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RESEARCH ARTICLE

# Two-dimensional and Three-dimensional Image-guided Evaluation of Patient Positioning for Intensity-modulated Radiation Therapy of Head and Neck Cancer

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Abstract Patient positioning accuracy is critical in radiation therapy, especially in intensity-modulated radiation therapy (IMRT) for head and neck cancer (HNC), as it can affect treatment effectiveness and safety. This retrospective study aimed to evaluate the accuracy of patient positioning techniques and compare the effectiveness of using multiple image-guided (IG) methods for IG-IMRT of HNC. Cone-beam computed tomography (CBCT) and kV-planar imaging (OBI) collected 3240 treatment couch coordinates in three translational directions from 60 HNC patients undergoing IMRT. Inter-fraction errors were assessed by registering the scans to the planning CT, and the population systematic set-up error (Σ), random error (σ), and planning target volume (PTV) margin were calculated. The results between OBI and CBCT were analyzed and compared using one-way ANOVA. The findings demonstrated that more than 80% of the image-guided patient positioning set-ups were acceptable. The mean couch displacement for image-guided techniques was negligible in all translational directions using OBI and CBCT. However, the PTV margin for both methods was more than 0.5 cm, except for the CBCTA-P direction. This study highlights the effectiveness of OBI and CBCT as modalities for evaluating and improving the accuracy of IMRT in HNC patients. Determination of the systematic and random errors and calculating the optimal PTV margin without rematching images can help improve the precision of patient positioning and ultimately lead to better treatment outcomes.

**Keywords**: Cone-beam computed tomography, Set-up error, Image-guided patient positioning, Head and Neck Cancer, intensity-modulated radiation therapy.

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## Introduction

Head and neck cancer (HNC) is a relatively rare form of cancer worldwide but still accounts for over half a million new cases annually [1]. Recently, the World Health Organisation (WHO) reported approximately 900,000 new cases of HNC worldwide, making up about 5% of all cancers [26]. With 595,049 new cases, Asia has the most significant frequency of HNC compared to other continents [26]. It is also the sixth most prevalent cancer globally [13]. The top five most common malignancies in Malaysia, according to the Malaysian National Cancer Registry (MNCR) report for the years 2007–2011, included HNC (nasopharynx) [4]. Human papillomavirus (HPV), Epstein-Barr virus (EBV), and environmental carcinogens, including tobacco and alcohol use, are among the aetiology risk factors for HNC [6, 13, 20, 23].

The principal treatment approach for HNC is still debated, but the current trend combines radiotherapy with chemotherapy and/or surgery [1, 16, 22]. Novel radiotherapy techniques for HNC, such as intensity-modulated radiation therapy (IMRT), have developed rapidly in the last decade. IMRT is chosen for most HNC cases because cancer grows in this area, surrounded by organs at high risk for surgery [21]. IMRT technology enables precise modification of dosage distribution to the target while avoiding healthy tissues [11, 24]. It permits highly conformal dose delivery to the planning target volume (PTV), including some margins accounting for uncertainties and organ motion directly affecting target volume coverage. Therefore, to prevent inadvertent irradiation of organs at risk (OARs), especially in regions with more sensitive organs like head and neck cancer, they should be optimized as ICRU recommends [3]. Hence, stringent QA methods and daily treatment settings are fundamental requirements for patient safety and accurate dose delivery [7].

Intensity-modulated radiation therapy (IMRT) is a widely used technique for treating head and neck cancer (HNC), which allows for the delivery of high doses of radiation to the tumor while sparing surrounding normal tissues. Patient positioning is critical to achieving accurate and precise radiation delivery during IMRT treatment. In recent years, image-guided radiation therapy (IGRT) using kV-planar imaging (OBI) and cone-beam computed tomography (CBCT) has become increasingly popular for improving patient positioning accuracy. However, there are still research gaps in the optimal patient positioning set-up for IMRT in HNC evaluation using OBI and CBCT. One area of research gap is the use of different imaging modalities for patient positioning and the impact of these modalities on treatment outcomes. For example, a study by Gurjar *et al*. [12] compared the accuracy of CBCT and OBI in patient positioning for IMRT for HNC and found that OBI resulted in better mean target localization compared to CBCT. However, further research is needed to confirm these findings.

Another area of research gap is the impact of patient motion on treatment-on-treatment outcomes. Despite the use of IGRT techniques, patient motion can still occur during treatment, leading to misalignment of the target area and healthy tissues. A study by Kearney *et al*. [15] found the impact of intrafraction motion on IMRT for HNC and found that even small motion during treatment can lead to significant dose differences in the target area and surrounding tissues. In conclusion, while using IGRT techniques such as OBI and CBCT has improved patient positioning accuracy in IMRT for HNC, there are still some research gaps related to using different imaging modalities and the impact of patient motion on treatment outcomes. Further research in these areas may help optimize patient positioning set-up and improve treatment outcomes in IMRT for HNC.

This study aims to evaluate the inter-fraction patient positioning set-up error and compare the use of multiple image-guided modalities, including OBI and CBCT, for intensity-modulated radiation therapy of head and neck cancer. The goal is to understand systematic and random errors and determine the optimal planning target volume (PTV) margin for improved treatment accuracy and precision.

# Materials and Methods

The research was a retrospective longitudinal study to evaluate the accuracy of inter-fraction patient positioning set-up using multiple types of image-guided intensity-modulated radiotherapy (IG-IMRT), kV-planar, and CBCT to investigate performance and compare these two types of imaging techniques in patients with head and neck cancer (HNC). This quantitative study was approved by the ethical committee members of Universiti Kebangsaan Malaysia on July 14, 2022 (ethical initial approval JEP-2022-296). The committee waived patient consent because the study involved a retrospective review of medical records. The study was conducted according to the ethical principles of the Declaration of Helsinki. Patient confidentiality was maintained by de-identifying the data during analysis and reporting. By comparing and investigating the performance of kV-planar and CBCT imaging techniques, this study aimed to improve patient positioning accuracy in IG-IMRT treatment for HNC.

## Patient Selection

Sixty patients with confirmed head and neck cancer (stages I–IV) received IMRT treatment. They were evaluated by image-guided imaging at least six times during treatment at the Department of Radiotherapy & Oncology, Hospital Canselor Tuanku Muhriz, Cheras, Kuala Lumpur, between 2016 and 2022. The patients had a mean age of 53.33 years old with a median age of 56, most of whom were male and of Malay ethnicity. The most common type of cancer was nasopharyngeal carcinoma. Still, other locations, including the oropharynx, larynx, oral cavity, salivary gland, hypopharynx, and head and neck (as written in the patient's medical record), were also included. The study was not negatively affected by the fact that females represented a minority of the patients, and 12 patients who did not meet the criteria were excluded from the study without compromising its validity. The patients' characteristics are presented in Table 1.

**Table 1**. Demographic profile of 60 head and neck cancer patients treated with IMRT

| Patients (N=60) | Frequency | % |
|---|---|---|
| Gender | | |
| Male | 40 | 66.7 |
| Female | 20 | 33.3 |
| Race | | |
| Chinese | 24 | 40.0 |
| Indian | 2 | 3.3 |
| Malay | 34 | 56.7 |
| Age | | |
| 0-30 | 6 | 10% |
| 31-60 | 33 | 55% |
| >60 | 21 | 35% |
| Tumour location | | |
| Head and Neck | 1 | 1.7 |
| Hypopharynx | 2 | 3.3 |
| Larynx | 7 | 11.7 |
| Nasopharynx | 34 | 56.7 |
| Oral Cavity | 5 | 8.3 |
| Oropharynx | 8 | 13.3 |
| Salivary Gland | 3 | 5 |

## CT Simulation and Treatment Planning

Patients with head and neck cancer were simulated using a CT simulator (Toshiba Acquilion LB) and immobilised with a 5-point fixation head and neck mask Type-S (Civco, Iowa, USA). The treatment planning images were acquired from a multi-slice CT scanner with a reconstructed slice thickness of 3 mm. These CT images were imported into the Varian Eclipse v16.1 treatment planning software (Varian Medical System Inc., Palo Alto, CA, USA) for IMRT treatment planning. The responsible physician contoured normal structures, OARs, and target volumes per the department's standard operating procedures. The OAR standard margin for HNC plans was 5 mm, and the CTV-PTV treatment margin followed the oncologist's practice. The treatment dose prescribed ranged between 50 and 70 Gy, delivered over 25 and 35 fractions using the intensity-modulated radiotherapy (IMRT) technique.

## Daily set-up and image guidance

The patients received treatment using a Varian Clinac iX linear accelerator (Varian Medical System, Palo Alto, CA, USA) and were aligned daily with the laser to the respective shell markings. The necessary couch shift was applied as planned for the daily set-up in all sessions. Onboard Imager (OBI) was used to acquire both orthogonal kV-planar and cone-beam computed tomography (CBCT) images (version 1.6). The imaging procedure for sessions 1 to 6 is depicted in Figure 1. The images were compared with digitally reconstructed radiographs (DRRs) according to the department's standard operating procedure (SOP). The matching methods were evaluated on anatomical bone reference marks visible on three axial views (sagittal, coronal, and horizontal). All images were evaluated using a 4DCT monitor (Varian Medical Systems, 4D Console version: 13.0). All couch coordinate values for any shift in all geometrical views were recorded in the Oncology Information System (OIS). For this study, the images were not rematches, and the couch coordinate values from each matched image were taken for analysis. A single-blinded design was adopted, where only the researcher was aware of the patient's report. A single-blinded design was adopted, where only the researcher was aware of the patient report. Two RTT observers and a radiation oncologist with over 10 years of experience were blinded to the patient data to evaluate the reliability of matched image-guided images.

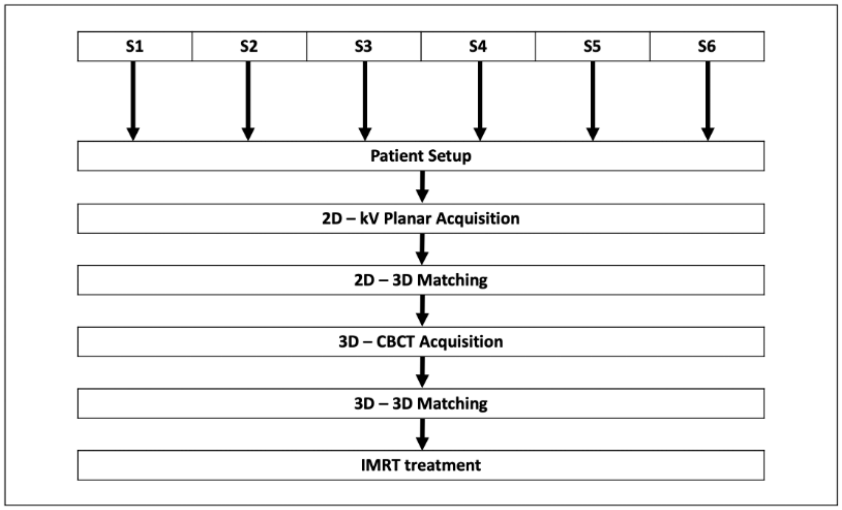



**Figure 1.** Imaging acquisition for multiple image-guided radiotherapy sessions

## Data Collection

In this study, we retrospectively retrieved matched image-guided data of head and neck cancer patients undergoing IMRT treatment with three translational axes from the oncology information system (OIS). Demographic information was obtained from patient medical records. A total of 1080 treatment sessions, comprising 360 sessions each of OBI, CBCT, and IMRT procedures, were evaluated. A total of 3240 treatment couch coordinates in the three translational directions, vertical (anterior-posterior, A-P), longitudinal (superior-inferior, S-I), and lateral (left-right, L-R), were collected and analysed from all patients in all sessions. All couch position coordinates and demographic data were recorded in a Microsoft Excel spreadsheet. To minimise bias during data collection, patient identification was excluded. To ensure patient confidentiality, image-guided image data were anonymized by assigning numbers to each patient.

## Statistical Analysis

The data analysis was performed in a scientifically rigorous manner. The three-direction couch coordinates for all sessions were entered into a spreadsheet programme, Microsoft Office Excel. The statistical analysis was performed using the Statistical Package for the Social Sciences software for Mac version 26.0 (IBM Corp., Armonk, NY, USA).

To estimate the patient set-up positioning shift, the couch position of each patient between treatment and image-guided procedures was calculated. The systematic error ($\sum$) was estimated by calculating the standard deviation of the averages (m) for each axis. The random error ($\sigma$) was determined as the square root of the average sum of the standard deviations per axis. The overall mean error (M), systematic SD ($\sum$), and random SD ($\sigma$) were calculated per patient and by groups of patients (determined according to the site).

Additionally, the planning target volume (PTV) margin for the A-P, S-I, and L-R directions was determined using the van Herk formula [28]: PTV margin = $2.5\sum + 0.7\sigma$. In a comparison of the results obtained from OBI and CBCT, a one-way analysis of variance (ANOVA) was performed. Finally, the relationship between couch directions and the image-guided session was analysed using Pearson's correlation coefficient. Overall, the data analysis was transparent, replicable, and scientifically sound, and the statistical methods used were appropriate for the study objectives.

# Results

A total of 360 OBI and CBCT scans in 60 HNC patients treated with the IMRT technique were acquired and analysed. The mean±SD of couch displacement (Table 2) for the OBI session was -0.05±0.19 in the OBIA-P direction, 0.00±0.20 in the OBIS-I direction, and -0.04±0.26 in the OBIL-R direction. The mean of couch displacement for the CBCT session was 0.01±0.10, 0.08±0.81, and -0.06±0.20 in the CBCTA-

P, CBCTS-I, and CBCTL-R directions respectively. The larger range couch displacement was found in the OBIL-R and CBCTS-I directions (Table 2).

Couch displacement distribution was shown in Figure 2 for OBI and Figure 3 for CBCT. The highest couch displacement was found in the superior-inferior (S-I) direction for both image-guided. Furthermore, couch displacement between 0.0 – 0.3 cm was higher in the OBIS-I direction and CBCTA-P directions. The maximum couch displacement was observed in the OBIL-R (4.2 cm) and the CBCTS-I (13.1 cm) directions. The couch displacement of more than 0.3 cm was less than 10% for both OBI (5%) and CBCT (0.3%) sessions. However, 8.9% of sessions exceeded this threshold in the OBIA-P direction for OBI sessions and 3.9% in the CBCTL-R direction for CBCT sessions.

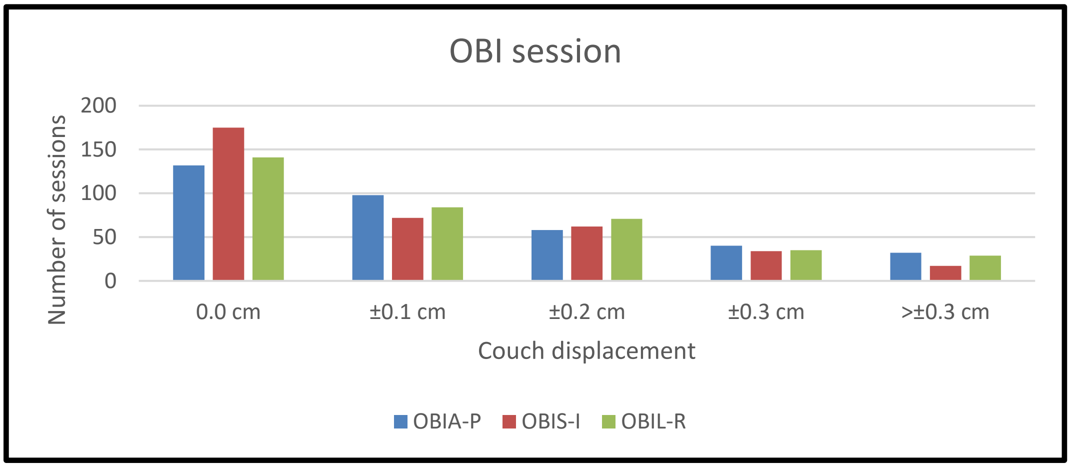



**Figure 2.** The analysis of couch displacement for OBI sessions. The highest couch displacement of 0.0 cm was observed in the OBIS-I direction (48.6%), followed by the OBIL-R (39.2%) and OBIA-P (36.7%) directions. Overall, the sessions of couch displacement between 0.0 – 0.3 cm were higher in the OBIS-I direction compared to the OBIA-P and OBIL-R directions

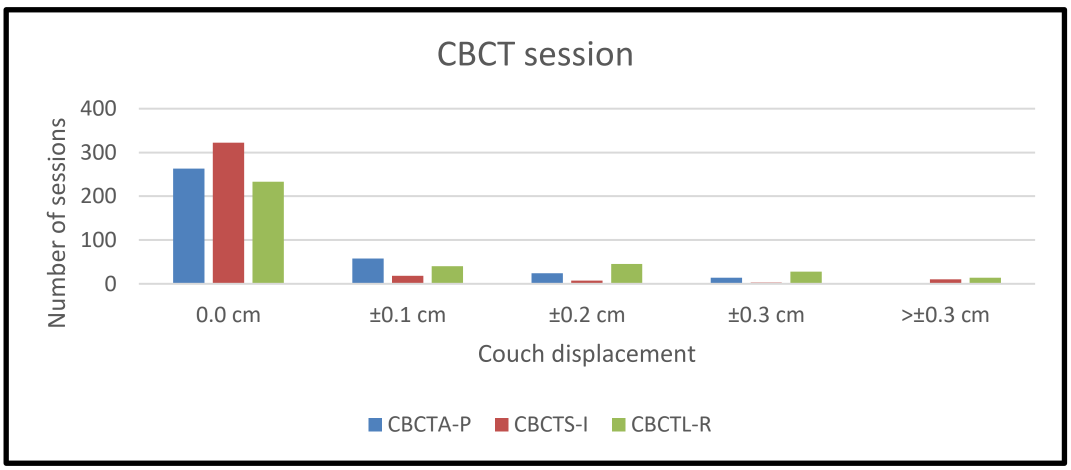



**Figure 3.** The analysis of couch displacement for CBCT sessions. The highest couch displacement of 0.0 cm was observed in the CBCTS-I direction (89.4%), followed by the CBCTA-P (73.1%) and CBCTL-R (64.7%) directions. The overall sessions of couch displacement between 0.0 – 0.3 cm were found to be higher in the CBCTA-P direction compared to the CBCTS-I and CBCTL-R directions

The present study compared patient positioning accuracy using OBI and CBCT in different translational directions (Figures 4 and 5). The statistical analyses investigated the differences between image-guided sessions and translational directions for both OBI and CBCT. The one-way ANOVA results showed a significant difference between the means of the OBIA-P direction for OBI ($p < 0.05$) and not for any translational directions for CBCT. This suggests that OBI may be more sensitive than CBCT at detecting changes in the A-P direction. The post hoc Tukey's-b test revealed that OBIsession2 and OBIsession5, as well as OBIsession2 and OBIsession6, were significantly different ($p < 0.05$), indicating the change in the A-P direction occurred between these sessions.

Moreover, the results of the correlation analysis showed a significant positive relationship between the image-guided session and the OBIA-P direction ($p < 0.05$) for OBI but not for any of the CBCT translational directions. This suggests that as the number of image-guided sessions increases, there is a corresponding increase in the A-P direction for OBI. These findings indicate that OBI may be more effective than CBCT in detecting changes in translational directions, particularly in the A-P direction. The significant positive relationship between image-guided sessions and OBIA-P direction further supports this observation, indicating that OBI may be more sensitive to changes in translational directions over time.

Table 3 showed that the systematic errors in patient positioning were less than 0.3 cm, except in the CBCTS-I direction (0.81 cm). The systematic error was minimal using OBI than CBCT in all translational directions. However, OBI and CBCT show random errors exceeding 0.3 mm, indicating some variability in patient positioning using both image-guided. CBCT exhibits more significant systematic and random errors in the CBCTS-I direction, suggesting this direction may be more challenging for accurate patient positioning.

Finally, according to the van Herk formula, adding a margin of 3-5 mm in all directions around the CTVs is sufficient to account for potential errors during patient set-up. The necessary margins for the PTVs may vary depending on the direction and imaging method used. For example, when using OBI, the required PTV margin is 0.8 cm in the OBIA-P and OBIS-I directions and 1.0 cm in the OBIL-R direction. However, when using CBCT, the PTV margin required is over 2.5 cm in CBCTS-I but less than 1.0 cm in CBCTA-P and CBCTL-R directions (Table 3).

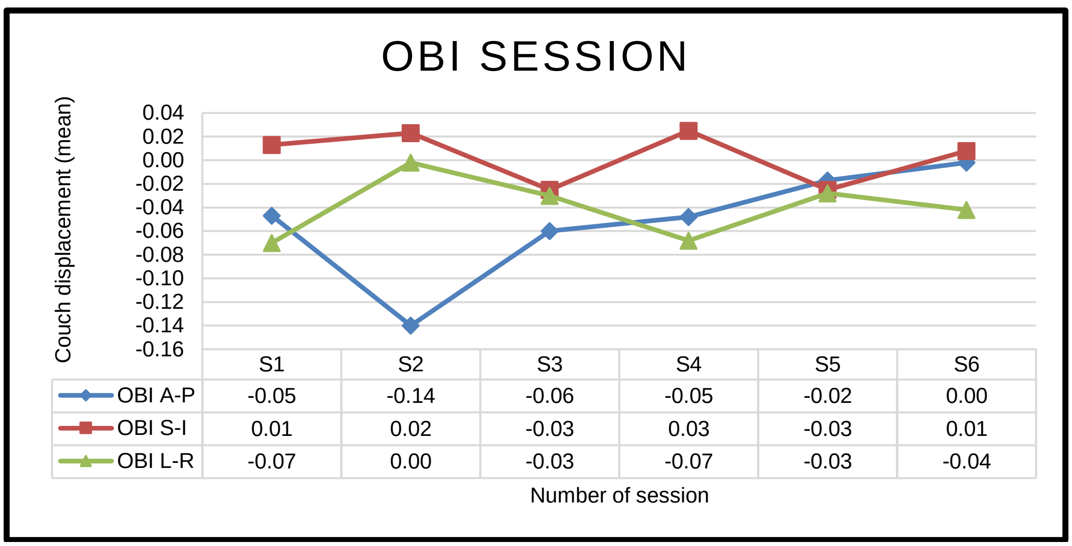
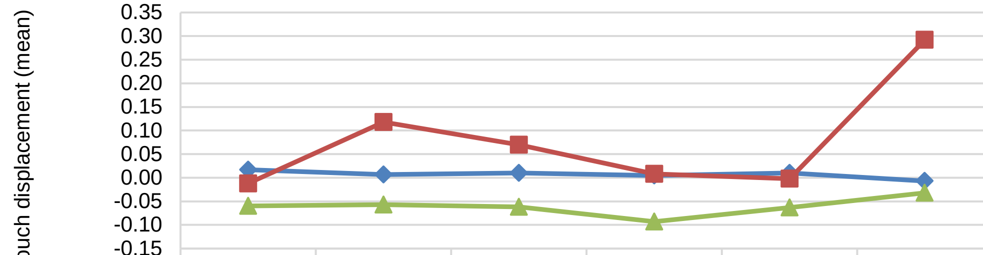



**Figure 4.** The mean of couch displacement distributions for six OBI sessions in three translational. A one-way ANOVA showed significant differences among the means in the OBIA-P direction ($p < 0.05$). Thus, significant differences exist between at least two groups in the A-P direction data. A post hoc Tukey's test was used to determine which groups differed. The result showed there are significant differences between OBIsession2 and OBIsession5 (alpha = 0.05, p = -0.0167) and between OBIsession2 and OBIsession6 (alpha = 0.05, p = -0.0017). The relationship between the image-guided session and translational directions was analysed. The results show a significant positive relationship between the image-guided session and the OBIA-P direction (p 0.05) but no significant relationship with the OBIS-I direction or the OBIL-R direction ($p > 0.05$).




| | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| CBCT A-P | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | -0.01 |
| CBCT S-I | -0.01 | 0.12 | 0.07 | 0.01 | 0.00 | 0.29 |
| CBCT L-R | -0.06 | -0.06 | -0.06 | -0.09 | -0.06 | -0.03 |

**Figure 5.** The mean of couch displacement distributions for six CBCT sessions in three translational. A one-way ANOVA showed no significant differences between sessions for CBCT ($p > 0.05$). The relationship between image-guided sessions and translational directions was also analysed. The results showed no significant relationship between image-guided sessions and all translational directions for CBCT sessions ($p > 0.05$)

## Discussion

In IMRT for HNC, systematic and random errors are essential considerations during patient positioning and treatment planning. Systematic errors refer to consistent and repeatable inaccuracies during treatment delivery. Various factors, including incorrect patient positioning, machine or equipment malfunctions, and operator error, can cause these errors. Systematic errors can be minimized through proper quality assurance procedures, including regular equipment calibration and careful attention to patient positioning. On the other hand, random errors are less predictable and can occur randomly during treatment delivery. Changes in patient anatomy, respiration, and movement can cause these errors. Random errors can be minimised using imaging modalities such as CBCT and OBI, allowing for more accurate patient positioning and treatment delivery verification. It is important to note that systematic and random errors can impact treatment and overall patient outcomes. Thus, carefully considering these factors is essential during treatment planning and delivery.

Accurate patient positioning is crucial in radiation therapy to ensure the prescribed radiation dose is delivered to the target volume while minimising radiation exposure to surrounding healthy tissues. Thermoplastic masks are effective for immobilising patients during radiation therapy. Studies consistently report an average systematic inter-fraction motion of 2–5 mm in various directions and translational shifts of up to 6 mm [9]. Rotational displacements have also been investigated, with pitch, yaw, and roll consistently reported to be less than 10° [9]. A five-point fixation is recommended to minimise sub-regional variations in set-up errors, including fixation at the lower neck and shoulders [18, 25]. Various image-guided techniques are used for patient set-up verification during radiation therapy, including cone-beam computed tomography (CBCT) and onboard imaging (OBI) systems. OBI and CBCT have been shown to improve patient set-up accuracy and reduce systematic and random errors. However, the accuracy and performance of these systems for detecting couch displacements in different translational directions still need to be determined.

The present study examined the differences in couch displacement between two image-guided techniques, OBI and CBCT, for radiation therapy. The results suggest no significant differences in mean couch displacement between the two techniques. However, there were differences in the mean and range of couch displacement for different translational directions and image-guided techniques. The result showed that the mean couch displacement was small in both image-guided techniques and similar to other studies (Table 4). One study by Djordjevic *et al*. [10] evaluated the set-up error in 80 HNC patients using daily OBI and reported that the mean couch displacement was -0.05 cm A-P, -0.06 cm S-I, and -0.06 cm L-R. Another study by Liu *et al*. [19] evaluated the daily set-up error in 120 HNC patients (NPC) using CBCT and reported that the mean couch displacement in A-P, S-I, and L-R directions was 0.19 cm, 0.13 cm, and 0.15 cm, respectively.

However, other studies have reported a more significant mean couch displacement with CBCT. For example, a study by Delishaj *et al*. [8] investigated the use of daily CBCT based on the first three days and weekly of irradiation after that for 60 patient set-up verification in HNC IMRT and reported the mean couch displacement of set-up errors in the A-P, S-I, and L-R directions were 0.20 cm, 0.13 cm, and 0.13 cm, respectively, while the corresponding standard deviations were 0.16 cm, 0.13 cm, and 0.15 cm, respectively.

The current study emphasises the need to avoid couch motion during image-guided radiation therapy sessions to administer treatments accurately. According to the survey, OBI may be less accurate in identifying more significant couch displacements. In contrast, CBCT may be more successful in detecting patient positioning mistakes with a couch displacement of 0.0 cm. In general, couch displacement was within acceptable bounds, but ongoing tuning and monitoring are crucial for effective and secure radiation administration in clinical practice. To validate these findings and evaluate their therapeutic relevance, more study is required.

**Table 2.** Population mean+SD and maximum couch displacement for OBI and CBCT translational direction, N=60

| Couch displacement, cm | OBIA-P | OBIS-I | OBIL-R | CBCTA-P | CBCTS-I | CBCTL-R |
|---|---|---|---|---|---|---|
| Mean | -0.05 | 0.00 | -0.04 | 0.01 | 0.08 | -0.06 |
| Std. Deviation | 0.194 | 0.196 | 0.256 | 0.096 | 0.814 | 0.199 |
| Minimum | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Maximum | -0.7, 0.6 | -1.0, 1.7 | -1.5, 2.7 | -0.3, 0.7 | -6.1, 7.0 | -1.9, 0.5 |
| Range | 1.3 | 2.7 | 4.2 | 1.0 | 13.1 | 2.4 |

**Table 3.** Overall systematic error (∑), random error (σ), and CTV to PTV margin for OBI and CBCT imaging without correction

| Direction | ∑ (cm) | σ (cm) | PTV margin (cm) |
|---|---|---|---|
| Two-dimensional imaging | | | |
| OBIA-P | 0.19 | 0.44 | 0.79 |
| OBIS-I | 0.20 | 0.44 | 0.80 |
| OBIL-R | 0.26 | 0.51 | 1.00 |
| Three-dimensional imaging | | | |
| CBCTA-P | 0.10 | 0.31 | 0.46 |
| CBCTS-I | 0.81 | 0.90 | 2.67 |
| CBCTL-R | 0.20 | 0.45 | 0.81 |

The current investigation discovered that, except in the CBCTS-I direction, the systematic error was less than 0.3 cm. Even with OBI, the random error consistently surpassed 0.3 cm. The CBCTS-I direction may present additional difficulties for precise patient placement since CBCT shows more notable systematic and random faults in this direction. The findings regarding systematic error, but not random error, were consistent with prior investigations (Table 5). For instance, Djordjevic *et al*. [10] discovered that utilising daily OBI, the systematic error was less than 0.3 cm, and the random error was less than 0.2 cm. When applying OBI, Anjanappa *et al*. [2] discovered that the systematic error was less than 0.3 cm, and the random error was less than 0.2 cm. However, Delishaj *et al*. [8]] discovered that the systematic and random errors were under 0.2 cm. The outcome was comparable to research by Biswas *et al*. [5], who discovered that all translation directions utilising CBCT had mean systematic and random errors of less than 0.2 cm. They claim that knowing these mistakes is essential for figuring out PTV margins, couch correction tolerance limits, and plan adaptation in HNC radiation.

**Table 4.** Comparison of mean couch displacement in A-P, S-I, and LR directions with previous studies

| Study | Imaging | AP | SI | LR |
|---|---|---|---|---|
| This study | OBI | -0.05 | 0.00 | -0.04 |
| | CBCT | 0.01 | 0.08 | -0.06 |
| Liu *et al*. [19] | CBCT | 0.19 | 0.13 | 0.15 |
| Djordjevic *et al*. [10] | OBI | -0.05 | -0.06 | -0.06 |
| Delishaj *et al*. [8] | CBCT | 0.20 | 0.13 | 0.13 |

**Table 5.** Comparison of systematic error (∑), random error (σ), and PTV margin with previous studies

| Study | Imaging | Systematic error | Random error | PTV margin |
|---|---|---|---|---|
| This study | OBI | < 0.3 | < 0.5 | < 1.0 |
| | CBCT | < 0.3, except for S-I (0.8) | < 0.5, except for S-I (0.9) | < 1.0, except for S-I (over 2.5) |
| Anjanappa *et al*. [2] | OBI | < 0.3 | < 0.2 | 0.3 – 0.7 |
| Biswas *et al*. [5], | CBCT | < 0.2 | < 0.2 | 0.5 – 0.6 |
| Delishaj *et al*. [8] | CBCT | < 0.2 | < 0.2 | 0.3 – 0.5 |
| Djordjevic *et al*. [10] | OBI | < 0.3 | < 0.2 | 0.3 – 0.7 |
| Liu *et al*. [19] | CBCT | < 0.1 | < 0.1 | < 0.2 |
| Thornberry, McLauchlan & Gujral [27] | OBI | | | 0.3 – 0.6 |
| | CBCT | | | 0.3 – 0.6 |

CTV-PTV margins for head and neck cancers depend on the practice of daily IGRT. Without daily IGRT, margins greater than 5 mm are recommended due to potential set-up variabilities and unstable set-ups in patients with high BMI [14, 17, 25, 29]. The present study found that the PTV margin required in all directions was less than 1.0 cm, except for the CBCT S-I direction, which required over 2.5 cm. Several studies have reported PTV margins and errors using OBI and CBCT for HNC in IMRT treatment. A survey by Thornberry, McLauchlan & Gujral [27] evaluated the adequacy of the PTV margin for 30 HNC patients treated with IMRT and found a PTV margin of 0.4–0.6 cm when using OBI and CBCT based on daily and weekly imaging. The author suggests achieving a minimum CTV-PTV margin of 0.3 cm, and all shifts should be corrected with a tolerance of >0.3 cm. However, this would necessitate daily imaging, which may have training and resource implications.

Similarly, Biswas *et al*. [5] investigated the frequency and magnitude of systematic and random errors in 32 HNC patients treated with IMRT using CBCT. It optimised the CTV to PTV margin using the NAL protocol and found that the PTV margin was 0.5–0.6 cm. They also found that patients had a systematic error ≥0.3 cm, and set-up margins ≥5 mm were reduced in all directions after correction. They reported that a simple offline-NAL protocol could correct set-up errors without requiring daily online imaging for patients undergoing IMRT. This protocol can be considered a resource-saving alternative. Additionally, a 5mm margin between CTVs was sufficient and safe for addressing set-up errors in head and neck IMRT.

Another study by Delishaj *et al*. [8] found that the PTV margin with no correction in the A-P, S-I, and L-R directions was 0.451 cm, 0.348 cm, and 0.376 cm, while after the correction, it was 0.298 cm, 0.259 cm, and 0.284 cm, respectively. After addressing the systematic errors in the set-up process, they found that a margin of 0.3 cm proved adequate to mitigate the set-up error issue. The authors concluded that CBCT at the first three fractions, followed by weekly CBCT, appears sufficient for significantly reducing set-up errors in H&N cancer treated with the IMRT technique. Another study by Anjanappa *et al*. [2] evaluated the set-up error in 20 HNC patients (NPC) using OBI on alternate days and reported that the PTV margin for clivus, C3, and C6 was 0.44-0.64 cm, 0.40-0.44 cm, and 0.32-0.69 cm in A-P, S-I, and L-R directions, respectively.

Accurate shift information might not be provided by OBI alone when used in therapy. Additional displacement information can be obtained from limited CBCT images without incurring substantial costs or resource demands. If the CTV-PTV margins are modified appropriately, it may be a substitute for daily CBCT imaging. However, daily imaging would be necessary to correct any changes with a tolerance or action level of >0.3 cm, imparting training and resource availability. The CTV-PTV margin may be decreased to "0" with daily imaging, and treatment accuracy might be improved by lowering the tolerance or action level and increasing imaging frequency. In conclusion, carefully assessing the systematic and random errors in patient positioning and the unique needs of the patient population and therapy should be the basis for choosing image-guided techniques and calculating PTV margins.

Overall, the study's contribution to the existing knowledge of patient positioning accuracy in HNC IMRT is significant. The findings underscore the effectiveness of both CBCT and OBI as valuable modalities for assessing and enhancing the precision of IMRT in HNC patients. The study highlights the critical role of identifying systematic and random errors while calculating the optimal PTV margin to improve patient positioning accuracy. However, there are notable concerns that should be addressed. The study's retrospective design introduces potential biases and limitations, inherent in analysing pre-existing data. Prospective studies provide better control over variables and offer more robust evidence by minimising biases. Therefore, the study's conclusions should be considered within the context of their retrospective nature.

The absence of a control group is another point of contention. Without a control group undergoing standard positioning techniques, it becomes challenging to ascertain the relative effectiveness of image-guided methods compared to conventional approaches. A control group would have provided a valuable baseline for comparison and a clearer understanding of the benefits offered by image-guided techniques. The study's emphasis on inter-fraction errors and PTV margin optimisation is valuable. However, to present a more comprehensive evaluation of patient positioning techniques, it's essential to include additional outcome measures. Incorporating treatment response rates and assessing long-term patient outcomes would provide a more holistic understanding of the impact of patient positioning accuracy on treatment efficacy and patient well-being.

To strengthen the study's findings, further research is warranted. Prospective studies, designed with larger sample sizes, can address the limitations of the retrospective approach, and provide more rigorous evidence. These studies could incorporate comprehensive outcome measures, including treatment response rates, disease control, and patient-reported outcomes, to enhance our understanding of how patient positioning accuracy influences treatment outcomes and patient experiences.

# Conclusions

In conclusion, this study yields crucial insights into the precision of patient positioning within the realm of Head and Neck Cancer (HNC) Intensity-Modulated Radiation Therapy (IMRT). Nevertheless, it underscores the necessity for further exploration and enhancement in various dimensions. By addressing the study's inherent constraints through prospective research endeavours, focusing on a diverse array of outcome metrics, we not only substantiate these findings but also establish a more robust groundwork for optimizing patient alignment methodologies in the intricate domain of HNC IMRT.

The eventual integration of cutting-edge imaging modalities and meticulously refined treatment planning processes stands as a promising avenue for elevating the quality of care for HNC patients undergoing IMRT regimens. Furthermore, it is imperative to acknowledge that these findings are intrinsically linked to the specific cohort of HNC patients under investigation and might not readily extrapolate to other patient categories or treatment contexts. The uniqueness of these outcomes to our institution emphasizes their contextual applicability and cautions against unreserved generalization to broader treatment facilities.

Considering the critical significance of precision in IMRT for HNC, it becomes paramount to meticulously account for both systematic and random discrepancies. These discrepancies, if left unaddressed, bear the potential to substantially impact therapeutic quality and, by extension, patient well-being. The integration of advanced imaging modalities, such as Cone-Beam Computed Tomography (CBCT) and Online Image Guidance (OBI), offers a plausible strategy for mitigating these inconsistencies. By discerning and rectifying systematic errors, bolstered by stringent quality control mechanisms, practitioners can significantly enhance therapeutic accuracy and position patients optimally.

Thus, the pursuit of refined patient positioning techniques in HNC IMRT necessitates a multi-pronged approach, encompassing prospective research, advanced imaging technologies, and stringent quality control protocols. These collective efforts have the potential to not only enhance the precision of therapeutic administration but also elevate the overall standard of care for individuals embarking on the challenging journey of IMRT within the HNC landscape.

## Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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