Head-to-Head: Evaluating Effect of Skin Tone on the Accuracy of Surface Imaging Systems for Intra-fraction Motion Monitoring of Intracranial Radiosurgery

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Objectives: During frameless stereotactic radiosurgery (fSRS), a thermoplastic mask is used to immobilize patients. Due to the use of small or no margins and single isocenter treatment planning, intra-fraction motion management having sub-millimeter performance is of the utmost importance during fSRS. An increasingly common approach to intra-fraction motion management is the use of optical surface imaging (SI). However, SI has been reported to have suboptimal performance for patients with darker skin tone, particularly at non-zero couch angles. It is challenging to quantify the effect of skin tone prior to human use of a system, presenting difficulties for vendors to design better systems and for users to assess systems prior to clinical use. Our objective was to design phantoms and a test protocol to quantitatively evaluate the performance of an SI system for a range of skin tones.

Methods: We used images from the Visible Human Project provided courtesy of the U.S. National Library of Medicine. The head CT was downloaded and imported into the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA). After the external contour was created, it was copied and cropped at the coronal plane passing through the ears to extract the anterior surface. Using the Eclipse Scripting API, the 3-dimensional triangle mesh, representing the anterior surface, was exported in STL file format into a 3D slicer software (IdeaMaker, Raise3D, Stafford, TX). The phantom was 3D printed using polyethylene terephthalate glycol (PETG) filament in each of four colors designed specifically to match skin tones: rose tan, light brown, medium brown, and dark brown (3DUniverse, Chicago, IL). We evaluated the SI systems of two vendors. Both systems use a similar camera geometry comprised of three camera pods separated by approximately 90 degrees mounted above isocenter. In the IEC room coordinate system, two of the pods are located symmetrically on the x-axis and the third is located on the negative side of the z-axis. The geometry is such that the gantry blocks one of the pods when it is in the range 260-350 degrees and 10-100 degrees. Both systems have the capability to export the reported offsets to text files. We evaluated SI system performance for each phantom at multiple table angles for both an unobstructed three-camera view and a two-camera view resulting from gantry obstruction of one of the camera pods. A plan was created having beams at table angles 0, 45, 90, 315, and 270 degrees and gantry angles 0, 50, and 310 degrees. At each table angle/gantry angle combination, we extracted approximately 5 seconds of reported offsets from the text file and computed the average magnitude of the translation offset.

Results: When all three cameras had an unobstructed view of the phantom, for SI System A the maximum difference in magnitude relative to the rose tan phantom at non-zero table angles was 0.11 mm, 0.96 mm, and 0.83 mm for the light brown, medium brown, and dark brown phantoms, respectively. For SI System B, the maximum difference was 0.85 mm, 2.81 mm, and 2.77 mm for the light brown, medium brown, and dark brown phantoms, respectively.

When one camera view was obstructed, for SI System A the maximum difference in magnitude relative to the rose tan phantom at non-zero table angles was 0.19 mm, 1.36 mm, and 1.73 mm for the light brown, medium brown, and dark brown phantoms, respectively. For SI System B, the maximum difference was 0.66 mm, 4.43 mm, and 3.02 mm for the light brown, medium brown, and dark brown phantoms, respectively.

Conclusion(s): The accuracy of both systems was dependent on skin tone, particularly when one camera was obstructed. The offset errors were sufficiently large to impact clinical decision making. Users should have a process for evaluating offsets that includes the patient skin color. In particular, patients should never be repositioned based on a surface imaging system. Vendors should incorporate skin tone into the engineering process and design their systems to minimize dependence of system accuracy on patient skin color.