Original Article

Comprehensive dosimetric study of the impact of beamlet width on IMRT plans for cervical cancer patients

Priya Saini, Mary Joan, Anirudh Pradhan

Abstract:

Introduction: Intensity Modulated Radiation Therapy (IMRT) had been widely used in the cervical cancer patient's treatment over last decade due to more conformal compared than three-dimensional conformal radiation therapy (3DCRT). The beamlet width in IMRT plans not only affects the plan quality but also affect treatment efficiency. The aim of this study was to investigate the influence of beamlet width on dose distribution in cervical cancer patients planned with dynamic (IMRT).

Methods: Twenty patients of cervical cancer were selected for this study. For each case, three plans were created with different beamlet width (3, 4 and 5mm). Only the beamlet width in the plans was changed (set to 3, 4, and 5 mm that were named BL03 mm, BL04 mm, and BL05 mm, respectively).

Results: 95% dose to PTV coverage decreased as the beamlet width increased. OARs doses of BL05 mm group was higher than other two groups except $V_{50\ Gy}$ for bladder and rectum and D_{max} (Gy) for bowel bag. BL04 mm group had lowest OARs doses among all three groups. In terms of PTV coverage, mean dose, maximum dose, HI and CI value BL03 mm and BL04 mm group plans were better than BL05 mm group. However, BL03 mm group plans had worse delivery accuracy and efficiency than other two groups.

Conclusion: BL04 mm group was the better to obtained a good balance between treatment efficiency, plan quality and execution accuracy. It can be set as optimal value for ca cervix patient in case of IMRT treatment for better clinical outcomes.

JK-Practitioner2025; 30 (2-3):08-13

INTRODUCTION

Cervical cancer remains the fourth most prevalent cancer among the female in the world[1,2]. IMRT had been widely used radiation technique in the cervical cancer patient's treatment over last decade. IMRT is more conformal compared with three-dimensional conformal radiation therapy (3DCRT) because of its dosimetric advantage. It could improve dose coverage of target volume and reduce the dose to surrounding normal tissues [3,4]. Non uniform beam intensities are used in IMRT treatment planning optimization. It could also reduce radiation induced toxicity [5,6]. Efficiency and quality of IMRT plan depends on so many different parameters in automatic optimization. Monaco treatment planning for IMRT starts dividing each beam into beamlets (pencil beams). Beamlet width is defined by user. During stage one and stage-two optimization, beamlet width is used. Resolution of the fluence map is defined by beamlet width. In general, the smaller the beamlet width, the finer the fluence grid.

In planning activity, an initial absolute dose distribution is computed from these beamlets. Initially, all beamlets are equally weighted and total dose distribution is weighted sum of the individual beamlet width dose distribution. Contributions of all individual beamlet widths are varied simultaneously by an iterative algorithm to meet prescription requirements. So many authors have been studied the effect of the beamlet width on IMRT treatment plans[8]. In all these studies beamlet width value was normally selected the between 0.1 cm to 1.0 cm in the optimizing window of IMRT parameters in treatment planning system (TPS)[8,9,10]. But,there have been no studies relating the effect of

Author Affiliations

Priya Saini, Department of Radiological Physics, S.M.S Medical College & Hospitals, Jaipur-(Rajasthan), Department of Physics, Institute of Applied Science and Humanities, GLA University,Mathura (U.P), Mary Joan, Department of Radiation Oncology, Christian Medical College, Ludhiana, Punjab, India, Anirudh Pradhan, Centre for Cosmology, Astrophysics and Space Science, GLA University, Mathura (U.P), India.

Correspondence

Priya Saini, Department of Radiological Physics, S.M.S Medical College & Hospitals, Jaipur-(Rajasthan), Department of Physics, Institute of Applied Science and Humanities, GLA University,Mathura (U.P),
Email: priyasaininkt@gmail.com

Indexed

EMBASE, SCOPUS, IndMED, ESBCO, Google Scholar besides other national and International Databases

Cite This Article as

Saini P, Joan Mary, Pradhan A, Comprehensive dosimetric study of the impact of beamlet width on IMRT plans for cervical cancer patients. JK Pract 2025;30 (2-3):08-13

Full length article available at **jkpractitioner.com** one month after publication

Keywords: IMRT, Beamlet width, cervical cancer

different beamlet widths optimization in IMRT plans of cervical cancer. Therefore, the aim of this work was to investigate the effect of the beamlet width on the IMRT treatment efficiency and plan quality for cervical cancer and also set an optimum value of beamlet width for clinical treatment planning.

MATERIALS AND METHODS:

Patients Selection and CT Simulation

Twenty patients of cervical cancer who received IMRT treatment at our hospital between January 2022 and December 2023 were taken for this study. All patients were instructed to follow institute bladder protocol (to void urine 1hr before each treatment and then drink 500ml water). All patients were scanned in most reproducible supine position using four clamp customized thermoplastic mask on acrylic base plate. CT scan was obtained with slice thickness of 2.5mm on Discovery GE 16 slice spiral CT scanner. These CT images were transferred to the Monaco TPS in DICOM format through local area network.

Contouring and dose prescription

Gross tumor volume (GTV),clinical target volume (CTV) and surrounding normal tissues were contoured by experienced radiation oncologist as per institute protocol .10mm margin in all direction to GTV with involved lymph nodes and 5mm margin in all direction to CTV was applied to delineate PTV with dose of 55Gy (PTV55) and 50Gy (PTV50) respectively. Bowel bags, bilateral head of femur, rectum, kidney and bladder were delineated as OARs.

Treatment Planning

Three IMRT plans were designed for each patient using the monte carlo (MC) algorithm with beamlet width of 3mm,4mm and 5mm respectively in Monaco version 6.1.2.0 TPS. They were named BL03 mm, BL04 mm and BL05 mm respectively. Only beamlet width was changed in all plans. Cost functions and remaining parameters were kept fixed with a dose calculation grid size 3mm. Maximum dose rate was used 600 MU/min. Treatment plans were delivered with 6MV X-ray photon beam using elekta versa HD linear accelerator. Seven fields with gantry angles 200º, 250º, 300º, 0º, 50, 100º and 150º were used to design the IMRT plan for each patient.

Plan Evaluation

The different beamlet width plans were analyzed in terms of dosimetric parameters such as median dose $D_{50\%,}$maximum dose $D_{2\%}$, minimum dose $D_{98\%}$ and 95% dose to PTV, MUs, Planning delivery time (PDT) and DVH parameters related to OARs.CI and HI values for target volume were calculated following ICRU 83 report using Eq. (1) and Eq. (2) respectively.

$$HI=(D_{2\%}-D_{98\%}) / D_{50\%} \quad (1)$$

$$CI = (TV_{RI})^2/ (TV * V_{RI}) \quad (2)$$

Where $D_{x\%}$ represent the minimum dose received by x% of PTV, TV represents total target volume, TV_{RI} represents the total target volume receiving the prescription dose and V_{RI} represents the total volume receiving prescription dose. Homogeneity index defines dose uniformity in the target volume. Lesser HI value represents the better uniformity in the target volume.CI represents the quality of conformation of the plan. Ideally, it should be near to 1. Larger CI value represents the better conformability of the plan. Rectum was evaluated using $V_{50}$and $D_{50\%.}$ Bladder was evaluated using $V_{50}$and $D_{45\%}$. Bowel was evaluated using 195 cc volume. Femur was evaluated using D_{mean}.

Dosimetric verification

Dosimetric verification of the plan was done using Octavius II system. The criteria for gamma passing rate(GPR) was dose to distance agreement 3%, 3mm. GPR, MU and PDT were noted.

Statistical Analysis

Results were performed as mean ± standard deviation. Primer software was used for statistical analysis. Wilcoxon signed rank test was performed to compared dosimetric parameters related to PTV and OARs between different beamlet groups. Beamlet width 3mm group was selected as the reference and compared with other groups. p value was calculated. p value <.05 represents a statistically significant difference.

RESULTS

Target doses

All the plan met the prescribed doses and limits of each OARs. Target doses, CI and HI values of all three beamlet widths groups for both PTVs were shown in Table2. BL03 mm group was taken as a reference group and other groups were compared with this group. There were no significant statistical difference in terms of 95% dose to PTV coverage and mean dose between BL03 mm and BL04 mm group plans ($p>0.05$) for both PTVs. There were found significant statistical difference in terms of 95% dose to PTV coverage and mean dose between BL03 mm and BL05 mm group plans ($p<0.02$) for both PTVs. Maximum dose had no significant statistical difference among all three groups for both PTVs (PTV50 & PTV55). Plans with BL03 mm group had highest value of 95% dose to PTV coverage, mean dose and maximum dose among all three groups. CI values are decreased as the beamlet width value increased for both PTV50 and PTV55. BL03 mm group had highest CI than BL04 mm and BL05 mm group plan. HI values for both PTV50 and PTV55 are increased as the beamlet width value increased and there were no significant statistical difference among all three groups for both PTVs.

OAR Doses

OARs doses of all three group BL03 mm, BL04 mm and BL05 mm were shown in Table 3. OARs doses of BL05 mm group were higher than BL03 mm andBL04 mm group except $V_{50\ Gy}$ for bladder and rectum and $D_{\ max}$ (Gy) for bowel bag. There was no significant statistical difference for OARs doses among all three groups plans except $V_{50\ Gy}$ for bladder. BL04 mm group had lowest OARs doses among all three groups.

Dosimetric verification, MU and plan delivery time

GPR, PDT and MUs for all three groups were shown in Table 4.Dosimetric plan evaluation was done using a comparison between measured planer dose and calculated dose by TPS studying the gamma passing criteria of a 3% dose difference (DD) and a 3mm distance to agreement (DTA). BL05 mm group plan had highest GPR value and BL03 mm group plan had lowest GPR value. As beamlet width increased, mean number of MUs in the cervical cancer of IMRT plan decreased. The mean number of MUs for the all three groups BL03 mm, BL04 mm and BL05 mm were 845,809 and 775 respectively (Table 3).BL03 mm group plans had highest MU and BL05 mm group plans had lowest MU. PDT for all 20 patients were shown from the beam turned on time to beam turned off time (Table 3). As beamlet width increased, MUs of IMRT plan decreased, as did the plan delivery time.

DISCUSSION

In IMRT optimization, beamlet width plays a crucial role.It is also easily overlooked. In first step of planning optimization, fluence segmentation is directly affected by beamlet width and in second step, segment optimization is indirectly affected by it. Theoretically, it is found that smaller the beamlet width give the finer fluence map. This may lead to more successful dose distribution [11]. The area of segments cannot read directly by TPS.It is not statistically analyzed; it may affect more small area segments [12]. When we design the IMRT plan for a cancer patient, there are so many different settings of optimized parameters including direction of fields, no of fields, no. of segments, area of segments, minimum segment width (MSW) and beamlet width etc. that affect the IMRT plan dose distribution. In this study, we compared the three beamlet width optimization schemes; each was based on different beamlet width value. It was observed that different beamlet width not only affects the PTV dose distribution and OARs, but it also affects the PDT and MU value. BL03mm was taken as reference group. BL03mm group had highest 95% dose to PTV coverage and BL05 mm had lowest. 95% dose to PTV coverage increased as beamlet width decreased. There were not found significant statistical difference in terms of 95% dose to PTV coverage between BL03mm and BL04mm group plan ($p>0.05$) for both PTVs. This study showed that there were no significant statistical difference for OARs doses among all three groups plan except $V_{50\ Gy}$ for bladder. BL04 mm group had lowest OARs doses among all three groups. As beamlet width increased, MUs, and PDT were decreased and GPR value increased.The range of MUs for each plan group was below 100 MUs and the range of PDT was within 20s. BL03 mm group had highest MUs and PDT value but lowest GPR. BL03 mm group had better dose distribution but treatment efficiency and execution accuracy were worse than BL04 mm and BL05 mm group. BL05 mm group had good treatment efficiency and execution accuracy than other group but lowest plan quality than other groups. The decrease of MUs and PDT could reduce patient displacement during patient treatment and improve the biological effect of treatment and enhance treatment efficiency.

CONCLUSION

From a comprehensive evaluation of all dosimetric parameters including 95% dose to PTV coverage, OARs sparing, HI, CI, maximum dose, mean dose, MUs, PDT and GPR of all three group plans, we concluded that all group were able to meet clinical treatments requirements. But BL04 mm group was the better to obtained a good balance between treatment efficiency, plan quality and execution accuracy. It can be set as optimal value for ca cervix patient in case of IMRT treatment.

Table 1 The optimization cost functions of IMRT plans for Cervical Cancer

Structure	Cost Function	Parameters	Isoconstraint
PTV 55	Target Penalty	98.80%	55 Gy
	Quadratic Overdose	56 Gy	1.5 Gy
	Target EUD	0.5	55 Gy
PTV 50	Target Penalty	98.90%	50.2 Gy
	Quadratic Overdose	52 Gy	1Gy
	Maximum Dose	53.69 Gy	53.69 Gy
	Target EUD	0.5	50.5 Gy
Bladder	Parallel	46 Gy, K=4, Shrink=0.3 cm	55%
Rectum	Parallel	40 Gy, K=4, Shrink=0.2 cm	55%
	Maximum	47.8 Gy, Shrink=0.3 cm	47.8 Gy
Right head of femur	Serial	38 Gy, K=16, Shrink=0 cm	38 Gy
Left head of femur	Serial	38 Gy, K=17, Shrink=0 cm	38 Gy
Bowel	Parallel	45 Gy, K=4, Shrink=0.3 cm	40%
	Maximum	48 Gy, Shrink=0.5 cm	48 Gy
Body	Quadratic Overdose	49 Gy, Shrink=0cm	0.1 Gy
	Maximum Dose	59 Gy	59.10 Gy
	Quadratic Overdose	30 Gy, Shrink=1.7 cm	1.6Gy
	Quadratic Overdose	25 Gy Shrink= 2cm	1.6 Gy

IMRT: Intensity Modulated Radiation Therapy; PTV: Planning Target Volume; EUD: Equivalent Uniform Dose

Tables2PTV dosimetric results of the IMRT plans used to treat 19 cervical cancer patients using three different beamlet widths.

Structure	Parameter	BL03	BL04	BL05	P^1	P^2
PTV 55	PTV Coverage 95% (Gy)	54.75± 0.47	54.71± 0.52	53.78± 0.42	P^1>0.05	P^2<0.02
	Mean Dose (Gy)	56.22± 0.25	56.19± 0.43	55.31± 0.30	P^1>0.05	P^2<0.02
	Maximum Dose (Gy)	59.52± 0.30	59.43± 0.54	59.27± 0.54	P^1>0.05	P^2>0.05
	HI	0.060± 0.03	0.064± 0.02	0.065± 0.01	P^1>0.05	P^2>0.05
	CI	0.75± 0.10	0.66± 0.18	0.65± 0.17	P>0.054	P>0.054
PTV 50	PTV Coverage 95% (Gy)	48.76± 0.17	48.73± 0.27	48.47± 0.35	P^1>0.05	P^2<0.02
	Mean Dose (Gy)	50.95± 0.45	50.92± 0.35	50.69± 0.41	P^1>0.05	P^2<0.02
	Maximum Dose (Gy)	59.51± 0.30	59.27± 0.54	59.14± 0.72	P^1>0.05	P^2>0.05
	HI	0.16± 0.01	0.17± 0.01	0.17± 0.01	P^1>0.05	P^2>0.05
	CI	0.70± 0.08	0.65± 0.06	0.62± 0.12	P^1>0.05	P^2<0.02

p1, p-value of comparison between BL03 and BL04; p2, p-value of comparison between BL03 and BL05; HI: Homogeneity index; CI: Conformity Index

Table 3 Doses to the OARs of the IMRT plans with three different beamlet widths for 20 cervical cancer patients.

OARs	Parameters	BL03	BL04	BL05	P^1	P^2
Rectum	$V_{50\ Gy}$ (%)	20.72± 2.23	20.5± 2.29	20.57± 2.89	$P^1>0.05$	$P^2>0.05$
	$D_{50\%}$ (Gy)	47.04± 2.23	46.97± 4.80	47.72± 4.80	$P^1>0.05$	$P^2>0.05$
Bladder	$V_{50\ Gy}$ (%)	34.03± 5.90	26.33± 9.70	29.77± 4.42	$P^1<0.05$	$P^2<0.05$
	$D_{45\%}$ (Gy)	48.39± 2.80	47.68± 2.33	48.82± 1.80	$P^1>0.05$	$P^2>0.05$
Bowel Bag	D_{max} (Gy)	57.07± 2.11	56.54± 2.44	57.04± 1.75	$P^1>0.05$	$P^2>0.05$
	$V_{45\ Gy}$ (%)	16.69±4.68	19.5± 3.60	19.57 ± 7.66	$P^1>0.05$	$P^2>0.05$
	195 cc (Gy)	43.83 ± 4.95	44.63 ± 4.34	46.69 ± 4.19	$P^1>0.05$	$P^2>0.05$
Left Femur	D_{mean}	38.00 ± 2.76	40.73 ± 3.93	40.99 ± 3.53	$P^1>0.05$	$P^2>0.05$
Right Femur	D_{mean}	35.01 ± 3.74	36.25 ± 3.38	37.12 ± 3.18	$P^1>0.05$	$P^2>0.05$

D_{max}, maximum dose; Vx, percentage volume of region
of interest receiving at least X Gy; $D_{x\%}$, minimum dose received by x% volume of PTV

Table 4Gamma passing rates, monitors units and plan delivery times for plans with different beamlet widths

Parameter	BL03	BL04	BL05
Mus	845.85±62.37	809.88± 85.08	775.23±62.99
PDT(s)	360.92 ± 22.55	355.29 ± 20.6	351.29 ± 20.6
GPR	95.5±1.35	96.3±1.20	96.5±1.23

REFERENCES:

1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA: A cancer journal for clinicians. 2021;71:209-49.
2. Verbakel WF, Cuijpers JP, Hoffmans D, Bieker M, Slotman BJ, Senan S. Volumetric intensity-modulated arc therapy vs. conventional IMRT in head-and-neck cancer: a comparative planning and dosimetric study. International Journal of RadiationOncology-Biology-Physics. 2009;74:252-9.
3. Coselmon MM, Moran JM, Radawski JD, Fraass BA. Improving IMRT delivery efficiency using intensity limits during inverse planning. Medical physics. 2005;32:1234-45.
4. Ur Rehman J, Ahmad N, Khalid M, Gilani ZA, Ullah I, Nasar G, et al. Intensity modulated radiation therapy: A review of current practice and future outlooks. Journal of radiation research and applied sciences. 2018;11:361-7.
5. Guowei Z, Ziping J, Shepard D, Earl M, Yu C. Effect of beamlet step-size on IMRT plan quality. Medical Physics. 2005;32 : 3448-54.
6. Sutterley C, Gautier Q, Graves Y, Li N, Jia X, Jiang S. SU-E-T-570: Optimizing Dose Calculation Parameters for GPU-Based Treatment Planning. Medical Physics. 2013;40:336.
7. Sun H, Wang N, Wang X, Huang G, Chang Y, Liu Y. A study of different minimum segment area parameters on automatic IMRT plans for cervical cancer using Pinnacle3 910 TPS. Medicine (Baltimore). 2022; 101:29290.
8. Hong J, Han JH, Luo HL, Song YQ. Optimization of Minimum Segment Width Parameter in the Intensity-Modulated Radiotherapy Plan for Esophageal Cancer. International Journal of General Medicine. 2021; 16:9913-21.
9. Wang Y, Chen L, Zhu F, Guo W, Zhang D, Sun W. A study of minimum segment width parameter on VMAT plan quality, delivery accuracy, and efficiency for cervical cancer using Monaco TPS. Journal of Applied Clinical Medical Physics. 2018;19:609-15.
10. Nguyen D, O'Connor D, Yu VY, Ruan D, Cao M, Low DA, et al. Dose domain regularization of MLC leaf patterns for highly complex IMRT plans. Medical Physics. 2015;42:1858-70.
11. Wu M, Jin J, Li Z, Kong F, He Y, Liu L, et al. Influence of beamlet width on dynamic IMRT plan quality in nasopharyngeal carcinoma. PeerJ. 2022;10:13748.
12. Coselmon MM, Moran JM, Radawski JD, Fraass BA. Improving IMRT delivery efficiency using intensity limits during inverse planning. Medical physics. 2005; 2:1234-45.
13. Yoosuf AM, Ahmad MB, AlShehri S, Alhadab A, Alqathami M. Investigation of optimum minimum segment width on VMAT plan quality and deliverability: A comprehensive dosimetric and clinical evaluation using DVH analysis. Journal of Applied Clinical Medical Physics. 2021;22:29-40.