Am J Transl Res 2026;18(7):6400-6410
www.ajtr.org /ISSN:1943-8141/AJTR0173447

Original Article

Application value of image-guided radiotherapy in reducing setup errors of head and neck tumors: a retrospective study

Zhetao Mi, Yongcheng Zou

Department of Radiation, Shanxi Provincial Cancer Hospital, Taiyuan 030013, Shanxi, China

Received April 20, 2026; Accepted June 13, 2026; Epub July 15, 2026; Published July 30, 2026

Abstract: Objective: To investigate the clinical value of image-guided radiotherapy (IGRT) in reducing setup errors and acute radiation-induced adverse reactions in patients with head and neck tumors. Methods: A retrospective analysis was conducted on 87 patients who underwent radiotherapy for head and neck tumors. Patients were divided into an IGRT group (n = 45) and a control group (n = 42). Setup errors, acute adverse reactions, and treatment completion rates were compared between the two groups. Results: Compared with the control group, the IGRT group demonstrated significantly smaller setup errors in all directions ($P < 0.001$) and lower incidences of ≥ Grade 2 dermatitis (24.4% vs. 45.2%, $P = 0.041$), ≥ Grade 3 mucositis (20.0% vs. 40.5%, $P = 0.036$), and ≥ Grade 2 xerostomia (17.8% vs. 38.1%, $P = 0.033$). The treatment completion rate was higher in the IGRT group ($P = 0.045$). Conclusion: IGRT effectively reduces setup errors, decreases the incidence of moderate to severe acute adverse reactions, and improves treatment completion rates in radiotherapy for head and neck cancers, demonstrating favorable clinical practicality.

Keywords: Image guidance, radiotherapy, head and neck tumors, setup error, complications

Introduction

Head and neck cancer is a common malignant tumor in clinical practice. Radiotherapy has become a cornerstone of both radical and postoperative adjuvant treatment for head and neck cancer due to the complex anatomical challenges in this region, including deep and irregularly shaped tumor lesions and the proximity of multiple critical organs at risk. Radiotherapy plays a key role in controlling tumor progression and prolonging patient survival [1, 2]. Clinical evidence indicates that the accuracy of radiotherapy directly affects both dose coverage of the tumor target area and the protection of normal tissues, with setup error representing a core risk factor affecting radiotherapy precision. Under conventional radiotherapy positioning, displacement and rotational deviations in the left-right, cranial-caudal, and anterior-posterior directions are prone to occur, which can reduce dose accuracy in tumor target area, increase exposure to normal tissues and organs at risk (such as parotid gland and spinal cord), induce various acute radiation-induced injuries, and even lead to interruption of the radiotherapy plan [3, 4].

Currently, routine clinical radiotherapy for head and neck tumors mostly relies on traditional immobilization devices for patient positioning. This method depends on external body surface markers and cannot perceive the subtle lesion displacement in real time, making it difficult to correct positioning deviations in real time, and limiting the overall precision of radiotherapy [5, 6]. Even when setup errors are compensated by expanding the planned target volume (PTV) margin, the irradiation of normal tissue increases, aggravating radiation-induced adverse reactions, which affects patient treatment tolerance, hinders the achievement of individualized and precise radiotherapy, consequently compromising long-term efficacy and quality of life. Therefore, exploring techniques that effectively reduce setup errors and improve radiotherapy

https://doi.org/10.62347/AIZC4494

accuracy has become a priority in optimizing treatment plans for head and neck tumors.

Image-guided radiotherapy (IGRT) is a core technology of precision radiotherapy. Cone-beam computed tomography (CBCT) can obtain three-dimensional imaging of lesions in real time before radiotherapy, accurately compare planned and actual positions, and complete online position correction. This approach minimizes setup deviations and enables integrated and accurate control of radiotherapy positioning, correction, and delivery [7, 8]. At present, although IGRT has gradually been applied to radiotherapy for head and neck tumors in clinical practice, systematic studies evaluating its effect of multi-directional setup error correction, optimization of margins, target area dose distribution, protection of organs at risk, radiation-related adverse reactions, and treatment completion rates remains limited [9]. Based on this, this study retrospectively analyzed the clinical data of patients with head and neck tumors to explore the application value of IGRT in reducing setup errors, providing evidence to optimize precise radiotherapy for these patients.

General information and methods

General information

The clinical data of 87 patients with head and neck tumors admitted to the Department of Radiation Oncology, Shanxi Provincial Cancer Hospital from January 2022 to December 2024 were retrospectively analyzed. According to whether IGRT was used during radiotherapy, patients were divided into the IGRT group (n = 45) and the control group (n = 42). This retrospective study was approved by the Institutional Ethics Committee of Shanxi Provincial Cancer Hospital. All patient data were anonymized prior to analysis. Due to the retrospective nature of the study and the use of anonymized clinical data, the requirement for written informed consent was waived by the Ethics Committee.

Inclusion criteria

(1) Histopathologically confirmed head and neck malignancy with an indication for radiotherapy; (2) Receiving radiotherapy for the first time, with no previous history of radiotherapy; (3) Karnofsky Performance Status (KPS) score ≥ Sr; (4) Able to undergo conventional head and neck immobilization with good treatment compliance; (5) Complete clinical records, radiotherapy data, and follow-up information.

Exclusion criteria

(1) Presence of distant metastasis, systemic cachexia, or inability to tolerate the full course of radiotherapy; (2) History of head and neck surgery, radiotherapy, or other treatments that could significantly affect the study outcomes; (3) Severe dysfunction of major organs, including the heart, liver, or kidneys, preventing completion of radiotherapy; (4) Inability to maintain stable immobilization during radiotherapy; (5) Incomplete clinical data, withdrawal during treatment, or loss to follow-up; (6) Psychiatric disorders or impaired consciousness that prevents treatment and data collection.

Inspection method

Control group: Patients in the control group received conventional radiotherapy using standard immobilization techniques throughout the course. Each patient was placed in the supine position, and a dedicated head and neck immobilization device was used to complete the position fixation that was employed to guide patient setup. After the conventional radiotherapy plan was formulated, treatment was delivered according to the plan without any image-guided online correction. The body surface markers were used to maintain positional consistency, and fractionated radiotherapy was completed according to the established radiotherapy plan (**Figure 1A**, **1B**).

IGRT group: In addition to conventional immobilization and radiotherapy planning, patients in the IGRT group received IGRT throughout the treatment course.

Before each treatment fraction, CBCT was performed using a linear accelerator-mounted imaging system. The scanning parameters were as follows: tube voltage, 120 kV; tube current, 80 mA; slice thickness, 2 mm; scanning range, 15-20 cm (adjusted according to target location); reconstruction matrix, 512 × 512; and a standard head-and-neck scanning protocol. The estimated imaging dose per scan was 2-3 mGy.

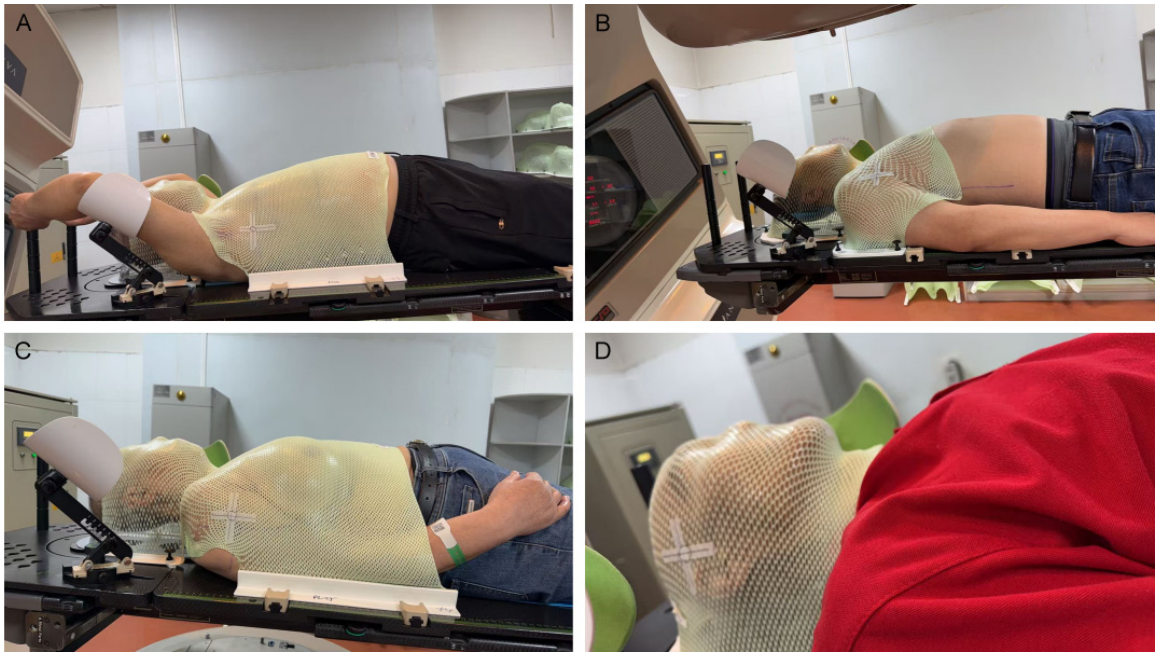

Figure 1. Comparison of patient positioning and immobilization procedures between conventional radiotherapy and image-guided radiotherapy (IGRT). A, B. Conventional radiotherapy: patients were immobilized in the supine position using a thermoplastic mask, and patient positioning was verified using skin markers without image-guided online correction. C, D. IGRT: patients were immobilized using the same thermoplastic mask, and cone-beam computed tomography (CBCT) was performed before each treatment fraction. Online position correction was applied when translational or rotational errors exceeded predefined thresholds to ensure treatment accuracy.

CBCT images were registered with the planning CT images using automatic gray-value-based bone matching, with the skull base, cervical vertebrae, and mandible serving as the primary anatomical landmarks. Manual fine-tuning was subsequently performed when necessary to optimize soft-tissue alignment. Three-dimensional translational setup errors in the left-right (x), cranial-caudal (y), and anterior-posterior (z) directions, as well as rotational errors (Roll, Pitch, and Yaw), were recorded.

Image registration and error measurements were independently performed by two radiation therapists with more than 5 years of experience. The average values were used for analysis. Inter-rater reliability was excellent, with an intraclass correlation coefficient (ICC) ranging from 0.901 to 0.931.

Online couch correction was performed when translational errors exceeded 3 mm in any direction or rotational errors exceeded 2° in any axis. If all errors were within the predefined tolerance limits, treatment was delivered without additional correction. Following position adjustment, a verification CBCT scan was acquired to confirm that residual setup errors were within the acceptable range before irradiation.

The procedures of CBCT acquisition, image registration, setup error assessment, and online correction were repeated before each treatment fraction to ensure positioning accuracy throughout the entire radiotherapy course (**Figure 1C**, **1D**) [10].

PTV margin calculation: PTV margins were calculated using the Van Herk formula: $M = 2.5\Sigma + 0.7\sigma$. Here, M stands for the PTV margin, Σ indicates systematic error (the standard deviation of the mean setup error across individual patients), and σ represents random error (the average of the standard deviations of setup errors for each patient). Both systematic and random errors were obtained from cone-beam computed tomography (CBCT) registration data acquired prior to each treatment fraction. The 95% confidence intervals (CIs) of systematic errors were calculated based on the chi-square distribution. Margin validation was conducted by analyzing residual setup errors and target

volume coverage (V95%) after margin reduction.

In the conventional radiotherapy (control) group, the systematic error (Σ) was 1.82 mm (95% CI: 1.52-2.12 mm), and the random error (σ) was 1.36 mm (95% CI: 1.18-1.54 mm). Using the Van Herk formula, the calculated PTV margin was 5.50 mm. In the image-guided radiotherapy (IGRT) group, the systematic error (Σ) decreased to 1.08 mm (95% CI: 0.89-1.27 mm) and the random error (σ) was 0.95 mm (95% CI: 0.81-1.09 mm). The corresponding PTV margin was calculated as 3.37 mm. Margin verification demonstrated that the adopted margins ensured sufficient target coverage in both groups, with V95% exceeding 95% for all enrolled patients.

Data collection and observation indicators

Assessment of setup errors: Setup error data were collected for both groups. In the IGRT group, translational and rotational setup errors were recorded before and after CBCT-guided online correction. In the control group, setup errors were assessed based on conventional positioning records. Translation errors in the left-right (x), cranial-caudal (y), and anterior-posterior (z) directions, and rotation errors (Roll, Pitch, and Yaw) in all directions were measured and compared between groups.

The prescribed dose for all patients was 50 Gy/25 fractions (2 Gy/fraction), with a simultaneous integrated boost (SIB) to the tumor bed of 60 Gy/25 fractions (2.4 Gy/fraction). Dose prescription and reporting followed the recommendations of ICRU Report 83. The plan acceptance criteria were: D95% ≥ 95% of the prescription dose (i.e., ≥ 47.5 Gy) and V95% ≥ 95% for adequate target coverage. Organ-at-risk constraints followed the QUANTEC guidelines.

Dose assessment of target volumes and organs at risk: Based on the setup error data, PTV margins were calculated for both groups. Dosimetric parameters were used to evaluate target coverage, including V95% (the proportion of target volume receiving at least 95% of the prescribed dose), and D95% (the absolute dose (in Gy) received by 95% of the target volume). In addition, dose exposure to organs at risk was assessed. The average dose to the parotid glands and the maximum dose to the spinal cord were recorded and compared between groups.

Evaluation of acute adverse reactions and treatment completion: The incidence of acute radiation-induced adverse reactions during radiotherapy was recorded for both groups, including acute radiation dermatitis, oral mucositis, and xerostomia. Adverse reactions were graded according to the Common Terminology Criteria for Adverse Events (CTCAE), version 5.0. For radiation dermatitis and oral mucositis, the RTOG/EORTC acute radiation morbidity scoring system was additionally used as a supplementary reference. The specific grading definitions were as follows:

Acute radiation dermatitis (CTCAE 5.0): Grade 1: mild erythema, or dry desquamation; Grade 2: moderate-to-severe erythema, or patchy moist desquamation confined to skin folds; Grade 3: moist desquamation extending beyond skin folds, or bleeding induced by minor trauma; and Grade 4: skin necrosis or full-thickness ulceration.

Oral mucositis (RTOG/EORTC): Grade 1: mucosal erythema, with mild pain not requiring analgesics; Grade 2: patchy mucositis, with moderate pain requiring soft diet; Grade 3: confluent fibrinous mucositis, with severe pain requiring narcotic analgesics and a liquid diet; Grade 4: ulceration, necrosis, or hemorrhage requiring enteral or parenteral nutritional support.

Xerostomia (CTCAE 5.0): Grade 1: mild oral dryness, not requiring intervention; Grade 2: moderate dryness, requiring occasional water intake; Grade 3: severe dryness, requiring frequent water intake or causing sleep disturbance.

The primary toxicity endpoints were the incidence of ≥ Grade 2 dermatitis, ≥ Grade 3 oral mucositis, and ≥ Grade 2 xerostomia. Treatment completion was evaluated according to the total treatment duration and the rate of radiotherapy interruption in both groups.

Quality of life assessment: Quality of life was evaluated using the EORTC QLQ-C30 (version 3.0) at one week after radiotherapy. The questionnaire covers global health status, five functional domains (physical, role, emotional, cognitive, and social function), and three symptom

scales (fatigue, pain, and appetite loss). All items were scored on a 0-100 scale. Higher scores on global health status and functional domains indicate better quality of life, while higher scores on symptom scales indicate worse symptoms.

Statistical analysis

SPSS 26.0 statistical software was used for data analysis. Measurement data conforming to normal distribution were expressed as mean ± standard deviation (SD). For repeated measurements of setup errors collected from multiple treatment fractions per patient, repeated measures analysis of variance (Repeated Measures ANOVA) was used to evaluate differences between groups (IGRT group vs. control group), across different time points (treatment fractions), and the group × time interaction. The within-subjects factor was treatment fraction (time), and the between-subjects factor was treatment group (IGRT vs. control). Greenhouse-Geisser correction was applied when the sphericity assumption (assessed using Mauchly's test) was violated. When significant interaction or main effects were detected, post-hoc multiple comparisons were performed using the Bonferroni correction. Inter-rater reliability of setup error measurements between two radiation therapists was assessed using the intraclass correlation coefficient (ICC). Count data were expressed as number of cases (percentage) [n (%)] and compared between groups using the chi-square test or Fisher's exact test, as appropriate. All tests were two-tailed, and a *P*-value < 0.05 was considered statistically significant.

Results

Baseline characteristics

As shown in **Table 1**, there were no significant differences between the IGRT group and the control group in terms of potential confounding factors, including KPS score (82.5 ± 8.6 vs. 80.9 ± 9.2, P = 0.402), radiotherapy fractionation method (88.9% vs. 85.7%, P = 0.654), concurrent chemotherapy (77.8% vs. 73.8%, P = 0.656), and immobilization device type (P = 0.957). These results demonstrate that the two groups were well balanced at baseline.

Setup errors

As shown in **Table 2**, after online correction, the setup errors in the IGRT group were significantly smaller than those of the control group (all P < 0.001). Specifically, left-right errors were 1.12 ± 0.45 mm versus 2.56 ± 0.83 mm, cranial-caudal errors were 1.28 ± 0.52 mm versus 2.87 ± 0.91 mm, and anterior-posterior errors were 1.05 ± 0.41 mm versus 2.34 ± 0.76 mm, respectively.

Rotational errors

Table 3 presents rotational errors and repeated measures ANOVA results. The IGRT group demonstrated significantly smaller translational and rotational errors in all directions compared with the control group (all P < 0.001). Repeated measures ANOVA revealed a significant main effect of group for all parameters (all F > 30, all P < 0.001), while no significant main effect of time or group × time interaction was observed (all P > 0.05), indicating consistent reduction of setup errors across all treatment fractions. Inter-rater reliability was excellent, with ICC values ranging from 0.901 to 0.931.

Target dose coverage and organ-at-risk doses

As shown in **Table 4**, the prescribed dose for all patients was 50 Gy/25 fractions (2 Gy/fraction), with D95% ≥ 95% of the prescription dose (≥ 47.5 Gy) considered clinically acceptable according to ICRU Report 83.

The D95% values in both groups met the clinical acceptance criteria. The V95% in the IGRT group was (98.2 ± 1.2)%, significantly higher than (95.6 ± 1.8)% in the control group (t = 8.05, P < 0.001). The D95% in the IGRT group was (52.8 ± 1.5) Gy, significantly higher than (51.2 ± 1.9) Gy in the control group (t = 4.44, P < 0.001). Expressed as a percentage of the prescription dose, the D95% in the IGRT group was (105.6 ± 3.0)%, significantly higher than (102.4 ± 3.8)% in the control group (t = 4.37, P < 0.001).

Regarding organ-at-risk (OAR) doses, the mean dose to the parotid glands was (24.6 ± 3.2) Gy in the IGRT group, significantly lower than (28.9 ± 4.1) Gy in the control group (t = 5.53, P < 0.001). The maximum dose to the spinal cord

Table 1. Comparison of baseline data between the two groups

Clinical features	IGRT group (n = 45)	Control group (n = 42)	Statistical value ($t/\chi^2/Z$)	*P* value
Age (years, Mean ± SD)	56.4 ± 9.2	57.1 ± 8.9	0.365	0.716
Gender [n (%)]			0.214	0.644
Male	28 (62.2)	24 (57.1)		
Female	17 (37.8)	18 (42.9)		
KPS score (Mean ± SD)	82.5 ± 8.6	80.9 ± 9.2	0.842	0.402
Tumor type [n (%)]			-*	0.997*
Nasopharyngeal carcinoma	15 (33.3)	14 (33.3)		
Oropharyngeal cancer	12 (26.7)	11 (26.2)		
Laryngeal cancer	10 (22.2)	9 (21.4)		
Oral cancer	5 (11.1)	5 (11.9)		
Other	3 (6.7)	3 (7.2)		
TNM staging [n (%)]			0.312	0.756
Stage I-II	18 (40.0)	15 (35.7)		
Stage III-IV	27 (60.0)	27 (64.3)		
Radiotherapy fractionation [n (%)]			0.201	0.654
Conventional fractionation	40 (88.9)	36 (85.7)		
Unconventional fractionation	5 (11.1)	6 (14.3)		
Concurrent chemotherapy [n (%)]			0.198	0.656
Yes	35 (77.8)	31 (73.8)		
No	10 (22.2)	11 (26.2)		
Immobilization device [n (%)]			0.089	0.957
Thermoplastic mask	38 (84.4)	35 (83.3)		
Polyurethane foam	5 (11.1)	5 (11.9)		
Other	2 (4.4)	2 (4.8)		
Total dose of radiotherapy (Gy, Mean ± SD)	66.5 ± 4.2	66.2 ± 4.5	0.328	0.744
Smoking history [n (%)]	20 (44.4)	19 (45.2)	0.006	0.939
Drinking history [n (%)]	18 (40.0)	17 (40.5)	0.002	0.963

Notes: KPS: Karnofsky Performance Status; IGRT: image-guided radiotherapy. Conventional fractionation is defined as 2 Gy/fraction, total dose 50-70 Gy; Unconventional fractionation included hyperfractionation and accelerated fractionation. *For tumor type (5 categories), the minimum expected frequency was 3.8 (< 5); *Fisher's exact test was used due to the minimum expected frequency of 3.8.

Table 2. Comparison of setup errors between the two groups (mm, Mean ± SD)

Groups	Number of cases	Left-right direction	Head-foot direction	Front and rear direction
IGRT group	45	1.12 ± 0.45	1.28 ± 0.52	1.05 ± 0.41
Control group	42	2.56 ± 0.83	2.87 ± 0.91	2.34 ± 0.76
t value		10.32	10.11	10.08
P value		< 0.001	< 0.001	< 0.001

Table 3. Comparison of rotational setup errors between the two groups

Parameter	IGRT Group (n = 45)	Control Group (n = 42)	t/P	Group Effect (F, P)	Time × Group (F, P)	ICC (95% CI)
Roll (°)	0.52 ± 0.21	1.18 ± 0.43	9.03/< 0.001	35.84/< 0.001	0.76/0.512	0.908 (0.851-0.942)
Pitch (°)	0.68 ± 0.25	1.35 ± 0.49	8.12/< 0.001	32.61/< 0.001	0.82/0.476	0.901 (0.842-0.938)
Yaw (°)	0.45 ± 0.18	1.02 ± 0.38	9.07/< 0.001	38.24/< 0.001	0.71/0.538	0.915 (0.862-0.948)

Table 4. Comparison of dose coverage of target area and exposure dose of organs at risk between the two groups

Parameter	IGRT Group (n = 45)	Control Group (n = 42)	t	P
Target dose coverage				
Prescription dose (Gy)	50	50	-	-
V95% (%)	98.2 ± 1.2	95.6 ± 1.8	8.05	< 0.001
D95% (Gy)	52.8 ± 1.5	51.2 ± 1.9	4.44	< 0.001
D2% (Gy)[1]	53.5 ± 1.4	52.6 ± 1.7	2.78	0.007
Organ-at-risk doses				
Parotid mean dose (Gy)	24.6 ± 3.2	28.9 ± 4.1	5.53	< 0.001
Spinal cord max dose (Gy)	38.5 ± 2.8	42.3 ± 3.6	5.55	< 0.001

Notes: [1]D2% represents the dose received by 2% of the target volume (near-maximum dose). Per ICRU 83, D2% ≤ 105-110% of prescription dose (52.5-55 Gy) is considered acceptable. P < 0.001, indicating a significant positive correlation between V95% and D95%, demonstrating consistent trends between the two indicators. IGRT: image-guided radiotherapy.

Table 5. Comparison of the incidence of adverse reactions between the two groups [n (%)]

Adverse Reactions	Grading Criteria	IGRT Group (n = 45)	Control Group (n = 42)	χ^2 value	*P* value
Acute radiation dermatitis (≥ Grade 2)	CTCAE v5.0	11 (24.4%)	19 (45.2%)	4.186	0.041
Radiation-induced oral mucositis (≥ Grade 3)	RTOG-EORTC	9 (20.0%)	17 (40.5%)	4.418	0.036
Radiation-induced xerostomia (≥ Grade 2)	CTCAE v5.0	8 (17.8%)	16 (38.1%)	4.550	0.033

Notes: IGRT: image-guided radiotherapy; CTCAE v5.0: Common Terminology Criteria for Adverse Events, version 5.0; RTOG-EORTCL: Radiation Therapy Oncology Group/European Organization for Research and Treatment of Cancer.

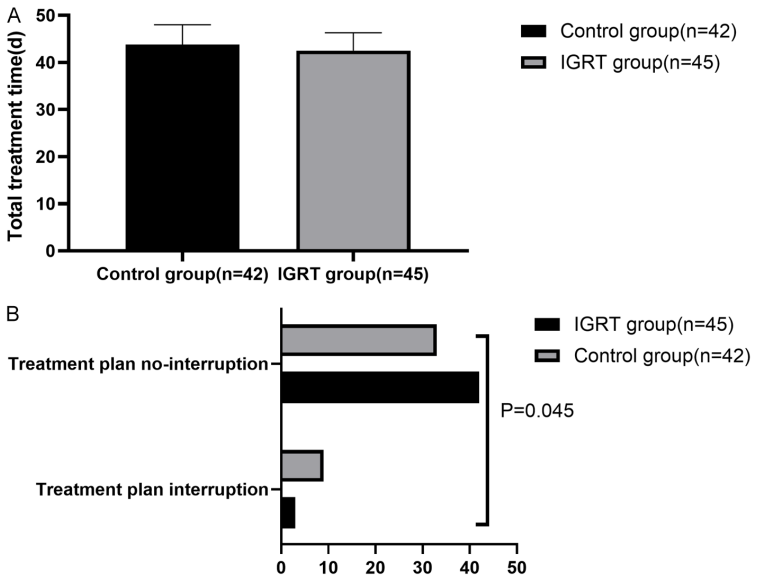

Figure 2. Comparison of treatment completion and overall treatment duration between the two groups of patients. A. Comparison of total treatment duration between the IGRT group and the control group. B. Comparison of treatment completion rates between the two groups.

was (38.5 ± 2.8) Gy in the IGRT group, also significantly lower than (42.3 ± 3.6) Gy in the control group (t = 5.55, P < 0.001).

Consistency validation using Pearson correlation analysis showed a significant positive correlation between V95% and D95% in both groups (IGRT group: r = 0.872, P < 0.001; control group: r = 0.845, P < 0.001), indicating good agreement between these two dose metrics.

Incidence of acute radiation-induced adverse reactions

As shown in **Table 5**, the incidence of acute radiation dermatitis (grade II and above), radiation oral mucositis (grade III and above), and radiation xerostomia (moderate and above) in the IGRT group were significantly lower than those in the control group (all P < 0.05). These results suggest that IGRT effectively reduces radiation-induced toxicity in normal tissues during head and neck cancer radiotherapy.

Table 6. Comparison of quality of life between the two groups after treatment

Quality of life dimension	IGRT group (n = 45)	Control group (n = 42)	t value	*P* value
Global health status				
Overall health score	72.5 ± 8.6	65.3 ± 9.2	3.82	< 0.001
Functional dimension				
Physical function	78.2 ± 7.5	70.1 ± 8.8	4.63	< 0.001
Role function	75.6 ± 8.9	68.4 ± 9.5	3.70	< 0.001
Emotional function	74.8 ± 7.8	69.2 ± 8.3	3.28	0.001
Cognitive function	80.1 ± 6.5	76.5 ± 7.2	2.49	0.015
Social function	76.3 ± 8.1	70.5 ± 8.7	3.24	0.002
Symptom dimension				
Fatigue	28.5 ± 6.8	35.2 ± 7.5	4.44	< 0.001
Pain	22.3 ± 5.6	30.1 ± 6.8	5.86	< 0.001
Loss of appetite	25.6 ± 7.2	33.8 ± 8.1	5.01	< 0.001

Notes: IGRT: image-guided radiotherapy.

Treatment interruption and total treatment time

As shown in **Figure 2**, the rate of treatment interruption was 6.7% in the IGRT group, significantly lower than 21.4% in the control group ($\chi^2 = 4.03$, P = 0.045). The total treatment time was (42.5 ± 3.8) days in the IGRT group, slightly shorter than that in the control group (43.8 ± 4.2) days (t = 1.53, P = 0.130). These findings suggest that IGRT can reduce the interruption rate of treatment plan, although its impact on overall treatment duration is limited.

Quality of life (QoL) after treatment

As shown in **Table 6**, patients in the IGRT group reported significantly higher scores in global health status (72.5 ± 8.6 vs. 65.3 ± 9.2, t = 3.82, P < 0.001) and all functional dimensions, including physical, role, emotional, cognitive, and social function (all P < 0.05). In terms of symptom scales, the IGRT group reported significantly lower scores for fatigue, pain, and loss of appetite than those in the control group (all P < 0.001). These results indicate that IGRT contributes to improved post-radiotherapy quality of life in patients with head and neck cancer.

Discussion

Image-guided radiotherapy (IGRT) is a core minimally invasive technology in precise radiotherapy for head and neck tumors. Its main principle is real-time image monitoring and online positional correction, which effectively solves clinical challenges such as set-up deviation, positional displacements, and organ micro-motion. IGRT has been widely used in radiotherapy of various head and neck malignancies, including nasopharyngeal carcinoma, laryngeal cancer, and oropharyngeal cancer, thereby improving treatment outcomes [11-13]. The complex anatomical structure of the head and neck region renders conventional radiotherapy prone to inaccuracies in dose delivery. Setup errors can cause underdosing of the target volume or overdosing of normal tissues, compromising both anti-tumor efficacy and treatment safety. In addition, radiation-induced acute and chronic injuries, including oral mucositis, radioactive dermatitis, and xerostomia, can activate inflammatory stress pathway, thus reducing patient tolerance and increasing treatment burden [14, 15]. Therefore, improving the accuracy of radiotherapy, particularly when combined with concurrent chemotherapy, is of great significance for optimizing patient prognosis.

Previous studies have highlighted that precise positioning is essential for radiotherapy effectiveness in patients with head and neck tumors [16, 17]. Even a slight spatial displacement can cause target underdosage and excessive irradiation of normal tissues. Our study shows that IGRT significantly reduced translational setup errors in all three axes and rotational errors around three axes compared with conventional radiotherapy after real-time image online correction. This improvement is attributable to several factors. Traditional radiotherapy primarily relies on body surface markers and

immobilization devices, which cannot avoid positional deviations caused by body weight fluctuations, muscle relaxation, swallowing, or subtle head and neck motion. In contrast, IGRT acquires high-definition images before each treatment fraction, enabling real-time registration of the target volume and precise correction of both translational and rotational errors. IGRT optimizes the accuracy of radiotherapy positioning from the source, optimizing target localization, laying the foundation for subsequent dose distribution refinement [18, 19].

Radiotherapy dose distribution is closely related to both local tumor control and the protection of surrounding normal tissues [20]. In the present study, two core dosimetric parameters reflecting target coverage, V95% and D95%, were significantly higher in the IGRT group than in the control group. These findings suggest that IGRT effectively improves prescription dose coverage of the target volume, reduces dose inhomogeneity caused by setup uncertainties, and ensures adequate irradiation of tumor tissues, strengthening local tumor control. In addition, in the protection of organs at risk, the average dose to the parotid glands and the maximum dose to the spinal cord were significantly lower in the IGRT group than in the control group, reflecting the unique advantages of image-guided radiotherapy. The parotid gland and spinal cord in the head and neck are highly sensitive to radiation, and conventional radiotherapy is more susceptible to setup deviations, resulting in unnecessary irradiation of adjacent normal tissues. Through precise field reduction and real-time correction, IGRT can avoid unwanted exposure to the greatest extent and allows for tighter treatment margins while maintaining adequate target coverage. These findings are consistent with previous reports demonstrating the superiority of precision radiotherapy techniques in improving target conformity and sparing organs at risk [21, 22].

Radiation-induced adverse reactions represent an important indicator for evaluating radiotherapy safety and are major determinants of treatment compliance [23]. This study found that the incidence of ≥ grade 2 radiation dermatitis, ≥ grade 3 oral mucositis, and ≥ Grade 2 xerostomia in the IGRT group were significantly lower than those in the control group. In conventional radiotherapy, setup error may lead to excessive irradiation of normal tissues, causing damage to the skin, oral mucosa, salivary glands, and surrounding soft tissues, thereby exacerbating inflammatory responses and radiation-induced toxicity. In contrast, IGRT reduces unnecessary radiation exposure to normal tissues, weakens radiation-mediated oxidative stress and inflammatory cascade, and consequently lowers the risk of severe acute injury. Moreover, reduced treatment-related adverse reactions may contribute to improved treatment adherence and continuity. In this study, the radiotherapy interruption rate was significantly lower in the IGRT group than in the control group, further supporting the role of IGRT in maintaining radiotherapy continuity. Although no significant difference was observed in overall treatment duration between the two groups, the lower interruption rate may help ensure completion of the planned radiotherapy course, avoid the accelerated re-proliferation of tumor cells due to the prolonged course of treatment, and consolidate the overall treatment effect. Similar findings have been reported in previous studies [24].

Previous studies have demonstrated that quality of life is an important long-term outcome for evaluating the benefits of comprehensive cancer treatment and represents a key endpoint in assessing therapeutic effectiveness [25, 26]. In this study, follow-up assessments showed that patients in the IGRT group achieved significantly higher scores in global health status, physical function, role function, emotional function, and other quality-of-life domains than those in the control group. In contrast, symptom scores for fatigue, pain, and appetite loss were significantly lower in the IGRT group. Several factors may account for these observations. First, IGRT significantly reduced the incidence of moderate to severe radiation-induced toxicities, thereby alleviating treatment-related symptoms such as skin ulceration, oral pain, and persistent xerostomia. Reduced toxicity may improve patients' ability to eat, communicate, and perform daily activities. Second, the remission of adverse reactions and the successful completion of treatment can effectively relieve patients' negative emotions such as anxiety and depression, improve their psychological tolerance, and social participation ability. Collectively, these factors may contribute to improvement in both physical and psychological well-being, consis-

tent with previous research conclusions [27, 28].

Several limitations of this study should be acknowledged. First, this was a single-center retrospective study with a relatively small sample size (n = 87), which may have introduced selection bias and limited the generalizability of the findings. Second, long-term follow-up data were unavailable; therefore, the effects of IGRT on long-term outcomes such as local control rate, progression-free survival, overall survival, and late radiation-induced toxicities (e.g., xerostomia, mandibular osteoradionecrosis, and radiation myelopathy) remain to be evaluated. Third, subgroup analyses based on important clinical variables - such as tumor stage (I-II vs. III-IV), tumor differentiation grade (well, moderate, poor), primary tumor site, and nodal status - were not performed due to the limited sample size, which may obscure differential treatment benefits across patient subgroups. Fourth, as noted above, this study primarily evaluated the clinical practicality of IGRT, and the complete translational evidence chain linking setup error reduction, dosimetric optimization, and long-term clinical benefit has not been fully established. Future prospective multicenter studies with larger sample sizes and longer follow-up periods are warranted. Such studies should incorporate comprehensive subgroup analyses stratified by tumor stage, differentiation grade, and other prognostic factors to identify patient populations most likely to benefit from IGRT. Additionally, the potential for dose escalation enabled by IGRT (e.g., increasing the tumor bed boost from 60 Gy to 66-70 Gy) should be prospectively evaluated to determine whether improved dosimetry may translate into enhanced local control without increasing late toxicity. These efforts will further enhance the clinical application value of IGRT in precision radiotherapy for head and neck tumors and provide higher-level evidence to inform standardized treatment protocols.

Conclusion

This study demonstrates that IGRT can significantly reduce translational and rotational setup errors during radiotherapy for head and neck cancer. Furthermore, improved positioning accuracy was associated with lower incidences of moderate to severe acute radiation dermatitis, oral mucositis, and xerostomia, as well as improved treatment completion rates. These findings support the clinical utility of IGRT. Future prospective studies with long-term follow-up are needed to evaluate the impact of IGRT on local tumor control, survival, and late radiation toxicities.

Disclosure of conflict of interest

None.

Address correspondence to: Yongcheng Zou, Department of Radiation, Shanxi Provincial Cancer Hospital, No. 3 Workers' New Village, Xinghualing District, Taiyuan 030013, Shanxi, China. Tel: +86-0351-4881611; E-mail: 18834840891@163.com

References

[1] Abiri A, Nguyen C, Latif K, Goshtasbi K, Torabi SJ, Birkenbeuel JL and Kuan EC. Head and neck solitary fibrous tumors: a review of the National Cancer Database. Head Neck 2023; 45: 1934-1942.

[2] Guo Y. Therapy of head and neck cancer in China: introduction to the special issue. Head Neck 2022; 44: 2007-2008.

[3] Mathlin J, Courtier N and Hopkinson J. Taste changes during radiotherapy for head and neck cancer. Radiography (Lond) 2023; 29: 746-751.

[4] Gómez Á, García-Chabur MA, Peñaranda D, Gómez-Mendoza A and Forero JC. Chemotherapy/radiotherapy-induced dysphagia in head and neck tumors: a challenge for otolaryngologists in low- to middle-income countries. Dysphagia 2025; 40: 515-527.

[5] Mail N, Alshamrani KM, Lodhi RN, Khawandanh E, Saleem A, Khan B, Alghamdi M, Nadershah M, Althaqafy MS, Subahi A and Alghamdi SM. Evaluation of positioning accuracy in head-and-neck cancer treatment: a cone beam computed tomography assessment of three immobilization devices with volumetric modulated arc therapy. J Biol Methods 2024; 11: e99010025.

[6] Zhang X, Wang T, Xiao X, Li X, Wang CY, Huang B, He L and Song Y. Radiotherapy for head and neck tumours using an oral fixation and parameter acquisition device and TOMO technology: a randomised controlled study. BMJ Open 2021; 11: e052542.

[7] Laaksomaa M, Aula A, Sarudis S, Keyriläinen J, Ahlroth J, Murtola A, Pynnönen K, Lehtonen T, Björkqvist M, Järvinen L and Rossi M. Surface-guided radiotherapy systems in locoregional deep inspiration breath hold radiotherapy for

breast cancer - a multicenter study on the setup accuracy. Rep Pract Oncol Radiother 2024; 29: 176-186.
[8] Gao B, Yao Z, Wu L, Shao K, Lin X, Liang Q, Huang X, Chen H and Lei Z. Necessity of daily IGRT? Dosimetric study of beam position offsets at central double-beam junction in pediatric craniospinal irradiation. BMC Cancer 2025; 26: 4.
[9] Zhang X, Hsi WC, Yang F, Wang Z, Sheng Y, Sun J, Yang C and Zhou R. Development of an isocentric rotating chair positioner to treat patients of head and neck cancer at upright seated position with multiple nonplanar fields in a fixed carbon-ion beamline. Med Phys 2020; 47: 2450-2460.
[10] Gram D, Haraldsson A, Brodin NP, Nysom K, Björk-Eriksson T and Munck Af Rosenschöld P. Residual positioning errors and uncertainties for pediatric craniospinal irradiation and the impact of image guidance. Radiat Oncol 2020; 15: 149.
[11] de Crevoisier R, Lafond C, Mervoyer A, Hulot C, Jaksic N, Bessières I and Delpon G. Image-guided radiotherapy. Cancer Radiother 2022; 26: 34-49.
[12] Dona Lemus OM, Cao M, Cai B, Cummings M and Zheng D. Adaptive radiotherapy: next-generation radiotherapy. Cancers (Basel) 2024; 16: 1206.
[13] Mireştean CC, Iancu RI and Iancu DPT. Image guided radiotherapy (IGRT) and delta (Δ) radiomics-an urgent alliance for the front line of the war against head and neck cancers. Diagnostics (Basel) 2023; 13: 2045.
[14] Wilson J, Jun Hua C, Aziminia N and Manisty C. Imaging of the acute and chronic cardiovascular complications of radiation therapy. Circ Cardiovasc Imaging 2025; 18: e017454.
[15] De Wolde SD, Hulskes RH, Weenink RP, Hollmann MW and Van Hulst RA. The effects of hyperbaric oxygenation on oxidative stress, inflammation and angiogenesis. Biomolecules 2021; 11: 1210.
[16] Li C, Lu Z, He M, Sui J, Lin T, Xie K, Sun J and Ni X. Augmented reality-guided positioning system for radiotherapy patients. J Appl Clin Med Phys 2022; 23: e13516.
[17] Volz L, Korte J, Martire MC, Zhang Y, Hardcastle N, Durante M, Kron T and Graeff C. Opportunities and challenges of upright patient positioning in radiotherapy. Phys Med Biol 2024; 69.
[18] Naidoo W and Leech M. Feasibility of surface guided radiotherapy for patient positioning in breast radiotherapy versus conventional tattoo-based setups- a systematic review. Tech Innov Patient Support Radiat Oncol 2022; 22: 39-49.
[19] Riis HL and Zimmermann SJ. Elekta precise table characteristics of IGRT remote table positioning. Acta Oncol 2009; 48: 267-270.
[20] Ramelyte E, Welti M, Gardin F, Maul JT, Dummer R and Imhof L. Post-excision soft X-ray radiotherapy for keloids: experience in a tertiary referral center. Dermatology 2024; 240: 572-580.
[21] Lefkopoulos D, Ferreira I, Isambert A, Le Péchoux C and Mornex F. Present and future of the image guided radiotherapy (IGRT) and its applications in lung cancer treatment. Cancer Radiother 2007; 11: 23-31.
[22] Verellen D, De Ridder M, Linthout N, Tournel K, Soete G and Storme G. Innovations in image-guided radiotherapy. Nat Rev Cancer 2007; 7: 949-960.
[23] Yang X, Ren H, Guo X, Hu C and Fu J. Radiation-induced skin injury: pathogenesis, treatment, and management. Aging (Albany NY) 2020; 12: 23379-23393.
[24] Onimaru R, Shirato H, Shimizu S, Kitamura K, Xu B, Fukumoto S, Chang TC, Fujita K, Oita M, Miyasaka K, Nishimura M and Dosaka-Akita H. Tolerance of organs at risk in small-volume, hypofractionated, image-guided radiotherapy for primary and metastatic lung cancers. Int J Radiat Oncol Biol Phys 2003; 56: 126-135.
[25] Bektas M, Bell T, Khan S, Tumminello B, Fernandez MM, Heyes C and Oton AB. Desmoid tumors: a comprehensive review. Adv Ther 2023 Sep; 40: 3697-3722.
[26] Hosseini MS, Sanaie S, Mahmoodpoor A, Jabbari Beyrami S, Jabbari Beyrami H, Fattahi S, Jahanshahlou F, Zarei M, Rahimi Mamaghani A and Kuchaki Rafsanjani M. Cancer treatment-related xerostomia: basics, therapeutics, and future perspectives. Eur J Med Res 2024; 29: 571.
[27] Maggio A, Rancati T, Gatti M, Cante D, Avuzzi B, Bianconi C, Badenchini F, Farina B, Ferrari P, Giandini T, Girelli G, Landoni V, Magli A, Moretti E, Petrucci E, Salmoiraghi P, Sanguineti G, Villa E, Waskiewicz JM, Guarneri A, Valdagni R, Fiorino C and Cozzarini C. Quality of life longitudinal evaluation in prostate cancer patients from radiotherapy start to 5 years after IMRT-IGRT. Curr Oncol 2024; 31: 839-848.
[28] Majewski W, Tabor K, Prokop E and Kulik R. Quality of life in patients with prostate cancer treated with radical image-guided radiotherapy. Contemp Oncol (Pozn) 2014; 18: 285-289.