3D Dosimetry with a Novel Optical CT Scanner Using Fiber Optic Taper for Collimated Images

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INTRODUCTION

Optical CT scanner has been used for 3D dose-readout in polymer gels and radiochromic plastic 3-D dosimeters for more than two decades. However 3-D dosimetry has been limited to research studies, not in the routine clinical QA, due to its clinical impracticality and various uncertainties. Optical CT scanners can be categorized as rastering single-beam and broad-beam geometries. Our single-beam optical CT scanner, modified from the original commercial OCTOPUS™ optical scanner, has been used for several 3D dosimetry studies (1-2) and was considered the "gold standard" technique in light of our previous studies showing its accuracy. The disadvantage with this type of scanner is the long scanning time for a 3-D dosimeter (8-10 hours). The broad-beam optical CT scanner with telecentric lenses and CCD camera design have a much faster scanning process (less than 20 minutes), but its dosimetric accuracy is compromised due to scatter artifacts and spectral artifacts. Both scattered artifacts and spectral artifacts are mainly caused by internal scattering within the imaging lenses and 3D dosimeter.

In this project, we developed a novel broad-beam optical CT scanner with a fiber optic taper for collimated images, which eliminates the scattered artifacts and spectral artifacts. The newly developed optical CT scanner consists of a telecentric broad parallel-beam source, an aquarium to house PRESAGE dosimeters, a fiber optic taper, and a CCD detector. Dose distribution comparison with TPS and gamma index evaluation indicated that the dose readout from this scanner is comparable or better than the results from the single-beam scanner. The scanning time for a complete 3-D dataset acquisition is 10-20 minutes.

MATERIALS AND METHODS

A schematic diagram of the fast optical CT scanner with fiber optic taper is shown in Figure 1. In this project, a novel broad-beam optical CT scanner with a collimated image was designed.

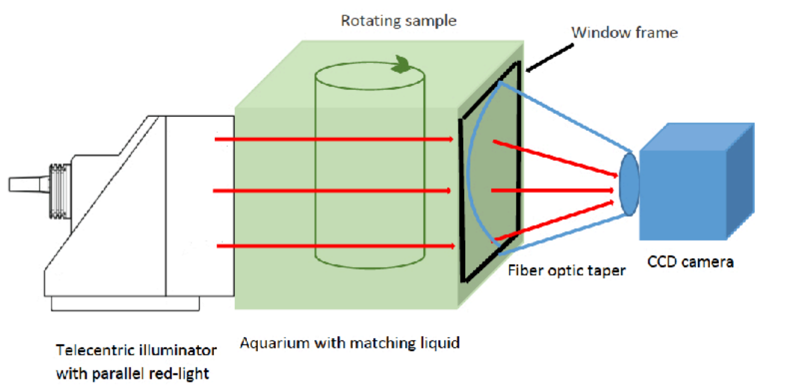

Figure 1. Schematic diagram of the fast optic CT scanner with fiber optic taper for collimated images (Patent Pending).

The main components in our design consists of 1. telecentric illuminator with parallel red-light beam (peak wavelength 630 nm), 2. aquarium filled with optical matching fluid to match the refractive index of a PRESAGE phantom placed on a rotating stage, 3. window frame, 4. fiber optic taper, 5. CCD detector. The key component of this novel design is the use of a fiber optic taper for collimated images in 3D dosimetry (Patent Pending). Most of the current broad-beam optical CT scanners utilize telecentric lenses to map the projected optical images to a CCD detector, which can limit the scanning time to less than 20 minutes. However, this type of CT scanner (broad-beam telecentric scanner) is prone to uncertainties due to stray-light artifacts and spectral artifacts. Fiber optic taper can be used to transfer and enlarge/reduce the size of an image with minimal distortion and high resolution. Specifically, the scatter artifact and other artifacts in the projected images can be removed almost completely due to the collimation effect of fiber optic taper. In this study, a pre-irradiation phantom scanning was performed for each phantom to reduce the effect of background noise, edge artifacts, and other artifacts. To demonstrate this system is capable of measuring 3-D dose distribution with high spatial resolution and dosimetry accuracy, am IMRT plan and a VMAT plan were used for testing.

RESULTS AND DISCUSSION

Figure 2 shows the experimental MTF as a function of lp/mm. In fiber optic taper, the resolution of big end is different from that at small end. Smaller fiber diameter will have a higher resolution. The highest resolution is estimated to be 0.07 mm with MTF 10%, a very high spatial resolution for external beam dosimetric measurements.

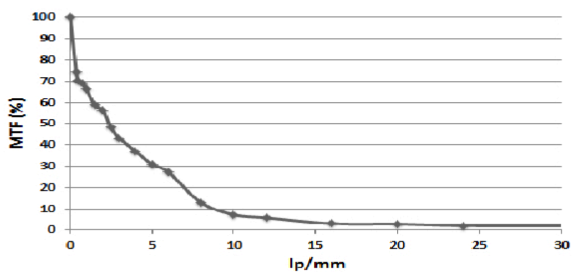

Figure 2. MTF as a function of lp/mm

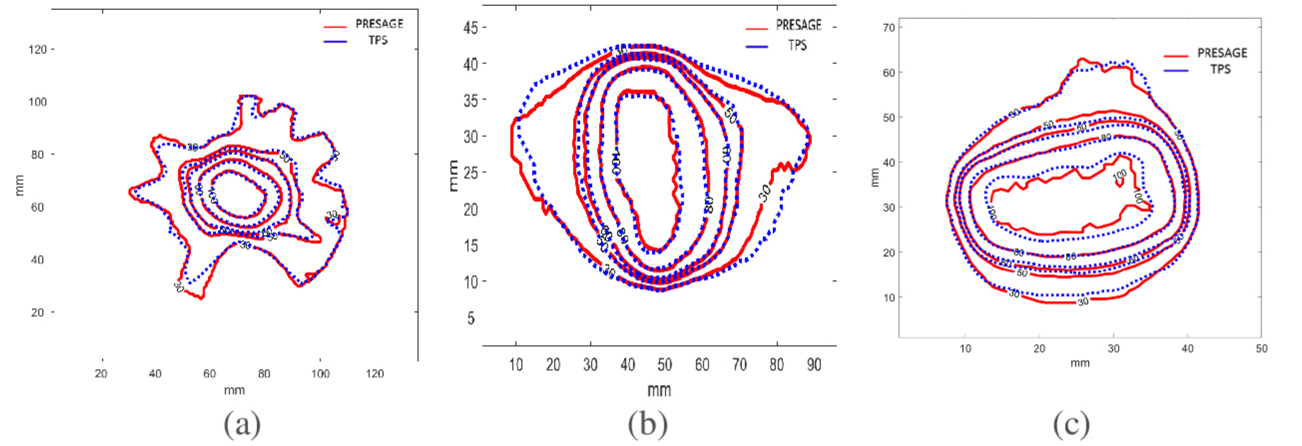

Figure 3. Comparison of dose distributions for a H&N 7-field IMRT plan between Eclipse planning calculation and PRESAGE measurement along central transverse (a), coronal (b), and sagittal (c) planes.

Figure 3 shows good agreement of dose distributions between planning calculation and PRESAGE measurement with optical density readout using the novel optical CT scanner from this study. The gamma index passing rates with the 3%/2mm criteria are 97.1% for the central transverse plane, 98.4% for the coronal plane, and 99.1% for the sagittal plane.

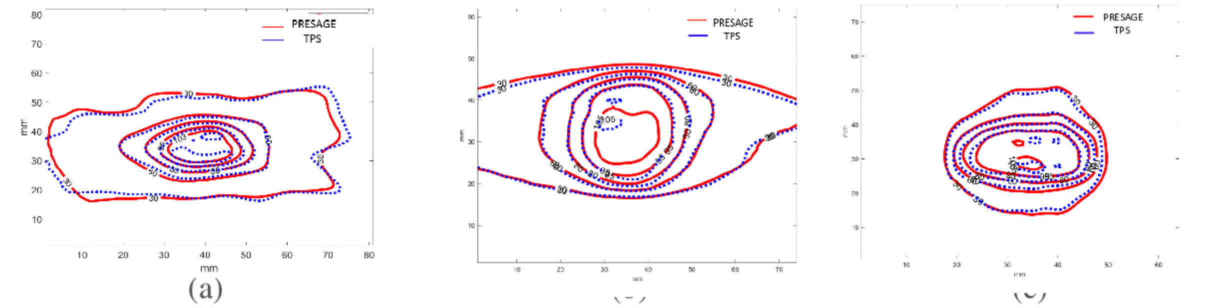

Figure 4. Comparison of dose distributions for a 2-arc VMAT plan between Eclipse planning calculation and PRESAGE measurement along central transverse (a), coronal (b), and sagittal (c) planes.

Figure 4 shows good agreement of dose distributions between planning calculation and PRESAGE measurement for a VMAT SBRT plan. The gamma index passing rates with 3%/2mm criteria are 99.4% for the central transverse plane, 98.0% for the central coronal plane, and 99.0% for the central sagittal plane, respectively.

Artifacts for broad-beam optical CT scanners can arise from several sources, including stray light, edge artifacts from refractive index mismatch, light-scattering impurities in the phantom and on the aquarium wall. The collimated images from the effect of fiber optic taper in this study can remove the scattered artifacts almost completely. The artifacts caused by the refraction and the impurities in the phantom can be corrected with a pre-irradiation phantom scan.

CONCLUSION

A novel broad-beam optical CT scanner, incorporating fiber optic taper for collimated images, has been successfully implemented in our lab. This newly designed optical scanner can be used for optical density readout of 3-D dosimeters. The quality of the 3-D readout from this optical CT scanner is comparable or better than the first-generation scanning system, but with a scanning time of less than 20 minutes. The scanning system is robust and the result is not operator-dependent (an important feature for routine clinical use).

REFERENCES

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