A Novel Method for Determining Optic Nerve and Disc Location for Eye Plaque Treatment Planning

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INTRODUCTION

Episcleral plaque brachytherapy is a well-established treatment modality for uveal melanoma and other ocular lesions [1-4]. The "inverse-square" nature of energy deposition surrounding a brachytherapy source leads to steep dose gradients in the vicinity of a source, and strong collimation of the low energy photons emitted from radionuclides such as I-125 by thin layers of high Z materials such as gold, combine to enable designing of conformal isodose treatments for small lesions within the eye. To deliver a conformal treatment, however, requires accurate surgical placement of the plaque. 3D modeling and mapping of patient specific eye anatomy can provide accurate tumor localization and suture coordinate guidance to assure plaque placement. It also enables accurate dose calculations to critical anatomic sites such as nerve and fovea to help optimize treatment plans [4, 5].

AIM

The aim of this study is to present a novel method for accounting for optic nerve, and hence optic disc, location in the CT-based patient specific eye models used for 3D treatment planning of episcleral plaque brachytherapy by Plaque Simulator.

METHOD

Plaque Simulator (Eye Physics, LLC) is image-based treatment planning software for episcleral eye plaques. CT-based, 3D eye models begin with a thin (<=1mm slices) axial series of the orbits. CT alone does not have the resolution to accurately map the base of an intraocular tumor. By fusing ultrasound b-scans and fundus photography or scanning laser ophthalmology images (Fig. 1) with the CT model, the tumor base can be accurately mapped. This fusion requires transformation of the pixels of the fundus image to CT-space 3D coordinates. This is accomplished by locating the geometric posterior pole of they eye (near the fovea) and the center of the optic disc in both CT–space and the fundus image.

Assuming that the center of the optic disc where blood vessels enter the eye (an easy location to find in the fundus image) can be modeled as a geometric extrapolation along the center of the optic nerve sheath, then determining where the optic nerve sheath connects to the eye can be used to closely estimate the center of the optic disc in CT space.

In addition, nerve sheath diameter can vary between 4 and 7 mm. Modelling the diameter of the nerve sheath where it connects to the eye becomes important in the treatment of peri-papillary tumors because the nerve can mechanically limit how closely a plaque can approach, and nerve position a radionuclide seed, to the edge of the optic disc.

The method described in this work requires only one additional planar CT reconstruction to visualize where the nerve connects to the sclera.

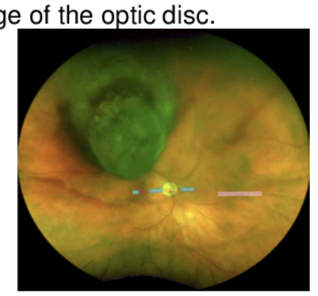
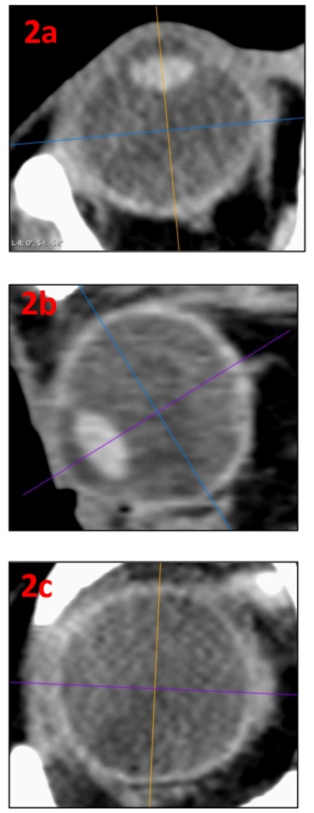


Figure 1: Fundus photography depicting a posterior uveal melanoma lesion in close proximity to the optic nerve and fovea.

RESULTS

Figure 2: The patient-specific eye model created by Plaque Simulator is generated by reconstructing orthogonal axial (Fig. 2a), sagittal (Fig. 2b), and equatorial-coronal (Fig. 2c) planes through the center of the globe in eye coordinate space. Note: depending upon the rotation of the eye within the orbit and rotation of the head within the CT scanner, these orthogonal planes might, or might not, correspond to axial, sagittal and coronal reconstructions of the head in CT space. These rotations are usually easy to account for by assuming medial-lateral orbital symmetry, so it is important that both eyes are included in the axial series. A pair of additional coronal and meridian reconstructions (not shown) through the tumor apex assist in defining tumor position. The orthogonal reconstructions determine the macroscopic dimensions and shape of the eye which are used to calibrate fundus images and calculate suture eyelet coordinates. The tumor reconstructions are used to help model tumor size and location.

By default, the center of the optic disc is assumed to be at an azimuthal angle of about 21.5 degrees medial to the posterior pole as viewed from the center of the eye. This corresponds to a chord distance about 4 mm medial to the posterior pole for a 24 mm diameter eye (measured at the equator), and centered (inf-sup) on the geometric axial bisector of the eye. This bisecting plane is equivalent to the 3 and 9 o'clock meridian plane in the azimuthal coordinate system common to ophthalmology mapping. You can see in Fig. 2a that the nerve appears to be quite narrow. This is because the reconstruction plane is not actually bisecting (inf-sup) the nerve.



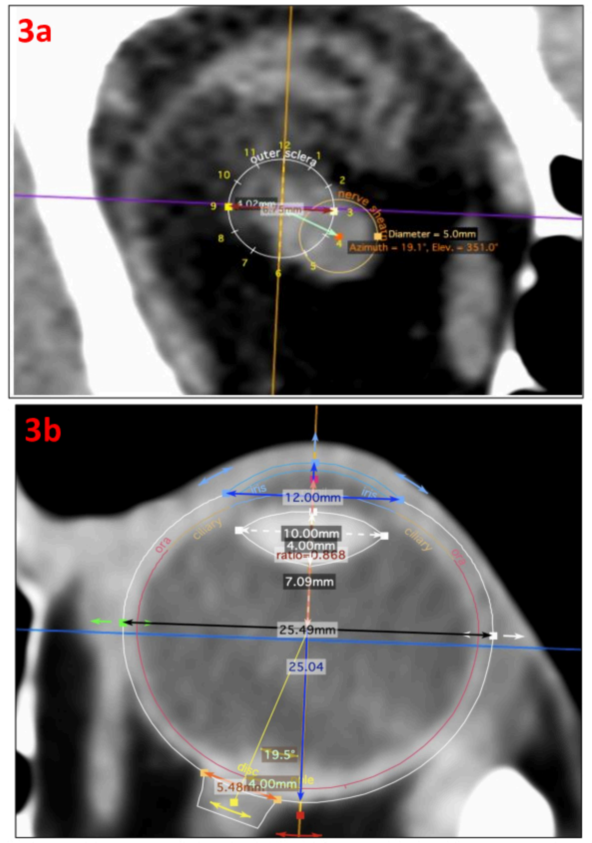
We have observed numerous clinical cases wherein the nerve connects to the sclera a mm or two superior or inferior to the axial geometric bisecting plane.

Fig. 3a is a coronal reconstruction passing through the posterior sclera and nerve (about 0.5mm posterior to the posterior pole). In this "nerve-coronal" plane, cross-sections through the posterior sclera and optic nerve are clearly visible. The diameter of the nerve sheath and azimuthal and elevation angles relative to the posterior pole (these angles are as viewed from the center of the eye) may then be adjusted interactively by simply fitting cross-sections of the computer model to the cross-sections in the nerve-coronal reconstruction.

This novel method requires only this one additional nerve-coronal reconstruction to localize the optic nerve for the 3D model of the eye.

The azimuthal location of the nerve, as well as the sheath diameter, can then be confirmed by projecting the intersection of the 3D model onto the axially bisecting reconstruction as illustrated in Fig. 3b.

Note: Fig. 3b is from a different patient than Figs. 2 and 3a, but it illustrates a far more oblately shaped eye than that seen in Fig.2.



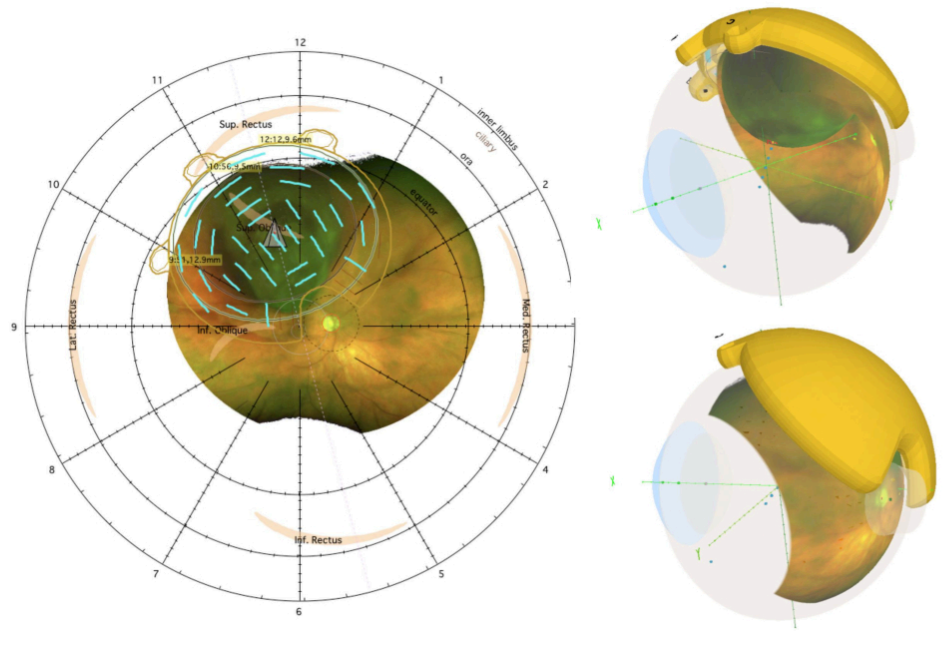


Figure 4: A retinal diagram (a posterior pole centered azimuthal equidistant projection) mapping plaque and seed positions and suture coordinates for a tumor located near the optic nerve. The 3D illustrations depict the plaque notch capturing the optic nerve, and suture eyelet positions.

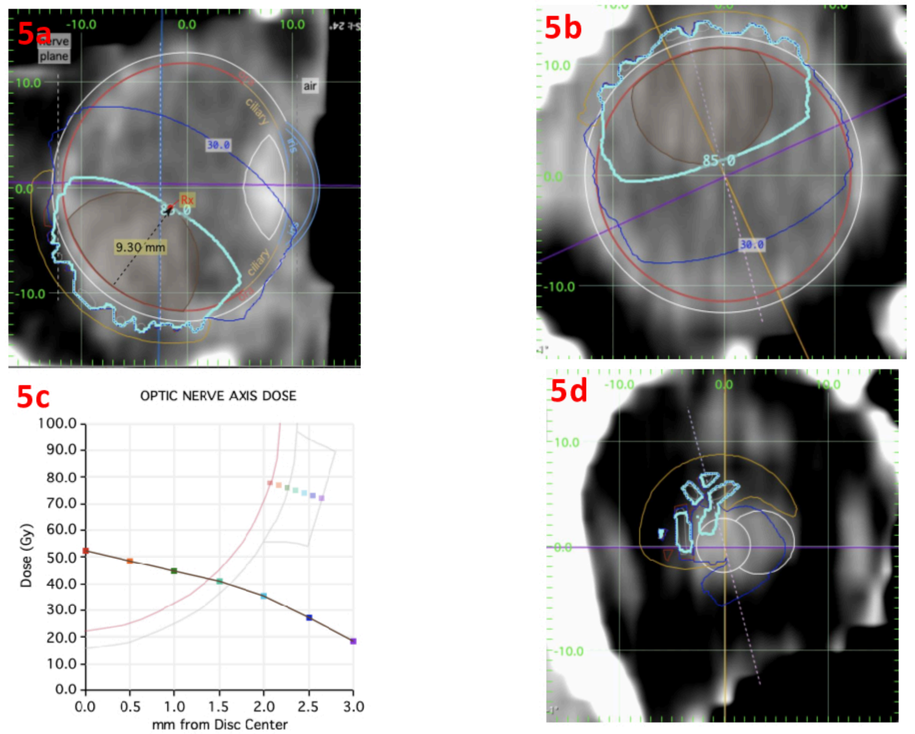


Figure 5: Dose calculation and isodose display for the tumor-meridian and tumor-coronal plans (Figs 5a and 5b), as well as for a nerve-coronal plane (Fig. 5d). Optic nerve dose as a function of distance from the inner disc center is also calculated for all Plaque Simulator calculations.

DISCUSSION

The described method improves the patient-specific eye model by accounting for optic nerve diameter and disc location. This can become especially important for medial posterior tumors that abut the optic disc and require notched plaques (as shown below). Posterior tumor treatment often benefits from using a notched plaque to avoid plaque collision with the nerve sheath.

In our 35 year clinical experience entailing about 2000 eye plaque cases, disc azimuth angles between 18 and 24 degrees (3.5 to 4.5 mm) medial to the posterior pole have been observed and nerve sheath diameters routinely vary between 4 and 7 mm.

Disc elevation angles of a couple of degrees from the axial bisector are common-place, and we have observed elevations of up to 6 degrees (about 1 mm) above and below the axial bisector of the eye.

CONCLUSIONS

The location of the optic disc center and nerve sheath diameter can vary by a few mm from their anticipated defaults. These variations are potentially of dosimetric concern for medial-posterior tumors because they might lead to reduced suture coordinate accuracy, and a wider than normal nerve sheath could mechanically impede posterior plaque placement if its diameter were ignored

DISCLOSURE

Melvin Astrahan, PhD is CEO of Eye Physics, LLC, the creator of the Plaque Simulator software and Eye Physics eye plaques.

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CONTACT INFORMATION

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