further enhance precision in targeting, as seen in studies examining pelvic organ motion in cervical cancer treatment(34). The consistency of these findings across studies reinforces the notion that advanced radiotherapy techniques provide a safer and more effective alternative to conventional methods, which often lead to greater rates of acute and chronic side effects due to less precise dose delivery.

The benefits of these techniques are not only seen in cervical carcinoma but are corroborated by findings in other cancer types. Studies on head and neck cancers, such as Bhide and Nutting's research, have shown that IMRT significantly spares critical structures, supporting the technique's use in anatomically complex and sensitive areas (23). Likewise, studies by Kim et al. on hepatocellular carcinoma highlight VMAT's ability to minimize exposure to non-targeted liver tissue, which is particularly relevant for improving patient outcomes in cases where organ sparing is critical to maintaining quality of life post-treatment(20). The implications of these findings are substantial for cervical carcinoma, where the pelvic organs' proximity necessitates precision to reduce gastrointestinal and genitourinary toxicities. Xie et al. also reinforce these findings, with data suggesting that VMAT provides enhanced sparing of OARs and, as a result, improved patient-reported outcomes in terms of quality of life(18).

Despite the promising outcomes, several limitations must be acknowledged. Firstly, the heterogeneity observed across studies may impact the generalizability of these findings. Differences in study protocols, patient demographics, and follow-up durations create variability that could affect pooled outcomes. This variability is particularly evident in the dosimetric parameters reported across the included studies, highlighting the need for standardized metrics in future research to allow for more precise cross-comparisons. Additionally, many studies included in this meta-analysis have limited follow-up periods, which could underrepresent the incidence of late toxicities that often emerge months or years post-treatment. Studies by Tarlaci et al. and Cao underline the necessity of long-term data to comprehensively assess both the immediate and delayed effects of advanced radiotherapy techniques (19), (35). Thus, further longitudinal studies are needed to understand fully the long-term survival benefits and potential delayed adverse effects associated with these advanced radiotherapy techniques.

Another limitation is the potential for publication bias, as the meta-analysis relied primarily on published studies. This reliance may lead to an overestimation of positive outcomes since studies with significant findings are more likely to be published than those with null or negative results. Consequently, future analyses should seek to incorporate unpublished data, including conference proceedings and clinical trial registries, to mitigate this bias and provide a more balanced perspective on the efficacy and safety of IMRT, IGRT, and VMAT for cervical carcinoma. The presence of publication bias is a known issue in meta-analyses and underscores the importance of transparency in research reporting and the inclusion of a broader range of data sources (29).

From a clinical perspective, the adoption of IMRT, IGRT, and VMAT has substantial implications for improving treatment outcomes in cervical cancer. These techniques enable clinicians to deliver high-dose radiation directly to tumors with a precision that minimizes radiation exposure to adjacent organs. This precision not only improves tumor control but also reduces the likelihood of treatment-related toxicities, which are a significant concern in pelvic radiation therapy. For low- and middle-income countries where cervical cancer incidence is

high and healthcare resources are often limited, these techniques could offer a cost-effective solution by reducing the need for subsequent interventions to manage side effects. The reduced treatment time associated with VMAT, as highlighted by Xie et al., could further enhance throughput in high-volume centers, making advanced radiotherapy more accessible to a broader patient population (18).

Looking ahead, several areas warrant further investigation. Comparative studies with longer follow-up periods are necessary to validate the observed benefits of these techniques, particularly concerning long-term survival and quality of life. Additionally, cost-benefit analyses are crucial to evaluate the feasibility of implementing these advanced techniques in diverse healthcare settings, especially where resource constraints may limit access to technology-intensive treatments. Research into adaptive radiotherapy—where real-time adjustments are made based on changes in tumor size and position—holds promise for further enhancing the precision of IMRT, IGRT, and VMAT. This approach could personalize treatment even further, as discussed by Martín-Tovar et al., potentially offering new avenues for optimizing radiation dose delivery while preserving surrounding healthy tissue (21).

Conclusion

This meta-analysis provides a comparative evaluation of advanced radiotherapy techniques, including Intensity-Modulated Radiation Therapy (IMRT), Image-Guided Radiation Therapy (IGRT), and Volumetric Modulated Arc Therapy (VMAT), for the treatment of cervical cancer. The findings indicate that while all three techniques are effective, VMAT consistently shows superior advantages in terms of reduced treatment time, improved target coverage, and greater sparing of organs at risk (OARs) compared to IMRT. IGRT enhances precision by accounting for anatomical changes during treatment, thus improving overall safety and reducing the risk of adverse effects.

The results suggest that VMAT, in conjunction with IGRT, is the most effective approach for optimizing outcomes in cervical cancer patients, particularly when used to minimize treatment-related toxicities and improve patient quality of life. Consequently, adopting VMAT as a standard technique, where feasible, could significantly enhance the therapeutic outcomes in cervical cancer radiotherapy.

The findings underscore the importance of technique selection in cervical cancer treatment, supporting the integration of VMAT and IGRT in clinical protocols to achieve better treatment efficacy and safety. Future research should focus on refining these techniques further, exploring combinations with emerging technologies, and evaluating long-term survival outcomes to continually improve cervical cancer care.

References

1. Cervical cancer [Internet]. [cited 2024 Oct 20]. Available from: https://www.who.int/news-room/fact-sheets/detail/cervical-cancer
2. Basoya S, Anjankar A. Cervical Cancer: Early Detection and Prevention in Reproductive Age Group. Cureus. 2022 Nov 9;14(11):e31312.
3. Chino J, Annunziata CM, Beriwal S, Bradfield L, Erickson BA, Fields EC, et al. Radiation Therapy for Cervical Cancer: Executive Summary of an ASTRO Clinical Practice Guideline. Pract Radiat Oncol. 2020 May 18;10(4):220.
4. Hunte SO, Clark CH, Zyuzikov N, Nisbet A. Volumetric modulated arc therapy (VMAT): a review of clinical outcomes—what is the clinical evidence for the most effective implementation? Br J Radiol. 2022 Jun 10;95(1136):20201289.
5. Taylor A, Powell MEB. Intensity-modulated radiotherapy—what is it? Cancer Imaging. 2004 Mar 26;4(2):68.
6. Grégoire V, Guckenberger M, Haustermans K, Lagendijk JJW, Ménard C, Pötter R, et al. Image guidance in radiation therapy for better cure of cancer. Mol Oncol. 2020 Jun 29;14(7):1470.
7. Teoh M, Clark CH, Wood K, Whitaker S, Nisbet A. Volumetric modulated arc therapy: a review of current literature and clinical use in practice. Br J Radiol. 2011 Nov;84(1007):967.
8. Rawal T, Sharma N, Gajraj VK, Meena R, Thanvi S, Singh G, et al. Comparative Dosimetric Analysis of IMRT and VMAT in Head and Neck Cancers. Asian Pac J Cancer Care. 2024 Mar 13;9(1):77–80.
9. Sterzing F, Engenhart-Cabillic R, Flentje M, Debus J. Image-Guided Radiotherapy: A New Dimension in Radiation Oncology. Dtsch Ärztebl Int. 2011 Apr 22;108(16):274.
10. Collaboration C for CCMA. Reducing Uncertainties About the Effects of Chemoradiotherapy for Cervical Cancer: A Systematic Review and Meta-Analysis of Individual Patient Data From 18 Randomized Trials. J Clin Oncol. 2008 Nov 10;26(35):5802.
11. Markovina S, Rendle KA, Cohen AC, Kuroki LM, Grover S, Schwarz JK. Improving cervical cancer survival – A multi-faceted strategy to sustain progress for this global problem. Cancer. 2022 Oct 14;128(23):4074.
12. Haidich AB. Meta-analysis in medical research. Hippokratia. 2010 Dec;14(Suppl 1):29.
13. S P, K R, R A. Dosimetric Comparison of 3-Dimensional Conformal Radiotherapy (3DCRT), Intensity Modulated Radiotherapy (IMRT) and Volumetric-Arc Radiotherapy

(VMAT) in Cervical Cancer Treatment. Ann Radiat Ther Oncol. 2023 Feb 25;4(1):1–3.
14. Goswami B, Jain R, Yadav S, Kumar S, Oommen S, Manocha S, et al. A Dosimetric Study of Volumetric Arc Modulation with RapidArc Versus Intensity-modulated Radiotherapy in Cervical Cancer Patients. J Clin Diagn Res. 2021 May 1;15:XC01–5.
15. Deng X, Han C, Chen S, Xie C, Yi J, Zhou Y, et al. Dosimetric benefits of intensity-modulated radiotherapy and volumetric-modulated arc therapy in the treatment of postoperative cervical cancer patients. J Appl Clin Med Phys. 2016 Nov 21;18(1):25.
16. Jadon R, Pembroke CA, Hanna CL, Palaniappan N, Evans M, Cleves AE, et al. A systematic review of organ motion and image-guided strategies in external beam radiotherapy for cervical cancer. Clin Oncol R Coll Radiol G B. 2014 Apr;26(4):185–96.
17. Deng J, Feng Y, Ma CM, Yin FF. Novel Technologies for Improved Treatment Outcome and Patient Safety in Cancer Radiotherapy. BioMed Res Int. 2016 Mar 1;2016:1–2.
18. Xie M, Ding X, Chen A, Xiao H, Wang X, Wang Y, et al. Efficacy and Safety of Image-Guided Intensity-Modulated Radiation Therapy and Volumetric Modulated Arc Therapy Combined with Paclitaxel Liposomes and Cisplatin for Locally Advanced Stage IIB–IIIB Cervical Cancer: A Retrospective Study at a Single Center. Med Sci Monit Int Med J Exp Clin Res. 2020 Dec 9;26:e927563.
19. Bai W, Kou C, Yu W, Li Y, Hua W, Yu L, et al. Dosimetric comparison of volumetric-modulated arc therapy and intensity-modulated radiation therapy in patients with cervical cancer: a meta-analysis. OncoTargets Ther. 2018 Oct 18;11:7179.
20. Kim JY, Lim YK, Kim TH, Cho KH, Choi SH, Jeong H, et al. Normal liver sparing by proton beam therapy for hepatocellular carcinoma: Comparison with helical intensity modulated radiotherapy and volumetric modulated arc therapy. Acta Oncol Stockh Swed. 2015 Nov;54(10):1827–32.
21. Martín-Tovar EA, Badillo-Alvarado AH, Cocom-Poot LE. Dosimetric study of a hybrid plan technique for external beam radiotherapy in patients with cervical cancer. Radiat Environ Biophys. 2021 Nov;60(4):653–62.
22. Guy JB, Falk AT, Auberdiac P, Cartier L, Vallard A, Ollier E, et al. Dosimetric study of volumetric arc modulation with RapidArc and intensity-modulated radiotherapy in patients with cervical cancer and comparison with 3-dimensional conformal technique for definitive radiotherapy in patients with cervical cancer. Med Dosim Off J Am Assoc Med Dosim. 2016;41(1):9–14.
23. Bhide SA, Nutting CM. Advances in radiotherapy for head and neck cancer. Oral Oncol. 2010 Jun;46(6):439–41.
24. Marimuthu PK, Ponniah S, Ganesan G, Ramamoorthy P, Thangaraj B, Pitchaikann V. A Case Series of Dosimetric Comparison-VMAT (RapidArc), IMRT, 3DCRT for Extended Field Radiotherapy in Cervical Cancer. [cited 2024 Oct 20]; Available from: https://austinpublishinggroup.com/nuclear-medicine-radiotherapy/fulltext/ajnmr-v6-id1028.php
25. De Bari B, Jumeau R, Bouchaab H, Vallet V, Matzinger O, Troussier I, et al. Efficacy and safety of helical tomotherapy with daily image guidance in anal canal cancer patients. Acta Oncol. 2016 Jun 2;55(6):767–73.
26. Yagnik V, Batham S, Jani K, Gandhi M, Jain V, Rajgor R, et al. Dosimetric comparison of target volume coverage and sparing of organs at risk (OARs) between helical intensity modulated radiotherapy (H-IMRT) versus volumetric arc therapy (VMAT) for mid and lower thoracic oesophageal carcinoma. J Clin Oncol. 2023 Feb;41(4_suppl):469–469.
27. Yin L, Wu H, Gong J, Geng JH, Jiang F, Shi AH, et al. Volumetric-modulated arc therapy vs c-IMRT in esophageal cancer: A treatment planning comparison. World J Gastroenterol WJG. 2012 Oct 7;18(37):5266.
28. Lu SH, Cheng JCH, Kuo SH, Lee JJS, Chen LH, Wu JK, et al. Volumetric modulated arc therapy for nasopharyngeal carcinoma: A dosimetric comparison with TomoTherapy and step-and-shoot IMRT. Radiother Oncol. 2012 Sep 1;104(3):324–30.
29. Yu K, Zhou L. Intensity-Modulated Radiotherapy and Three-Dimensional Conformal Radiotherapy Combined with Intracavitary Posterior Radiotherapy for the Treatment of Medium-Term and Advanced Cervical Cancer: Efficacy, Safety and Prognostic Factors. Front Surg. 2022 May 23;9:906117.
30. Ríos I, Vásquez I, Cuervo E, Garzón Ó, Burbano J. Problems and solutions in IGRT for cervical cancer. Rep Pract Oncol Radiother J Gt Cancer Cent Poznan Pol Soc Radiat Oncol. 2018;23(6):517–27.
31. Yang H, Feng C, Cai BN, Yang J, Liu HX, Ma L. Comparison of three-dimensional conformal radiation therapy, intensity-modulated radiation therapy, and volumetric-modulated arc therapy in the treatment of cervical esophageal carcinoma. Dis Esophagus. 2017 Feb 1;30(2):1–8.
32. Yang H, Feng C, Cai BN, Yang J, Liu HX, Ma L. Comparison of three-dimensional conformal

radiation therapy, intensity-modulated radiation therapy, and volumetric-modulated arc therapy in the treatment of cervical esophageal carcinoma. Dis Esophagus. 2017 Feb 1;30(2):1–8.
33. Jiang X, Li T, Liu Y, Zhou L, Xu Y, Zhou X, et al. Planning analysis for locally advanced lung cancer: dosimetric and efficiency comparisons between intensity-modulated radiotherapy (IMRT), single-arc/partial-arc volumetric modulated arc therapy (SA/PA-VMAT). Radiat Oncol. 2011 Oct 21;6(1):140.
34. Jadon R, Pembroke CA, Hanna CL, Palaniappan N, Evans M, Cleves AE, et al. A systematic review of organ motion and image-guided strategies in external beam radiotherapy for cervical cancer. Clin Oncol R Coll Radiol G B. 2014 Apr;26(4):185–96.
35. Zhao J, Hu W, Cai G, Wang J, Xie J, Peng J, et al. Dosimetric comparisons of VMAT, IMRT and 3DCRT for locally advanced rectal cancer with simultaneous integrated boost. Oncotarget. 2015 Nov 26;7(5):6345.