Dosimetric Analysis of Box and Cross Field Isodose Distribution Technique in Ca Cervix Using Different Algorithm

Bandal Akshay Namdev[1], Dr Sarath S Nair[2], Jyothi Nagesh[2], Dr Sajeesh S Nair[3], Sumeer Hussain[4]
[1] *Dept of Radiotherapy Oncology, Aditya Birla Memorial Hospital, Pune Maharashtra India,*
[2]*Dept of Radiation Oncology, Kasturba medical college Manipal, Manipal Academy of Higher Education Manipal Karnataka,*
[3]*Department of Radiotherapy, K M Cherian Institute of Medical Sciences, Chengannur, Kerala*
[4]*Department of Radiation oncology, AL Moosa Specialist Hospital AL Ahsa, Saudi Arabia.*

***Abstract*—The main modality of treating locally advanced cervical cancer is by external beam radiotherapy to the pelvis alone or in combination with chemotherapy, followed by intracavitary brachytherapy. The study aims to evaluate and compare different Dosimetric parameters of treatment fields for ca cervix 3DCRT technique and algorithms. Methods: A Retrospective observational study was done for fifteen patients with cervical cancer between January to December 2021, four sets of 3DCRT plans-box field with collapsed cone algorithm, box field with Monte Carlo algorithm, cross beam field with collapsed cone algorithm and cross beam field with Monte Carlo algorithm were planned for each patient. The four plans were later compared adopting DVH analysis for the PTV, and Dmean and Dmax doses for bladder, rectum and both femoral heads. Results: From the generated plans it was observed that though the tumor coverage was sufficiently covered in all the plans, box field plan with collapsed cone algorithm showed the least OAR dose. Conclusion: From this study, we can conclude that the 3DCRT technique plans generated with box field technique using collapsed cone algorithm can be adopted for the treatment of cervical cancer as it can deliver highly conformal dose to the target volume without increasing the dose to bladder, rectum, and bilateral femoral heads.**

***Index Terms*—Monte Carlo (MC), Collapse Cone (CC), Organ at Risk (OAR), Dose Volume Histogram (DVH).**

1.INTRODUCTION

Cervical carcinoma (Ca) is considered as one of the most common categories of cancer for women worldwide and by its frequency in women. It is the type of cancer that occurs cells of cervix which are lower part of uterus. It comes fourth after breast, Colo-rectal and cancer for lungs[1]. Talking about statistics it is believed that 500,000 women all over develop cervical tumor and close to 46% of this population succumb to it. Surgery, chemotherapy and Radiation therapy are main treatment modalities of Ca. Cervix. Radiation therapy plays an important role in treatment with or without combination with chemo-radiotherapy as per oncologist prescription. The objective of radiation therapy is to deliver lethal dose to target cancer cells with minimal damage to surrounding normal tissues hence dosimetry plays vital role in radiation therapy[2]. Radiation therapy can be given by External beam therapy i.e. teletherapy and Brachytherapy or in combination of both. Three-Dimensional Conformal Therapy (3DCRT) is the most used radiation plan for treatment. The main feature of this protocol is delivering dose to the tumor site with the aid of external beam. Most commonly four field technique or "Box Field Technique" is practiced which consists of opposed anteroposterior or posteroanterior and lateral fields from both sides of the patient depending upon the anatomy. This results in a dose distribution which is box shape in nature, and it encloses both the target and the healthy tissues mainly Pelvic bone marrow, bowel, femoral heads on both sides, rectum and bladder. In modification to conventional Box field cross beam field technique can be used which includes 4 oblique fields (2 anterior and 2 posterior) replaced with standard box fields. Oblique beams results in dose distribution which is approx.

diamond shape in nature and its dose distribution covers tumor volume.

Algorithms play an important role in calculating the distributions of a planning station. Different planning stations have different algorithms such as Monte Carlo (MC) algorithm, Collapsed cone (CC) algorithm, pencil beam algorithm etc[3]. CC calculation algorithm is a methodology wherein a ray-trace procedure through the irradiated object is used to get the Total Energy Released Per Unit Mass (TERMA) at all points in the dose calculation matrix. The TERMA is divided into an essential part (collision kerma) and a scatter part. MC calculation from Elekta (MONACO/ MC) depends on a fluence model utilizing virtual energy fluence model, while the dose distribution inside the patient is determined by the photon voxel MC calculation. Studies were done primarily with the aim of finding the best option among box field and diamond field and also among different algorithms for efficient sparing of Organ at Risk (OAR) in Ca cervix cases. In this study of Dosimetric analysis of diamond and box field isodose distribution in 15 patients Ca cervix were selected, and 2 dose calculation algorithms are used i.e. MC and CC algorithm, along with two planning 3DCRT planning technique.

Many studies were done about Dosimetric analysis of dose distribution in case of cervical cancer treatment[4,5,6], handful investigation were conducted with the approach of comparing the box and diamond dose distribution technique planning while using different algorithms for cervix cases to see which among these two techniques effectively reduce the dose to OAR. Reducing dose to the OAR (rectum, bladder and femur) is an essential task for treatment planning of cervical cancer. As rectum, bladder and femur are highly radio sensitive and if irradiated can result in damage of lining of bladder, effective sparing needs to be achieved. This study aims to analyze the box field and cross beam field isodose distribution using different algorithm in carcinoma cervix in our center

II. MATERIAL AND METHODOLOGY

The objectives of this study are to evaluate and compare different Dosimetric parameters of treatment fields and algorithms combination 3DCRT for sparing OAR. Fifteen Cervical cancer patients with stage I with IIIB and Para aortic nodes negative during January 2021 to December 2021 are included in this retrospective observational study, where Palliative cases, T4 stages were excluded from the study.

i) Monaco Version 5.11 Treatment Planning System:

Monaco Treatment Planning System has the capability to generate highly precise radiotherapy treatment plans for techniques using photons as well as electron beams. It has been designed to confront the challenges of modern radiation oncology centers regarding treatment planning. It possesses numerous intuitive tools which make the planning procedure easier, speedy and highly reliable in clinical aspects. Combining these inherent and advance optimization tools with the calculation accuracy of the MC and CC algorithms, Monaco can deliver 3DCRT, VMAT, IMRT, SRS and SBRT plans seamlessly by ensuring consistency and efficiency in their plans within a user friendly and instinctive workspace. 3DCRT planning technique requires forward planning which Monaco can handle with ease while for IMRT and VMAT techniques, inverse planning is employed by Monaco. In terms of inverse planning. Monaco massively depends upon the biological cost functions for achieving OAR dose constraints. The algorithms which are in use for radiotherapy treatment planning can be mainly categorized into correction based, model based and MC algorithms. These planning algorithms have advantages as well as disadvantages during calculating the absorbed dose, mainly in case of transition from a medium to another medium, a tissue – air interface, small irregular fields or in the skin entrance. Pencil Beam algorithm is a correction-based algorithm which is formalized on an assumption that the photon beams[7], that are coming after different collimation process, when incident on patient surface is considered as a cluster of many smaller and narrower photon beams. From a homogenous medium like water, dose kernels are obtained for calculating the absorbed dose. In homogeneity correction in the longitudinal direction in the central axis of beam is considered by the Pencil Beam algorithm but it ignores lateral scatter. Therefore, Pencil beam algorithm is not well suited for heterogeneous medium as the distribution of secondary electrons within heterogeneous media is not accurately depicted. Since it only uses density correction in only one dimension,

In CC algorithm, for implementing attenuation coefficients and material specific stopping power ratios, relative electron density values are adopted

directly. Modeling the distribution of the energy fluence is the initial step in calculating dose with CC algorithm. It is a volume-based algorithm, and the dose calculation is with the guidance of3Dkernels which were precalculated thus enabling the dose to be calculated within each voxel of the patient model. CC algorithm considers both primary photons and scattered photons. It also corrects for energy distributions of primary and scattered beams for off-axis as well as beam hardening effects. These are then made to reach the patient model and deposit energy as absorbed dose. 3DCRT and CC algorithm combine seamlessly to produce efficient and conformal radiotherapy plans. MC algorithm is a statistical approach for performing numerical integrations. It makes use of mathematical phantoms to handle practical difficulties. This algorithm employs a system where the x-ray interactions are mathematically simulated to execute dose calculations to organs. In an MC algorithm, the distance traversed in a phantom or patient body by each photon of a certain x ray spectrum is monitored, and the energy released to the medium is detected using the interaction probabilities through its track. Particle transport simulation proposed by MC algorithm was thus found to be very effective and because of its superior accuracy to LINAC head models, mainly in Dosimetric conditions which are of non-standard in nature like in VMAT treatments[8,9,10]. MC algorithm is considered as the gold standard for the purpose of dose calculation since it is the only algorithm which can accurately account for the lack of secondary build up and electronic equilibrium. The downside of this algorithm is the undesirable amount of time it takes to compute.

ii) Computed Tomography Simulation:

All the selected cases had followed Bladder protocol (500ml water/30 mins before scan) were positioned in the flat couch and simulated in a manner of headfirst supine position and immobilized by pillow for head rest and knee rest for foot support. Axial CT images with a thickness of 3mm were acquired for the study after the permission for extracting data is granted. CT images of these cases were taken using Philips Brilliance Big Bore CT. The acquired images after reconstruction were then later transferred to Monaco (Version 1.11) Treatment Planning System for delineating target volumes as well as OARs within the CT images.

iii) Image Registration and Contouring:

Gross Tumor Volume (GTV) which is defined as the extent of gross tumor along with positive lymph nodes is identified from the image and based on the extent of primary tumor and the involved positive nodes, Clinical Target Volume (CTV) was defined by giving an additional margin over GTV to account for microscopic spread[11]. Over the CTV, Planning Target Volume (PTV)was then created with additional margin of 7mm over every direction. Delineation of OARs which are Bladder, Rectum and Left and Right Femoral heads were delineated based on standard guidelines recommended by Radiation Therapy Oncology Group (RTOG). Contouring extent for rectum was from anus to the sigmoid flexure. The contouring of bowels was done from the L4-L5 interspace to lowest extent in the pelvic region. Figure.1 shows depicts contoured OAR's with ptv volume in an axial slice of the CT image. The healthy tissues were then made by subtracting PTV from the volume of the patient covered by the CT scan.

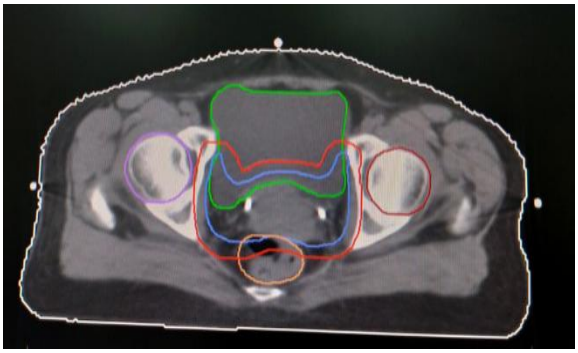
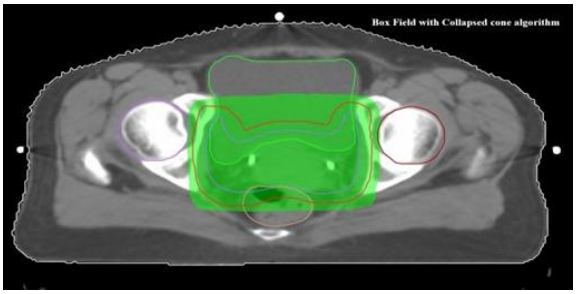


Fig 1: Delineation of Cervix CT

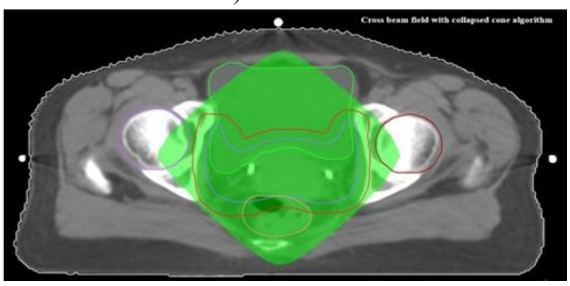
iv) Treatment Planning:

The dose that was prescribed to PTV to the selected cases was 45Gy in 25 Fractions which translates to1.8Gy/ Fraction.3DCRT plans with box field and cross beam field for all the 15 cases were generated by Monaco 1.11 TPS which uses both CC and MC algorithm (Figure.2). Four sets of plans, one box field plan with collapsed cone algorithm, second box field with MC algorithm, third is cross beam field with CC algorithm and fourth are cross beam field with MC algorithm, were made which were delivered by Elekta Versa HD Linear Accelerator. Elekta Versa HD could deliver five photon energies and six electron energies and is equipped with 160 Agility Multi Leaf Collimators with a spatial resolution of5mm at the isocentre (Maximum leaf speed 6.5cm/second and leaf transmission<0.5%). The grid space for all the generated plans was kept at a fixed value of 3mm.

Likewise, minimum segment width was kept at 5mm for each plan. All the fields were then made to conform to PTV by giving a margin of 7mm to account for penumbra. Without compromising the PTV coverage and by keeping OAR within tolerance limit, planning calculations were made. The quantitative evaluation and analysis of the 3D CRT plans made with box field and cross beam field by using CC and MC algorithm was performed by means of standard Dose Volume Histogram (DVH).



a) Box field



b) Cross field

Figure 2: Beam Isodose distributions for box and cross field beam

v) Outcome Measures:

Maximum dose as well as mean doses for OAR and the target along with V95% is noted by the DVH. Homogeneity Index is a simple scoring tool which quantifies homogeneity of dose in the target volume, which can be used to select the best optimized plan out of the available plans by comparing their distributions[12]. Ideally HI should be 1. If the value of HI is coming closer to 1, then the homogeneity of dose distribution is considered good and if the value obtained is more than 1 then the homogeneity in dose distribution is less. Equation used for Homogeneity Index is; HI=D5%/D95%Where, D5% and D95% are minimum doses to 5% and 95% of target volumes respectively.

Conformity Index: Conformity Index on other hand, is a plan evaluation index proposed by RTOG which can compare different plans based on target coverage[13]. Conformity Index helps to find the degree of congruence existing between the dose that was prescribed and the planning target volume. CI=VRI/TV Where, CI is the Conformity Index, VRI is the volume covered by the reference isodose and PTV is the Planning Target Volume. Unity is the ideal value for this Index and deviation implies the absence of conformity.

III.RESULTS

In the four 3DCRT plans generated, prescribed dose was 45Gy in 25 fractions was adequately achieved and a detailed Dosimetric difference in terms of target coverage and OAR sparing were calculated and then presented (Table 1). Among all, box field technique with CC algorithm shows superior target coverage along with significant sparing of OARs. Target coverage (99.5453 ± 0.3961) was obtained for the same. Conformity Index (1.7007 ± 0.1729) was obtained for box field technique with CC algorithm. Best Homogeneity Index of (1.05±0.017) was obtained for CC box field technique (Table 2). However, cross beam field technique with MC algorithm it was noticed that it has less target coverage along with more doses to the OARs. For bladder the best value for D30 and D40 was obtained for MC box field technique with a value of (4571.0133± 50.8116) and (4550.0467 ±51.4842) respectively. However, no significance was obtained for right and left femoral head among all the plans. For D30 and D40 values, much significance was obtained for all the OARs in the given plan.

Table I: organ at risk doses for both box and cross Field for two algorithm calculations

		Collapsed Cone		Monte Carlo		
		Box Filed	Cross Field	Box Field	Cross Field	P value
Bladder	D30	4577.41± 33.35	4627.86± 59.29	4571.01± 50.81	4622.29± 58.10	0.0040
	D40	4563.6±31.8	4613.17±61.3	4550.04±51.48	4603.79±59.40	0.0033
	Dmax	4677.72±40.81	4724.74±66.55	4808.84±45.36	4840.36±137.2	<0.00001

	Dmean	4409.06±159	4593.6±100	4398.2±174.6	4575.74±61.44	0.00003
Rectum	D30	4482.45±58.1	4680.10±61.2	4506.87±57.7	4790.10±50.21	<0.00001
	D40	4450.08±65.26	4665.72±62.40	4469.3±65.5	4653.64±82.26	<0.00001
	Dmax	4591.66±44.25	4760.6933±67.79	4758.0667±65.87	4891.0533±114.3	<0.00001
	Dmean	4194.84±228.07	4482.17±215.94	4237.80±228.83	4476.16±204.61	0.0003
Right Femoral Head	D30	3698.90±626.23	4331.02±219.05	3723.30±666.67	4345.36±217.13	0.0001
	D40	3445.78±632.75	4131.2533±315.74	3457.5533±656.61	3904.2533±1022.8	0.0211
	Dmax	4549.45±79.65	4621.44±73.51	4640.26±110.46	4713.43±88.29	0.00008
	Dmean	3334.74±492.56	3632.53±413.62	3353.58±492.76	3629.34±420.29	0.1276
Left Femoral Head	D30	3509.25±691.86	4210.07±328.42	3623.34±688.15	4241.34±286.53	0.0002
	D40	3283.59±688.28	3983.02±491.23	3388.70±664.60	4015.62±474.40	0.0007
	Dmax	4547.28±84.31	4577.03±85.56	4615.66±121.13	4662.34±97.67	0.0141
	Dmean	3192.31±609.69	3511.39±557.17	3318.61±477.36	3518.06±544.64	0.3015

The DVH parameters of PTV and OAR were analyzed using repeated measures of Anova technique with the help of SPSS Software (Version16). Repeated measures Anova are highly like the One-Way Anova but the only difference being that the former is for related groups while the latter is efficient for independent groups. Repeated measures Anova can be viewed as an extension of the dependent t-test. This method can provide overall info regarding the difference between related means. This measure includes measurement of subjects at different times as in this study different techniques are adopted for each subject. The assumptions used for this method are same as those of a paired sample t-test. The p value is used to determine if there is any statistical significance. The p value set was< 0.05, that is less than 5 percent chance of getting a result like the one that was observed if the null hypothesis was true. If the p value measured is greater than 0.05, then it can be said that there is no statistical significance between the tested three groups.

Table II: Planning target volume dose indexes for box and cross field with two algorithms

		Collapsed Cone		Monte Carlo	
		Box Field	Cross Field	Box Field	Cross Field
Total PTV (cc) (113.22±166.26)	D95%	99.54 ±0.39	98.65 ±1.14	99.35 ±0.51	98.52 ±1.21
	MU	217.17±7.57	208.7±6.33	216.4±8.17	207.39±6.25
	Max Dose (cGy)	4724.3±35.37	4844.11±65.07	4915.7±59.3	5020.39±85.77
	CI	1.7±0.17	2.17±0.19	1.77 ±0.17	2.2± 0.18
	HI	1.05±0.01	1.07 ±0.016	1.06 ±0.01	1.07 ±0.01

IV. DISCUSSION

In a study conducted by "Silvia Zunino, Otilio Rosato" et al," they review the radiation therapy "box" technique for cancer of the cervix by means of magnetic resonance imaging (MRI), lymphangiography, and anatomic studies on cadavers. They found out that the design of the lateral fields of the four-field technique for the irradiation of the uterine cervix based on anatomic bone references failed to encompass the planning-target volume in a significant number of patients. So, it is evident that there is need for another field [14]. Across all organs (Bladder, Rectum, Right and Left Femoral Heads) and dose metrics (D30, D40, dmax, dmean), MC consistently predicts higher doses compared to CC. The p-values show these differences are statistically significant in most cases ($p < 0.05$), especially for dose metrics in Bladder and Rectum, which are critical organs at risk (OARs) in pelvic radiotherapy. This

pattern holds true for both box field and cross beam field setups, though the exact values differ. Differences are most pronounced in the dmax and dmean doses of Bladder and Rectum, with MC predicting notably higher maximum and mean doses. For femoral heads, although MC predicts higher doses, the mean dose differences are less often statistically significant, indicating a smaller discrepancy in these bony structures or less clinical impact. Standard deviations indicate greater variability in MC doses for some parameters, particularly in femoral heads, suggesting MC's sensitivity to heterogeneity and small field effects. MC simulations use stochastic methods modeling particle interactions in detail, making them more accurate in heterogeneous media and complex geometries. CC is a deterministic algorithm using approximations that can underestimate dose, especially in areas with sharp tissue density changes (e.g., interfaces between soft tissue and bone or air cavities). The higher doses predicted by MC may represent a more realistic assessment of actual delivered dose, particularly relevant for tissues sensitive to radiation toxicity like the bladder and rectum.

The lower doses predicted by CC could risk underestimating dose to organs at risk, potentially leading to higher toxicity than anticipated. This could impact treatment planning, where constraints are set based on DVH data derived from CC calculations. Importance of MC in Treatment Planning Using MC may improve dose accuracy and patient safety by providing a better estimate of dose distributions. Especially relevant for advanced radiotherapy techniques (e.g., IMRT, VMAT) and heterogeneous treatment sites like the pelvis. Larger standard deviations with MC indicate patient-to-patient or sample variability that should be considered.MC dose calculations are computationally expensive but are increasingly feasible with modern computing. While MC predicts higher doses, the true biological effect depends on many factors including fractionation, tissue repair, and individual sensitivity. Treatment planning may need to adjust dose constraints or margins if switching to MC-based planning. MC is more demanding; centers must balance accuracy with workflow efficiency.

The data clearly demonstrates that MC provides systematically higher and statistically significantly different dose estimates than CC, particularly in the bladder and rectum. This suggests that treatment plans relying solely on CC could underestimate risk to critical organs. Incorporating MC dose calculation could improve treatment accuracy and patient safety, especially in complex pelvic treatments. However, increased computational demand and clinical integration challenges must be addressed.

There were studies done by several researchers who proposed that the advantage of 4-field radiation to the pelvis is that the use of lateral portals spares a portion of the small bowel anteriorly and rectum posteriorly[15-18]. The standard lateral portals defined in textbooks are not always adequate especially in advanced cancer cervix. They also recommend that without the knowledge of precise tumor volume, the 4-fieldtechnique with standard portals is potentially risky as it may underdose the tumor through lateral portals and the standard AP/PA portals are a safer option. From our study it is found that Both algorithms achieve excellent target coverage (~99–100%). Cross field plans slightly reduce coverage (98.5–98.6%), likely due to geometric complexity. The MC and CC require similar Mus for the same technique. Cross fields require slightly fewer MUs than box fields.

MC predicts consistently higher maximum doses (~200 cGy higher), reflecting its more accurate scatter modeling and heterogeneity corrections. This could mean MC is more conservative in hotspots. CI – Significant difference ($p < 0.00001$) Cross field plans have much higher CI (poorer conformity) than box fields. MC shows slightly worse CI than CC, but both degrade significantly in cross fields. HI– Statistically significant ($p = 0.0035$) HI values are slightly worse in cross fields and in MC plans (1.07 vs 1.05–1.06). This indicates slightly less uniform dose distribution, but clinically still acceptable. Algorithm Effect of Monte Carlo, being more accurate in dose calculation, shows higher maximum doses and slightly worse homogeneity/conformity indices.CC is slightly more optimistic (lower max dose, slightly better CI/HI). Field Arrangement Effect (Box vs Cross): Box fields perform better overall, with tighter conformity and more homogeneous coverage. Cross fields, due to beam overlapping and complex geometry, increase hotspots (higher max dose) and worsen CI and HI. All plans achieve acceptable D95% coverage. However, cross field plans may lead to increased dose spillage and hotspots, requiring careful evaluation. MC higher predicted maximum dose suggests that treatment

planning with MC might be safer, as it avoids underestimating high-dose regions.

Distribution technique is required than box field Cervix carcinoma is a common cancer in females in the developing world, and radiotherapy is the cornerstone of treatment at all locally advanced stages. The treatment modality for these is radiotherapy in combination with chemotherapy. Radiation treatment consists of combination of external beam RT and intracavitary brachytherapy. This study was able to quantify different Dosimetric parameters of PTV and OARs for efficient sparing which was obtained by generating four sets of plans with box field technique and cross beam field technique for each CC algorithm and MC algorithm. The results obtained from this study indicate that the plans which were generated by box field technique with collapsed cone algorithm showed superior target coverage along with significant sparing of OARs. The prescribed dose of 45Gy was adequately achieved in all cases using the four techniques used in this study. The plan evaluation indices like Homogeneity and Conformity Index were analyzed and found out that there was significant difference between these indices throughout the plans generated in four techniques. Likewise, the average value of Target Coverage also had a similarity in all four techniques. However, 3DCRT with all these techniques could not obtain any significant difference for maximum dose in right and left femur heads plans. For plans generated with MC algorithm obtained more hotspot in the PTV target. One of the limitations that could be pointed out from this study is that the Dosimetric parameters of bowel bag are not taken.

V. CONCLUSION

From this study, we can conclude that the 3DCRT technique plans generated with box field technique by CC algorithm can be adopted for the treatment of cervical cancer as it can deliver highly conformal dose to the target volume without increasing the dose to bladder, rectum and bilateral femoral heads. Box fields outperform cross fields in conformity and homogeneity. Where MC gives more conservative (higher) maximum dose estimates and slightly worse indices, but is more accurate for patient safety

REFERENCE

[1] Brisson M, Drolet M. Global elimination of cervical cancer as a public health problem. Lancet Oncol. 2019 Mar;20(3):319-321

[2] Ringborg U, Bergqvist D, Brorsson B, Cavallin-Ståhl E, Ceberg J, Einhorn N, Frödin JE, Järhult J, Lamnevik G, Lindholm C, Litt brand B, Norlund A, Nylén U, Rosén M, Svensson H, Möller TR. The Swedish Council on Technology Assessment in Health Care: systematic overview of radiotherapy for cancer including a prospective survey of radiotherapy practice in Sweden 2001-summary and conclusions. Acta Oncol. 2003; 42:357–365. doi: 10.1080/02841860310010826

[3] Chen, W. Z., Xiao, Y., & Li, J. (2014). Impact of dose calculation algorithm on radiation therapy. World journal of radiology, 6(11), 874–880. https://doi.org/10.4329/wjr.v6.i11.874

[4] Kaur, G., Garg, P., Srivastava, A. K., Gaur, G., Sheetal, Grover, R., Kang, M. S., & Dangwal, V. K. (2022). Dosimetric and radiobiological evaluation of treatment plan for cervical cancer high-dose-rate intracavitary brachytherapy. Journal of contemporary brachytherapy, 14(3), 253–259. https://doi.org/10.5114/jcb.2022.117729.

[5] Bhushan, Manindra1, 2, Tripathi, Deepak2; Yadav, Girigesh1; Kumar, Lalit1,3; Chowdhary, Rahul Lal1; Pahuja, Anjali K.1; Suhail, Mahamood1; Mitra, Swarupa1; Gairola, Munish1. Dosimetric analysis of intensity-modulated radiation therapy and volumetric-modulated arc therapy in comparison with conventional box technique in the treatment of carcinoma cervix: An impact of prosthetic implant. Journal of Cancer Research and Therapeutics 18(6): p 1504-1512, Oct–Dec 2022. | DOI: 10.4103/jcrt.JCRT_835_20.

[6] Pritanjali S, Rajhans K, Amrita R. 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; 4(1): 1022.

[7] Ahnesjö A, Saxner M, Trepp A. A pencil beam model for photon dose calculation. Med Phys.

1992 Mar-Apr;19(2):263-73. doi: 10.1118/1.596856. PMID: 1584117.

[8] Elcim, Y., Dirican, B., & Yavas, O. (2018). Dosimetric comparison of pencil beam and Monte Carlo algorithms in conformal lung radiotherapy. Journal of applied clinical medical physics, 19(5), 616–624. https://doi.org/10.1002/acm2.12426

[9] Kang, K. M., Jeong, B. K., Choi, H. S., Song, J. H., Park, B. D., Lim, Y. K., & Jeong, H. (2016). Effectiveness of the Monte Carlo method in stereotactic radiation therapy applied to quasi-homogenous brain tumors. Oncotarget, 7(11), 12662–12671. https://doi.org/10.18632/oncotarget.7280.

[10] Cristiano Queiroz Melo Reis, Patricia Nicolucci, Saulo S. Fortes, Leonardo P. Silva,Effects of heterogeneities in dose distributions under nonreference conditions: Monte Carlo simulation vs dose calculation algorithms, Medical Dosimetry, Volume 44, Issue 1,2019, Pages 74-82, ISSN 0958-3947, https://doi.org/10.1016/j.meddos.2018.02.009.

[11] Burnet, N. G., Thomas, S. J., Burton, K. E., & Jefferies, S. J. (2004). Defining the tumour and target volumes for radiotherapy. Cancer imaging: the official publication of the International Cancer Imaging Society, 4(2), 153–161. https://doi.org/10.1102/1470-7330.2004.0054

[12] Petrova, D., Smickovska, S., & Lazarevska, E. (2017). Conformity Index and Homogeneity Index of the Postoperative Whole Breast Radiotherapy. Open access Macedonian journal of medical sciences, 5(6), 736–739. https://doi.org/10.3889/oamjms.2017.161

[13] Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: a review. Int J Radiat Oncol Biol Phys. 2006 Feb 1;64(2):333-42. doi: 10.1016/j.ijrobp.2005.09.028. PMID: 16414369.

[14] Silvia Zunino, M.D., Otilio Rosato, M.D., Sergio Lucino, M.D., Esteban Jauregui, M.D., Luis Rossi, M.D., And Daniel Venencia, Ph.D. Anatomic Study of the Pelvis in Carcinoma of The Uterine Cervix as Related to the Box Technique.

[15] Goswami J, Patra NB, Sarkar B, Basu A, Pal S. Dosimetric comparison between conventional and conformal radiotherapy for carcinoma cervix: Are we treating the right volumes? South Asian J Cancer, Jul, 2013; 2(3):128-31. doi: 10.4103/2278- 330X.114112

[16] Nagar YS, Singh S, Kumar S, Lal P. Conventional 4-field box radiotherapy technique for cancer cervix: potential for geographic miss without CECT scan-based planning. Int J Gynecol Cancer.2004;14(5):865 –70.48

[17] Zunino S, Rosato O, Lucino S, Jauregui E, Rossi L, Venencia D. Anatomic study of the pelvis in carcinoma of the uterine cervix as related to the box technique. Int J Radiat Oncol Biol Phys 1999; 44:53—9.

[18] A. Nourreddine, H. Sfaoua, M. A. Krabch, F. Z. Lahlali, J. Aarab, A. Allam,Y. Moukasse, El Majjaoui, T. Kebdani, H. El Kacemi, N. Benjaafar and R.C. El Moursli. Radiation Therapy in Cervical Cancer: Comparative Study Of 3d Advanced Conformal Technique and Classic Box Technique. 2019June 6, 28-33.