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RESEARCH

The impact of setup errors on dose distribution in cervical cancer radiotherapy and the margin from CTV to PTV

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Abstract

Purpose This study calculates the needed margin from clinical target volume (CTV) to planning target volume (PTV) in IMRT for cervical cancer. It also assesses the impact of setup errors on target and organ at risk (OAR) dose distribution.

Methods We retrospectively analyzed 50 cervical cancer patients who underwent IMRT, with 210 CBCT scans. We calculated the CTV-to-PTV margin and simulated setup errors in the TPS to reassess dose distribution impacts on targets and OAR.

Results Setup errors in X(anterior–posterior,AP), Y(cranial–caudal,CC), and Z(left–right,LR) directions were (1.4 ± 1.0) mm, (2.3 ± 1.5) mm, and (1.9 ± 1.2) mm, respectively, leading to CTV-to-PTV margins of 4.4 mm, 6.4 mm, and 5.8 mm. X-axis errors did not significantly affect target dosimetry ($P > 0.05$), but Y and Z errors did ($P < 0.05$). X-axis errors impacted the small intestine and rectum ($P < 0.05$), Y-axis errors mainly affected the colon ($P < 0.05$), and Z-axis errors affected the colon, small intestine, and rectum ($P < 0.05$).

Conclusion Our study underscores the need to account for setup errors in radiotherapy for cervical cancer. Customizing the CTV-to-PTV margin based on institutional error data is key to maintaining target dose coverage and optimizing treatment outcomes.

Keywords Setup errors · Cervical cancer · CBCT · Dose distribution · Intensity-modulated radiotherapy

Introduction

In 2020, global cervical cancer incidence exceeded 600,000 new cases, with 340,000 deaths, mainly in Asia. Annually, China records approximately 50,000 cervical cancer deaths, and the escalating incidence poses a substantial health challenge for women (Sung et al. 2021; Ahmad and Kumar 2018).IMRT is a sophisticated radiotherapy technique known for its steep dose gradients and stringent patient positioning accuracy requirements. It has become a crucial treatment modality for cervical cancer, providing benefits such as enhanced dose conformity and reduced radiation toxicity (Badajena et al. 2020a).Setup errors in radiotherapy reflect the misalignment between planned and actual patient/target positions, attributable to factors such as the reliability of immobilization devices, inaccuracies in linear accelerator mechanics and laser alignment, and positioning errors during patient transfer from CT simulators to treatment units, as well as those introduced by technical staff (Fu et al. 2020; Zhong et al. 2021).Patients with pelvic malignancies may experience dose distribution alterations during radiotherapy

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due to respiratory motion, gastrointestinal peristalsis, and interfractional positional changes (Petric et al. 2021; Ogawa et al. 2023). Setup errors are unavoidable during fractionated treatment, risking underdosage to the CTV. Consequently, it is necessary to expand the CTV by a certain margin to generate the PTV (Pramanik et al. 2020; Patni et al. 2017). Institution-specific CTV expansion margins for PTV definition vary due to uncertainties in organ motion, setup errors, and equipment alignment discrepancies.

CBCT was used in this study to evaluate the impact of interfractional setup errors on the dosimetry of target volumes and OARs in cervical cancer IMRT. Offline TPS simulations using actual setup error data calculated dose deviations and examined dose distribution effects. An empirical formula was applied to determine optimal CTV expansion margins, guiding clinical decisions for CTV margin definition in cervical cancer radiotherapy.

Materials and methods

Clinical data

A retrospective analysis was conducted on 50 patients with pathologically confirmed cervical or endometrial cancer who received radiotherapy at our institution from January 2020 to October 2023. Patients aged 18–75 years with stage IA-IIIC cancer, postoperative radical surgery, and indications for postoperative EBRT were included. Those with prior pelvic or abdominal EBRT, setup errors > 0.5 cm, EBRT dose > 50Gy, or severe comorbidities unsuitable for radiotherapy were excluded. Fifty patients met the inclusion criteria and were analyzed.

Patient positioning

Because prone positioning in IMRT for gynecological cancers significantly reduces small bowel and colon radiation exposure, potentially decreasing acute gastrointestinal side effects(Yan et al. 2023).Patients were immobilized in the prone position using a specialized pelvic fixation device. Bladder filling was standardized by drinking 800 ml of water one hour before the CT scan. Ultrasound was used to measure bladder volume at positioning, with a recommended range of 200–300 ml, and this was re-evaluated before each treatment. Three-axis laser alignment confirmed correct positioning without tilt, distortion, or rotation (Fig. 1).

Target volume delineation and treatment planning

Patients underwent contrast-enhanced and non-contrast CT scans with a Siemens CT simulator, slice thickness 5mm, from T11 to 5cm below the ischial tuberosity. The scans

Fig. 1 Prone positioning with postural fixation for cervical cancer treatment

were imported into the Monaco TPS for 3D reconstruction. The CTV and OARs were delineated by a radiation oncologist according to ICRU 62 guidelines(Report , 1999). A 5mm isotropic margin was added to create the PTV. OARs included the small intestine, colon, rectum, bladder, and femoral heads. The PTV received 45-50Gy in 25 fractions (1.8–2.0Gy per fraction). Planning objectives were to ensure 95% PTV coverage, prevent cold spots, avoid hot spots, and minimize hot spots in the intestines and bladder. OAR dose constraints were set for the bladder, femoral heads, rectum, small intestine, and colon. IMRT plans with 7 fields (6MV X-rays) were created using Monaco TPS and optimized for target coverage and OAR sparing. Plans were reviewed and approved by the radiation oncologist before delivery on an Elekta Synergy linear accelerator.

Setup error measurement and plan simulation

Patients were positioned on the linear accelerator for kV-CBCT scanning to register images with the planning CT in three planes (Fig. 2). Bony anatomy and manual alignment refinement were used for registration optimization. Once satisfactory, the system automatically calculated setup errors in X, Y, and Z axes, which were documented.The CTV-to-PTV margin (MPTV) was calculated using van Herk's formula: $MPTV = 2.5\Sigma + 0.7\sigma$, where Σ is the population systematic error (SD of mean setup errors) and σ is the population random error (RMS of setup errors)(Herk 2004). Individual errors were represented by mean and standard deviation of setup errors for each patient.Measured setup errors were used to simulate error plans in the TPS by shifting the isocenter of the original plan without altering field angles, shapes, or weights. The simulated plans were then recalculated to evaluate the dosimetric impact of setup errors on target volumes and OARs by comparing dose parameters between the simulated and original plans.

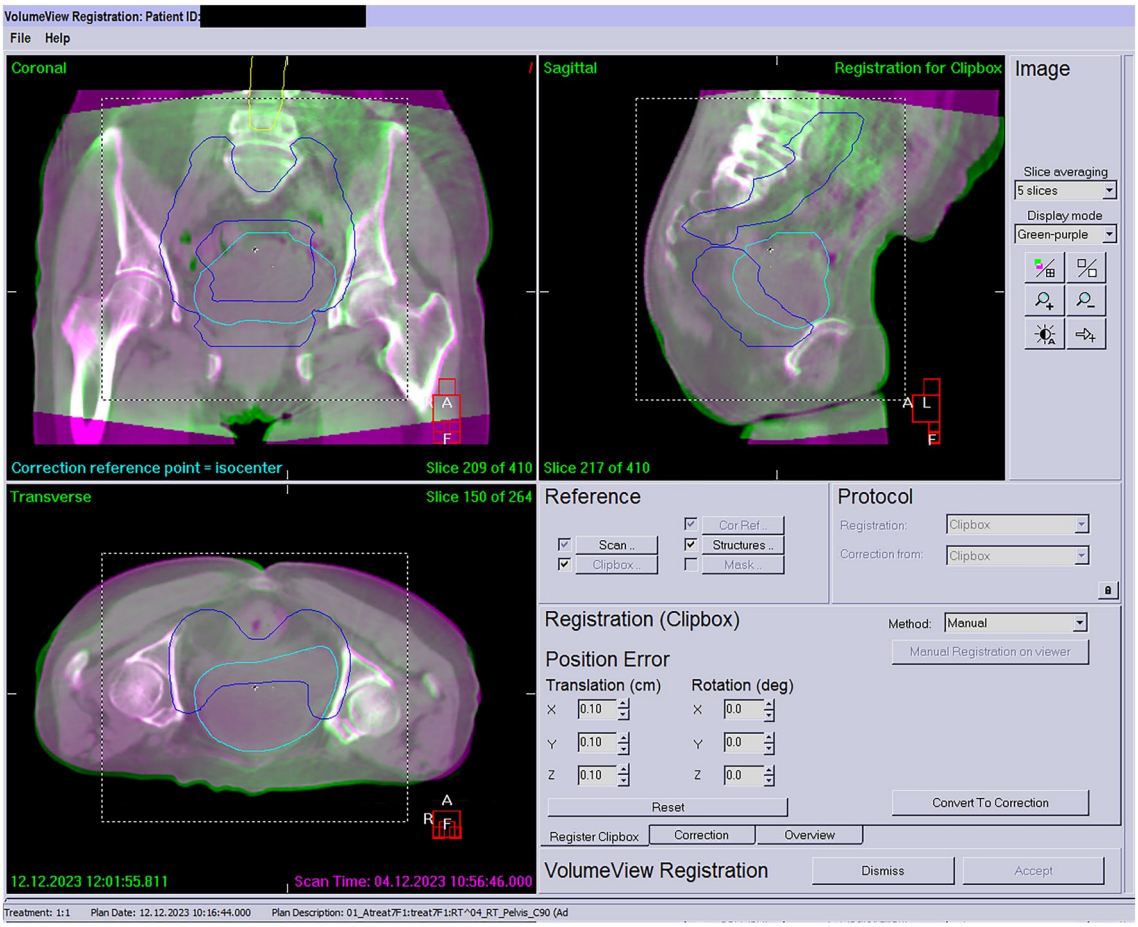


Fig. 2 Measurement of setup errors using kV-CBCT

Evaluation of treatment plans

The dosimetric parameters for the CTV and PTV were assessed, focusing on the homogeneity index (HI), conformity index (CI), and target coverage (TC). For the OAR, including the bladder, rectum, small intestine, colon, and femoral heads, the parameters evaluated included the maximum dose (Dmax), mean dose (Dmean)and Vxx (Vxx is defined as the percentage of normal tissue volume that receives at least xx Gy).In the calculation methods for HI, CI, and TC, Vref,t refers to the target volume receiving the prescribed dose, t denotes the total target volume, and Vref represents the volume receiving the prescribed dose. D2% and D98% represent the 2% and 98% dose levels within the target, respectively, while D50% signifies the median dose (Wu et al. 2022).

$$TC(\%) = \left(V_{ref,t} / V_{ref}\right) \times 100 \quad (1)$$

$$HI = \left(D_{2\%} / D_{98\%}\right) / D_{50\%} \quad (2)$$

$$CI = \left(V_{ref,t}\right)^2 / \left(V_{ref} \times t\right) \quad (3)$$

Statistical analysis

Statistical analyses were conducted using SPSS v.25.0. Systematic and random errors, as well as the sum and standard deviation of errors in the X, Y, and Z directions, were calculated. Continuous variables were expressed as means ± standard deviations, while categorical variables were reported as frequencies or percentages. Linear regression analysis was employed to assess the impact of setup errors on dosimetric parameters. A significance level of $\alpha = 0.05$ was used, with $P < 0.05$ considered statistically significant.

Table 1 Setup errors of 210 CBCT scans in 50 patients (mm)

Patient no	X(mm)	Y(mm)	Z(mm)	Patient no	X(mm)	Y(mm)	Z(mm)
1	− 1.0 ± 1.0	1.2 ± 1.7	− 1.2 ± 1.0	26	1.0 ± 0.3	1.9 ± 2.5	2.2 ± 1.3
2	2.5 ± 0.7	0.3 ± 2.9	0.2 ± 1.5	27	1.8 ± 0.9	1.3 ± 0.7	2.4 ± 1.1
3	− 0.7 ± 1.6	1.6 ± 1.7	1.8 ± 0.9	28	0.5 ± 1.3	0.5 ± 2.9	2.5 ± 2.1
4	− 0.1 ± 0.9	1.9 ± 0.9	1.8 ± 0.5	29	− 2.2 ± 0.4	3.5 ± 0.2	2.0 ± 1.6
5	2.0 ± 2.7	− 2.1 ± 1.3	− 0.6 ± 2.0	30	0.9 ± 1.0	1.3 ± 4.0	2.8 ± 1.1
6	− 3.2 ± 0.6	3.4 ± 0.6	3.1 ± 1.0	31	− 0.1 ± 0.9	0.9 ± 2.4	− 0.1 ± 0.3
7	2.6 ± 0.4	2.4 ± 3.6	− 1.5 ± 3.1	32	− 2.3 ± 1.4	3.1 ± 0.7	0.7 ± 0.3
8	− 0.6 ± 0.3	− 0.6 ± 0.2	1.5 ± 0.8	33	0.5 ± 0.7	− 1.9 ± 2.7	0.4 ± 1.9
9	− 0.5 ± 1.5	1.0 ± 0.4	− 1.5 ± 0.7	34	1.7 ± 1.2	− 0.7 ± 2.4	1.6 ± 0.1
10	− 2.7 ± 1.7	1.0 ± 0.4	− 1.5 ± 0.7	35	0.8 ± 1.2	1.1 ± 3.0	1.9 ± 1.0
11	− 0.2 ± 1.1	− 1.1 ± 3.0	0.8 ± 0.4	36	1.2 ± 1.7	0.4 ± 0.5	1.7 ± 2.3
12	0.6 ± 2.6	− 0.7 ± 2.7	1.3 ± 1.9	37	0.6 ± 1.5	− 0.1 ± 2.1	− 1.1 ± 0.8
13	1.3 ± 1.2	2.4 ± 1.6	− 1.1 ± 1.5	38	1.4 ± 1.4	1.1 ± 1.2	0.1 ± 1.0
14	− 0.1 ± 0.6	− 0.4 ± 2.4	2.3 ± 2.5	39	0.6 ± 0.7	3.9 ± 2.1	2.6 ± 0.7
15	− 1.2 ± 1.2	− 3.2 ± 1.3	− 2.8 ± 0.7	40	0.9 ± 2.6	2.5 ± 2.4	− 0.4 ± 3.6
16	1.7 ± 1.0	1.1 ± 1.2	− 3.2 ± 1.0	41	− 3.0 ± 1.4	− 1.5 ± 1.2	− 2.1 ± 0.3
17	0.1 ± 0.2	3.0 ± 1.9	− 0.3 ± 1.5	42	− 0.5 ± 1.5	3.9 ± 0.6	− 2.0 ± 0.9
18	− 1.0 ± 1.0	− 3.4 ± 0.8	1.4 ± 0.4	43	0.1 ± 1.5	1.8 ± 2.3	− 2.5 ± 1.0
19	0.3 ± 1.0	1.7 ± 1.4	2.1 ± 2.1	44	− 3.0 ± 1.3	− 0.5 ± 2.0	1.7 ± 2.5
20	− 1.7 ± 0.5	− 2.6 ± 1.1	− 1.0 ± 0.9	45	0.6 ± 0.3	0.9 ± 2.8	− 1.2 ± 1.0
21	2.5 ± 0.6	3.1 ± 2.5	0.4 ± 0.7	46	0.8 ± 2.3	0.7 ± 0.9	− 0.4 ± 1.7
22	0.7 ± 1.7	− 1.9 ± 1.3	1.5 ± 0.7	47	0.6 ± 1.0	− 3.9 ± 0.8	0.4 ± 2.2
23	0.4 ± 0.6	0.5 ± 1.3	− 1.5 ± 1.1	48	− 2.1 ± 0.8	− 0.7 ± 3.7	− 0.9 ± 0.5
24	− 0.6 ± 1.0	− 2.6 ± 1.4	2.0 ± 0.4	49	0.9 ± 1.1	0.5 ± 2.9	− 2.4 ± 3.1
25	1.6 ± 0.6	− 0.2 ± 1.7	3.4 ± 0.2	50	0.3 ± 1.9	3.6 ± 1.3	− 03.4 ± 0.9

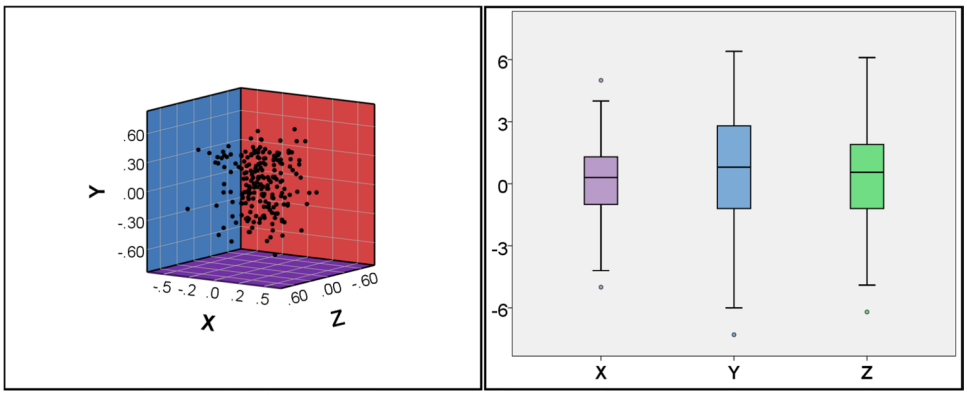


Fig. 3 3D scatter plot of set-up-error

Table 2 Absolute values of setup errors in 210 CBCT scans of 50 patients (mm)

Direction	Set-up-error(mm)	95% CI
X	1.4 ± 1.0	1.3 ~ 1.5
Y	2.3 ± 1.5	2.0 ~ 2.5
Z	1.9 ± 1.2	1.7 ~ 2.0

Results

Comparison of setup errors in three dimensions

The study analyzed 210 cone-beam computed tomography (CBCT) scans from 50 patients during radiotherapy. Displacement errors in the X, Y, and Z axes were recorded after

Table 3 Setup errors and MPTV analysis of 50 patients (mm)

Direction	Individual systematic error (mm)	Standard deviation of population systematic error (∑) (mm)	Individual random error (mm)	Population random error (σ) (mm) MPV (mm)	MPV (mm)
X	0.2	1.4	0.6	1.3	4.4
Y	0.6	2.0	1.0	2.0	6.4
Z	0.3	1.9	0.8	1.5	5.8

each scan. Table 1 and Fig. 3 demonstrated that 18 (8.57%, 18/210) scans exhibited displacements exceeding 3mm in the X direction, 74 (35.23%, 74/210) in the Y direction, and 40 (19.05%, 40/210) in the Z direction. Table 2 summarized the setup error findings for the 210 CBCT scans across the 50 patients, indicating that the Y direction had the greatest error, followed by the Z direction, with the X direction exhibiting the least error. Applying the formula $MPTV = 2.5\sum + 0.7\sigma$, the expansion margins of the clinical target volume (CTV) in the X, Y, and Z directions were

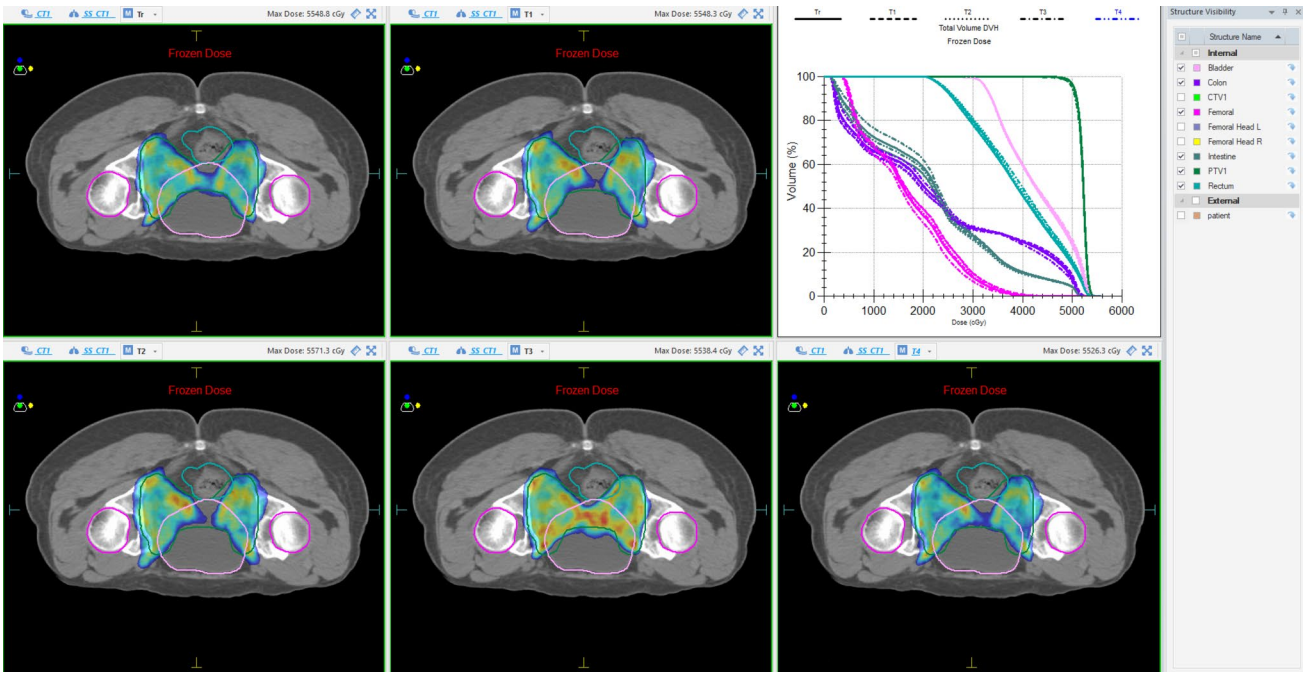
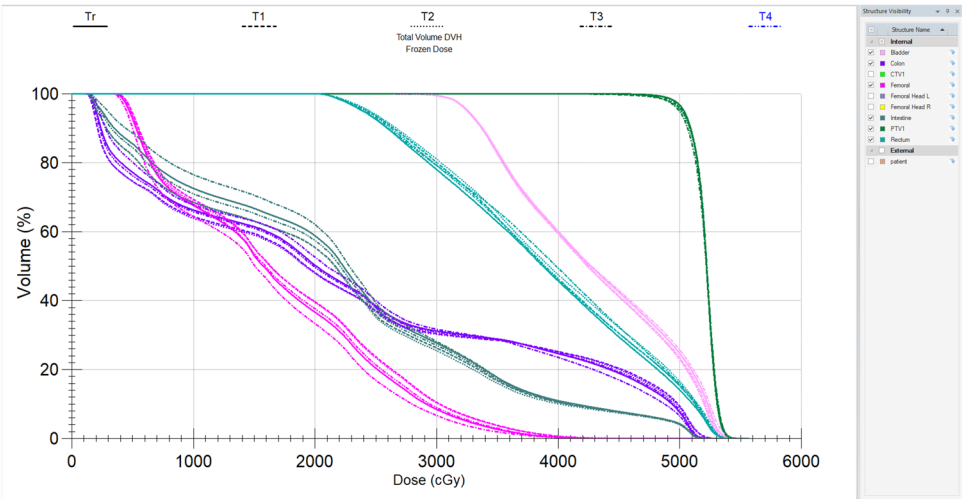


Fig. 4 Original isodose line (Tr) and isodose line distribution after introducing errors (T1, T2, T3, T4)

Fig. 5 Original DVH (Tr) and DVH distribution after introducing errors (T1, T2, T3, T4)



calculated to be 4.4mm, 6.4mm, and 5.8mm, respectively, as detailed in Table 3.

Effect of setup errors on dose distribution

Upon integration of setup errors into the TPS and subsequent dose recalculation, dosimetry to both the irradiated area and OARs exhibited substantial variability. Figures 4 and 5 depict the DVH of the IMRT dose distribution for a cervical cancer patient following setup error introduction. The original plan is denoted as Tr, with T1–T4 representing subsequent dose modifications due to setup errors (− 4.1, 4.0, 3.8) mm, (− 3.0, 3.8, 3.8) mm, (− 2.9, 2.7, 2.9) mm, and (− 2.9, 3.0, 1.8) mm, respectively. With setup errors of (− 4.1, 4.0, 3.8) mm, TC decreased from 95.2 to 88.4%, a 7.14% reduction. Setup errors primarily affected target coverage, with minimal impact on high-dose target regions; for OARs, the errors predominantly influenced the overall irradiation dose, as shown in Fig. 5.

Table 4 Linear regression analysis of PTV dosimetry and X/Y/Z direction error values

Structure	Direction	B	P value	VIF	R^2
PTV_TC		− 2.278	0		0.204
	X	0.278	0.722	1.001	
	Y	− 1.925	0	1.002	
	Z	− 3.953	0	1.001	
PTV_HI		2.307	0		0.086
	X	− 0.416	0.689	1.001	
	Y	1.619	0.019	1.002	
	Z	3.306	0	1.001	
PTV_CI		− 5.328	0		0.173
	X	1.215	0.442	1.001	
	Y	− 4.39	0	1.002	
	Z	− 6.484	0	1.001	
CTV_TC		− 0.351	0		0.131
	X	− 0.059	0.827	1.001	
	Y	− 0.564	0.002	1.002	
	Z	− 1.032	0	1.001	
CTV_HI		0.522	0		0.01
	X	0.017	0.962	1.001	
	Y	0.374	0.109	1.002	
	Z	0.43	0.124	1.001	
CTV_CI		− 1.163	0		0.013
	X	− 0.121	0.939	1.001	
	Y	0.493	0.635	1.002	
	Z	0.134	0.914	1.001	

Table 5 Correlation analysis of intestinal dosimetry and X/Y/Z direction error values

Structure	Direction	B	*P* value	VIF	R^2
Colon_D_{max}		0.296	0		0.057
	X	− 0.057	0.838	1.001	
	Y	− 0.709	0	1.002	
	Z	− 0.344	0.118	1.001	
Colon_V_{30}		− 0.645	0.232		0.121
	X	− 3.207	0.284	1.001	
	Y	6.466	0.001	1.002	
	Z	− 10.749	0	1.001	
Colon_V_{40}		3.093	0.009		0.013
	X	2.716	0.677	1.001	
	Y	− 9.986	0.021	1.002	
	Z	− 2.197	0.669	1.001	
Colon_V_{50}		6.09	0		0.105
	X	1.304	0.889	1.001	
	Y	− 18.651	0.003	1.002	
	Z	− 30.938	0	1.001	
Intestine_D_{max}		1.011	0.004		0.077
	X	− 6.752	0	1.001	
	Y	1.265	0.314	1.002	
	Z	4.035	0.008	1.001	
Intestine_D_{mean}		− 0.342	0.431		0.111
	X	− 3.738	0.123	1.001	
	Y	6.2	0	1.002	
	Z	− 6.696	0.001	1.001	
Intestine_V_{30}		− 0.465	0.402		0.261
	X	− 7.36	0.018	1.001	
	Y	2.138	0.293	1.002	
	Z	− 20.375	0	1.001	
Intestine_V_{40}		− 0.99	0.238		0.227
	X	− 17.279	0	1.001	
	Y	− 2.486	0.418	1.002	
	Z	− 25.529	0	1.001	
Intestine_V_{50}		10.149	0.001		0.194
	X	− 12.566	0.472	1.001	
	Y	− 43.412	0	1.002	
	Z	− 83.301	0	1.001	
Rectum_D_{max}		3.345	0.029		0.059
	X	− 21.304	0.013	1.001	
	Y	0.489	0.93	1.002	
	Z	21.084	0.002	1.001	
Rectum_D_{mean}		0.014	0.966		0.016
	X	2.555	0.166	1.001	
	Y	− 2.444	0.045	1.002	
	Z	1.029	0.479	1.001	
Rectum_V_{30}		− 0.22	0.225		0.056
	X	3.017	0.003	1.001	
	Y	− 1.701	0.011	1.002	
	Z	0.232	0.771	1.001	
Rectum_V_{40}		0.758	0.051		0.058

Table 5 (continued)

Structure	Direction	B	*P* value	VIF	R^2
	X	4.437	0.04	1.001	
	Y	− 2.008	0.157	1.002	
	Z	5.311	0.002	1.001	
Rectum_V_{50}		3.861	0		0.193
	X	14.93	0.008	1.001	
	Y	− 9.991	0.007	1.002	
	Z	27.628	0	1.001	

The change of dosimetric parameters caused by setup errors

Effect of setup errors on dosimetric parameters of target volume

Table 4 displays the results of linear regression analysis examining the relationship between PTV dosimetry and setup errors in the X, Y, and Z directions. The analysis revealed that setup errors in the X direction did not significantly impact PTV dosimetry (P > 0.05). Conversely, setup errors in the Y and Z directions were found to significantly affect PTV_TC, PTV_HI, PTV_CI, and CTV_TC (P < 0.05). However, setup errors in the X, Y, and Z directions did not significantly influence CTV_HI and CTV_CI (P > 0.05).

Correlation between setup errors and OAR dosimetry parameters

Table 5 reveals that linear regression analysis of intestinal dosimetry and setup errors in the X, Y, and Z directions showed no statistically significant impact of X-direction errors on Colon_Dmax, Colon_V30, Colon_V40, Colon_V50, Intestine_Dmean, Intestine_V50, and Rectum_Dmean (P > 0.05). However, X-direction errors did have a statistically significant effect on Intestine_Dmax, Intestine_V30, Intestine_V40, Rectum_Dmax, Rectum_V30, and Rectum_V40 (P < 0.05). For Y-direction errors, there was no significant effect on Intestine_Dmax, Intestine_V30, Intestine_V40, Rectum_Dmax, and Rectum_V40 (P > 0.05), but a significant effect on Colon_Dmax, Colon_V30, Colon_V40, Colon_V50, Intestine_Dmean, Intestine_V50, Rectum_V30, and Rectum_V50 (P < 0.05). Lastly, Z-direction errors did not significantly affect Colon_V40, Rectum_Dmean, and Rectum_V30 (P > 0.05), but did significantly impact Colon_Dmax, Colon_V30, Colon_V50, Intestine_Dmax, Intestine_Dmean, Intestine_V30, Intestine_V40, Intestine_V50, Rectum_Dmax, Rectum_V40, and Rectum_V50 (P < 0.05).

Table 6 Correlation analysis of femoral head and bladder dosimetry and X/Y/Z direction error values

Structure	Direction	B	*P* value	VIF	R^2
FemoralHead_D_{max}		0.062	0.892		0.171
	X	10.91	0	1.001	
	Y	− 6.538	0	1.002	
	Z	− 7.091	0	1.001	
FemoralHead_V_{30}		− 1.054	0.105		0.632
	X	3.835	0.287	1.001	
	Y	− 44.004	0	1.002	
	Z	− 9.631	0.001	1.001	
FemoralHead_V_{40}		5.305	0.018		0.354
	X	− 27.852	0.025	1.001	
	Y	− 85.541	0	1.002	
	Z	−4.588	0.639	1.001	
Bladder_D_{max}		− 0.032	0.412		0.043
	X	− 0.449	0.037	1.001	
	Y	0.394	0.006	1.002	
	Z	− 0.109	0.519	1.001	
Bladder_D_{mean}		−1.359	0.072		0.001
	X	− 3.398	0.418	1.001	
	Y	2.049	0.458	1.002	
	Z	− 4.703	0.156	1.001	
Bladder_V_{30}		− 0.104	0.367		0.043
	X	− 1.082	0.092	1.001	
	Y	0.432	0.307	1.002	
	Z	− 1.484	0.004	1.001	
Bladder_V_{40}		− 0.513	0.287		0.072
	X	− 6.927	0.01	1.001	
	Y	1.804	0.306	1.002	
	Z	− 7.139	0.001	1.001	
Bladder_V_{50}		− 1.054	0.105		0.632
	X	3.835	0.287	1.001	
	Y	− 44.004	0	1.002	
	Z	− 9.631	0.001	1.001	

Table 6 shows the results of linear regression analysis on femoral head and bladder dosimetry in relation to setup errors in the X, Y, and Z directions. The analysis found no significant effect of X-direction errors on FemoralHead_V30, Bladder_Dmean, Bladder_V30, and Bladder_V50 (P > 0.05), but did reveal significant effects on FemoralHead_Dmax, FemoralHead_V40, Bladder_Dmax, and Bladder_V40 (P < 0.05). Y-direction errors significantly affected Bladder_Dmean, Bladder_V30, and Bladder_V40 (P > 0.05), as well as FemoralHead_Dmax, FemoralHead_V30, FemoralHead_V40, Bladder_Dmax, and Bladder_V50 (P < 0.05). Z-direction errors did not significantly impact FemoralHead_V40, Bladder_Dmax,

and Bladder_Dmean ($P > 0.05$), but did significantly affect FemoralHead_Dmax, FemoralHead_V30, Bladder_V30, Bladder_V40, and Bladder_V50 ($P < 0.05$).

Discussion

Gynecological malignant tumors pose a significant threat to women's health, with high rates of incidence and mortality (Kyung et al. 2020).IMRT is a critical treatment modality for gynecological malignant tumors, offering the potential to reduce radiation dose to normal tissues while improving dose conformity to the tumor area (Badajena et al. 2020b).Setup errors, which denote discrepancies between the intended and the actual target volume during radiotherapy, are categorized as systematic and random errors. These errors are pivotal determinants of radiotherapy precision. Research by Kuar et al. (Kaur et al. 2016; Ahmed et al. 2016) has underscored the potential of setup errors to influence dosimetry. Cone-beam computed tomography (CBCT) offers several benefits, including high-resolution imaging, efficient data capture, minimal patient radiation exposure, and robust automatic alignment capabilities, thereby making it a pivotal image-guided radiotherapy tool (Sun et al. 2016). The integration of CBCT technology has been demonstrated to significantly reduce setup errors and bolster treatment precision (Bapst et al. 2016; C-arm Lipiodol CT in transcatheter arterial chemoembolization for small hepatocellular carcinoma[J].World 2015; Bahig, et al. 2015). Since the onboard CT scan of the therapeutic equipment is adopted, the scanning range is smaller than that of the original CT image, and the image quality is relatively poor. It is impossible to accurately identify various OARs, such as the colon and small intestine. Naturally, it is also impossible to accurately delineate these OARs on the CBCT images. Additionally, these OARs are constantly changing. Ultimately, it is impossible to accurately assess the dose of these OARs. Therefore, the delineation and assessment of OARs on CBCT have not been conducted in this paper.

Currently, not all patients receiving radiation therapy have IGRT image verification before each treatment, and usually only verification is done once a week and corrections are made, so errors still exist without additional correction treatments, so the expansion of CTV to PTV is still necessary. To ensure robust local control, radiation oncologists incorporate a margin from the CTV to delineate the PTV, ensuring that the tumor receives an adequate dose even in the presence of setup errors. Consequently, the establishment of institution-specific setup error values is of pivotal clinical importance for precise radiotherapy.In this study, we analyzed pre-treatment CBCT data from 210 fractions across 50 patients. Our findings indicated that the frequency of errors exceeding 3 mm in the X, Y, and Z directions was 8.57%, 35.23%, and 19.05%, respectively. The calculated margins for expanding the CTV to the PTV in the X, Y, and Z directions were 4.4 mm, 6.4 mm, and 5.8 mm, respectively, with the Y direction exhibiting the largest displacement errors. Notably, setup errors were most prevalent in the Y direction during treatment, consistent with our findings (Wang et al. 2021; He et al. 2021).

The observed setup errors in the Y direction can be attributed to the use of thermoplastic masks for patient immobilization, limiting X and Z movements. Factors such as poor reproducibility of arm posture, loose skin, excess fat, and blurred markings contribute to increased setup errors in the Y direction. Setup errors in the X direction did not significantly impact target dosimetry, whereas those in the Y and Z directions did significantly affect PTV_TC, PTV_HI, PTV_CI, and CTV_TC. Notably, setup errors in all three directions did not significantly influence CTV_HI and CTV_CI.

Setup errors exert varying effects on intestinal organs depending on the direction. Errors in the X direction primarily affect the small intestine and rectum, with minimal impact on colon dose. In contrast, Y-direction errors have the most significant impact on the colon, while Z-direction errors affect the colon, small intestine, and rectum.Setup errors in the X direction significantly impacted FemoralHead_Dmax, FemoralHead_V40, Bladder_V40, Bladder_Dmax, and Bladder_V40. Y-direction errors influenced FemoralHead_Dmax, FemoralHead_V30, FemoralHead_V40, Bladder_Dmax, and Bladder_V50, while Z-direction errors affected FemoralHead_Dmax, FemoralHead_V30, Bladder_V30, Bladder_V40, and Bladder_V50.

In radiotherapy, setup errors can compromise target volume coverage and alter radiation dose to organs at risk. Notably, Z-direction errors significantly affect the dose to intestinal organs. Our institution's data indicate CTV-to-PTV expansion margins of 4.4 mm, 6.4 mm, and 5.8 mm in X, Y, and Z directions, respectively. Institutions should minimize setup errors during IMRT and calculate margins based on their specific error data for precise radiotherapy.

Author contribution Zhenghuan Li: Writing—Original Draft. Yuan Cheng: Methodology. Jie Dong: Validation, Investigation. Liwan Han: Visualization. Luxi Chen: Formal analysis. Shen Huang: Resources. Meifang Zhang: Data Curation, Software. Manya Wu:Conceptualization. Famtu Kong: Supervision, Writing—Review & Editing. Huamei Yan: Project administration, Writing—Review & Editing.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

References

Ahmad H, Kumar VL (2018) Pharmacotherapy of ulcerative colitis—current status and emerging trends. J Basic Clin Physiol Pharmacol 29(6):581–592. https://doi.org/10.1515/jbcpp-2016-0014

Ahmed F, Sarkar V, Gaffney DK et al (2016) Analysis of nodal coverage utilizing image guided radiation therapy for primary gynecologic tumor volumes[J]. Med Dosim Off J Am Association Med Dosim. https://doi.org/10.1016/j.meddos.2015.12.005

Badajena A, Raturi VP, Sirvastava K et al (2020a) Prospective evaluation of the setup errors and its impact on safety margin for cervical cancer pelvic conformal radiotherapy. Rep Pract Oncol Radiother 25(2):260–265. https://doi.org/10.1016/j.rpor.2020.02.006

Badajena A, Raturi VP, Srivastava K et al (2020) Prospective evaluation of the setup errors and its impact on safety margin for cervical cancer pelvic conformal radiotherapy[J]. Rep Pract Oncol Radiother. https://doi.org/10.1016/j.rpor.2020.02.006

Bahig H, Roussin E, Yassa M et al (2015) Partial kilovoltage cone beam computed tomography, complete kilovoltage cone beam computed tomography, and electronic portal images for breast radiation therapy: a dose-comparison study[J]. Pract Radiat Oncol 5(5):e521–e529. https://doi.org/10.1016/j.prro.2015.02.009

Bapst B, Lagadec M, Breguet R, Vilgrain V, Ronot M (2016) Cone beam computed tomography (CBCT) in the field of interventional oncology of the liver. Cardiovasc Intervent Radiol 39(1):8–20. https://doi.org/10.1007/s00270-015-1180-6

C-arm Lipiodol CT in transcatheter arterial chemoembolization for small hepatocellular carcinoma[J].World Journal of Gastroenterology, 2015.CNKI:SUN:ZXXY.0.2015–10–023.

Fu WK, Liu LB, Chen CX et al (2020) Application study of styrofoam pillow in intensity modulated radiotherapy for nasopharyngeal carcinoma[J]. J Modern Oncol 28(19):3413–3416

He DC, Zhu ZJ, Zhang XY et al (2021) Positioning error analysis of the fraxion localization system in the intracranial stereotactic radiotherapy of tumors. Clin Transl Oncol 23(1):43–47. https://doi.org/10.1007/s12094-020-02382-y

Herk MV (2004) Errors and margins in radiotherapy[J]. Semin Radiat Oncol 14(1):52–64. https://doi.org/10.1053/j.semradonc.2003.10.003

Kaur I, Rawat S, Ahlawat P et al (2016) Dosimetric impact of setup errors in head and neck cancer patients treated by image-guided radiotherapy[J]. J Med Phys 41(2):144–148. https://doi.org/10.4103/0971-6203.181640

Kyung CW, Heejung K, Won P et al (2020) A dummy-run evaluation of postoperative hypofractionated intensity-modulated radiation therapy (POHIM-RT) trials for cervical cancer[J]. J Radiat Res. https://doi.org/10.1093/jrr/rraa085

Ogawa A, Nakamura M, Iramina H, Yoshimura M, Mizowaki T (2023) Potential utility of cone-beam CT-guided adaptive radiotherapy under end-exhalation breath-hold conditions for pancreatic cancer. J Appl Clin Med Phys 24(2):e13827. https://doi.org/10.1002/acm2.13827

Patni N, Burela N, Pasricha R et al (2017) Assessment of three-dimensional setup errors in image-guided pelvic radiotherapy for uterine and cervical cancer using kilovoltage cone-beam computed tomography and its effect on planning target volume margins. J Cancer Res Ther 13(1):131–136

Petric P, Lindegaard JC, Sturdza A et al (2021) Results of image guided brachytherapy for stage IB cervical cancer in the retroembrace study. Radiother Oncol 157:24–31. https://doi.org/10.1016/j.radonc.2021.01.005

Pramanik S, Ray KD, Bera S et al (2020) Analysis of setup uncertainties and determine the variation of the clinical target volume (CTV) to planning target volume (PTV) margin for various tumor sites treated with threedimensional IGRT couch using KV-CBCT [J]. J Radiat Oncol 9(7):25–35

ICRU Report 62. Prescribing, Recording, and Reporting Photon Beam Therapy (Supplement to ICRU Report 50). Bethesda, MD, International Commission on Radiation Units and Measurements,1999.

Sun Y, Ge H, Cheng S et al (2016) Evaluation of interfractional variation of the centroid position and volume of internal target volume during stereotactic body radiotherapy of lung cancer using cone-beam computed tomography[J]. J Appl Clin Med Phys 17(2):5835. https://doi.org/10.1120/jacmp.v17i2.5835

Sung H, Ferlay J, Siegel RL et al (2021) Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 71(3):209–249. https://doi.org/10.3322/caac.21660

Wang M, Gu H, Hu J et al (2021) Evaluation of a highly refined prediction model in knowledge-based volumetric modulated arc therapy planning for cervical cancer[J]. Radiat Oncol. https://doi.org/10.1186/s13014-021-01783-9

Wu M, Jin J, Li Z et al (2022) Influence of beamlet width on dynamic IMRT plan quality in nasopharyngeal carcinoma. PeerJ 10:e13748. https://doi.org/10.7717/peerj.13748

Yan H, Wu M, Wang W et al (2023) Dosimetry and acute radiation enteritis comparison between prone and supine position in IMRT for gynecological cancers. J Appl Clin Med Phys 24(12):e14135. https://doi.org/10.1002/acm2.14135

Zhong QC, Huang JS, Lin CY et al (2021) Effect of two different body surface marking methods on cervical spine positioning error in patients with nasopharyngeal carcinoma[J]. Guangdong Med J 42(9):1092–1096