When does Brain Motion Interfere with the Accuracy of Stereotactic Radiosurgery? Investigation of Brain Motion in the Presence of Stereotactic Frame.

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Introduction: A major aim of stereotactic radiosurgery is to provide accurate placement of radiation localized to targeted diseased tissues while minimizing the delivery of large radiation doses into sensitive normal tissues (such as motor strip, brain stem, optic nerve, internal capsules, and other major nerve bundles). It is well known that the brain moves during the cardiac cycle. This can result from the action of pulsatile blood flow which produces brain expansion and contraction. Such movement is a challenge to the overall goal of providing submillimeter to millimeter localization accuracy of radiation treatment dose. If significant brain movement is detected for a particular patient (as has been shown in the other organs such as lung), electronic gating of radiosurgery placement would likely be required. Our goal, therefore, was to provide a controlled study of brain motion in patients (already predisposed to) having stereotactic frame fixation for radiation treatment and to estimate this motion at the tumor periphery from CINE based images.

Brain motion was studied extensively in the early 1990s[1, 2]. There has been recent debate regarding the degree of head fixation required for presurgical planning with fMRI[3]. Such brain motion has estimated to be on the order of 0.5 mm for controlled studies over a short period of time (minutes), to a range for head motion of 1-3 millimeters over the course of an fMRI experiment when standard to minimal head fixation was used[4]. None of these previous studies were performed with such stringent fixation as that provided during radiotherapy planning. The frames used in gamma knife stereotactic radiation therapy include head fixation (with insertion of metal pins attached to the patient skull with metallic frames in a bone-to-solid metal contact). Also external motion has been shown to be very different from that within the organs of interest; therefore, our goal was to produce internal image maps that evaluate motion at the tumor boundary level.

Methods: Images from 11 patients with brain tumors were acquired with gated 2D GRE sequences that were acquired at 384x512 matrix with FA=20^0, FOV=256mm, BW=61kHz/pixel and 16-32 CINE phases over a cardiac cycle. The maximal motion was anticipated to be along the sagittal cranial-caudal direction and so was the primary acquisition direction. For each of the 11 patients, the tumor was manually delineated by an region of interest(ROI) Optical flow estimation (Eq 1) was evaluated for the entire image, however only pixels on the perimeter were statistically analyzed to evaluate the tumor movement in the ROI periphery. Optical flow techniques permit subvoxel estimation[5] of motion as they use the inherent variation in image intensity (I) to predict the vectorial motion $\vec{u}$.

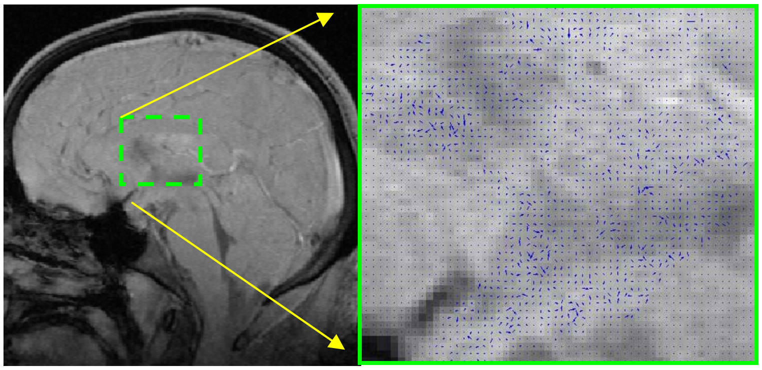

Figure 1: A patient with a primary central tumor, where optical glow images illustrate motion within a cardiac cycle (for subvoxel estimation of motion)

$$\min_{u} \int_{\Omega}(|\nabla u_1|^2+|\nabla u_2|^2)d\Omega \quad +\lambda \int_{\Omega}(I_1(x+u(x))-I_0(x))^2\,d\Omega \qquad (1)$$

Results: In this study, the mean amount of on the tumor periphery movement across 11 patients was calculated to be 0.256 mm with a standard deviation of 0.319 mm with a confidence interval range from 10% - 90% equal to.0213- 0.555 mm movement. As shown in figure 2, on a patient by patient basis, the mean movement per patient ranged from 0.12 -0.49 mm. However, in one case (PA8) the top quintile (20% of the voxels) of the tumor periphery had motion greater than 1mm. This could indicate a concern for brain movement in that patient and may alter therapeutic efficacy.

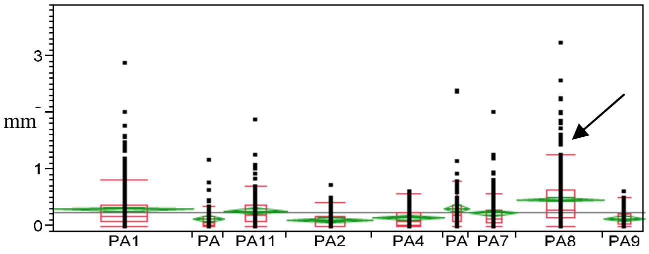

Figure 2: Green triangle is the mean (center) +/- 1 standard deviation from the mean. The Red box-whiskers plot reflect the quintiles of pixel distributions. Note that in patient 8 that one of the quintiles is above 1 pixel (arrow pointing at top quintile).

Discussion: This study shows that despite recent advancements in the ability to better 'sculpt' radiation dose profiles; internal organ motion remains one of the dominant challenges to treatment efficacy. It may therefore be vital on a patient by patient basis to evaluate the range of motion of organs proximal to the tumor that is being treated. To our knowledge this is the first report which both evaluates locally (not at an external marker) and under stringent fixation control for head movement the pulsatile nature of brain motion. Our results illustrate that most tumors in the brain have limited motion (averaged less than 0.5 mm) over the cardiac cycle. However, in 1 of 11 patients, the need to provide radiation motion compensatory techniques may be required, as suggested by the 20% of the periphery of the voxels which had motion greater than 1 mm.

References:

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