Optimum elevation between the skin surface and the skin markers for proton therapy CT simulation

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ABSTRACT

Radiopaque wires are placed on the patient's skin during CT simulation to precisely outline the location of surgical scars and the intended radiation treatment field borders. However, the proton dose calculation is sensitive to the metal wires. To avoid the dose uncertainties, the skin markers are removed by manually assigning a density of air before the planning, as the wires will not be present during the treatment. This is a time-consuming process for the planner. Hence, markers elevated from the skin are needed, which can mitigate these issues and strike a balance between acceptable contouring time and geometric accuracy. Commercially available markers (RT-SPOT, Beekley Medical, Bristol, CT) were modified so that the markers are elevated from the skin with various thicknesses of radiolucent foam backing. The contouring time has been dramatically reduced by 40% or more with the elevated markers; the thicker the elevation, the shorter the contouring time. Geometric errors, however, increased when the elevation increased. The elevation of 1.5 – 3 mm from the skin showed optimum thickness; a reduction in contouring time by 37%, while geometric error was <1 mm.

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INTRODUCTION

Patient setup plays a major role in radiation therapy in delivering the right amount of dose to the right location. For a reproducible setup throughout the course of treatment, it's important to scan the patient with the required supporting devices and to mark any identifiable landmarks on the patient's skin. Radiopaque wires are placed on the patient's skin during CT simulation to precisely outline the location of surgical scars and the intended radiation treatment field borders, allowing the radiation oncologist to accurately target the treatment area while minimizing damage to surrounding tissues. This is particularly important in cases like breast cancer, where identifying the scar from a lumpectomy or mastectomy is critical.

Proton dose calculation is sensitive to the metal wires. In order to avoid these uncertainties, the skin markers are often contoured and are assigned a density of air as the wires become transparent to the incoming proton beams. Any mistakes, either missing the markers or inaccurate contouring, may cause dose perturbations. In addition, it is a tedious, time-consuming process to manually contour the body and the wires as they stick to the skin, increasing the planner's time spent per patient. To reduce the contouring time and chances of mistakes, a marker, elevated from the skin, is needed, which can mitigate the above-mentioned issues, since autodetection of the skin is possible if the marker is backed up by a low-density material. However, there is a lack of literature on the optimal height of such markers to keep a perfect balance between lowering contouring time and acceptable geometric accuracy.

This report uses a type of foam elevation marker (RT-SPOT, Beekley Medical, Bristol, CT) to seek the optimal elevation height of the marker by analyzing the skin contouring time and the geometric error for different heights.

METHODS AND MATERIALS

Clinical Efficiency:

We use an anthropomorphic phantom to evaluate the clinical efficiency and dosimetric accuracy of the foam elevation marker (*Figure 1A*). Four marker strips were placed on the phantom. Number "0" is the skin marker (CT-SPOT, Beekley Medical, Bristol, CT), while numbers "1", "2", and "3" are the elevated foam marker (RT-SPOT, Beekley Medical, Bristol, CT) with 1, 2, and 3 layers of radiolucent backup foam material. The thickness of the foam is 1.5mm per layer. The phantom with markers was scanned with a 3.0 mm slice thickness (*Figure 1B*). Body and marker structures were contoured by 3 similar expert-level dosimetrists, as per our clinical guidelines. The body and marker contouring times were evaluated for the CT-SPOT and RT-SPOT markers with different thicknesses of layers of radiolucent foam backing.

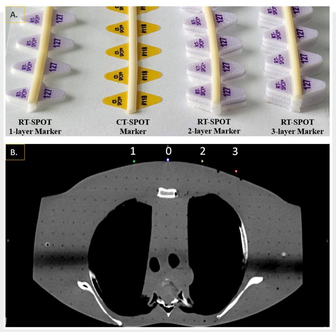

Figure 1. A) Samples of skin markers without and with 1-, 2-, 3- layers foam back-up, B) A representative slice of the CT image set, current marker on the central line, and the RT-SPOT foam marker on the left and right sides. 0: CT-SPOT marker, 1,2,3: RT-SPOT foam marker with 1.5 mm (1-layer), 3 mm (2-layers), and 4.5 mm (3-layers) of backing foam respectively.

METHODS AND MATERIALS (*cont.*)

Dosimetric Accuracy:

To evaluate the dosimetric accuracy, three monoenergetic proton plans, comprising the proton energies of 70 MeV, 160 MeV, and 200 MeV, were generated on image sets with and without overriding the marker to air, with a single beam at gantry angle 0o and snout position at 42 cm. For each plan, the field size was 25cm x 25cm, 0.25 cm voxel size, 0.25 cm spot spacing, and 0.4 cm spot size with 10 MUs per spot. Due to the size limitation of the phantom, the 200 MeV plan was done using a 5-cm range shifter to capture the Bragg peak within the phantom. The dose lines were drawn on slices with the isocenter from the anterior to posterior direction within the patient contour along the marker.

Geometric Accuracy:

To evaluate the positional accuracy of markers with varying foam thicknesses, we used the CT-SPOT marker placed directly on the skin surface as a reference marker. New markers with foam backup of different thicknesses were carefully attached to the reference markers, using best visual alignment (*Figure 2*). A CT scan of the phantom was subsequently acquired to assess the relative positional shift between each foam-mounted marker and its corresponding underlying reference marker. To simulate realistic clinical variability, four clinical personnel, i.e., a radiation oncologist, a medical physicist, a dosimetrist, and a radiation therapist, were asked to independently apply the markers on the phantom surface. Everyone placed four sets of markers on the phantom's anterior chest, anterior abdomen, left lateral abdomen, and right lateral abdomen. Each set included three elevated markers of different thicknesses, so a total of 16 data points per elevation thickness group were used to analyze the positional accuracy under conditions representative of actual clinical practice.

Figure 2. Image of anthropomorphic phantom with A) anterior, and B) lateral markers. The text boxes labelled the clinical personnel who placed the wires for each group. The location of the physician-labeled markers is relatively flat, so we can test the 1, 2, and 3 -layer samples together. However, some locations in other groups have relatively larger local curvature which will affect the accuracy of the position error, so we only use a single reference marker for each group and repeat three CT scans by replacing different layers of foam markers on the top to get more accurate data.

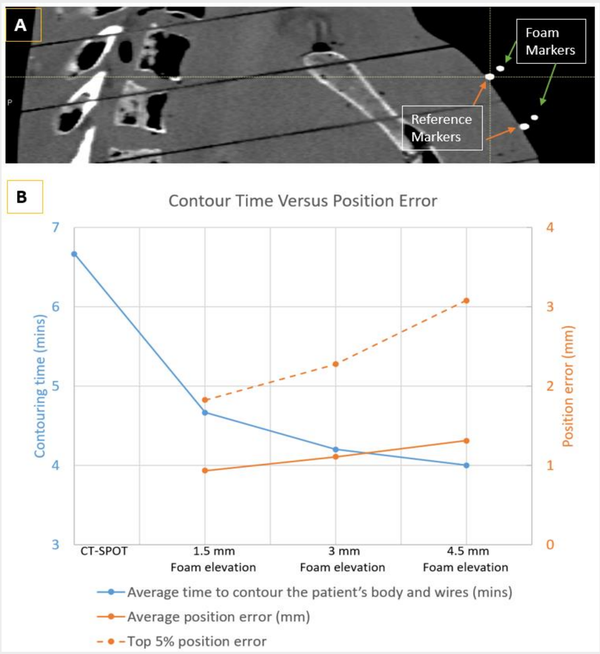

Figure 4. A) A representative CT image of the phantom with embedded markers. The BBs located near the skin surface serve as reference markers, while the BBs positioned above each reference marker—separated by a defined thickness of foam—act as testing markers. The red line segment represent the position difference Δx in the inferior/superior direction. Panel (B) illustrates both the average and the top 5% of positional errors (represented by orange lines), along with the average skin contouring time for each group (shown as a blue line).

RESULTS & DISCUSSION

Clinical Efficiency:

It was found that the time needed to contour the patient's body and wires was reduced by 30% (6.7 to 4.7 minutes), 37% (6.7 to 4.2 minutes), and 40% (6.7 to 4.0 minutes) when changing from skin marker to 1-layer, 2-layer, and 3-layer of foam backing, respectively. As a result, the foam evaluated marker can save a good fraction of contouring time for the planner and enhance clinical efficiency. Saving time in contouring becomes increasingly beneficial in scenarios involving repeated quality assurance CT (QACT) scans followed by QA plan evaluations and adaptive replanning throughout the course of treatment during proton therapy. Biswal et. al. reported that QACT is performed approximately 2-6 times during proton therapy, and that approximately 40% of head-and-neck (HN) cases ultimately require replanning.

Dosimetric Accuracy:

The CT numbers were measured for all the markers by contouring them at the Mediastinum window (Level: 40 HU, Window: 400 HU). The average Hounsfield units (HU) for skin and elevated markers were 876.2 (44-2354 HU), 318 (68-625 HU), respectively. The dose perturbations due to the skin markers (marker_0) and the elevated (marker_1,2,3) markers are presented in Figure 3. At 70 MeV (Figures 3 A, B, C, D), a 2.6 mm shift in Bragg peak and 2.2% change in dose is observed with the skin marker (0 layer). However, with the elevated markers (1,2,3 layers back up), there is no shift in the Bragg peak, but a change of 2% in dose is observed. With the 160 MeV (Figures 3 E, F, G, H), there are no changes in dose observed for any marker, but a shift of 1.9 mm in the Bragg peak is observed for the skin marker. Similarly, for the 200 MeV with 5 cm range shifter (Figures 3 I-L), there are no changes in dose or with the Bragg peak position for any of the markers. The dose perturbations were slightly larger for lower energies than for those with higher energies. Also, if a planner forgets to contour and override the elevated markers to air, then the dosimetric differences are smaller in comparison to the skin marker.

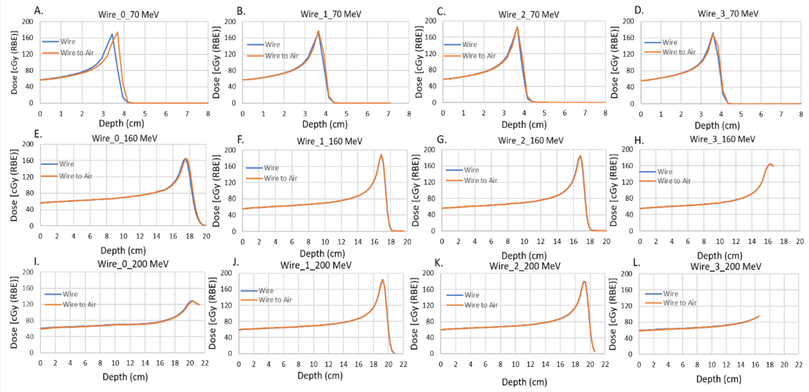

Figure 3. Dose-depth profiles along the marker wires for wires leave as it is (Wire) and wires overridden to air (Wire to Air). A-D) profiles for 70 MeV along the wires, E-H) profiles for 160 MeV along the wires, and I-L) profiles for 200 MeV with 5 cm range shifter along the wires. 0: CT-SPOT marker, 1,2,3: foam spot marker with 1.5 mm, 3 mm, and 4.5 mm layers of backing foam respectively.

Geometric Accuracy:

Figure-4A shows a representative CT image of the phantom with attached markers. *Figure-4B* illustrates both the average and the top 5% of positional errors (represented by orange lines), along with the average contouring time for each group (shown as a blue line). The results indicate that using a 1.5 mm foam spacer reduces the average contouring time by 30%. However, further increase in foam thickness (beyond 1.5 mm) results in insignificant lowering of contouring time at the cost of positional errors. Based on these findings, foam thicknesses of 1.5 mm – 3.0 mm offer a favorable balance between minimizing contouring time and maintaining good positional accuracy, making them optimal choices for practical implementation. After successfully evaluating all the markers for clinical use for proton therapy planning, the 1.5 mm (one-layer) foam back-up RT-SPOT marker has been used in our clinic for breast and head-and-neck patients.

CONCLUSIONS

Optimal thickness of the elevation backing of the skin markers was evaluated in terms of the contouring efficiency and the geometrical accuracy. It was found that the dose perturbations were smaller for the new marker due to the material differences used in this study between the skin and the elevated markers, unless the marker wire densities were overridden to air. The dose perturbations were larger for lower energies, and that gets smaller with increasing energy unless the density override is properly applied. Elevated markers save time by reducing the need for additional manual contouring. Foam thickness of 1.5-3.0 mm showed 30% - 40% reduction of the contouring time of the patient's body and marker wires, while not compromising the geometrical accuracy significantly.

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