Journal of Medical Radiation Sciences

Open Access

ORIGINAL ARTICLE

Comparison of set up accuracy among three common immobilisation systems for intensity modulated radiotherapy of nasopharyngeal carcinoma patients

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Keywords
Cone beam CT, immobilisation system, intensity modulated radiotherapy, nasopharyngeal carcinoma, set up accuracy

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Funding Information
No funding information provided.

Chen-guang Lin and Sen-kui Xu have equal contribution in this paper.

Received: 8 January 2016; Revised: 20 July 2016; Accepted: 22 July 2016

J Med Radiat Sci **64** (2017) 106–113

doi: 10.1002/jmrs.189

Abstract

Introduction: In intensity modulated radiotherapy (IMRT) of nasopharyngeal carcinoma (NPC) patients, an effective immobilisation system is important to minimise set up deviation. This study evaluated the effectiveness of three immobilisation systems by assessing their set up deviations. **Methods:** Patients were randomly assigned to one of the three immobilisation systems: (1) supine on head rest and base plate (HB); (2) supine with alpha cradle supporting the head and shoulder (AC); (3) supine with vacuum bag supporting the head and shoulder (VB). CBCT was conducted weekly for each patient on the linear accelerator. Image registration was conducted at the nasopharynx (NP) and cervical regions. The translational displacements (latero-medial, antero-posterior and cranio-caudal), rotational displacements (pitch, yaw and roll) and 3D vectors obtained at the NP and cervical regions were recorded and compared among the three systems. **Results:** The mean translational and rotational deviations were within 3 mm and 2°, respectively, and the range of 3D vector was 1.53–3.47 mm. At the NP region, the AC system demonstrated the smallest translational and rotational deviations and 3D vector. The differences were significant except for the latero-medial, yaw and roll directions. Similarly, at the cervical region, the AC system showed smaller translational and rotational deviations and 3D vector, with only the cranio-caudal and yaw deviations that did not reach statistical significance. **Conclusions:** Set up deviation was greater in the neck than the NP region. The set up accuracy of the AC system was better than the other two systems, and it is recommended for IMRT of NPC patients in our institution.

Introduction

The goals of radiotherapy are to maximise tumour control and minimise complications in the organs at risk (OARs). The success of radiotherapy depends on the accuracy and reproducibility of daily treatment delivery.[1,2] Many studies showed that an effective immobilisation system can reduce positioning variations[3–5] and improve the outcome of radiotherapy. With the introduction of many commercially available immobilisation devices and accessories, radiation oncology departments have developed their own immobilisation systems for specific cancer patients and radiotherapy techniques based on their available resources and treatment protocols.[6–8] It is in the interest of the clinicians to understand the effectiveness of individual immobilisation devices and establish an optimal system that offers the least set up deviations during treatment.

For this reason, many studies have been conducted in the past to investigate the effectiveness of different immobilisation systems, and many of which employed portal imaging as the verification method.[9,10] However, since portal images can only provide two-dimensional (2D) information, it is difficult to detect three-dimensional (3D) and rotational set up errors. The recent integration of computed tomography (CT) with the radiotherapy treatment machine has solved this problem and provides a

3D verification application.[11] Such systems include the cone beam computed tomography (CBCT) capability available in many linear accelerators. Many previous studies including the one by Li et al. have already demonstrated that the 3D approach in CBCT was superior to the 2D portal images in the verification of head and neck patients.[12,13]

CBCT incorporated in a linear accelerator provides more detailed set up data and is more reliable in assessing positional deviations compared to the portal imaging method. Furthermore, the data collected from the CBCT verification system can be used to generate the systematic and random errors of each treatment, which are useful for the evaluation of set up accuracy.

Nasopharyngeal carcinoma (NPC) is a common cancer in southern China. Advanced radiotherapy techniques such as intensity modulated radiotherapy (IMRT) are routinely used for treating NPC. As IMRT delivers a highly conformal radiation dose to the target with steep dose gradients at the target boundary, a slight deviation of the dose distribution due to set up error may lead to dramatic dosimetric changes. As a result, geometric miss of the target leading to treatment failure and adjacent OARs may receive unexpected high dose leading to undesirable complications.

The aim of this study was to evaluate the effectiveness of three commonly used immobilisation systems for NPC by assessing their set up deviations generated from CBCT data. The results would provide reference information for the choice of immobilisation devices for treating NPC patients, which would lead to more accurate treatment and subsequently better treatment outcomes.

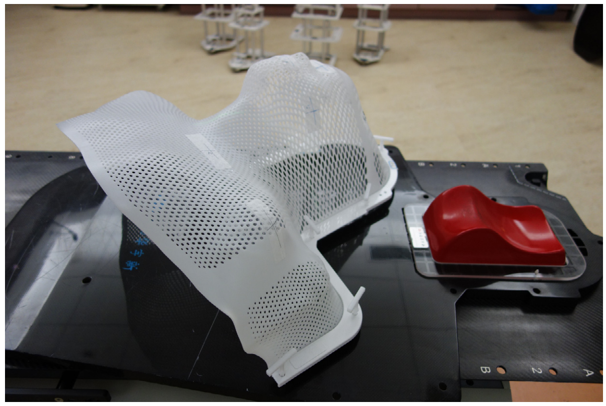

Figure 1. Photo showing the immobilisation system of HB group: supine on head rest and base plate with thermoplastic shell covering the skull.

Methods

The three types of immobilisation systems commonly used for IMRT of NPC patients in the local oncology department were: (1) patient lying supine on head rest and base plate with thermoplastic shell covering the skull (HB system) (Fig. 1); (2) patient lying supine with alpha cradle supporting the head, neck and shoulder, and with thermoplastic shell covering the head and neck down to upper chest (AC system) (Fig. 2); (3) patient lying supine with vacuum bag supporting the head, neck and shoulder, and with thermoplastic shell covering the head and neck down to upper chest (VB system) (Fig. 3).

A total of 77 primary NPC patients treated by a standard course of IMRT were recruited between 2011 and 2013. They were randomly assigned to each of the three immobilisation systems. The original plan was to recruit 30 patients in each group, but due to some interruptions and unexpected changes during the treatment course, some patient data were discarded from the study and the number of patients in the HB, AC and VB systems were 29, 27 and 21 respectively. The patient characteristics are shown in Table 1. Ethical approval was obtained from the Cancer Hospital, Sun Yat-sen University. Each patient was treated with equal-spaced nine fields using 6 MV photons and was prescribed with a planning target volume (PTV) dose of 66 Gy in 33 daily fractions. The PTV covered from primary NP tumour at the base of skull to the bilateral neck lymphatics with margins. Kilovoltage CBCT verification was conducted weekly in the Synergy (Elekta, Stockholm, Sweden) linear accelerator using the XVI volumetric imaging system. Ideally, daily CBCT would give more reliable results, however due to the resources constraint in the department, weekly CBCT verification was the routine and this was a limitation of this study. Therefore, for a 6½-week treatment course, a total of six CBCTs were performed for each patient. In each treatment fraction, the patients of each group were set up in the treatment position using their respective immobilisation systems. During each CBCT session, the patient was scanned using parameters of 100 kV and 10 mA with a field of view of 27.7 cm in diameter and scanning angle of 160–200°. After each scan, the CBCT images generated were matched with the planning kVCT following the local IGRT Working Group guidelines using the software of the XVI volumetric imaging system. The CBCT images were first automatically registered with the planning kVCT images using the bony anatomy as reference followed by manual refinement. It was reported by Lin et al.[14] that in the IMRT of NPC, where the target volumes extended from base of skull to the lower cervical region, the set up deviations were significantly different between the NP region and cervical region parts. Therefore, the image registration in this study was

Figure 2. Photos showing the immobilisation system of AC group: supine with alpha cradle supporting the head to shoulder, and with thermoplastic shell covering the head and neck down to upper chest.

Figure 3. Photos showing the immobilisation system of VB group: supine with vacuum bag supporting the head and shoulder, and with thermoplastic shell covering the head and neck down to upper chest.

conducted in two stages: the first matching was carried out at the NP region (from sella turcica to upper atlas), while the second stage was conducted by matching the second to sixth cervical spines (cervical region). All the matching work was carried out by the same radiation therapist to eliminate inter-operator variation. Although having a single operator might introduce a systematic error to the results, this error was minimised by having a 'double check' system by another radiation therapist and the radiation therapist conducting the study had over 5 years of experience in conducting CBCT verification. When the image registration was completed, the translational position deviations at the medial–lateral (x), cranial–caudal (y) and anterior–posterior (z) directions and rotational deviations of pitch, yaw and roll were displayed in the monitor, the absolute values of these deviations were recorded. If the deviation was large and exceeded the local tolerance (2 mm or 2°), re-adjustment and re-matching of the patient's position were carried out. However, only the readings of the deviation generated from the first matching (non-corrected results) were taken for analysis in this study. The evaluation of the effectiveness of each immobilisation system was based on their respective set up deviations in the three axes after matching. In addition, while the rotational deviations were presented to provide clarity on their magnitude, the 3D vector was used, which was an indicator of the resultant displacement of the treatment position from the reference position[4,15] and calculated using the formula:

$$\text{3D vector} = \sqrt{[(\text{lateral deviation})^2 + (\text{longitudinal deviation})^2 + (\text{vertical deviation})^2]}.$$

The translational displacements and the 3D vectors obtained from the NP and cervical regions were compared among the different immobilisation systems. The smaller the value of the deviation, the better accuracy was the immobilisation system. The differences in the deviation means were analysed using the one-way ANOVA followed by the post hoc Tukey test when $P < 0.05$ using the SPSS (19.0) software (IBM, New York, US).

Results

A total of 407 sets of CBCT images were collected from the 77 patients. Each patient underwent six sets of CBCT throughout the radiotherapy course on a weekly basis.

Table 1. Patient characteristics of the three immobilisation groups.

	VB	AC	HB
Patient number (n)	29	27	21
Gender			
Male	18	19	18
Female	11	8	3
Stage			
I	2	2	2
II	4	4	2
III	15	18	15
IV	6	3	3
Age			
Maximum	76	69	66
Minimum	22	25	30
Median	43	45	44
Mean	43.9	45.6	46.3

VB, vacuum bag system; AC, alpha cradle system; HB, head rest + base plate system.

The mean translational and rotational deviations obtained when the matching was conducted at the NP and cervical regions were all within 3 mm and 2°, respectively, whereas for the mean 3D vectors, they ranged from 1.53 to 3.47 mm.

When the matching was performed at the NP region, the AC system demonstrated the smallest in all the directional and rotational deviations. The differences were significant except for the *x*, yaw and roll directions ($P = 0.375$, 0.609 and 0.123 respectively) (Table 2). When comparing the mean 3D vector among the three systems, the AC system also demonstrated a significantly lower deviation relative to the other two systems ($P = 0.001$) (Fig. 4). Similarly, when the matching was performed at the cervical region, the AC system showed lower translational and rotational deviations with only the *y*-direction deviation that did not reach statistical significance ($P = 0.052$) (Table 3). For the mean 3D vector, the VB system was also significantly smaller ($P < 0.044$) (Fig. 5).

Based on the results of this study, our team further estimated the margins that were added to the clinical target volume to form the planning target volume (CTV–PTV margins) in each direction by adopting the van Herk's margin recipe[16] in which the margin is equal to 2.5Σ (systematic error) + 0.7σ (random error) (Table 4).

Discussion

The recent advancement in radiotherapy techniques including IMRT for NPC has offered better target dose conformity and steeper dose gradients at the target boundary. It is the reason why a more sophisticated immobilisation technique is required to avoid positional deviation during treatment, as even a small displacement may lead to serious dosimetric changes in the target and OARs.

In our study, the overall set up accuracy performed by the three immobilisation systems for the NPC patients was satisfactory, with most of the mean set up deviations fell within 3 mm, compared to the 2 mm tolerance for IMRT of head and neck cancers in the local department. There were differences in set up accuracy when comparing among the three different immobilisation systems. The AC system demonstrated the best immobilisation results as its mean translational and rotational deviations and 3D vector were lower than the other two systems (HB and VB), whereas the results from the VB and HB systems did not show any significant difference.

The head rest and base plate system (HB) has been the conventional immobilisation system in the local department. Although there is a range of head rest sizes and shapes provided from the supplier, they cannot fit the shape and curvature of the head and neck for all patients. Gaps between patient and the head rest may

Table 2. Comparison of translational deviations among the three immobilisation systems when the matching was performed around the nasopharynx region.

	Set up deviations				
	VB (n = 153) Mean ± SD	AC (n = 137) Mean ± SD	HB (n = 117) Mean ± SD	ANOVA *P* value	Ranking after post hoc test
x-axis (mm)	1.02 ± 0.74	0.92 ± 0.71	1.03 ± 0.80	0.375	
y-axis (mm)	1.06 ± 0.75	0.80 ± 0.61	1.10 ± 0.93	0.002	VB, HB > AC
z-axis (mm)	0.82 ± 0.66	0.56 ± 0.47	0.91 ± 0.61	0.001	VB, HB > AC
Pitch (°)	0.73 ± 1.01	0.31 ± 0.87	0.49 ± 0.73	0.001	VB > HB, AC
Yaw (°)	0.77 ± 1.07	0.64 ± 0.98	0.75 ± 1.47	0.609	
Roll (°)	0.35 ± 1.09	0.18 ± 0.91	0.42 ± 0.87	0.123	
3D vector (mm)	1.93 ± 0.83	1.53 ± 0.60	2.00 ± 0.97	0.001	VB, HB > AC

VB, vacuum bag system; AC, alpha cradle system; HB, head rest + base plate system.

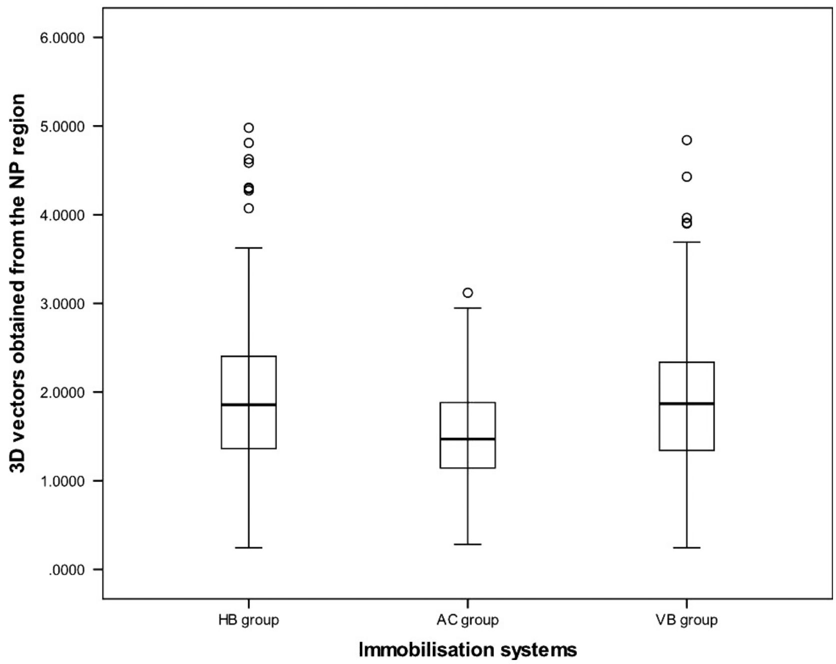

Figure 4. Comparison of average translations deviations among the three immobilisation systems when the matching was performed at the nasopharynx region.

Table 3. Comparison of translational deviations among the three immobilisation systems when the matching was performed around the cervical region.

	Set up deviations				
	VB (*n* = 153) Mean ± SD	AC (*n* = 137) Mean ± SD	HB (*n* = 117) Mean ± SD	ANOVA *P*-value	Ranking after post hoc test
x-axis (mm)	1.68 ± 1.41	1.25 ± 1.07	2.11 ± 1.67	<0.001	VB, HB > AC
y-axis (mm)	2.20 ± 2.08	1.70 ± 1.72	1.64 ± 1.28	0.052	
z-axis (mm)	1.29 ± 1.16	0.96 ± 0.84	1.46 ± 1.09	0.002	VB, HB > AC
Pitch (°)	1.57 ± 1.17	0.85 ± 1.76	0.92 ± 1.84	0.002	VB > HB, AC
Yaw (°)	0.35 ± 1.69	0.58 ± 1.56	0.81 ± 1.28	0.052	
Roll (°)	0.58 ± 1.52	0.16 ± 1.40	0.16 ± 1.08	0.012	VB > HB, AC
3D vector (mm)	3.52 ± 2.13	2.70 ± 1.70	3.47 ± 1.66	0.044	VB, HB > AC

VB, vacuum bag system; AC, alpha cradle system; HB, head rest + base plate system.

occur and result in less stable patient position. The vacuum bag system (VB) was introduced a few years ago in the local department. It uses a tailor made vacuum bag placed at the back of the patient. By evacuating air from the bag, it fits the posterior part of the head to the upper chest. However, the bag often cannot provide a deep enough depression to stabilise the head and air leakage sometime happens in the later part of the treatment course. The shortcomings of these two immobilisation systems could be the reasons for the relatively greater set up discrepancies obtained in this study. The alpha cradle system (AC) is a recently introduced immobilisation system in which an alpha cradle back rest is tailor made by mixing two chemical compounds in a plastic bag for the patients. The expanded mixture solidifies and wraps around the posterior half of the patient from the posterior skull down to the neck and both shoulders. Such patient-specific head support has been proven to give positive effect in immobilisation during radiotherapy of head and neck cancer patients.[17] Although the alpha cradle material is not re-usable, the immobilisation system is more robust and durable.

When the matching was performed with structures at the NP region, the set up deviation along the *x*-axis did not show significant difference. This could be explained by the fact that the immobilisation effect at the head region was

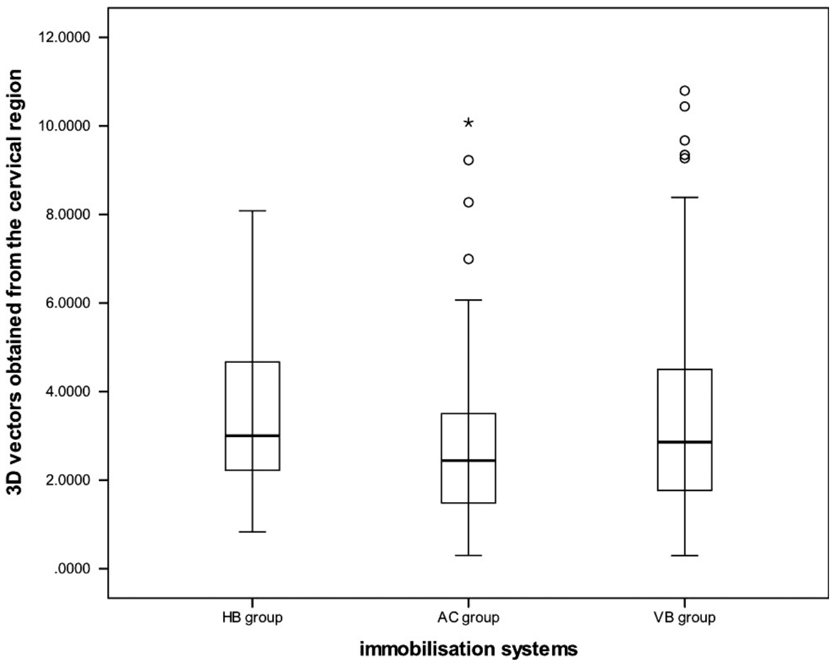

Figure 5. Comparison of average translations deviations among the three immobilisation systems when the matching was performed at the cervical region.

Table 4. Estimated CTV–PTV margins of *x*-, *y*- and *z*- axes for the three immobilisation systems.

	Estimated margin (mm)					
	Nasopharynx region			Cervical region		
	VB	AC	HB	VB	AC	HB
x-axis	2.6	2.0	3.3	5.0	3.6	6.0
y-axis	3.2	2.3	3.5	6.0	5.8	4.7
z-axis	2.2	1.6	2.4	3.8	2.9	4.1

Calculation was referenced from the margin recipe reported by van Herk et al.[16] VB, vacuum bag system; AC, alpha cradle system; HB, head rest + base plate system.

effectively controlled by the thermoplastic shell as it was tightly fitted to the patient's anterior contour up to the lateral side of the head. This restricted the shifting of the head along the lateral–medial direction. For the cranial–caudal direction (*y*-axis), the HB system did not have any constraint at the vertex and the head depression in the VB system was relatively shallow, the movement along this direction tended to be greater than the AC system. For the antero-posterior direction (*z*-axis), since the fitting of the head to the head rest was less perfect in the HB and VB system than that with the AC system, the vertical displacement of the head would be relatively greater.

When the matching was performed at the cervical region, there was virtually nothing at the back of the neck and shoulders in the HB system and a relatively flat padding was present in the VB system to support the neck and shoulders. A study by Nuebauer et al. reported that shoulder motion existed in radiotherapy of head and neck cancers and had dosimetric impacts on IMRT.[18] Therefore, the HB and VB systems were both less effective to restrict the antero-posterior (*z*-axis) and lateral–medial (*x*-axis) displacements of the neck and shoulders compared with the AC system, which had the alpha cradle chemical compound filling the entire gap between the posterior neck, shoulders and base plate. For the cranio-caudal direction (*y*-axis) at the neck region, the immobilisation effect was mainly dependent on the head region where the thermoplastic shell played a more important role; therefore, the difference among the three immobilisation system along this direction became less significant. In the radiotherapy of the neck region in NPC, deviations in the antero-posterior direction (*z*-axis) might unnecessarily increase the dose to the spinal cord, while deviations in the medio-lateral direction (*x*-axis) may lead to geometric miss of the cervical lymphatic targets. The extent of dosimetric impacts on the targets and spinal cord can be followed up by further studies. The AC system, that demonstrated relatively smaller mean *z*- and *x*-direction deviations in the neck region in this study, may be able to better minimise these two set up uncertainties compared with the other two systems.

In addition, the set up deviation in the cervical region was generally greater than that of the NP region for all the three immobilisation systems, indicating that the immobilisation effect was less effective in the neck region. This result was consistent with the study from Lin et al.[14] and it would be a good reference to the oncologists when they decide planning target margin; a larger margin may be required for target at the neck region.

The results of margin estimation based on this study (Table 4) would be the basis for the creation of non-uniform CTV–PTV margins for NPC patients. In accordance to the results of set up deviations, the AC system demonstrated the smallest margins in both NP and cervical regions, while the margins for the VB and HB groups did not show much difference in most directions. In general, the margins required in the cervical region were larger than those of the NP region.

Although a similar study has been conducted for head and neck cancer,[19] our study evaluated different immobilisation systems and was the first one performed solely on radiotherapy of NPC, which was unique in a way that the treatment fields extended from the base of skull to the supraclavicular fossa. Because of this, the immobilisation region covered from the vertex down to the upper chest. A related study from Cheng et al.[20] that included the comparison of two immobilisation systems in head and neck patients reported that the Orfit system (Orfit Industries NV, Wijnegem, Belgium) was better than the standard head rest system indicating that conventional head rest system was not adequate for head and neck immobilisation, which was consistent with our study.

Despite our study was focused on NPC patients, the results provide useful reference in designing an optimum immobilisation system for radiotherapy of other head and neck cancers, especially when the treatment fields extend from the head to the lower neck region. When considering the cost, the materials for the HB and VB systems are reusable and therefore are relatively cheaper than the AC system. However, since set up accuracy is of higher priority in treating NPC patients, the AC system was recommended.

Conclusion

The three immobilisation systems for NPC patients offered acceptable set up accuracy, in which the set up deviation was generally greater in the neck than the NP region. When comparing the three systems, the performance of the AC system was better than the other two as it demonstrated the smallest 3D vector and translational deviations when the matching was conducted in both the NP and cervical regions, and therefore it is recommended for IMRT of NPC patients in the local institution.

Conflict of Interest

The authors declare no conflict of interest.

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