A Quantitative Analysis of the Reliability of Aquaplast Mask Immobilization for Cranial Radiosurgery With TomoTherapy

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Abstract*— Patient treatment setup accuracy for cranial radiosurgery (SRS) is dependent on a number of parameters; including localization and immobilization. In this study we carried out a quantitative analysis of the reliability of a radiosurgery immobilization mask system in maintaining patient position during SRS treatment sessions. Patients were fitted with a thermoplastic mask and a customized pillow designed for SRS. TomoTherapy MVCT, using 1 mm slice thickness, was carried out and the required shifts, based on bony anatomy, were applied to the patient position prior to radiotherapy. At the completion of the treatment a second MVCT was carried out to determine if any patient movement had taken place. Typical time on the treatment couch varied from 25-60 minutes. A total of 26 patients were analyzed. Some patients received more than one treatment fraction. A total of 38 MVCT measurements were included in this study. The mean absolute shift for the 38 measurements was 0.42 mm (SD=0.29) lateral, 0.75 mm (SD=0.94) longitudinal, and 0.44 mm (SD=0.42) in the vertical direction. Overall, the average vector displacement was 1.18 mm (SD=0.82). The variation in shifts between different patients was significant. Two patients had a vector shift of greater than 3.0 mm; largely due to a longitudinal displacement. Based on these results a margin of approximately 1 mm is sufficient for patient lateral and vertical motion but up to a 2 mm margin may be needed for longitudinal motion. Hence a PRV and PTV of 3 mm is required to account for patient position uncertainty. Care in the initial molding of the mask, and a customized pillow, may be key in ensuring minimal patient motion during cranial SRS.

Keywords—**IGRT, radiosurgery, TomoTherapy. immobilization**

I. INTRODUCTION

Cranial radiosurgery represents an important procedure in medical technology, allowing healthcare professionals to treat brain tumors that may otherwise be untreatable [1,2]. However, this procedure also carries with it a set of unique challenges. The clinician must ensure that there is an effective dose delivery to a very specific localized area while at the same time keeping the patient immobilized. Image-Guided Radiation Therapy (IGRT) utilizes volumetric CT scans to localize the patient prior to the start of their treatment. In order to keep the patient immobilized throughout the treatment session a variety of devices, such as the halo and Brown-Roberts-Wells (BRW) frames, are implemented. These frames can accurately localize the target area to within 1 mm [3] and also serve as an immobilizer during the treatment session. Unfortunately, these devices are also highly invasive requiring that screws be inserted through the skin and into the patient's skull. This invasive nature makes it difficult to treat the patient more than one fraction. This puts them at an inherent disadvantage when receiving therapy for conditions that are more responsive to fractionated treatments. In recent years efforts have been focused on producing stabilization devices that are less invasive and yet still provide a high degree of accuracy [4-6]. An alternative to traditional immobilizers is a hard plastic radiosurgery mask that is custom built for each patient, allowing the device to conform to the patient's head and face. Image guided radiation therapy (IGRT) may be used to achieve high accuracy in the initial localization, and a mask may be employed to take advantage of a non-invasive immobilization system. A potential drawback to this technology is that the initial setup accuracy may be lost during the course of treatment due to greater patient head movement than would be allowed with an invasive frame. Little quantitative data indicating patient stability during SRS in a non-invasive mask is available. Our intent in this study was to assess patient movement after IGRT during typical SRS procedures lasting up to 60 minutes.

II. MATERIALS AND METHODS

A. Patient immobilization:

Patients were initially set up in a standard supine position on a commercial pre-molded head support. We found this process lacking in stability and after the first six patients we used a custom-formed rigid pillow under the head (Civco Medical, Orange City, Iowa). A 3 mm radiosurgery thermoplastic mask was formed over the face and cranium and fixed to an S-frame carbon fiber support (Civco Medical, Orange City, Iowa). Three points were identified on the mask as an arbitrary reference plane.

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These were used to approximate initial setup on TomoTherapy.

B. CT/MR Imaging and treatment planning:

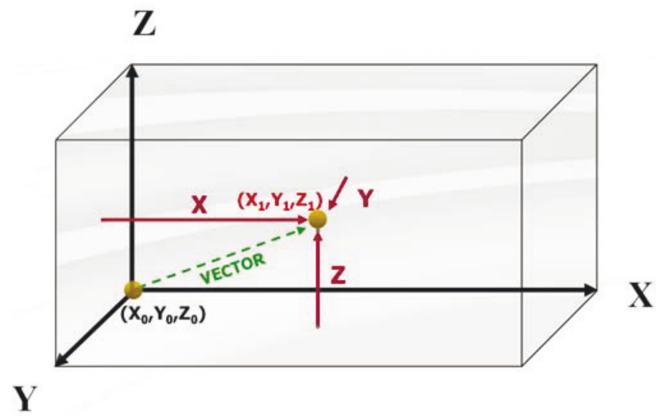
CT imaging was carried out on a Siemens Open Sensation using the 40 slice by 0.65 mm collimator mode. Slice thickness was 1 mm with 512x512 resolution and contrast was used. The CT images were fused to a T1 or T2 MRI dataset. Normal structures were identified and contoured including lens, orbits, optic nerves, optic chiasm, brain stem and whole brain. The CT dataset and all contours were transferred to a TomoTherapy HiArt treatment planning workstation. A single fraction dose ranging from 12 Gy to 35 Gy was planned using the 10 mm collimator mode. Total beam-on time varied from 12 minutes to 48 minutes.

C. TomoTherapy patient setup and imaging:

Patients were set up on the treatment couch in the same manner as during the CT simulation. A new "Ultra Fine" imaging mode was implemented for TomoTherapy megavoltage CT (MVCT). In this imaging mode the collimator is reduced from the standard 4 mm opening to a 1 mm setting. This configuration significantly improves imaging resolution for setup accuracy, especially in the sagittal direction. Details of this configuration are published elsewhere [7,8]. Between one and three treatment passes were required to deliver the full treatment dose. The patients were imaged just prior to initiation of treatment, and the table was shifted to the appropriate position in the lateral, longitudinal and vertical directions. After the completion of treatment patients were imaged once again and any net movement, based on bony anatomy, was recorded. Total time on the treatment couch, including the imaging sessions, ranged from 25-60 minutes.

D. Data analysis:

The process of data acquisition and analysis has been previously published [9]. In brief, the three dimensional coordinate point of interest is identified on the CT images prior to treatment, and its displacement based on the megavoltage CT images after treatment. A vector shift is calculated for the distance that relates the actual position from the expected. The magnitude of the vector shift is a measure of any patient movement, within the mask, during the treatment (figure 1).



Where:

v – is the vector distance
$X_0 - X_1$ is shift in the lateral direction
$Y_0 - Y_1$ is shift in the longitudinal direction
$Z_0 - Z_1$ is shift in the vertical direction

$$v = \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2 + (z_0 - z_1)^2}$$

Fig. 1. The vector distance is the distance from the expected (X_0,Y_0,Z_0) to actual (X_1,Y_1,Z_1) and is calculated by the formula above.

III. Results and discussion

The stability of patient setup in an aquaplast mask for TomoTherapy radiosurgery procedures was determined quantitatively. MVCT were carried out prior to, and at the completion of a radiosurgery session to measure any patient movement during the procedure. The mean absolute shift for the 38 measurements was 0.42 mm (SD=0.29) lateral, 0.75 mm (SD=0.94) longitudinal, and 0.44 mm (SD=0.42 mm) in the vertical direction. Overall, the average vector displacement was 1.18 mm (SD=0.82). Of the 38 imaging sessions 35 (92%) had a total vector shift ≤ 2 mm (figure 2).

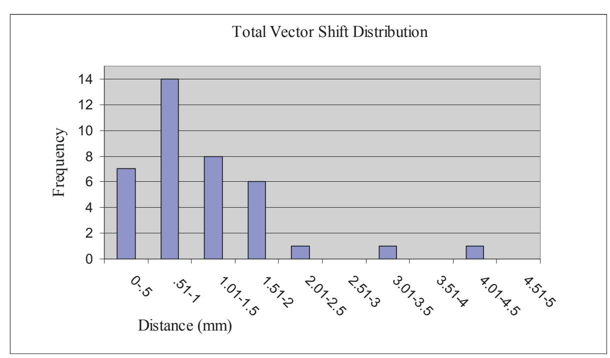


Fig. 2. Histogram of vector displacement in increments of 0.5 mm for 38 imaging sessions.

The variation in shifts between different patients was significant. Of the 38 imaging sessions, two resulted in a vector shift of greater than 3.0 mm; largely due to a longitudinal displacement (figures 2,3). Interestingly, with experience our ability to build more stable

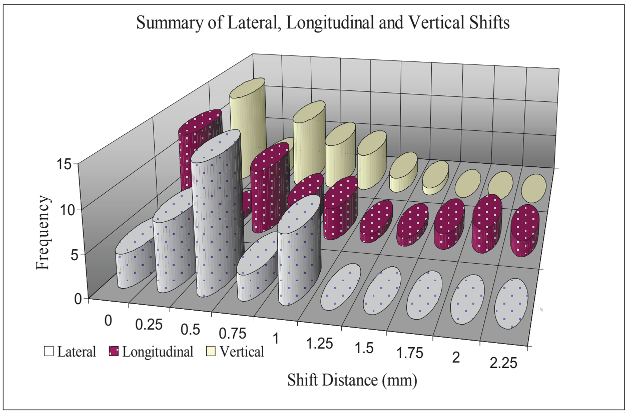


Fig. 3. Histogram of displacement in the lateral, longitudinal and vertical directions for 38 imaging session

masks improved. After the first 6 patients we implemented a custom-formed pillow which allowed more stable patient positioning. In figure 4 the improved stability after 2007 is apparent. Our most recent experience is that immobilization is within a vector of 1.5 mm. Similarly to Sanghera et al [10], we typically apply a margin of 3 mm PRV for our normal structures, and a 3 mm PTV to our target. As the typical shift, in the lateral longitudinal or vertical directions, is less than one millimeter we expect this margin to be adequate for the majority of cases. The use of a non-invasive immobilizer mask for radiosurgery offers the advantage of comfort for the patient, and the potential for fractionation. The localization method used in this study was TomoTherapy MVCT. However, this process can be adapted to any treatment unit where IGRT is available for accurate localization.

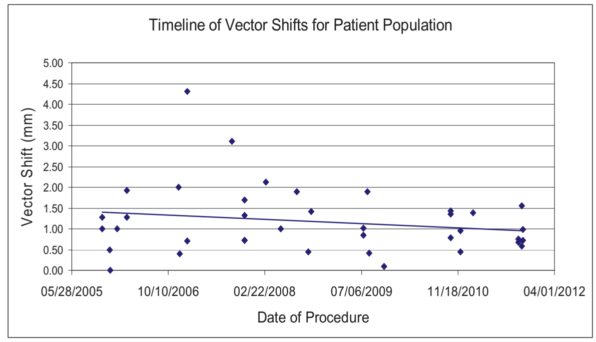


Fig. 4. A study of patient stability in a non-invasive radiosurgery mask. Note the improved stability from 2005 to 2011.

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