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Bowel Sparing with Intensity-modulated Proton Therapy (IMPT) in Cervical Cancer: A Dosimetric Study with Intensity-modulated Radiation Therapy (IMRT)

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Objectives

To compare dosimetric parameters of bowel dose, a key predictor of gastrointestinal toxicities in pelvic radiotherapy, between IMRT and IMPT for locally advanced cervical cancer. Additional parameters, including bladder, rectum, and sigmoid colon doses, will also be evaluated.

Methods

A retrospective analysis was conducted on twenty cervical cancer patients. The target volumes and organ-at-risk (OAR) definitions, including dose constraint parameters, were based on the EMBRACE-II protocol. The prescription included 45 Gy in 25 fractions with a simultaneous boost to pelvic lymph nodes at 55 Gy. IMRT was designed using a seven-beam photon configuration based on the planning target volume (PTV), while IMPT utilized an internal target volume (ITV)-based approach with an additional 5 mm robust optimization, incorporating pencil beam scanning with the Monte Carlo algorithm. Target coverage and doses to OAR, including the bowel, sigmoid colon, bladder, and rectum, were evaluated and compared between IMRT and IMPT.

Results

Both techniques provided comparable target volume coverage (table 1). However, due to differences in the methods and volumes used for optimization, the homogeneity index and conformity index cannot be directly compared. Details of OAR dose-volume parameters are shown in Table 2. In IMPT, there was a significant reduction in the mean volumes of V30Gy and V40Gy for the bowel compared to IMRT, corresponding to reductions of 39.88% (95% CI: 46.73–33.04) and 28.35% (95% CI: 38.30–18.10), respectively ($P < 0.001$ for all comparisons). IMPT significantly diminished the volumes of the sigmoid and rectum at V40 Gy. The sigmoid volume decreased by 8.72% (95% CI: 0.56–18.01; $P = 0.042$). Similarly, the rectum volume showed a reduction of 21.10% (95% CI: 6.93–35.28; $P = 0.001$). Furthermore, the body volume receiving 43 Gy (V43) Gy was significantly lowered using IMPT, from 1153.79 ± 163.25 cm^3 with IMRT to 981.85 ± 205.62 cm^3 with IMPT, representing a reduction of 14.87% (95% CI: 8.46–21.28; $P < 0.001$). However, V30Gy and V40 Gy of the bladder were not significantly different between the two techniques.

Conclusions

IMPT demonstrated significant sparing of the small bowel, sigmoid colon, and rectum while providing comparable target coverage. This could potentially reduce the risk of gastrointestinal toxicity in cervical cancer treatment. To validate the findings of this dosimetric study and support the use of IMPT for locally advanced cervical cancer, clinical research is required.

Table 1 Summary of DVH analysis for target volume

Target parameter IMRT/IMPT	IMRT	IMPT	Mean diffence(%) (95% Confidence Interval), P-value
ITV45 volume (cm^3) (Median; IQR)	619.66 (550.5-685.42)		-
PTV45 volume (cm^3) (Median; IQR)	1074.14 (964.86-1137.28)		-
D98 of PTV45/ ITV45 (Gy) (Median; IQR)	43.27 (42.12-43.39)	42.75 (42.75-42.75)	0.36 (-1.02-1.70), P = 0.627
V95 of PTV45/ ITV45 (%) (Median; IQR)	98.75 (96.27-99.02)	96.35 (96.18-96.69)	1.07 (-1.8-3.95), P = 0.247
D98 PTV-N(1)/CTV-N(1) (Gy) (Median; IQR)	53.56 (53.38-54.08)	52.32 (52.29-53.45)	P = 0.109

Table 2 Summary of DVH analysis for organs at risk

OAR Parameters	RT tecnique		Mean diffence (%) (95% Confidence Interval), P-value
	IMRT	IMPT	
Bowel V15Gy (cm^3) (Mean±SD)	769.61 ± 310.30	284.70± 91.59	60.82 (65.34-56.30), P<0.001
Bowel V30Gy (cm^3) (Mean±SD)	294.68±98.42	172.14±57.58	39.88 (46.73-33.04), P<0.001
Bowel V40Gy (cm^3) (Mean±SD)	152.04±61.75	103.80±38.06	28.35 (38.30-18.40), P<0.001
Sigmoid V30Gy (%) (Median; IQR)	98.70 (92.55-100)	98.65 (89.9-100)	4.52 (10.81-1.77), P= 0.331
Sigmoid V40Gy (%) (Mean±SD)	81.20±17.49	74.63±22.21	8.72 (0.56-18.01), P = 0.042
Bladder V30Gy (%) (Mean±SD)	65.31±10.04	61.78±6.42	3.06 (7.35-13.46), P = 0.126
Bladder V40Gy (%) (Mean±SD)	43.62±12.74	39.03±9.68	3.70 (16.77-24.18), P = 0.102
Rectum V30Gy (%) (Median; IQR)	77.80 (62.4-83.63)	76.53 (73.12-79.97)	P = 0.470
Rectum V40Gy (%) (Median; IQR)	44.80 (36.6-52.67)	33.76 (23.06-37.23)	21.10 (6.93-35.28), P = 0.001
Body V43Gy (cm^3) (Mean±SD)	1153.79±163.25	981.85±205.62	14.87 (8.46-21.28), p < 0.001

Table 3 Scatter plot with mean ± SD comparing OAR dosimetry between IMRT and IMPT.