Original Article

Comparative study of setup errors between new and reused thermoplastic masks in irradiated head and neck cancer patients

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Abstract

Background: The accuracy and precision of patient setup are important in radiotherapy. The thermoplastic mask is used to immobilize head and neck cancer patient. However, the mask is reused for low-income patients. Therefore, the setup error should be evaluated to approve that these patients remain in the exact position during treatment.

Objective: To investigate setup errors with the use of thermoplastic masks in head and neck cancer patients and to compare setup errors of new and reused thermoplastic masks.

Materials and Methods: Eighty patients who underwent volumetric modulated arc radiotherapy (VMAT) for head and neck cancer lesions were retrospectively evaluated. The setup error, population systematic error, and population random error were calculated. Subsequently, setup errors in patients using the new and reused thermoplastic masks were compared.

Results: The population systematic error in the vertical, longitudinal, and lateral directions for new masks was 2.02, 2.27, and 2.13 mm, respectively, and that for reused masks was 2.37, 1.96, and 2.33 mm, respectively. The population random error in the vertical, longitudinal, and lateral direction for new masks was 1.46, 1.54, and 1.57 mm, respectively, and that for reused masks was 1.65, 1.63, and 1.87 mm, respectively. The results showed no statistically significant difference supported by p value > 0.05 in the setup error between using the new and reused thermoplastic masks in all directions.

Conclusion: For head and neck radiotherapy, the population setup errors were < 3 mm in all directions. Moreover, thermoplastic masks can be reused in patients with head and neck cancer.

Keywords: Setup error, Head and neck cancer, Image-guided radiotherapy, Thermoplastic mask.

Introduction

There are many treatment methods for cancer, including radiotherapy, surgery, chemotherapy, and hormone therapy. Treatments can be used individually or in a combination. Radiotherapy is one of the most common methods for treatment of head and neck cancer [1-3]. Modern techniques are used in radiotherapy, including image-guided radiotherapy (IGRT), which uses an imaging system in the treatment room before or during radiotherapy [4-7]. This is a tool for improving the accuracy and precision of treatment delivery. In addition, immobilization devices are used to ensure the accurate positioning and repositioning of patients during treatment delivery, which can reduce the setup margin. Therefore, immobilization devices are necessary, especially thermoplastic masks for head and neck cancer [8-9].

A head-and-shoulder mask that covers the length from the head to the shoulder is used to immobilize the patient in the supine position [10-11]. However, the high cost of cancer treatment is related to the treatment techniques and immobilization devices. A thermoplastic mask is a device that is relatively expensive. Consequently, the mask is reused once more for low-income patients. However, accuracy and precision should be considered in patients undergoing radiotherapy. Therefore, the setup error should be evaluated to approve that the patient remains in the exact position during treatment delivery. The random errors are the deviations between different fractions that can vary in direction. Random errors introduced by organ motion and patient setup. The systematic errors are the deviations between the planned patient position and the average patient position over the entire course of treatment, which occurs in the same direction. Systematic errors introduced by target volume delineation, organ motion, and patient setup. The current study is a retrospective analysis aimed to investigate the setup errors in head and neck cancer patients with thermoplastic masks and to compare the setup errors of patients with new and reused thermoplastic masks.

Materials and methods

Institutional Review Board Statement: The study protocol was approved by Ethics Committee of Faculty of Medicine (REC 63-566-7-2), date of approval; 13/01/2021.

Treatment procedure

Eighty head and neck cancer patients were retrospectively evaluated. The number of patients with new and reused thermoplastic masks was 40 and 40 cases, respectively. The reused masks were reused only once. The masks were warmed and flattened using water bath before being moulded on the patient's skin. Computed tomography (CT) images were received using the Brilliance CT Big Bore (Philips, Amsterdam, The Netherlands), and a head-and-shoulder thermoplastic mask (Type-S™, CIVCO, IA, U.S.A.) was used to immobilize the patients with head and neck cancer. An example of the head-and-shoulder mask used in a patient is shown in Figure 1. The VMAT treatment plans were performed using the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA, USA). Patients were treated with 6 MV photon beams using TrueBeam STx and Unique machines (Varian Medical Systems.Inc., Palo Alto, CA). For treatment delivery, patients were positioned and immobilized in the same manner as in CT planning. Imaging, including electronic portal imaging device (EPID), 2D-kV planar (AP-Lat), or cone beam CT (CBCT), were performed on the first three fractions then weekly. The images were acquired more than 5 times in each patient. The registration was first performed automatically by the system and was then manually checked by radiological technologists and confirmed by treating oncologists to ensure that the matching was accurate. The registration between the acquired images and planning images was performed according to the bony and soft tissue anatomy. The patient positioning was modified using delta couch shift. The treatment couch was capable of shifting direction vertically (up and down), longitudinally (in and out), and laterally (right and left) without a rotational direction.

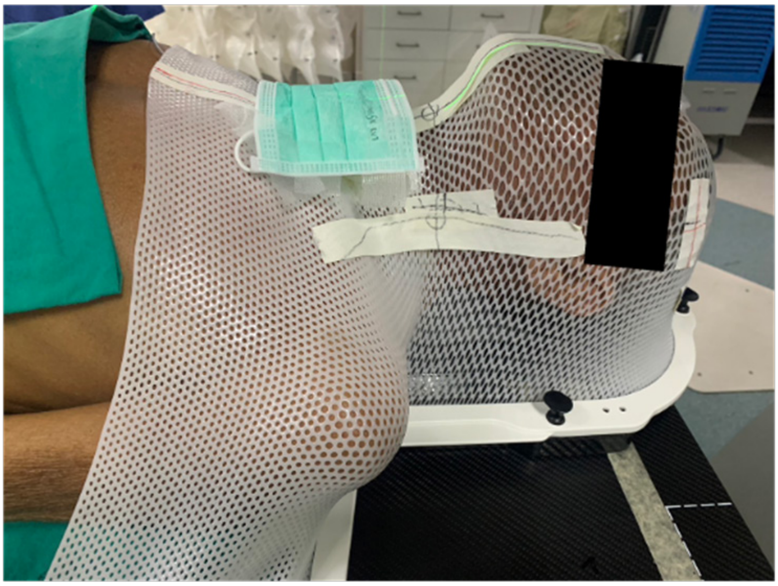

Figure 1. *An example of a head-and-shoulder thermoplastic mask used to immobilize the patient.*

Setup error quantification

Simulation images and pretreatment images (EPID, 2D-kV, or CBCT) were compared to calculate the setup errors. For all matches, the ARIA oncology information system with offline review (Varian Medical Systems.Inc., Palo Alto, CA) was used. The example of matching images during IGRT in offline review is shown in Figure 2. The setup errors, systematic error, population systematic error, random error, and population random error in the patients with head and neck cancer were determined. The setup errors or setup displacement is the difference between the actual and planed position of the patient. The mean of the averages and the standard deviation (SD) per axis were calculated. The systematic error (Σ) for an individual patient was represented by mean values of all the displacements. The population systematic error was estimated from the calculation of SD from the values of mean displacement for all patients. The random error (σ) for individual patient was assessed by SD per axis from calculation of systematic displacement. The population random error is the square root of the average of the sum of the SD^2 per axis for all patients. The PTV margin was calculated using Van Herk's formula ($2.5\Sigma+0.7\sigma$) [12-13]. The 3D vector length was calculated for every patient and averaged to give the mean 3D vector of displacement. Subsequently, the setup errors of patients were calculated by comparing the new and reused thermoplastic masks.

Statistical analysis

IGRT was performed according to the schedule. The positioning translations were determined in three directions: vertical, longitudinal, and lateral. Mean and standard deviation (SD) values were calculated for each patient. Individual systematic and random errors were determined. Subsequently, population systematic and random errors were determined. The systematic and random discrepancies in the population were calculated. Statistically significant differences between the two groups were compared. The normality of the data was checked by using the Shapiro–Wilk test. Significant differences between the two groups were determined using the Mann–Whitney U test [14-15]. Differences were considered statistically significant when p value < 0.05.

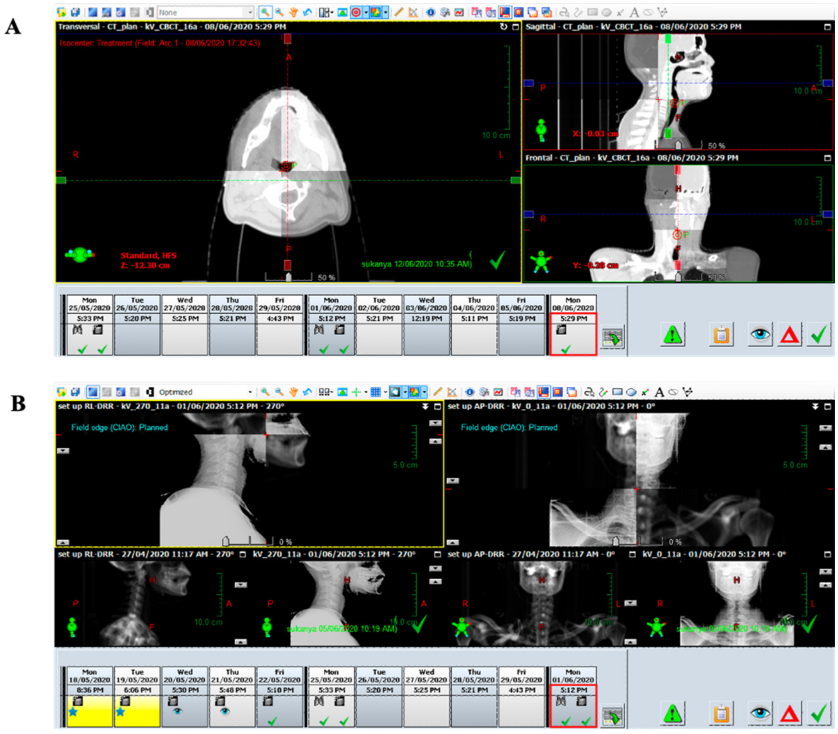

Figure 2. *An example of (A) CBCT and (B) 2D kV-OBI matching images during IGRT in Offline review image process.*

Results

Patient demographics

Eighty patients with head and neck cancer who underwent VMAT treatment with head-and-shoulder masks were included in this study. Patient demographics are summarized in Table 1. The median value BMI was 19.99 kg/m2 (range, 13.6 to 37.17 kg/m^2). The most common treatment site was the tongue, followed by the nasopharynx, tonsil, and pyriform sinus in 12, 10, 9, and 9 patients, respectively. The median number of images obtained per treatment was 9 (range, 4–22). Finally, 760 images were collected for analysis.

Table 1. *Correlation between BMD and various factors.*

Characteristics (N = 80)	
Age; years, median (range)	55.5 (25-87)
Gender; Male, n (%)	74 (92.50)
Female, n (%)	6 (7.50)
BMI; kg/m^2, median (range)	19.99 (13.6-37.17)
<18.5, n (%)	25 (31.25)
18.5-23, n (%)	36 (45.00)
≥23, n (%)	19 (23.75)
Imaging acquisition; number, median (range)	9 (4-22)
Imaging modality; n (%)	
EPID	20 (25.0)
2D-kV	6 (7.5)
CBCT	54 (67.5)
Treatment sites; n (%)	
Tongue	12 (15.00)
Nasopharynx	10 (12.50)
Tonsil	9 (11.25)
Pyriform sinus	9 (11.25)

Individual systematic error and individual random error

The individual systematic errors in the vertical, longitudinal, and lateral directions ranged from -3.8 to 2.7 mm, -2.9 to 3.5 mm, and -3.0 to 3.1 mm, respectively, for patients using new masks. The individual systematic error in the vertical, longitudinal, and lateral directions ranged from -4.4 to 2.1 mm, -2.0 to 4.4 mm, and -3.8 to 2.8 mm, respectively, for patients using reused masks. Individual systematic errors in the vertical, longitudinal, and lateral directions are shown in Figure 3.

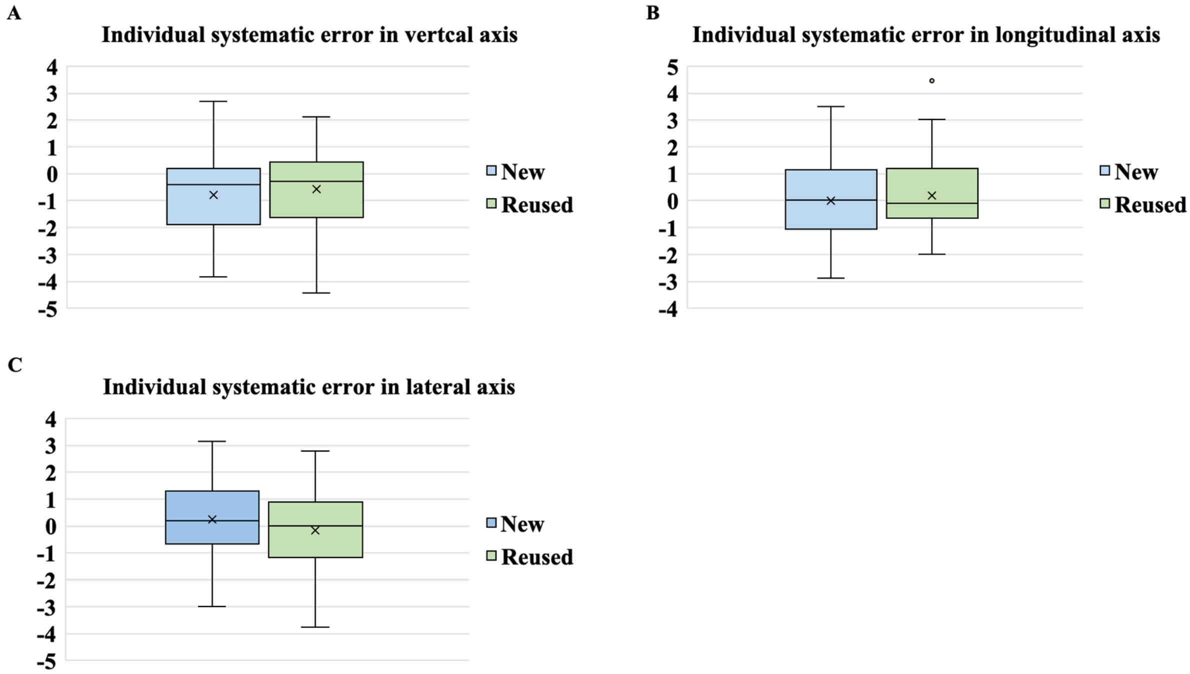

Figure 3. *Box plots of the individual systematic error in the (A) vertical, (B) longitudinal, and (C) lateral directions.*

The individual random error in the vertical, longitudinal, and lateral directions for patients using new masks ranged from 0.0 to 3.2 mm, 0.5 to 3.4 mm, and 0.5 to 3.3 mm, respectively. The individual random error in the vertical, longitudinal, and lateral directions for patients using reused masks ranged from 0.7 to 3.5 mm, 0.8 to 3.7 mm, and 0.5 to 5.9 mm, respectively. The individual run errors in the vertical, longitudinal, and lateral directions are shown in Figure 4.

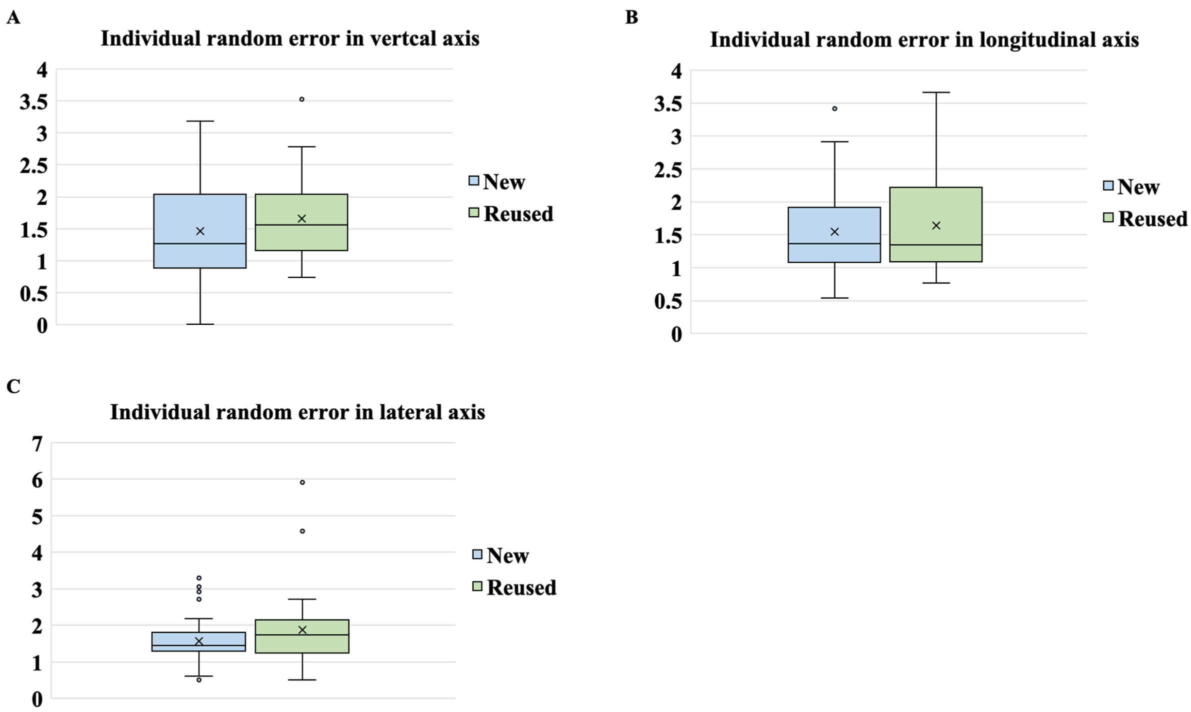

Figure 4. *Box plots of the individual random error in the (A) vertical, (B) longitudinal, and (C) lateral directions.*

Population systematic error and population random error

The population systematic error for patients using the new masks ranged from 2.02 to 2.27 mm, and for those with reused masks ranged from 1.96 to 2.37 mm. The population random error for patients using the new masks ranged from 1.46 to 1.57 mm and for those with reused ranged from 1.63 to 1.87 mm. The population systematic and random errors and CTV to PTV margins for patients using new and reused masks are shown in Table 2. The 3D vectors for combining setup errors in all directions of the new and reused masks were 6.8 mm and 7.2 mm, respectively.

Table 2. *Population systematic and random error and CTV to PTV margins in three directions.*

Axis	Population setup error (mm)				CTV to PTV margins (mm)	
	Systematic error		Random error			
	New	Reuse	New	Reuse	New	Reuse
Vertical	2.02	2.37	1.46	1.65	6.072	7.080
Longitudinal	2.27	1.96	1.54	1.63	6.703	6.041
Lateral	2.13	2.33	1.57	1.87	6.424	7.134

Setup error between using the new and reused thermoplastic masks

The differences in systematic and random errors between the new and reused thermoplastic masks are listed in Table 3. No statistically significant difference was found in the individual systematic error along the vertical, longitudinal and lateral directions between the new and reused masks.

Table 3. *The difference in systematic and random error between using the new and reuse thermoplastic masks.*

Setup error	Axis	Mask	Mean Rank	Mann-Whitney U	p value
Systematic	Vertical	New	-0.805	-0.700	0.486
		Reuse	-0.573		
Systematic	Longitudinal	New	-0.004	-0.595	0.553
		Reuse	0.189		
Systematic	Lateral	New	0.227	1.208	0.231
		Reuse	-0.177		
Random	Vertical	New	1.457	-1.237	0.220
		Reuse	1.651		
Random	Longitudinal	New	1.538	-0.605	0.547
		Reuse	1.630		
Random	Lateral	New	1.566	-1.660	0.101
		Reuse	1.868		

No statistically significant difference was found in individual random error along the vertical, longitudinal and lateral directions between the new and reused masks as shown in Table 3.

Discussion

Eighty patients who underwent VMAT radiotherapy for head and neck lesions with 760 images were analyzed. Setup errors in patients with head and neck cancer using head-and-shoulder thermoplastic masks were determined. Furthermore, the setup errors of patients using new and reused thermoplastic masks were compared. Individual systematic errors for patients using new masks were found to have maximum values of 3.8, 3.5, and 3.1 mm in the vertical, longitudinal, and lateral directions, respectively. For patients using reused masks, systematic errors were determined to have maximum values of 4.4, 4.4 and 3.8 mm in the vertical, longitudinal, and lateral directions, respectively. Individual random errors for patients using new masks had maximum values of 3.2, 3.4 and 3.3 mm in the vertical, longitudinal, and lateral directions, respectively. For patients using reused masks, the random errors in the vertical, longitudinal, and lateral directions were 3.5, 3.7 and 5.9 mm, respectively. The systematic and random error values were comparable. Individual errors of up to 5.9 mm were observed, which is consistent with a previous study that revealed a maximum individual error value of 6.8 mm [16].

The current study observed that the population systematic error for patients using new masks ranged between 2.02 and 2.27 mm. The values for patients using reused masks varied from 1.96 to 2.37 mm. The random population error for patients using the new mask was 1.46 - 1.57 mm. For patients using reused masks, the random error was 1.63 - 1.87 mm. The error in the longitudinal direction was highest for patients using new masks, which is consistent with a previous study that indicated that the error in the longitudinal direction was the largest [13]. However, our findings showed that the error in the vertical direction was highest for patients using reused masks. In a previous study that evaluated setup errors in three directions, it was reported that the setup error was < 3 mm for head and neck radiotherapy treatment, which is consistent with the findings of this study for both patients using new and reused masks. In addition, this research is consistent with previous research, which investigated setup errors in different types of masks, and showed that the setup errors were < 2.4 mm [17-20].

Several mathematical formulae have been introduced for calculating CTV to PTV margins. Van Herk' formula seems to be the most appropriate as it ensures that the patients receive the optimal CTV dose for target coverage. In the present study, the CTV to PTV margins in all directions for new and reused masks were less than 7 and 7.5 mm, respectively. The suggestion when using reused masks is setup margins that are larger than new masks. On analyzing the statistical difference between the two types of masks, it was noted that the individual systematic errors in the vertical, longitudinal, and lateral directions had p values of 0.319, 0.553, and 0.231, respectively. The p-values for the individual random errors in the vertical, longitudinal, and lateral directions were 0.220, 0.855, and 0.161, respectively. Thus, the systemic and random errors associated with the use of new masks and reused masks were not significantly different ($p < 0.05$).

Conclusion

For head and neck radiotherapy, the population setup errors were < 3 mm in all directions. Most errors associated with the reuse of masks were larger than those associated with the new masks. However, the errors were not significantly different. Consequently, they may be considered appropriate alternatives. Nevertheless, in terms of limitations of this study, the reused masks were reused only once because the number of times that a mask was reused influenced its elasticity. Furthermore, the patient setup was corrected in three translational directions without the rotational direction. The results of this research can be used as guidelines for selecting masks for low-income patients or patients who use fundamental techniques.

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