

Dosimetric Comparison of Half-Beam Block and Feathering Techniques for Junction Hotspot Management in Extended-Field Radiotherapy for Cervical Cancer

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ABSTRACT

Extended-field radiotherapy for cervical cancer with Para-aortic lymph node involvement presents significant dosimetric challenges due to the need, to irradiate both pelvic and para-aortic planning target volumes (PTVs) while maintaining dose homogeneity at the field junction and keeping organ at risk (OAR) tolerance within tolerance limits. This case study aimed to evaluate and compare the dosimetric outcomes of the half-beam block (HBB) and junction translation ("feathering") techniques for hotspot management at this junction using combined 3DCRT and hybrid IMRT approaches. Two patients with FIGO IIC2 cervical cancer and PET/CT-confirmed PALN involvement were planned. For scenarios where the field size was less than the PTV (single isocenter), the hotspot for 3DCRT-3DCRT plans was managed with HBB and field-in-field (FIF) optimization, reducing the maximum dose (D_{max}) from 49.1 Gy to 48.8 Gy. For hybrid 3DCRT-IMRT plans, feathering by adjusting the IMRT sub-plan junction reduced D_{max} from 57.0 Gy to 49.6 Gy. Where the field size exceeded the PTV (dual isocenter, 1.5 cm gap), FIF reduced D_{max} from 52.3 Gy to 48.8 Gy for 3DCRT-3DCRT, while feathering in the hybrid plan reduced D_{max} from 60.1 Gy to 49.4 Gy. All techniques achieved the primary goal of bringing the junction D_{max} below 110% of the prescription dose (45Gy) while maintaining full PTV coverage ($V_{95\%} = 100\%$) and respecting organ-at-risk constraints. The study concludes that feathering is highly effective for hybrid IMRT junction management, while HBB with FIF is sufficient for 3DCRT junctions, providing practical solutions for safe extended-field delivery.

1. Introduction

This case study aims to evaluate dosimetric outcomes of half beam block and junction translation (feathering) techniques for the management of hot spot at field junction in extended field radiotherapy for cervical cancer patients with positive Para-aortic lymph nodes (PALNs) using 3DCRT and hybrid IMRT approaches. Large radiation treatment fields are required for external beam radiotherapy (EBRT) for (PALN) involved patients (Pt) of Ca-cervix and Ca-endometrium as an adjuvant therapy and has greater chance of recurrence if remain untreated [1].

Traditionally, extended-field radiotherapy (EFRT) has been delivered using three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT) treatment techniques for Ca-cervix and Ca-endometrium patients with PALN involvement. Although these modalities provide acceptable target coverage, they are associated with specific dosimetric challenges, particularly when treating large longitudinal target volumes. In clinical practice, factors such as patient anatomy, extent of disease spread, setup uncertainties, and limited availability of image-guided radiotherapy (IGRT) often necessitate the use of larger planning target volume (PTV) margins.

As a result, the required treatment fields frequently extend beyond the maximum allowable

field size of the treatment machine making junction management at field's border unavoidable. When the total target length (PTV) exceeds the maximum field size ($F.S_{max}$) of the treatment machine, multiple adjacent fields are employed with more than one treatment plan having different isocenter, thereby increasing the risk of dose inhomogeneity at field junctions and the potential for clinically significant hot spots[2,3]. Furthermore, the junction between the two sub plans corresponding to the respective PTVs is managed by superior-inferior (Y-jaw) translation to control dose inhomogeneity at the match line.

In scenarios where the maximum field size ($F.S_{max}$) exceeds the PTV length ($F.S_{max} > PTV$), hotspot formation at the junction is mitigated by positioning a single isocenter at the junction, allowing PTV_{pelvis} and PTV_{aorta} to share a common isocenter. This configuration facilitates implementation of the half-beam block (HBB) technique at the L5-L4 vertebral level, thereby minimizing beam divergence and dose overlap at the match plane.

Conversely, in cases where the target length exceeds the maximum available field size ($F.S_{max} < PTV$), junctional dose inhomogeneity is addressed using a dual-isocenter feathering approach, in which the match line is periodically shifted to distribute potential hotspots and cold spots over a larger longitudinal extent [4].

In this study the focus is on the junction to limit hot spot for 3DCRT-3DCRT and 3DCRT-IMRT combined treatment plan for $(F.S)_{max} < PTV$ and vice versa with condition that PTV_{aorta} is plan with 3DCRT technique only and PTV_{pelvis} with 3DCRT and IMRT.

Eclipse planning system (version 15.6) developed by Varian Medical System USA were used to generate 3DCRT and IMRT treatment plans. The combined treatment plan or the Plan sum (P.S) was calculated by inserting PTV_{pelvis} and PTV_{aorta} into the plan sum tool of Eclipse TPS as:

$$PTV_{comb} = (PTV_{Pelvis} + PTV_{aorta}) \quad (1)$$

for the final PTV coverage. Usually 45 to 50 Gy dose is delivered to PTV_{comb} for RT with a sequential boost of 5-10 Gy to enlarged nodes to prevent recurrence [5]. In conventional 3DCRT treatment planning large AP/PA with lateral fields are used to cover entire PTV_{comb} in single plan with lateral fields weightage adjusted in such a way that kidney, bowel and spinal cord tolerance doses remain intact[6], however due to kidneys in lateral fields there is a risk of over dosage, as result another method i.e. half beam block (HBB) approach is adopted in which PTV_{pelvis} is planned with box technique with isocenter place between L₄-L₅ vertebral level i.e where PTV_{aorta} starts and PTV_{pelvis} ends. PTV_{aorta} is covered with AP/PA fields with addition of two lateral oblique fields to limit Spinal Cord (SC) dose [7]. The hot spot at junction is further fine-tuned by applying field in field (FIF) technique. However when $F.S_{max} < PTV_{comb}$, FIF technique doesn't works well then fields are angled away to avoid overlapping or junction is translated along the upper border of the field to limit the hot spot at the junction [8].

Feathering or junction translation approach was adopted in the hot spot management for hybrid IMRT i.e IMRT+ 3DCRT. In hybrid IMRT planning of PTV_{comb} , PTV_{pelvis} was planned with 7 RT fields using 6 MV (Mega Volt) energy to get more conformity to target volume and greater sparing of normal tissue as compared to 3DCRT and also to reduce acute and late toxicity to gastrointestinal and genitourinary [9].

The main reason for not planning of PTV_{comb} with IMRT is because of less data available on extended field EF-IMRT [10]. The hot spot at the junction was analyzed and managed by inserting final normalize plan of PTV_{pelvis} and PTV_{aorta} in the plan sum tool of Eclipse TPS and dosimetric parameters were obtained from dose volume histogram DVH.

2. Material and Methods

2.1 Patient Selection

For this technical case study, two consecutive female patients with biopsy-proven cervical cancer and radio logically confirmed PALN involvement were selected retrospectively. Both patients were staged as FIGO 2018 IIC2. PALN involvement was defined on FDG-PET/CT imaging by nodes with a short-axis diameter >1 cm. The case study format with a small sample size was chosen to provide a detailed proof of concept demonstration of the junction management techniques for this specific clinical scenario, with findings to be validated in larger cohorts.

2.2 CT Simulation (CT-Sim)

Prior to the CT-Sim urea creatinine level were checked of both patients and then they were asked to empty rectum and fill bladder with 450 ml of water 40 minutes prior to be scanned in supine position with patient heads towards Ct-Bore gantry. Both hands of patient were placed above heads, knee and foot lock support of Klarity (China) were used to minimize patient variability during treatment. The knee and foot locks were adjustable plastic supports that secured the patient's legs in a reproducible, neutral position.

Patients were then injected with IV contrast for target delineation using a power injector at a rate of 2 mL/sec, with a scan delay of 80 seconds to achieve optimal vascular and soft tissue enhancement, and were scanned with 3mm of slice from T₁₀ vertebral level to mid-thigh. For isocenter marking three fiducially radiopaque markers were placed at the lateral side and anteriorly on midline which were then marked with permanent tattoo. The scanned DICOM images were then exported to treatment planning system (TPS).

2.3 Delineation of Target and OARs

Target volumes and organ at risk were drawn by the expert Oncologist and radiologist as per ICRU report 80 for IMRT and for 3DCRT [11]. Specifically, the clinical target volumes (CTVs) were delineated following the ESTRO consensus guidelines [12]. The CTV primary included the gross tumor volume (GTV), entire cervix, uterus, parametria, and upper vagina. The CTV aorta encompassed the involved PALN (GTVn) with a 7-mm margin, edited for anatomical boundaries, and the elective para-aortic nodal volume from the T₁₂/L₁ to L₄/L₅ vertebral junction. Two PTVs of 10mm around clinical target volume CTV primary and CTV aorta were created for target coverage PTV_{pelvis} and PTV_{aorta} which includes set up errors and internal target as per our institutional policy.

The PTV_{pelvis} is divided in to sub three PTVs labeled as $PTV_{pelvis1}$, $PTV_{pelvis2}$, $PTV_{pelvis3}$, with volume reduction per 3mm slice in descending order from the Junction strip. This subdivision was designed to create a tapered dose gradient at the superior border of the PTV_{pelvis} , facilitating a smoother dose match (feathering) with the inferior border of the PTV_{aorta} and minimizing the dose heterogeneity at the junction. Both PTV_{pelvis} and PTV_{aorta} were merged to create final target volume PTV_{comb} . Small bowel, rectum, bladder, femoral heads, bilateral kidneys delineated as organs at risk in both patients as per RTOG female pelvic normal tissue consensus guidelines [13].

2.4 3DCRT Treatment Planning

Both PTVs PTV_{pelvis} and PTV_{aorta} were treated with prescribed dose (P.D) of 45 Gy in 25 fractions (fr). Four field technique was designed for PTV_{pelvis} coverage with 15 MV and 6 MV lateral and AP/PA fields combination. Specifically, a standard four-field box technique was used with anterior (gantry 0°), posterior (gantry 180°), left lateral (gantry 90°), and right lateral (gantry 270°) beams. The collimator angle was set to 0° for all fields. The isocenter of LINAC was placed at the upper border where the PTV_{pelvis} ends to achieve zero divergence.

PTV_{pelvis} was covered by opening the A symmetric lower Jaw Y1 and keeping the upper Jaw Y2 at zero(0,Y1). PTV_{aorta} was planned with AP/PA 15 MV

fields combination to maximum spare kidneys and to keep spinal cord dose at its limits two lateral oblique fields of 15 MV with weightage in range of (10 to 15) % was applied , PTV_{aorta} was covered using the lower Y2 Jaw at zero and Y1(Y1,0) kept open as desired for PTV_{aorta} required field size for single isocenter half beam block technique. For PTV_{combo} > F.S of linac, the dual isocentric technique were used for with isocentric gap of 1.5 cm so, that the divergence is minimum. JAW (Y2, 1.5cm) and (Y1, 0) were open to cover PTV_{pelvis} and PTV_{aorta} adequately. Both PTVs were normalized to achieved 100% coverage of the target PTV_{comb} with 95% of the P.D with keeping the tolerance dose of OAR at their limit The normalization objective was for 95% of the PTV volume (D95) to receive 100% of the prescribed dose (45 Gy).

2.5. IMRT Treatment Planning

The isocenter for the IMRT plan was positioned at the L4-L5 vertebral junction, corresponding to the planned match line between the superior border of the PTV_{pelvis} and the inferior border of the PTV_{Aorta}. Combination of Seven field IMRT plan was designed to deliver total sum of 45Gy in 25 fraction to PTV_{pelvis1}, PTV_{pelvis2}, PTV_{pelvis3} with angle starting from 0°, 50°, 100°, 150°, 200°, 250°, 300° with energy of 6MV photon energy. The plan was optimized using the Photon Optimizer in Eclipse (Varian Medical Systems). The following dose-volume objectives were prioritized during optimization: PTV D95% ≥ 45 Gy; Small Bowel V40Gy < 30%; Rectum V40Gy < 60%; Bladder V45Gy < 35%; Femoral Heads V30Gy < 15%. The plan was delivered using a sliding window technique (Dynamic IMRT) on a Varian linear accelerator. All PTVs were normalized to achieve 100% of the target volume received 95% of the P.D with keeping the tolerance dose of OAR at their limits.

2.6. Combining Plan Sum of 3DCRT - 3DCRT and 3D-CRT - IMRT Treatment Plan

Plan Sum of PTV_{pelvis} and PTV_{aorta} in 3DCRT, and P.S of PTV_{aorta} and IMRT sub treatment plan of PTV_{pelvis} i.e. PTV_{pelvis 1}, PTV_{pelvis 2}, PTV_{pelvis 3}, for single isocenter and dual isocenter technique were generated using ECLIPSE TPS. The hot spot at the junction were analyzed and were bring down to permissible limits by making minor adjustments using filed in field technique in PTV_{aorta} and in PTV_{pelvis} by changing the number of fraction in IMRT sub treatment plan. Specifically, the 'Plan Sum' tool in Eclipse was used to add the dose distributions of the separate plans. For the hybrid IMRT plan, the fraction number assigned to the IMRT sub-plan within the sum tool was adjusted (e.g., from a nominal 25 fractions to a lower effective number like 15 or 20) to modulate its relative weight.

This approach reduce the high-dose region over approximately 1 cm longitudinally rather than concentrating at a single match plane. This strategy, combined with the predefined dose gradient from the subdivided PTV_{pelvis}, volumes constituted the feathering technique.

2.7 Organ-at-Risk (OAR) Doses

The doses to critical OARs for both single and dual isocenter techniques are summarized in Tables 1 and 2. For the 3DCRT-3DCRT technique all OAR doses remained within QUANTEC and clinical constraints. The hybrid 3DCRT-IMRT technique demonstrated improved sparing, notably reducing the V45 volume

for the rectum and bladder and the mean dose to the femoral head.

2.8 Homogeneity Index (HI) Evaluation

Dose homogeneity within the planning target volume (PTV) was assessed using homogeneity indices defined by ICRU Report 83 and RTOG 0915. According to ICRU Report 83, the homogeneity index (HI) was calculated as:

$$HI_{ICRU\ 83} = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \quad (2)$$

Here D_{2%} represents the volume receiving the maximum dose, D_{98%} represents the volume receiving the minimum dose and D_{50%} represents the volumes receiving the median dose.

DP represents dosimetric parameter.

$$HI_{RTOG0915} = D_{max}/D_p$$

Where, D_{max} represents the maximum point dose. D_p is the prescribed dose to the target volume i.e., 95 % of the P.D covers 100 % of the target Volume. The application of both indices allowed complementary assessment of volumetric dose uniformity and localized dose hot spots within the PTV.

3. Results

3.1 Dosimetric Outcomes at the Junction (Half Beam Block Technique)

The primary dosimetric results for hotspot management at the junction between PTV_{pelvis} and PTV_{aorta} are shown in figure 1,2. For the single isocenter (half-beam block) setup, the initial hotspot (D_{max}) in the 3DCRT-3DCRT plan was 49.1 Gy, which was reduced to 48.8 Gy using field-in-field (FIF) optimization. The hotspot in the hybrid 3DCRT-IMRT plan was initially much higher at 57.0 Gy but was successfully reduced to 49.6 Gy through the feathering technique (junction translation via IMRT sub-plan adjustment and PTV subdivision).

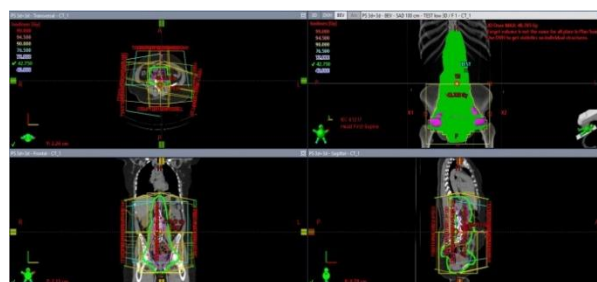


Fig. 1: Hot Spot in the Plan Sum (P.S) of 3DCRT-3DCRT after Applying FIF Technique

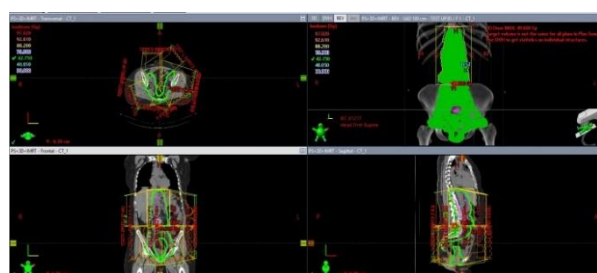


Fig. 2: Hot Spot in the P.S of 3DCRT- Sub IMRT Treatment Plan

3.2. Dosimetric Outcomes at the Junction (Dual Isocentric Set Up)

For the dual isocenter setup (1.5 cm gap), the initial D_{max} for the 3DCRT-3DCRT plan was 52.3 Gy, reduced to 48.8 Gy with FIF. The hybrid plan's initial D_{max} of 60.1 Gy as was reduced to 49.4 Gy via feathering. In all four scenarios, shown in figures 3, 4. The final D_{max} was successfully brought below 110% of the prescription dose (49.5 Gy), meeting the primary clinical objective.

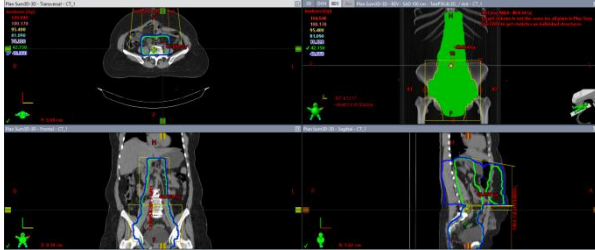


Fig. 3: Hot Spot after in the P.S of 3DCRT- 3DCRT

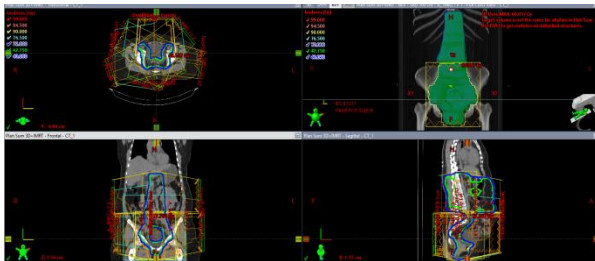


Fig. 4: Hot Spot in the P.S of 3DCRT- Sub IMRT Treatment Plan.

3.3 Organ-at-Risk (OAR) Doses

A critical aspect of plan quality is the dose to surrounding normal tissues. The dose volume metrics for key OARs for both patients, averaged across the final optimized plans, are presented in Table 1&2. All doses remained well within commonly accepted tolerance limits derived from QUANTEC and clinical protocols [25, 26], confirming that hotspot

reduction was achieved without compromising normal tissue sparing.

Table 1: OAR doses for single-isocenter plans

OAR	QUANTEC Constraints (Gy)	3DCRT-3DCRT (Gy)	3DCRT-IMRT (Gy)
Bowel	$V45 \leq 195\text{cc}$	$V45 = 185\text{cc}$	$V45 = 135\text{cc}$
Rectum	$V50 < 50\%$	Mean dose 43	$V45 = 50\%$
Spinal Cord	$D_{max} < 50$	44.3	44.3
Rt. Femoral head	Mean dose Alara	31	22
Rt. Femoral head	Mean dose Alara	32	21
Lt Kidney	Mean Dose $< 18\text{Gy}$	12.3	12.3
Rt kidney	Mean < 18	7.5	7.5
Bladder	$V65 < 50\%$	45	mean38

Table 2: OAR Doses for Dual Isocenter Plans

OAR	QUANTEC Constraints (Gy)	3DCRT-3DCRT (Gy)	3DCRT-IMRT (Gy)
Bowel	$V45 \leq 195\text{cc}$	$V45 = 210\text{cc}$	$V45 = 127\text{cc}$
Rectum	$V50 < 50\%$	Mean dose 41	$V45 = 50\%$
Spinal Cord	$D_{max} < 50$	44.3	44.3
Rt. Femoral head	Mean dose Alara	31	19.2
Lt .Femoral head	Mean dose Alara	32	20
Lt Kidney	Mean Dose $< 18\text{Gy}$	9.6	9.6
Rt kidney	3.4	3.6	3.6
Combined kidney	Mean Dose $< 18\text{Gy}$	13.2	13.2
Bladder	$V65 < 50\%$	42	34

Table 3: HI (Homogeneity Index) for single Isocenter Technique

DP	After Hot Spot Managed		Before Hot Spot Managed	
	PTV comb 3DCRT+IMRT (Gy)	PTV comb 3DCRT+3DCRT (Gy)	PTV comb 3DCRT+IMRT (Gy)	PTV comb 3DCRT+3DCRT (Gy)
D 2%	48.83	48.16	50.135	48.83
D 50%	46.04	46.56	46.56	46.56
D 98%	43.6	43.49	43.68	43.68
D max	49.6	48.78	56.59	49.1
V 95% (combined PTV)	100	100	100	100
HI ICRu 83	0.11	0.089	0.14	0.089
HI RTOG 0915	1.16	1.14	1.32	1.14

Table 4: HI (Homogeneity Index) for dual Isocenter Technique

	After Hot Spot Managed		Before Hot Spot Managed	
DP	PTV comb 3DCRT+IMRT (Gy)	PTV comb 3DCRT+3DCRT (Gy)	PTV comb 3DCRT+IMRT (Gy)	PTV comb 3DCRT+3DCRT (Gy)
D 2%	48.62	47.9	49.21	50.8
D 50%	45.45	45.7	45.8	45.34
D 98%	43.11	43.89	43.34	43.87
D max	49.42	48.83	60.057	51.7
V 95% (combined PTV)	100	100	100	100
HI ICRu 83	0.12	0.087	0.13	0.15
HI RTOG 0915	1.15	1.14	1.4	1.21

4. Discussion

Junction management remains a critical dosimetric challenge in extended-field radiotherapy for cervical cancer, particularly when different treatment techniques are combined. In this case study, we demonstrate that both conventional approaches, such as the half-beam block (HBB) with field-in-field (FIF), and adapted strategies, including junction feathering in hybrid IMRT, are effective in controlling dose distribution at the junction region. These techniques successfully limit junction hotspots to clinically acceptable levels below 110% of the prescribed dose.

In conventional 2D and 3DCRT planning, junction hotspots are typically mitigated by shifting the hotspot across the irradiated region through Y-jaw adjustments, careful field abutment, and the use of HBB techniques [14]. In the present work, a similar junction translation concept was extended to hybrid IMRT planning, where it was combined with the field-in-field (FIF) technique to manage dose inhomogeneities at the match line. The clinical rationale for adopting a hybrid IMRT approach IMRT for the pelvic PTV and 3DCRT for the para-aortic PTV is well justified, IMRT in the pelvis provides improved dose conformity and superior sparing of organs at risk (OARs), particularly the bowel and bladder, which is essential for reducing both acute and late gastrointestinal and genitourinary toxicities.

Conversely, the para-aortic region can be adequately treated with 3DCRT using relatively simple AP/PA and lateral field arrangements, ensuring reliable target coverage with minimal planning complexity [15]. Although randomized studies have shown no significant differences in local control, disease-free survival, or overall survival between IMRT and 3DCRT for gynecological malignancies [16], the dosimetric advantages of IMRT make it preferable for pelvic irradiation in extended-field settings.

Our findings highlight an important limitation of the single-isocenter HBB technique when applied to hybrid 3DCRT-aorta/IMRT-pelvis plans. While HBB along with FIF approach effectively improves dose homogeneity in 3DCRT-aorta/3DCRT-pelvis

configurations, it does not adequately control junctional hotspots in hybrid plans.

For hybrid IMRT plans, junction feathering proved to be a robust solution. By subdividing the PTV and applying differential sub-plan weighting, a controlled dose gradient was created across a 9-mm junction region. This approach effectively smoothed the dose transition between adjacent fields and significantly reduced localized dose escalation, resulting in improved overall dose uniformity.

As summarized in Tables 1 and 2, all organ-at-risk (OAR) doses were evaluated against established QUANTEC-based constraints to ensure clinical acceptability[19,20].In the single-isocenter plans, bowel V45, rectal dose-volume parameters, femoral head mean doses, spinal cord maximum dose, renal mean doses, and bladder dose metrics remained within recommended tolerance levels. In the dual-isocenter configuration, although the conventional 3DCRT plan approached or exceeded the bowel V45 constraint, the hybrid technique restored compliance while maintaining acceptable rectal and bladder dose-volume parameters. Mean doses to the femoral heads were consistently reduced with modulation and spinal cord as well as renal doses remained well below tolerance thresholds in all plans. Importantly, hotspot reduction and junction optimization were achieved without escalation of clinically relevant OAR doses. These findings confirm that the proposed junction management strategy preserves normal tissue sparing while improving dose homogeneity across extended fields, thereby addressing both plan quality and safety considerations highlighted in prior clinical guidelines.

Dose homogeneity was further evaluated using the Homogeneity Index (HI), which is commonly calculated from $D_{2\%}$ and $D_{98\%}$ as recommended by RTOG 0915. However, this protocol does not explicitly consider D_{max} within the combined PTV. In contrast, ICRU Report 83 emphasizes the relevance of D_{max} , particularly in assessing clinically significant hotspots that may affect both target volumes and adjacent OARs [17, 18].

In the present study, reducing the maximum dose (D_{max}) from values exceeding 115–120% of the

prescribed dose (e.g., 57.0 Gy and 60.1 Gy) to approximately 110% (49.6 Gy and 49.4 Gy) resulted in a clear improvement in the Homogeneity Index (HI), indicating enhanced dose uniformity across the target volume. Specifically, D_{max} decreased from 57.0 Gy to 49.6 Gy in the hybrid single-isocenter plan and from 60.1 Gy to 49.4 Gy in the hybrid dual-isocenter plan. This reduction represents a clinically meaningful improvement in dose distribution.

Maintaining D_{max} below 110% of the prescription dose (49.5 Gy) is clinically important because higher hotspot levels may increase the risk of late radiation-induced toxicities. Previous studies have reported that excessive dose regions, particularly volumes receiving more than 50 Gy, are associated with complications such as subcutaneous fibrosis and bowel injury [16].

In addition, the 21% improvement in the HI_ICRU83 observed for the hybrid single-isocenter plans indicates a more uniform dose distribution within the target volume. Improved dose homogeneity may contribute to a better therapeutic ratio by maintaining adequate tumor coverage while reducing unnecessary dose escalation in surrounding tissues.

These dosimetric improvements are particularly important in extended-field radiotherapy, where larger treatment volumes inherently increase the risk of normal tissue complications. The threshold of 110% of the prescription dose (<49.5 Gy for a 45 Gy prescription) is therefore clinically relevant, as multiple studies have shown that tissue volumes receiving more than 50 Gy are associated with an increased risk of late gastrointestinal toxicity [19]. By maintaining D_{max} below this threshold while ensuring full target coverage, the proposed junction management strategy contributes to safer and more clinically acceptable treatment delivery in extended-field radiotherapy.

By systematically addressing junctional dose inhomogeneities and improving the HI, the techniques described in this study enhance the therapeutic ratio, ensuring adequate tumor coverage while potentially minimizing normal tissue toxicity. These considerations are particularly important in extended-field radiotherapy, where radiosensitive structures such as the small bowel are often in close proximity to the target volume [19, 20].

As a case study of two consecutively selected patients, this work serves as a detailed proof of concept. The techniques are clearly explained and demonstrated to be feasible within a modern TPS. However, the small sample size is an acknowledged limitation.

The generalizability of the specific dose gradients and weighting factors to patients with vastly different anatomies or body habitus requires validation in larger, prospective studies. Furthermore, the plan evaluation relies on calculated dose; the impact of daily setup variation on the junction dose in a clinical setting should be assessed with image-guided radiotherapy (IGRT). Future work could compare this hybrid approach directly with full extended-field IMRT or VMAT plans, which are now more commonly implemented with advanced image guidance.

To our knowledge, limited literature is available specifically evaluating feathering-based hotspot control in hybrid 3DCRT-IMRT extended-field

cervical radiotherapy. The findings should therefore be interpreted as a technical proof-of-concept rather than definitive clinical evidence.

5. Conclusion

Effective junction hotspot management is essential for achieving homogenous target dose distribution while minimizing radiation-induced toxicity to surrounding organs at risk. On inside PTV and to avoid early and late toxicity of OAR. The study concludes that, in case of hybrid IMRT the hot spot at the junction can easily be brought down to acceptable limit by This case study demonstrates that both half-beam block with FIF optimization and feathering techniques effectively manage junction hotspots in extended-field radiotherapy for cervical cancer patients with PALN involvement. Feathering is highly effective for hybrid IMRT junction management, reducing D_{max} from as high as 60.1 Gy to below 49.5 Gy while improving homogeneity index by up to 21%. Half-beam block with FIF is sufficient for 3DCRT junctions, consistently achieving D_{max} below 49 Gy. Both techniques maintain full PTV coverage ($V_{95\%} = 100\%$) and respect OAR constraints, with hybrid IMRT providing superior normal tissue sparing (27-39% reduction in bowel V_{45}). These practical solutions enable safe delivery of extended-field radiotherapy in both resource-limited and advanced treatment settings.

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