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CLINICAL INVESTIGATION **Head and Neck**

COMPARISON OF REPOSITIONING ACCURACY OF TWO COMMERCIALLY AVAILABLE IMMOBILIZATION SYSTEMS FOR TREATMENT OF HEAD-AND-NECK TUMORS USING SIMULATION COMPUTED TOMOGRAPHY IMAGING

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Purpose: To compare the setup accuracy, comfort level, and setup time of two immobilization systems used in head-and-neck radiotherapy.

Methods and Materials: Between February 2004 and January 2005, 21 patients undergoing radiotherapy for head-and-neck tumors were assigned to one of two immobilization devices: a standard thermoplastic head-and-shoulder mask fixed to a carbon fiber base (Type S) or a thermoplastic head mask fixed to the Accufix cantilever board equipped with the shoulder depression system. All patients underwent planning computed tomography (CT) followed by repeated control CT under simulation conditions during the course of therapy. The CT images were subsequently co-registered and setup accuracy was examined by recording displacement in the three cartesian planes at six anatomic landmarks and calculating the three-dimensional vector errors. In addition, the setup time and comfort of the two systems were compared.

Results: A total of 64 CT data sets were analyzed. No difference was found in the cartesian total displacement errors or total vector displacement errors between the two populations at any landmark considered. A trend was noted toward a smaller mean systemic error for the upper landmarks favoring the Accufix system. No difference was noted in the setup time or comfort level between the two systems.

Conclusion: No significant difference in the three-dimensional setup accuracy was identified between the two immobilization systems compared. The data from this study reassure us that our technique provides accurate patient immobilization, allowing us to limit our planning target volume to <4 mm when treating head-and-neck tumors.

Immobilization, Mask system, Repositioning accuracy, Radiotherapy, Head-and-neck tumor.

INTRODUCTION

Accurate and reproducible positioning throughout a treatment course is critical in fractionated radiotherapy (RT) of patients with head-and-neck (H&N) tumors. Treatment setup inaccuracies can lead to underdosing of the target volume, increasing the risk of treatment failure. Conversely, setup errors can lead to overdosing of adjacent normal tissues and organs at risk (*e.g.,* salivary glands, eyes, optic chiasm, brain stem), which could result in increased treatment morbidity. Setup precision and intertreatment position reproducibility becomes particularly important in intensity-modulated RT, for which minimizing safety margins around a clinical target volume is necessary to safely deliver higher radiation doses to target volumes situated in close proximity to critical structures.

Various invasive and noninvasive immobilization systems have been developed over the years for H&N RT to ensure reliable alignment and accurate repositioning between and during daily treatments. The design of such devices must ensure adequate rigidity for maximal immobilization and an adequate level of comfort to ensure patient compliance. Invasive devices have typically been used for the treatment of intracranial lesions using stereotactic RT. Patients with extracranial tumors are more commonly immobilized using less-invasive techniques. The device routinely used in our radiation oncology department is the standard thermoplastic head-and-shoulder mask fixed to a carbon fiber base plate. Although peer-reviewed data on H&N repositioning accuracy are rather limited, the range of setup inaccuracies using

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such mask systems have been reported at 2–5 mm in the anteroposterior (AP), craniocaudal (CC), and mediolateral (ML) directions (1–5).

The accuracy of patient repositioning is ascertained by determining the displacement between the actual patient position for a given treatment session and the intended position established at treatment planning. The intended patient treatment position must be registered as a reference image using any of a number of simulator imaging modalities and specific structures such as anatomic landmarks or radiopaque markers are identified as points of reference from which displacement errors can be calculated. Serial imaging in the treatment position is acquired during the treatment course and compared with the reference image with respect to the location of the pre-established reference points. Displacement errors may occur and can be measured in any of the three cartesian dimensions as described by El-Gayed *et al*. (6). These displacements can be of two types: systematic and random setup errors. The systematic component corresponds to the deviation that is constant throughout the entire treatment course. Among the many factors that can result in systematic errors, inaccuracy in transferring the patient from the simulator to the treatment couch is the most common. Random setup errors correspond to the interfraction deviations. These errors arise from a multitude of factors, such as random patient movements, inadvertent misalignment or inaccurate patient positioning by radiation therapists, and organ motion.

Although analysis of displacements along each individual cartesian axis provides useful directional information, a summation of these orthogonal displacements in the form of a three-dimensional (3D) vector length provides a more global assessment of spatial deviations from a specific reference point. Immobilization of the shoulders, as well as the head and neck, is thought to decrease overall setup inaccuracies.

The Accufix cantilever board equipped with the Bear-Claw shoulder depression system is a more recent addition to the inventory of immobilization systems available to H&N radiation oncologists. No comparative data are available for the Accufix system *vis-à-vis* the standard head-and-shoulder mask immobilization system (Type S). Consequently, we performed a comparative prospective study of the two immobilization systems treating patients with H&N tumors in the radiation oncology department of the Jewish General Hospital of McGill University. The purpose of this study was to compare the setup accuracy, comfort level, and ease of use of these two commercially available immobilization systems used in H&N RT.

METHODS AND MATERIALS

Patient cohort and immobilization devices

Between February 2004 and January 2005, 21 patients undergoing RT for H&N tumors were prospectively entered into the study after the patients provided consent. No explicit inclusion or exclusion criteria were specified for participation. All patients were treated locoregionally with 3D-conformal RT, and no patient experienced significant weight loss requiring readjustment of their treatment plan. The patients entered into the study were consecutively assigned to one of the two commercially available H&N immobilization devices evaluated in this prospective study: a standard perforated thermoplastic head-and-shoulder mask fixed to a carbon fiber base plate (Type S) (10 patients) or a perforated thermoplastic head mask fixed to the Accufix cantilever board equipped with the Bear-Claw shoulder depression system (11 patients) (Fig. 1).

The Type S immobilization technique consists of a carbon fiber base plate with slots to stabilize the head supports and vacuum cushion supports. The customized perforated thermoplastic masks used in this technique encompass the patient's head, neck, and shoulders and are fastened to the base plate by rigid polymer attachments. The Accufix immobilization technique consists of the manufacturer's radiolucent carbon fiber cantilever board, which accommodates head and vacuum cushion supports. The cantilever board can be implemented using almost any treatment or simulation table. The Accufix cantilever board used in this study was also equipped with the Accufix carbon fiber Bear-Claw shoulder depression system. This fully adjustable shoulder depression system was conceptualized to enhance patient immobilization and setup reproducibility while avoiding the need for molding the shoulders with a large thermoplastic sheet. Perforated Aquaplast RT thermoplastic head masks were used in the Accufix system. In both techniques, a customized support conforming to the posterior contour of the patient's head and neck was made using radiolucent vacuum cushions filled with small polystyrene beads.

Image acquisition and analysis

All patients underwent treatment simulation using a dedicated RT computed tomography (CT) simulator. During the planned RT course, repeated control CT imaging was acquired using the same CT simulator for each patient under simulation conditions. Generally, one control CT study was performed per week of therapy. The number of control CT studies acquired per patient was dictated by the availability of the CT simulator, as well as that of the dedicated radiation oncology technicians who operate the facilities, and ranged from two to five studies (median, three) per patient. The CT image slice thickness was 3 mm for both the initial simulation and the control CT studies. The voxel size of the images acquired using our CT simulator was 1.17 mm $\times$ 1.17 mm $\times$ 3 mm. Thus, the systematic position uncertainty arising from the limited spatial resolution of our CT simulator was about 0.59 mm $\times$ 0.59 mm $\times$ 1.5 mm (CT voxel dimension/2).

All CT images from the treatment simulation studies and control sessions were analyzed using the AQ-Sim treatment planning software. Six bony landmarks (right styloid process, left styloid process, odontoid, spinous process of C7, and acromial extremities of the right and left clavicles) were manually outlined on the simulation CT images and saved as templates. The simulation CT studies were then co-registered to each CT control study using lead markers at three laser projection points on the masks. The contours of the six bony landmarks on the simulation images were visualized on the control studies, and deviations in terms of translocation displacements were calculated in all three cartesian planes for each previously specified landmark in relation to the simulation CT outlined structures (Fig. 2). The measurements were recorded in a manner so as to account for the directionality of displacements by respecting the axis positivity and negativity. The AP and ML displacements were measured using the AQ-Sim software measurement tool, with the greatest displacement in either of the individual one-dimensional directions recorded to 1 decimal point in millimeters. The CC displacements were visually approximated on the basis of the known 3-mm thickness of each CT image slice. Hence, each CT control

Fig. 1. Two types of immobilization devices used in study. (A) Type S carbon fiber base plate. (B) Type S thermoplastic head-and-shoulder mask fixed to the carbon fiber base plate. (C) Accufix cantilever base board. (D) Thermoplastic head mask fixed to Accufix cantilever board with Bear-Claw shoulder depression system.

image acquired generated a total of 18 one-dimensional displacements (540 for Type S and 612 for Accufix). Outlining all the bony landmark structures and all the measurements of displacement was conducted by the same investigator to avoid interinvestigator variations.

Comparison of immobilization setup time

To evaluate the ease of use of the two immobilization systems during a course of fractionated RT, the radiation therapists were asked to record the time required to immobilize the patients for the initial simulation phase, as well as for each of the subsequent control CT imaging sessions. The same team of radiation therapists performed the immobilization of patients for both immobilization systems throughout the study.

Patient comfort survey

To evaluate patient comfort of the standard Type S and the Accufix immobilization systems, the patients were asked to complete a survey of four questions, separately evaluating their head comfort, shoulder comfort, degree of breathing difficulties, and extent of shoulder mobility (Appendix). The patients were asked to rate their comfort on a visual scale of 1 to 10, with a score of 10 representing the least comfortable state. Patients were asked to complete their questionnaire on concluding their RT course.

Statistical analysis

For each patient, we measured the translocation between the simulation CT study and each individual control CT study for each of the three cartesian dimensions at each bony landmark. Thereafter, the systematic and random displacements between the simulation CT and control CT scans were calculated for each bony landmark using the approach described by El-Gayed *et al.* (6) and outlined below. Mathematically, the systematic error for a particular patient and for a specific reference point in a particular cartesian dimension is expressed as the mean of all displacements during their treatment course. For the entire population, the systematic error is

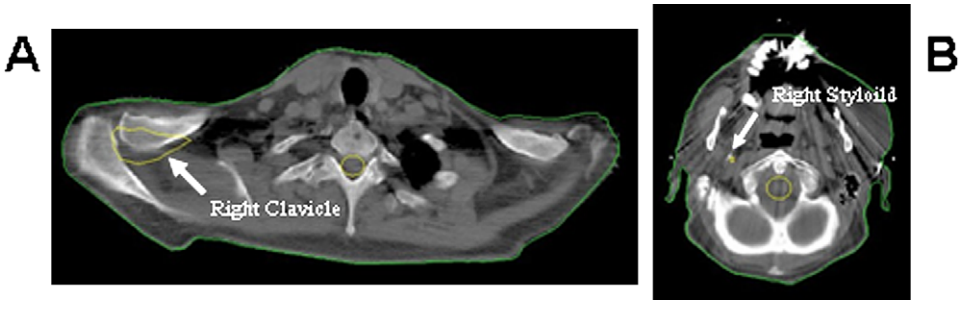

Fig. 2. Axial computed tomography slices showing how setup displacements were determined. Computed tomography images from reference simulation studies and control sessions were co-registered using AQ-Sim treatment planning software. Maximal displacement in anteroposterior, craniocaudal, and mediolateral directions calculated using software measurement tool. (A) Displacement of acromial extremity of right clavicle. (B) Displacement of right styloid process.

Table 1. Total population CC, AP, and ML displacements for upper and lower landmarks*

Device	Landmark grouping†	Total population displacements (mm) (1 SD) CC	AP	ML
Type S	Upper	2.5 (−9.0 to 11)	1.8 (−3.9 to 4.9)	1.7 (−5.0 to 4.1)
	Lower	5.8 (−17 to 18)	6.4 (−25 to 14)	4.9 (−9.6 to 17)
Accufix system	Upper	1.7 (−4.5 to 3.5)	2.0 (−6.4 to 3.4)	1.2 (−2.5 to 3.4)
	Lower	4.6 (−21 to 9.0)	6.0 (−18 to 20)	6.3 (−22 to 14)

Abbreviations: CC = craniocaudal; AP = anteroposterior; ML = mediolateral; SD = standard deviation.
Data in parentheses are percentages.
* Setup errors assessed for each anatomic landmark according to device (10 patients for Type S and 11 for Accufix system).
† Upper included odontoid and right and left styloid, and lower, C7 spinous process and right and left clavicles (acromial extremities).

represented by the standard deviation (SD) of the mean displacements of all patients. For a particular patient and for a specific reference point in a particular cartesian dimension, the random error was calculated by subtracting the systematic error from the individual daily displacements. For the entire population, the random error is represented by the SD of all the daily random errors.

The total population displacement, for a specific bony landmark and cartesian axis, was expressed as the SD of all individual CT control session displacements for all patients in the respective cohort. For each individual patient, 3D vector displacements were calculated for each bony landmark from the displacement in each axis using the following formula:

$$d_{3D} = \sqrt{d_{A-P}^2 + d_{C-C}^2 + d_{M-L}^2}$$

where d_{AP}, d_{CC}, and d_{ML} are the setup errors in the AP, CC, and ML direction, respectively. The systematic and random vector displacements, as well as population systematic, mean systematic, random, and total vector displacements, for each bony landmark were calculated.

The two immobilization systems were compared with regard to displacements about each bony landmark in all cartesian axes. Also, to compare global setup accuracy in the upper H&N areas and the shoulder area, displacements at the level of the odontoid, right styloid, and left styloid were regrouped as upper landmarks, and displacements at the level of the spinous process of C7 and the acromial extremities of the clavicles were regrouped and designated the lower landmarks. The collective upper and lower landmark displacements were processed as described to determine the systematic, random, and total displacement components. The mean systematic displacements were compared using the *t* test and the distributions (>1 or <1 SD) of the population systematic displacement, random displacement, and total displacement were compared using Fisher's exact test. The mean setup time required for immobilization of the patient, for both the simulation CT and the control CT sessions, was compared using the *t* test analysis. Similarly, the mean score for each of the four questions on the patient comfort survey was compared using the *t* test.

RESULTS

Setup accuracy and reproducibility between immobilization devices

A total of 64 CT control images (30 for Type S and 34 for Accufix) were obtained and analyzed. No significant difference was found in the AP, CC, and ML systematic, random, and total displacement errors (1 SD) between the two populations at any individual landmark considered. Regrouping the data into upper and lower landmarks as single groups similarly failed to reveal significant differences between the two immobilization systems with respect to population systematic, random, and total displacement errors (1 SD) (Table 1).

The mean systematic displacement errors were plotted for both immobilization devices in two scatter plots representing the CC–ML and CC–AP planes. Figure 3A,C provides examples of the scatter plots for the lower landmark grouping. Both the patient mean systematic displacement errors for the lower landmarks collectively and all the individual patient systematic displacement errors for each lower landmark considered separately are shown. Similarly, Fig. 3B,D provides examples of scatter plots of all the individual patient random displacement errors for both populations for the lower landmarks grouping. No significant preferential displacement was found in any particular cartesian plane for any individual landmark using either immobilization system. Likewise, the upper and lower landmark groupings did not display a tendency for displacement in any specific cartesian axis. Nonetheless, as illustrated in Fig. 3, greater displacement errors were consistently noted in all cartesian planes in the lower landmarks compared with the upper landmarks for both immobilization systems, whether considered individually or as collective groupings.

Additionally, comparative analysis using 3D vector displacement data did not reveal any significant difference in setup accuracy or reproducibility between the two immobilization devices studied. Specifically, no statistically significant difference was found between the Type S and Accufix immobilization systems with respect to total vector displacement at any individual landmark considered (Table 2). Similarly, regrouping the total vector displacement data into upper and lower landmarks as single groups also failed to demonstrate significant differences between the two study arms. The Type S total vector displacement for the upper landmark grouping was 1.9 mm and that of the Accufix system was 1.2 mm (SD). The corresponding total vector displacements for the lower landmark grouping for the Type S and Accufix arms were 5.7 mm and 5.8 mm (SD), respectively. Likewise, no significant difference was found in the population vector systematic and random displacements

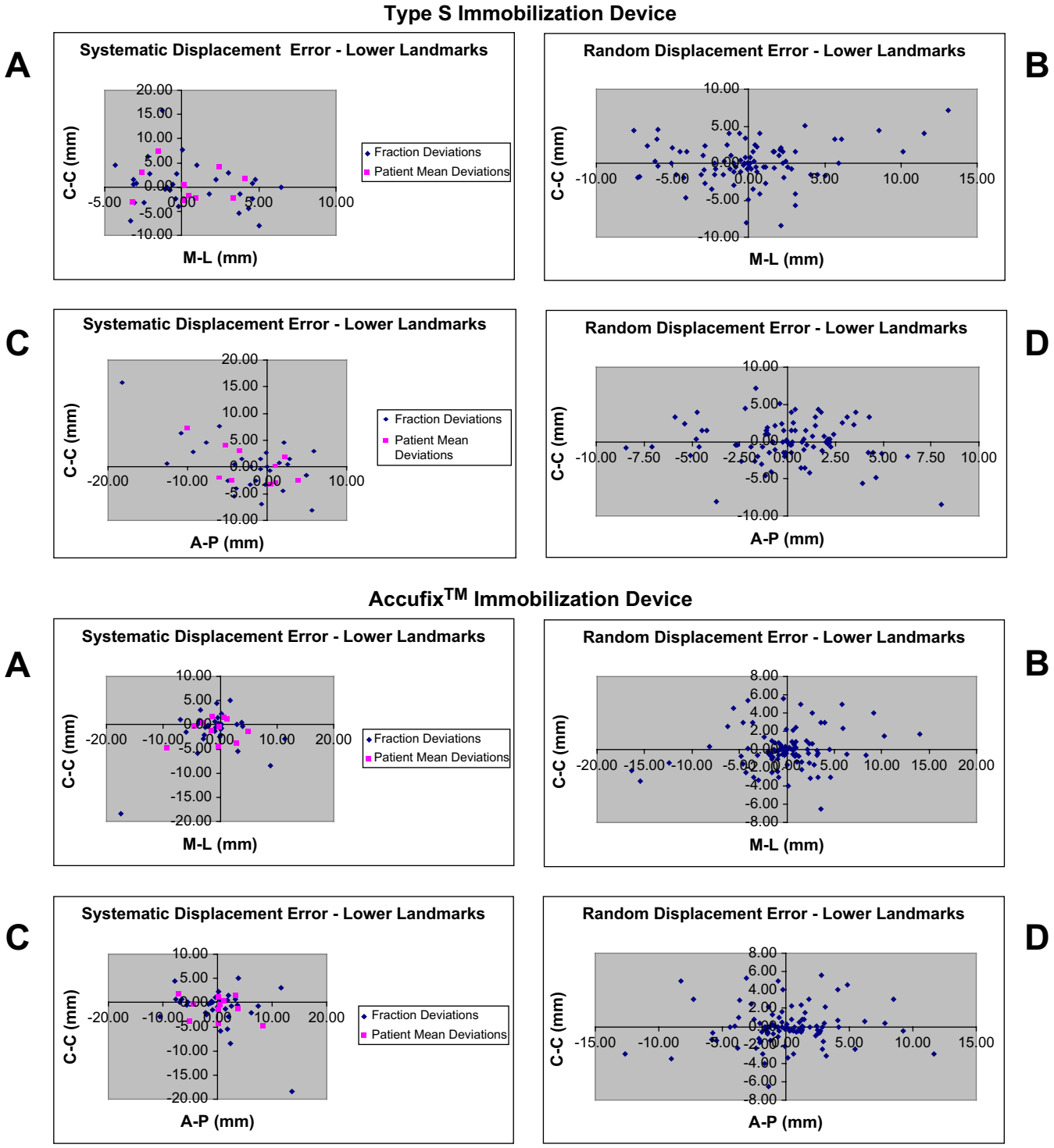

Fig. 3. (A–D) Scatter plots of setup displacements for lower landmarks along anteroposterior (A-P), craniocaudal (C-C), and mediolateral (M-L) directions using Type S and Accufix immobilization systems. Squares represent systematic displacement in 1 patient. (A,C) Diamonds represent all systematic deviations obtained from entire population. (B,D) Diamonds represent all random deviations obtained from entire population.

errors (1 SD) between the two populations at any individual landmark considered or after the collective comparison of the upper and lower landmarks.

The Type S population mean ± SD systematic vector displacement error was 2.9 ± 1.2, 2.9 ± 1.4, 3.6 ± 2.1, 8.8 ± 3.1, 10 ± 6.1, 5.1 ± 2.1, 3.1 ± 1.6, and 8.0 ± 4.5 mm at the odontoid, right styloid, left styloid, C7 spinous process, right and left acromial extremities, upper landmarks, and lower landmarks, respectively. The corresponding population mean systematic vector displacement errors for the Accufix system were 3.0 ± 1.0, 2.6 ± 0.9, 2.7 ± 0.9, 10.2 ± 7.2, 8.0 ± 5.1, 5.7 ± 2.4, 2.8 ± 0.9, and 8.0 ± 5.5 mm

Table 2. Total vector errors for all 21 patients*

Device	Total 3D error (mm) (1SD)							
	Odontoid	Right styloid	Left styloid	C7 spinous process	Right clavicle	Left clavicle	Upper landmarks†	Lower landmarks‡
Type S	1.8	1.8	2.3	3.4	4.8	6.9	1.9	5.7
Accufix system	1.3	1.2	1.1	2.8	7.5	5.4	1.2	5.8

Abbreviations: 3D = three-dimensional; SD = standard deviation.
* Setup errors assessed for each anatomic landmark according to device (10 patients for Type S and 11 for Accufix system).
† Odontoid and right and left styloid.
‡ C7 spinous process and right and left clavicles (acromial extremities).

(Fig. 4). The comparisons of the population mean systematic vector displacement errors, using individual landmarks as well as grouped landmarks, also failed to expose significant differences between the two immobilization methods. However, a trend was noted toward a smaller population mean systemic error for the upper landmarks as a single group, favoring the Accufix system.

Setup time

The setup times required to immobilize patients before the control CT imaging studies were available for 8 and 10 patients in the Type S and Accufix arms, respectively. No significant difference was found between the day-to-day setup times required to immobilize patients between the two immobilization systems. The mean setup time required for the Type S and Accufix immobilization device was 5.2 ± 1.4 min and 5.0 ± 1.1 min, respectively.

Patient comfort

Data from the patient comfort questionnaire were available for 8 and 11 patients in the Type S and Accufix arms, respectively. No significant difference was found in the degree of comfort at the level of the face and shoulders between the two immobilization devices. Also, no significant difference was noted in the degree of perceived respiratory difficulty or shoulder mobility between the two systems (Fig. 5).

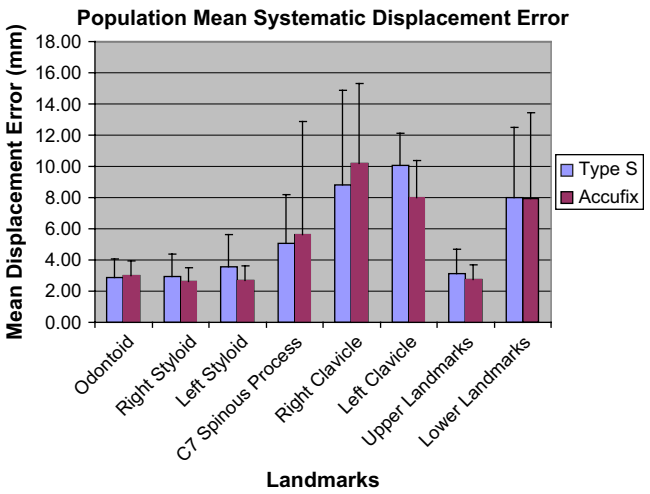

Fig. 4. Population mean ± SD systemic displacement errors obtained at each individual landmark considered, as well as upper (odontoid and right and left styloid) and lower (spinous process of C7 and acromial extremities of right and left clavicles) landmarks as single groups. No significant difference found between two immobilization devices at any landmark considered.

DISCUSSION

Success in modern RT for H&N tumors is dependant on precise and reproducible patient positioning. Poor patient immobilization can result in a geographic miss of the intended target volume and an increased risk of local failure, as well as irradiation of healthy tissues, particularly critical organs, increasing the risk of treatment-associated morbidity.

In our study, the total vector displacement error for the Type S device for the upper landmark grouping was 1.9 mm and that of the Accufix system was 1.2 mm (SD). The corresponding total vector displacement for the lower landmark grouping for the Type S and Accufix arms was 5.7 mm and 5.8 mm (SD), respectively. The corresponding population vector systematic and random displacements errors (1 SD) were similar. Likewise, assessment of the total population displacements for each individual cartesian component yielded similar degrees of error. The total population CC, AP, and ML displacements for the upper landmarks in the Type S arm ranged from 1.7 to 2.5 mm (SD) and those of the Accufix arm ranged from 1.2 to 2.0 mm (SD). For the lower bony landmarks, the total population CC, AP, and ML displacements for the Type S arm were 4.9–6.4 mm (SD) and for the Accufix arm were 4.6–6.3 mm (SD). Although no significant difference were noted in setup accuracy between the

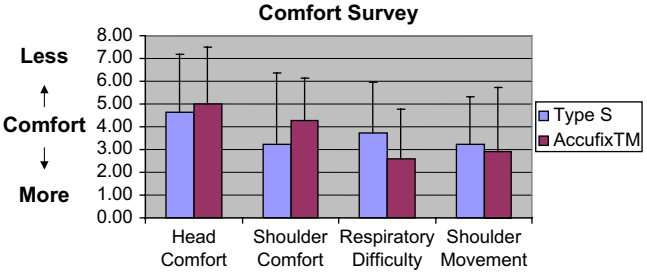

Fig. 5. Comparison of comfort level of two head-and-neck immobilization systems used in study. No significant difference found in head comfort, shoulder comfort, respiratory difficulty, or shoulder movement between two study arms.

two immobilization devices assessed, they both equally demonstrated larger setup errors in the lower landmark grouping than in the upper landmark grouping. This could imply that great margins are needed if either of these systems is used to treat caudal target volumes in proximity to the shoulder level.

Our data are quite comparable to the total displacements reported in published studies, which have ranged from 2 to 5 mm (1 SD) (1–5, 7–10). Using CT topograms as reference images, Tsai *et al*. (11) reported setup displacements of 1.3 and 2.2 mm (1 SD) between portal films and topograms for the CC and AP cartesian dimensions, respectively. Hess *et al*. (2) assessed the accuracy of field alignment in a group of 95 H&N cancer patients immobilized using individualized Orfit face masks and found overall discrepancies of 3–5 mm (1 SD) (2). A more recent study by Gilbeau *et al*. (9) comparing portal images to digitized simulator films found the whole population total displacements to reach a standard deviation of 2.2 mm at the level of the head and neck. They also noted a worse patient setup at the shoulder level compared with the more cranial points from which displacement errors were determined.

In comparing our data with those of many of the published series on setup accuracy in H&N RT, several differences in method were noted. Of importance, our study was performed prospectively. Moreover, many studies assessed a single reference landmark by manual methods such as using simulation and serial portal radiographic films. In our study, we assessed six anatomic landmarks within the H&N region, both individually and as a part of collective groupings, using CT digitized imaging. Furthermore, we assessed setup discrepancies in the three cartesian dimensions and as the summative 3D vector displacements. Nevertheless, we acknowledge that we did not perform on-line positioning correction, such as has been performed in various studies concerned with real-time positioning correction.

In addition to setup accuracy, patient comfort is another important parameter when comparing immobilization devices. Fixation devices must be rigid enough to limit mobility; however, they must also be tolerable for the patient. Our comparison of the Type S and Accufix systems failed to reveal any noticeable differences regarding patient comfort. Moreover, our department radiation therapists found the Accufix system equally easy to use on a daily basis. More importantly, no significant difference was found in the daily setup time required by either immobilization devices. Taking these two additional factors into account, the Accufix H&N immobilization system appears to be equivalent to the Type S system traditionally used in our radiation oncology department.

CONCLUSION

The results of the present study have demonstrated that the Accufix cantilever board equipped with the Bear-Claw shoulder depression system is equivalent to the standard thermoplastic head-and-shoulder mask system (Type S) in setup accuracy, setup time required, and comfort level. Moreover, our results emphasize the lack of adequate immobilization of the lower neck and shoulders with the commercially available H&N immobilization devices. This is especially important when dealing with lower lying targets. Verification of the accuracy of H&N immobilization is a necessary step for each radiation oncology department, especially when using intensity-modulated RT planning techniques. In our center, we elected to limit the planning target volume for upper H&N targets to $\leq$4 mm (2 SD of the total vector displacement) according to the findings of our study.

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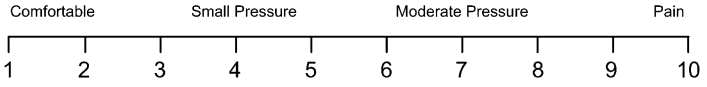
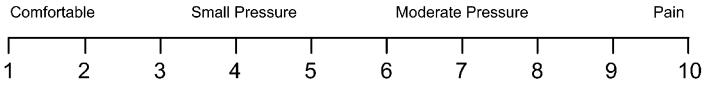
APPENDIX

Comfort Questionnaire

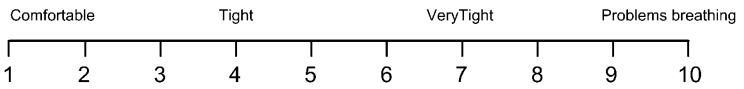
1. Is your mask comfortable on your **face**? Use the following scale to evaluate your comfort.



2. Are your **shoulders** comfortable? Use the following scale to evaluate your comfort.



3. Is the mask causing you respiratory problems? Use the following scale to evaluate the tightness of your mask at the level of your chest.



4. Are you able to move your shoulders? Use the following scale between on to ten, one being completely immobilized and ten being very mobile.