Evaluation of a PAGAT Gel for Use in an Anthropomorphic Phantom

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Introduction

The Radiological Physics Center (RPC) uses anthropomorphic phantoms to remotely audit an institution's ability to plan and deliver radiation treatments. Currently, the RPC has five anthropomorphic phantoms that simulate different treatment sites. The phantoms are equipped with inserts that allow for imaging of targets and critical structures contained within. The inserts also contain film and TLD that allow for measurement at selected points and planes within the dose distribution. Ideally, the RPC would be able to evaluate the entire dose distribution that was delivered to the phantom. As a result, the RPC has the interest and need for 3D dosimetry to be implemented in its anthropomorphic phantoms. The RPC has conducted previous investigations with three-dimensional dosimeters and also has an optical CT system for imaging of 3D dosimeters.[1,2] There exist several three-dimensional (3D) dosimeters, each having unique advantages over the others. The polymer gel formulation, PAGAT, was chosen for this investigation. PAGAT gel is a polyacrylamide gel that contains an oxygen scavenger, therefore the gels can be made without the use of a glove box to remove oxygen. De Deene et al.[3] demonstrated that PAGAT gel has superior spatial integrity, less dose rate dependency, and less temperature sensitivity than several other polymer gel formulations.

The purpose of this investigation was to evaluate the use of PAGAT gel in the Radiological Physics Center's (RPC) Head and Neck Phantom.

Materials and Methods

The insert of the head and neck phantom contains several structures used for planning: two target volumes (PTV1 and PTV2) and an organ at risk (OAR). The insert is designed to hold film in two planes: one piece of film in the axial plane, and two pieces of radiochromic film that lie in the sagittal plane.

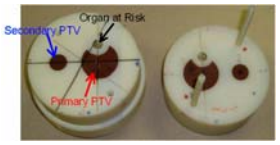

Fig. 1 Photograph of the insert for the RPC head and neck phantom. Both primary target volumes (PTV) and the organ at risk are identified. The insert is designed to hold film and TLD to perform measurement of the delivered dose distribution.

An unmodulated treatment plan was developed using Pinnacle (Phillips Medical Systems, Milpitas, CA) using the x-ray CT images of the phantom equipped with the insert. Two pairs of parallel-opposed beams was used to deliver different doses to the each structure within the conventional dosimetry insert. An IMRT treatment plan was also developed for the phantom. The plan employed the use of 9 fields with gantry angles in 40° increments from 0 to 320 degrees.

Support:

The investigation was supported by PHS grant CA10953 awarded by the NCI, DHHS.

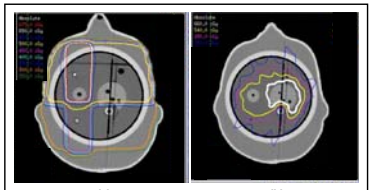

Fig. 2 (a) Isodose curves from an unmodulated treatment plan. (b) Isodose curves from an IMRT treatment plan.

A batch of PAGAT gel was prepared to fill two 9-cm diameter PET jars and five 5-cm diameter PET jars. The 5-cm dosimeters were used to develop a calibration curve for the batch of gel. Each jar was placed in a water tank and irradiated using a pair of parallel-opposed beams to doses from 0 to 5 Gy. The 9-cm dosimeters were irradiated in the head and neck phantom. One 9-cm dosimeter was irradiated with an unmodulated treatment plan. Doses of 325 cGy, 250 cGy, and 150 cGy were delivered to PTV2, PTV1, and OAR respectively. The other 9-cm dosimeter was irradiated with an IMRT plan. Doses of 280 cGy, 240 cGy, and 100 cGy were delivered to PTV2, PTV1, and OAR respectively.

An investigation of the dependence of PAGAT gel to fractionation was performed. A 750 mL batch of PAGAT gel was made and used to fill six 5-cm diameter PET jars. A parallel-opposed technique was used to irradiate each dosimeter uniformly to 3 Gy. The number of fractions was varied from 2 to 32 fractions. Each jar was placed in a water tank during irradiation. A delay of 1 minute was used between fractions.

Immediately after irradiation, all polymer gel dosimeters were stored at room temperature overnight prior to imaging. The next day, optical CT (OCT) imaging was performed using the OCTOPUS™ OCT scanner at the RPC. A 1 mm pixel size was used for imaging of all dosimeters.

Results

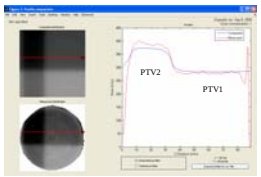

Fig. 3 Profiles through PTV2 and PTV1 from gel measurements (red) and the unmodulated treatment plan (blue).

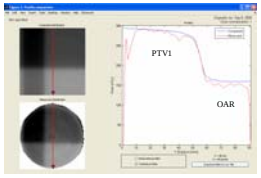

Fig. 4 Profiles through PTV1 and the OAR from gel measurements (red) and the unmodulated treatment plan (blue).

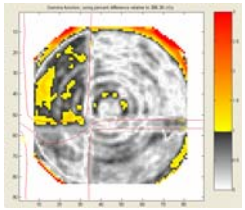

Fig. 5 Gamma index comparison (5% or 3 mm) between gel and unmodulated treatment plan. 88% of the pixels pass the gamma comparison.

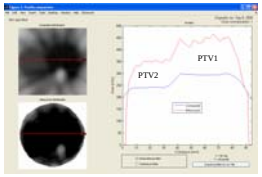

Fig. 6 Profiles through PTV 2 and PTV 1 from absolute gel measurements (red) and the IMRT treatment plan (blue). These look reversed from plan – confusing?

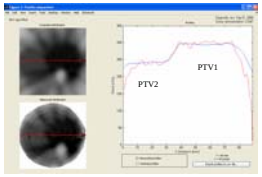

Fig. 7 Normalized profiles through PTV 2 and PTV 1 from gel measurements (red) and the IMRT treatment plan (blue).

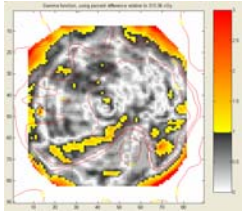

Fig. 8 Gamma index comparison (5% or 3 mm) between gel and IMRT treatment plan. 84% of the pixels pass the gamma comparison.

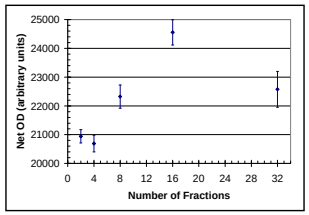

Fig. 9 Net OD for dosimeters irradiated to 3 Gy using a different number of fractions. Error bars represent one standard deviation.

Discussion

Profiles of the unmodulated treatment plan, Figure 3, show an area of disagreement in PTV2 due to the gel overestimating the dose. A gamma index comparison, Figure 5, also showed significant disagreement in PTV2. Pixels in the periphery of the gel also disagreed with the treatment plan. The edges of the distribution should be removed from consideration in the gamma comparison, however the software used in this project prevented removal of the entire periphery of the gel distribution. An absolute dose profile comparison of the IMRT plan is shown in Figure 6. There is a 35% difference in the dose from the gel measurement and the treatment plan. The distributions were then normalized to the dose in PTV1, Figure 7. Good agreement was observed throughout the distribution, with the exception of an area in PTV2. The periphery of the gel distribution again resulted in significant disagreement.

Investigation of the fractionation dependence of PAGAT gel showed a percent difference in the net OD between 2 fractions and 4, 8, 16, and 32 fractions of -1.2%, 6.6%, 17.3%, and 7.8% respectively. Investigation of the dose integration ability of PAGAT gel showed that the response of the gel is dependent on the number of fractions used to deliver the dose. As the number of fractions is increased, there is an increase in the response of the gel. The data point at 32 fractions is less than expected, but still greater than the response at 2 fractions. The dependence of the response on the number of fractions is consistent with results from Karlsson et al[4]. When the dose is fractionated, fewer free radicals are terminated due to recombination. This results in a larger number of radicals initiating a response in the gel. Therefore, a gel irradiated to a given dose with multiple fractions will have a greater response than a gel irradiated to the same dose in a single fraction.

The overestimation of dose by the gel in the unmodulated and IMRT treatments is attributed to the gel's fractionation dependence. The calibration dosimeters were irradiated using 2 fractions. The dose to PTV 2 in the unmodulated treatment, where the dose was overestimated, was delivered in 6 fractions. The dose to the gel receiving the IMRT treatment was in effect delivered using a larger number of fractions, therefore the gel overestimated the dose by a larger percentage.

Prior to implementation in an anthropomorphic phantom, a new calibration procedure should be developed that uses a similar number of fractions as those used in the treatment. This investigation demonstrated that the use of a three-dimensional dosimeter would allow for 2D comparisons to be performed as is currently done. The use of a three-dimensional dosimeter provides the advantage of evaluating any plane of interest and the ability to perform DVH comparisons with treatment plans.

References

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