

## Assessment of Margins for Set-up Errors in Head-and-Neck IMRT

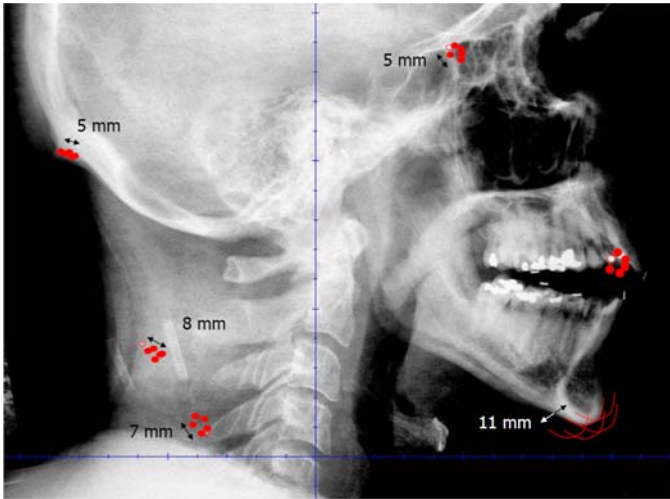
In order to account for random and systematic set-up errors, a CTV-to-PTV margin is applied. A margin that is too small will lead to underdosing some tumors while an excessive margin causes unnecessary treatment of normal tissue that could be spared. Therefore, it is important that the margin accurately reflect the actual set-up uncertainty associated with a particular treatment site and immobilization technique. In this study, we calculate appropriate margins based on measured daily set-up errors and intrafraction motion for patients undergoing postoperative IMRT to the head and neck.

The current practice at our institution is to use a Type-S<sup>TM</sup> thermoplastic mask for immobilization. Patients are often treated with fluoride carriers in place to absorb radiation scattered from dental hardware. In this study all patients were fitted with fluoride carriers with gold fiducial markers inserted in order to facilitate measurement of set-up errors away from isocenter. Localization was performed using orthogonal 2D kV images obtained from an On-Board Imager® (OBI, Varian Medical Systems, Palo Alto, CA). Therapists perform a manual image registration, matching bony anatomy near the treatment isocenter and apply the required shifts to the couch. An additional set of kV images was also recorded immediately following delivery of the treatment every day.

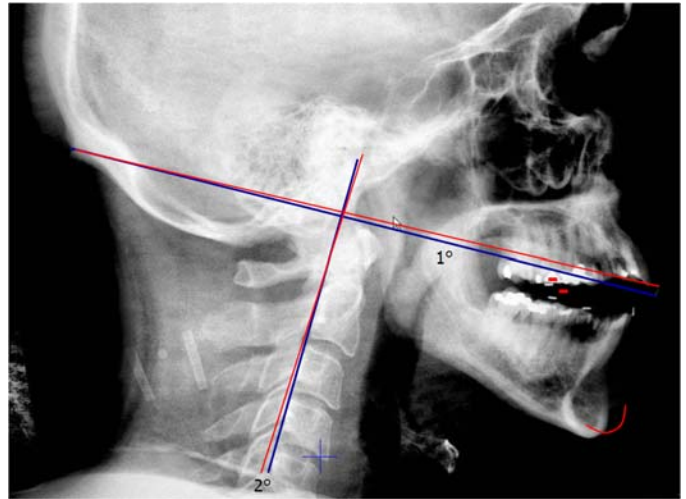
Daily set-up uncertainty was investigated by performing off-line image registration, recording proposed shifts, and comparing them to the actual shifts performed at the treatment. Since the off-line registration was performed on all of a patient's images by one individual in one sitting, the differences between the off-line and treatment shifts is a good measure of the daily set-up variability. Two sets of proposed shifts were recorded for separate registrations based on aligning bony anatomy near isocenter and the fiducial markers in the fluoride carriers. This process was then repeated using the post-treatment images. Margins to account for set-up uncertainty were calculated using the van Herk recipe of  $2.5\sum + 0.7\sigma$ . The goal of this recipe is to ensure that 90% of patients receive a minimum cumulative dose to the CTV of at least 95% of the dose prescribed. The systematic error  $\sum$  is calculated by taking the standard deviation of the mean set-up errors calculated for each patient. The random error  $\sigma$  is the root mean square of the standard deviation of set-up errors calculated for each patient.

A verification radiograph recorded immediately before the first treatment for one patient is shown in Figure 1. The red marks demonstrate the extent of interfraction motion by recording the location of certain anatomical features at subsequent treatments. The margins calculated for each Cartesian direction and each registration position based on pre-treatment and post-treatment images are presented in Table 1. For points near isocenter a margin of 2.5 mm would seem to be appropriate for the observed set-up uncertainty. Based on the post-treatment imaging, however, it is clear that the margin should be closer to 4 mm in order to account for intrafraction motion. This data supports the current practice of adding a 5-mm margin for expansion from CTV to PTV. Although we expected the required margin to be larger for points away from isocenter, we were somewhat surprised that our measurements indicated a margin of at least 8 mm based on aligning fiducial markers near the front teeth. It is also interesting to note that this margin was not significantly affected by intrafraction motion.

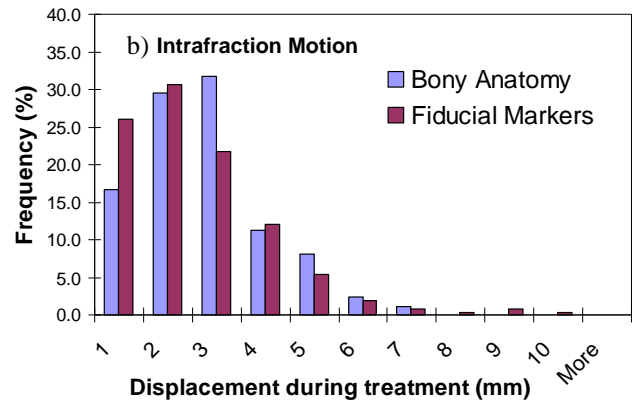
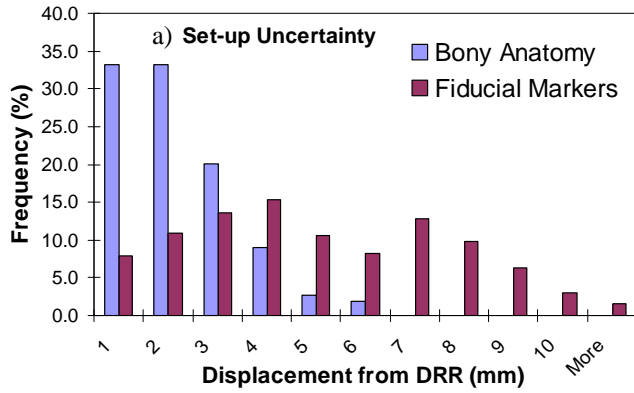
The relative importance of set-up uncertainty and intrafraction motion is demonstrated by the histograms in figure 2. It can be seen that for anatomy near isocenter they are about equally important, having a similar distribution of displacements. For the fiducial markers, located about 10 cm from isocenter, the distribution of set-up errors is approximately twice as wide compared to anatomy near isocenter. This discrepancy is attributed to the fact that the position of points far removed from isocenter is strongly affected by rotational set-up errors that are not corrected when performing a translational match at isocenter. Intrafractional rotation can be seen in figure 3 where blue lines are drawn connecting anatomical reference points on the post-treatment image. The red lines and marks indicate the initial position of the patient as recorded immediately prior to treatment on the same day. The opposite direction of these rotations demonstrates that some rotational errors are due to flexure in the neck and, therefore, cannot be completely corrected, even with a six degree of freedom couch. Therefore, it is clear that the best way to reduce these errors, and the associated margins, is to strive for more reproducible set-up with regard to the patient's angular positioning. Based on this evidence we have modified our treatment protocol to include a Precise Bite mouthguard (Civco Medical Solutions, Orange City, Iowa) that engages both upper and lower teeth and attaches directly to the thermoplastic mask. We are currently evaluating whether this modification reduces set-up errors away from isocenter as well as intrafraction motion.



**Figure 1.** Interfraction motion. Right lateral radiograph from first treatment. Red marks indicate locations of various anatomical points at subsequent treatments.



**Figure 3.** Intrafraction motion. Blue lines connect anatomical reference points. Red lines and marks indicate positions at the start of the same treatment.



**Figure 2.** a) Histogram of the magnitude of set-up errors based on bony anatomy and fiducial markers. b) Histogram of the magnitude of intrafraction displacements.

Table 1. Set-up Margins (mm)		S/I	R/L	A/P
Pre-Treatment Isocenter	Systematic $\Sigma$	0.3	0.6	0.7
	Random $\sigma$	0.9	1.2	1.1
	Margin	1.3	2.3	2.5
Pre-Treatment Fiducial Markers	Systematic $\Sigma$	2.6	2.2	2.9
	Random $\sigma$	1.5	1.9	1.7
	Margin	7.4	6.9	8.5
Post-Treatment Isocenter	Systematic $\Sigma$	0.4	1.2	0.9
	Random $\sigma$	1.0	1.5	1.4
	Margin	1.6	4.0	3.2
Post-Treatment Fiducial Markers	Systematic $\Sigma$	2.6	2.3	1.8
	Random $\sigma$	1.6	2.2	1.8
	Margin	7.7	7.4	7.3