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Comparison of Head Immobilization with a Metal Frame and Two Different Models of Face Masks

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Abstract

Purpose: Use optical imaging guidance to test the effectiveness of three different methods for immobilizing stereotactic radio surgery patients.

Methods: Patients were immobilized with a BRW stereotactic head frame, an Orfit model 33759: 3-point Hybrid open face thermoplastic mask, or an Orfit face mask with Nanor reinforcement. The face masks are open around the mouth, nose, eyes, brows, and temples so that the optical system images the face of the patient not the mask itself. Real time 3D surface images of the patient are compared by AlignRT software against this reference image. Changes in patient alignment are reported as a vector distances every 0.2s during the treatment.

Results: A histogram analysis of the optical noise signal in the AlignRT system shows an equivalent average motion of 0.05 mm and 90% of the time has a motion less than 0.07 mm. For 26 patients with the model 33759 face masks, the average motion is found to be 0.34 mm and for 26 patients with the Nanor mask 0.32 mm. 90% of the time motion was less than 0.50 mm with a range of 0.28 mm to 1.85 mm. When the head frame was used the average motion is 0.93 mm and 90% of the time the motion was less than 1.4 mm.

Conclusion: Both types of open-face masks immobilize patients to ≤ 0.4 mm of motion. The head ring allows 3 fold more patient motion than an open-face mask. AlignRT is a useful tool for monitoring motion of stereotactic radiosurgery patients.

Keywords: Optical guidance radiation therapy; Stereotactic radiosurgery; Head immobilization; Thermoplastic face mask

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Introduction

Stereotactic radio surgery, SRS, is a radiation technique that requires the delivery of dose to have spatial accuracy of a few millimeters or less [1-3]. The accuracy of radiation hitting a target depends on the alignment and collimation of the beams of the radiation machine as well as the positioning and immobilization of the patient. The measurement and achievement of patient immobilization are the subjects of this work. The original use of SRS employed metal frames that were physically attached to the patient's skull for immobilization [3-9]. Besides immobilization of the patient the frame also served as a fiducial coordinate system for the target since targets inside the brain did not move with respect to the skull during a treatment. Frame systems can provide excellent immobilization but have drawbacks of frame slippage [7] and patient discomfort during application of the frame for use in radiation treatment. The frame method also has disadvantages of requiring coordination of radiation oncology and neurosurgery schedules; CT scan, treatment planning and delivery on the same day; and exclusion of the use for fractionated delivery on sequential days. Alternate, frameless, methods of immobilization and positioning have been developed for use with linear accelerator based SRS [10-29]. The immobilization is accomplished with face masks and conformal headrests that are custom fitted to each patient [29]. The alignment of the patient is verified by a comparison of cone beam computed tomography, CBCT, images with CT images used for the treatment plan [26,28-35]. To monitor and maintain correct positioning of the patient during treatment various techniques have been employed: external infrared markers [10,15,17,18,22] biplanar x-ray imaging [14,19], and optical surface imaging [20,22-24]. These various imaging systems have been reported [27,29,36-40] to have accuracy of better than 2 mm. Advantages of the frameless method are improved patient comfort, the possibility of fractionation of dose delivery if needed, and all procedures can be performed in the radiation therapy department. It is noteworthy that besides the difference in hardware and techniques a significant change in paradigm has occurred with the shift

Table 1: Vector motion of 3 patients immobilized with the OrfitNanor reinforced mask.

Patient	Couch angle,°	Average motion, mm	Motion for 90% of the time, mm
1, arc 1	0	0.32	0.47
1, arc 2	90	0.22	0.34
1, arc 3	45	0.31	0.46
1, arc 4	315	0.21	0.32
Average		0.27±0.06	0.40±0.08
2, arc 1	0	0.52	0.73
2, arc 2	90	0.32	0.43
2, arc 3	45	0.31	0.42
2, arc 4	315	0.52	0.78
Average		0.42±0.12	0.59±0.19
3, arc 1	295	0.32	0.46
3, arc 2	340	0.29	0.43
3, arc 3	20	0.19	0.27
3, arc 4	65	0.33	0.47
Average		0.28±0.06	0.41±0.09

The motion values shown in this table have not been corrected for intrinsic motion due to AlignRT noise that is shown in Figures 4 and 5.The uncertainty in the average is 1 standard deviation.

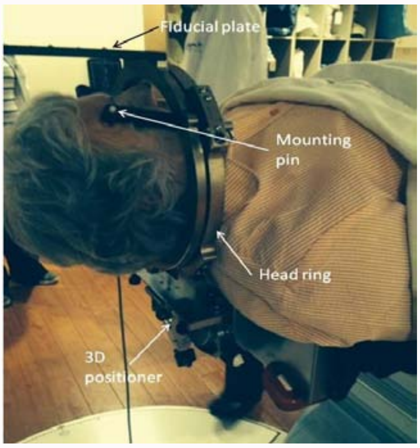

Figure 1: Stereotactic head ring mounted to a patient and the treatment couch.

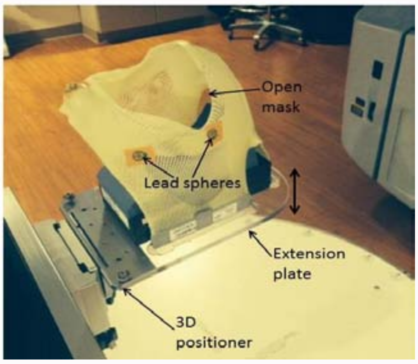

Figure 2: A thermoplastic Nanor mask mounted on the 3D positioner. The black double arrow line indicates the major direction of flex in the anterior-posterior direction.

from using a frame to a frameless system. A change in the coordinate system has been made. The frame system uses a secondary fiducial system that is mounted to the frame while the frameless system uses a primary fiducial system, the patient's face. This work uses an optical imaging system to measure patient motion when using two versions of a face mask system and compares this to motion when the patient is immobilized with a metal frame.

Materials and Methods

Patient immobilization was accomplished with two systems. The first system, which had been used for many years in our clinic, was the BRW stereotactic head frame (Varian Medical Systems, Palo Alto, CA). Figure 1 shows the frame (head ring) attached to a patient. The head ring is secured to the skull with four mounting pins. The head ring is attached to the treatment couch via the 3D positioner, model 970355A (Varian Medical Systems, Palo Alto, CA). This positioner allows pitch and roll to be adjusted by ±10°. Yaw and linear position adjustments are made with the treatment couch. The fiducial plate, which shown in Figure 1, has six infrared emitters that are imaged by a system with two cameras and establishes a secondary coordinate system to identify the patient position. Patient position is established with the fiducial plate and no CBCT images are used. The second immobilization system uses a thermoplastic mask system (Orfit Industries America, Jericho, NY). Two styles of masks were used: model 33759: 3-point Hybrid Open-face Mask and the model 33759/16MI/12MI+N: 3-point Hybrid Open-face Mask with Nanor reinforcement. Figure 2 shows a Nanor mask mounted on the 3D positioner with a custom extension plate, model 32809 (Orfit Industries America, Jericho, NY) to which the mask is fixed. The mask is heated and form fitted to the patient before the computed tomography, CT, scans are done. The Nanor mask can be reheated and formed multiple times to obtain a fit that adequately immobilizes the patient. This mask is designed with an open face, (Figure 2), which allows the mouth, nose, eyes, brows, and temples to be visible. This is necessary so that the optical guidance system, to be described below, can image the patients face and not the mask itself. During the CT simulation, the mask is marked with 1 mm diameter lead spheres, as shown in Figure 2. These spheres establish a reference CT position and are used in treatment planning as a common reference position. Additionally, the spheres are used in treatment setup with treatment

Table 2: Vector motion of 52 patients immobilized with two types of Orfit masks.

Orfit Mask, model 33579			Orfit Mask, Nanor reinforced		
Patient	Average motion, mm	Motion for 90% of the time, mm	Patient	Average motion, mm	Motion for 90% of the time, mm
1	0.45	0.67	1	0.36	0.52
2	0.29	0.44	2	0.42	0.58
3	0.16	0.31	3	0.44	0.59
4	0.34	0.47	4	0.29	0.52
5	0.36	0.65	5	0.43	0.59
6	0.33	0.44	6	0.36	0.53
7	0.25	0.4	7	0.29	0.42
8	0.26	0.38	8	0.52	0.75
9	0.38	0.64	9	0.17	0.24
10	0.2	0.28	10	0.17	0.3
11	0.28	0.43	11	0.25	0.34
12	0.35	0.47	12	0.3	0.42
13	0.59	0.96	13	0.3	0.42
14	0.24	0.37	14	0.24	0.41
15	0.28	0.41	15	0.24	0.41
16	0.42	0.63	16	0.15	0.26
17	0.29	0.43	17	0.35	0.47
18	0.25	0.42	18	0.26	0.39
19	0.43	0.58	19	0.25	0.34
20	0.6	0.75	20	0.23	0.34
21	0.3	0.38	21	0.24	0.41
22	0.2	0.33	22	0.25	0.36
23	0.2	0.28	23	0.38	0.58
24	0.59	0.96	24	0.23	0.32
25	0.51	0.99	25	0.24	0.35
26	0.2	0.28	26	1.06	1.85
average, mm	0.34	0.51	average, mm	0.32	0.49
Stddev, mm	0.13	0.21	Stddev, mm	0.18	0.30
Coefvar, %	37.9	41.1	Coefvar, %	54.1	61.9

The motion values shown in this table have not been corrected for intrinsic motion due to AlignRT noise that is shown in Figures 4 and 5.

Figure 3: A skull phantom that is secured to the couch.

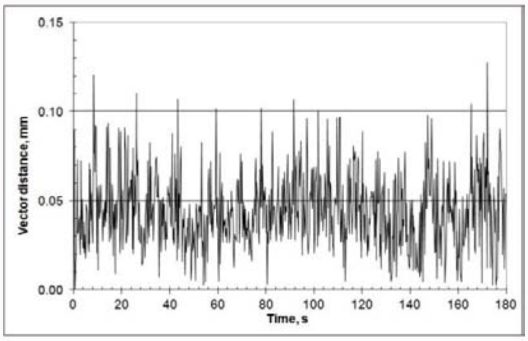

Figure 4: A plot of the motion vector from the reference position as a function of time for the skull phantom in Fig. 3.

room alignment lasers for approximate patient positioning along linear and angular axes. When CT images are taken the patient is secured on the CT couch with the mask. An optical imaging system, GateCT (VisionRT, London, UK) is used to measure the patient's motion in 3D space during the CT session. The system consists of one set of stereo cameras, called a pod, which is mounted on the CT room ceiling. An observation area is chosen in the open portion of the patient's face and the GateCT software reports the anterior-posterior

Table 3: Vector motion of 2 patients immobilized with the Varian head frame.

Patient	Couch angle,°	Average motion, mm	Motion for 90% of the time, mm
1, arc 1	50	0.8	1.4
2, arc 1	50	0.6	0.9
2, arc 2	285	1.0	1.5
2, arc 3	80	1.2	1.7
2, arc 4	65	1.1	1.5
2, arc 5	270	0.9	1.4
Average, mm		0.93	1.40
Stddev, mm		0.22	0.27
Coefvar, %		23.1	19.2

The motion values shown in this table have not been corrected for intrinsic motion due to AlignRT noise that is shown in Figures 4 and 5.

position or this area in real time. The patient is observed over a five minute period and if the patient motion is greater than 0.5 mm, then the mask is reformed. When motion cannot be reduced below 0.5 mm, then the margins used during the contouring of the target are increased. This same mask is used to immobilize the patient during eventual radiation treatment. In the treatment room an optical system that monitors surface images, AlignRT (VisionRT, London, UK) is used to setup the patient and monitor patient motion during treatment. The system consists of three sets of stereo cameras, called pods, which are mounted on the accelerator vault ceiling. Two pods are mounted to the left and right of the patient and one is toward the feet of the patient. These three pods capture a surface image of the open face of the patient, as shown in (Figure 2), from different perspectives. AlignRT software combines these images of the patient's face to reconstruct a three-dimensional (3D) surface image of the patient. The three pods are used for redundancy so that as the linear accelerator gantry is rotated the 3D surface image is maintained even if the view one of the pods is blocked by the gantry. When a patient is positioned for treatment a rough setup is made by aligning the lead spheres on the mask with the reticle projection of the linear accelerator and the room alignment lasers. A cone beam CT, CBCT, is taken and compared to planning CT images and the patient is moved in six degrees of freedom to accomplish coincidence of the two CTs. At this time a 3D reference optical image is taken with AlignRT. Subsequent real time 3D surface images of the patient are continually captured during the patient treatment at all couch angles used in the treatment. The captured optical surface images are compared by AlignRT software against the reference optical image. Patient alignment and motion are reported in real time in the 3 rotational and 3 translational directions. These real time differences are reported every 0.2 s with a precision of 0.2° and 0.05 mm, respectively. If the patient position is in question, then another CBCT can be acquired and compared to treatment planning CT images. When a treatment requires more than one isocenter the CBCT comparison and AlignRT reference image procedure are carried out for each isocenter. At the time of treatment, the patient's position was monitored with AlignRT software for a few minutes before and then during the entire treatment. A research module that captures patient motion data versus time was made available to our clinic by the VisionRT Company. The patient's motion is measured in the anterior-posterior, superior-inferior, and left-right directions compared to the reference image. The vector distance from the reference position is the following: The motion file generated by the research module is saved and analyzed with a Microsoft Excel spreadsheet that was developed by the author.

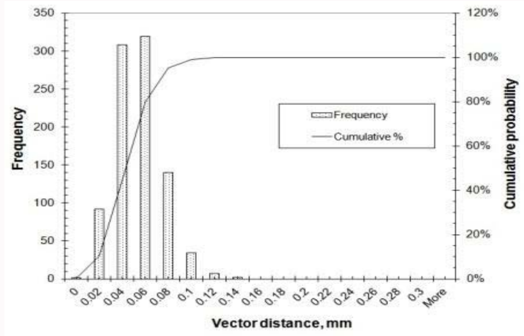

Figure 5: Histogram analysis of the motion data shown in Figure 4.

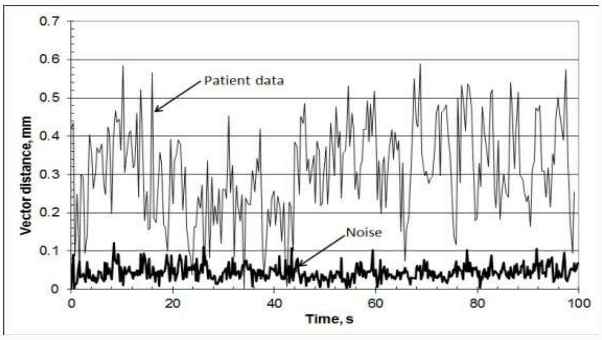

Figure 6: A plot of the motion vector from the reference position as a function of time for a typical patient and the apparent motion from noise in AlignRT.

Results

All optical signals have noise and in the case of AlignRT this noise is interpreted as motion. The magnitude of this noise motion measured by AlignRT was established by measuring the position of a skull phantom that is kept motionless by its attachment to the treatment couch. The experimental setup is shown in (Figure 3). The motion versus time due to AlignRT noise is shown in (Figure 4). A histogram analysis of the noise data in (Figure 4) is shown in (Figure 5) and has an equivalent average motion of 0.05 mm and 90% of the time has a motion less than 0.07 mm. The histogram analysis function of Microsoft Excel was used. A motion-versus-time plot is shown in (Figure 6) for a typical patient. The motion of the patient is monitored throughout the entire treatment and (Figure 6) shows the motion during a 100 s interval during the treatment. The apparent motion from AlignRT noise is also shown in (Figure 6). The magnitude of the vector distance of the motion versus time for the patient is further analyzed as a histogram of the data as shown in (Figure 7). For the motion data of (Figure 6), which was analyzed in (Figure 7), the average motion is 0.33 mm and 90% of the motion is less than 0.47 mm. Comparing (Figure 7) to (Figure 5), this typical patient motion is seven fold greater than motion that is observed due to AlignRT noise that was shown in Figure 4. The motion of three patients who were treated with multiple arcs was measured with AlignRT and analyzed. These results are shown in Table 1. It is clear that patient 2 has more motion than patients 1 and 3. Also, while there is variation in the amount of motion observed during different arcs and couch angles the first arc does characterize the overall motion of the patient during the treatment. Patient motion data were gathered with AlignRT and analyzed for 26 patients immobilized with the Orfit 33579 mask and 26 patients immobilized with the OrfitNanor mask. These data are shown in (Table 2). For these 52 patients, the average motion is found

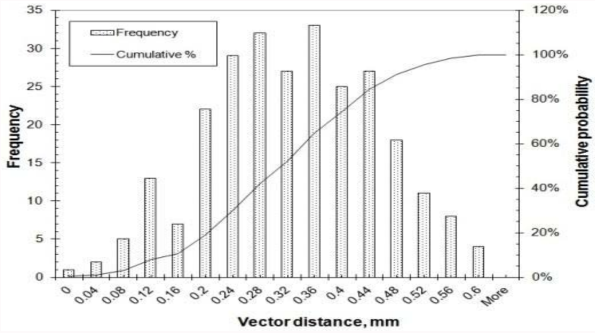

Figure 7: Histogram analysis of the patient motion data shown in Figure 6.

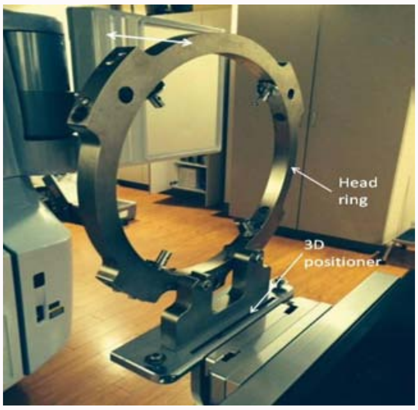

Figure 8: Head frame shown mounted on the 3D positioner. The frame can move in the superior-inferior direction as shown by the white, double-headed, arrow.

to be 0.33 mm. with a range of 0.15 mm to 1.06 mm. Ninety per center of the time the motions was less than 0.50 mm with a range of 0.28 mm to 1.85 mm. Only 1 case out of the 52 had average motion greater than 0.7 mm. The difference between the average motion of the two type of masks is 0.02 mm, which is 6 fold smaller than the standard deviation of 0.13 mm. There is no significant difference in the immobilization provided by these two types of masks. Two patients were treated for trigeminal neuralgia. For these patients a head ring was used based on our clinics historical methods and the belief that this would provide better immobilization than an open face mask. The head ring, model 970279 (Varian Medical Systems, Palo Alto, CA), which requires four pins to be screwed into the patients skull by a neurosurgeon. Figure 1 shows the ring mounted to a patient and the 3D positioner mounted to the end of the treatment couch. For these two patients their motion was evaluated with AlignRT, which had a region of interest placed on their open face. For these measurements the fiducial plate shown in (Figure 1) was removed and this gave an unobstructed view of the patient's face and a region of interest signal with low noise. The motion analysis was carried out during the treatment as for the above patients that had face masks. The results are shown in (Table 3). A comparison to the data in Tables 1 and 2 indicates that the patient's average motion with a head ring is about 3 fold greater than with an open face mask.

Discussion

There have been previous comparisons of frame and frameless techniques that have shown [41-43] these techniques result in similar localization accuracy of 0.5 mm to 1.0 mm. Additionally it was shown 43 that intra-fraction motion had a mean value of 0.4 mm for a frame system and 0.7 mm for a frameless system. The results presented in this work indicate that for a frameless system both types of open-face masks that were used in this work immobilize patients to ≤ 0.4 mm of motion. This result is a smaller motion value than reported previously 43. Immobilization of ≤ 0.4 mm is acceptable1-3 for stereotactic radio surgery. The Nanor reinforced mask provides no benefit compared to the model 33579 mask. In our clinic, prior to installing the AlignRT system, all stereotactic patients were immobilized with a head frame. At the time AlignRT was installed Orfit masks were also being evaluated for stereotactic work. The addition of the AlignRT system to our clinic allowed a quantitative method for measuring the effectiveness of our immobilization methods. As shown in (Tables 1,2 and 3) patient motion in a head frame was 3 fold greater than what was found with the open face mask immobilization. Based on this finding, further use of the head frame system was halted in our clinic. At this time the OrfitNanor reinforced mask is used exclusively. Patient motion in the mask is monitored at the time of CT imaging and during the entire time of treatment with AlignRT. If a patient's position deviates by more than ±0.5 mm during treatment, then the treatment is halted, the patient is repositioned, and the treatment is resumed. A possible explanation for the 3 fold greater motion with the frame versus the mask can be understood by looking at (Figures 1 and 8). The four pins set into the patient's skull do not allow ring motion with respect to the skull and therefore the brain. However, in our clinic the ring is secured to the 3D positioner with two bolts and the entire ring is cantilevered 34 cm above the positioner as can be seen in (Figure 8). The ring mount can flex in a superior-inferior direction and this was measured to be as much as 10 mm with only a small force being applied. This flex in a superior-inferior direction can cause a pitch in the patient's position and this can result in a change in the anterior-posterior and superior-inferior position of a target in the brain with respect to the isocenter of the accelerator. This flexing can be seen to occur as the patient breaths. After a patient becomes relaxed in the ring the flex motion is still greater than 1 millimeter as shown in (Table 3). It should be kept in mind that others, with different head frame mounting systems, have reported43 that intra-fraction motion with a mean value of 0.4 mm for a frame system. The result reported here for the head frame may not be representative of other clinics. The mask mount shown in (Figure 2) is stable but can flex in an anterior-posterior direction by about 5 mm with a substantial force being needed. This motion of the plate can cause a pitch in the patient's position and a change in the anterior-posterior and superior-inferior position of a target in the brain. After a patient becomes comfortable in the mask the flex motion is sub-millimeter as shown in (Tables 1 and 2). The decision to stop using head frame immobilization after 6 AlignRT measurements in two patients, data shown in Table 3, has weakened the statistical significance of this report. However, it was decided that for best clinical practice a change to face mask immobilization was warranted based on these limited data.

Conclusions

Both types of open-face masks immobilize patients to ≤ 0.4 mm of motion. This is acceptable for stereotactic radio surgery. The Nanor reinforced mask provides no benefit compared to the model 33579 mask.

The head ring as implemented in our clinic allows 3 fold more patient motion than an open-face mask.

Open-face masks immobilize stereotactic radiosurgery patients as well or better than the head ring support used in our clinic.

The AlignRT optical guidance system is a useful tool for monitoring motion of stereotactic radiosurgery patients.

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