Validating Superficial Radiotherapy Dosimetry: Beyond Manual Dose Calculations

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BACKGROUND

Superficial, kilovoltage or low- to medium-energy x-ray radiotherapy is an effective treatment modality for non-melanoma skin cancer and other diseases.

Manual dose calculations for these treatments using surface dose rates are comparatively simple compared to megavoltage beams. Calculations are subject to high uncertainties near heterogeneous and topographically complex targets, as found in head & neck treatments.

A key factor limiting the broader use of superficial (and orthovoltage) therapy is the lack of a commercial treatment planning system. Without accurately calculated dose, it is difficult to compare achievable dose distributions against other treatment modalities, such as brachy-therapy or megavoltage x-rays and electrons.

Monte Carlo dose calculations can address this gap, though care must be taken to verify calculations using end-to-end testing.

This study describes a program of research including the application of the OrthoPlan software[1] and EGSnrc to estimate dose in patients, with verifications done using 3D-printed phantoms and film measurements.

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CLINICAL WORKFLOW

Superficial x-ray therapy treatments are manually planned for a WOmed T-300 system. A clinical mark-up is made by the radiation oncologist and transferred to sarin wrap for shielding design.

CT images are acquired at the request of the treating radiation oncologist on an ad hoc basis, to inform treatment depth and beam quality selection, or when there is potential to instead use an electron or VMAT plan. For some patients, an optical 3D scan is acquired to print a positive for forming the lead shielding device, shown in Figure 1.

DOSE CALCULATIONS

As a quality improvement and educational project, dose calculations have performed retrospectively for a selection of patients, where CT or optical scan derived pseudo-CT data was available[2-4]. The objective of this study was to develop an educational handbook, consisting of example dose calculations for different sites, along with dose quality metrics.

The dose calculation workflow is shown in Figure 2. Pseudo-CT data was generated, as required, using in-house Python code[2-4]. CT data was segmented using 3D Slicer[5], with contours saved using the RTSTRUCT format. Orthoplan[1], adapted for use with the WOmed T-300 treatment unit, was used to generate input files for simulation using DOSXYZnrc. The phase space files used in simulations were generated with a BEAMnrc model commissioned against microDiamond water tank measurements.

PHANTOM VALIDATION

Dose calculations and estimates have been validated using Gafchromic EBT4 film measurements in 3D printed phantoms. Figure 3 presents an example, where a reference CT image was approximately registered with a 3D optical scan. HU thresholds of <-500, -500 to 800 and >800 were used to define air cavities, soft tissue and bone volumes, and these volumes were exported as a 3D model using the STL format.

The model was then printed with a Bambu Lab X1C printer, using 85% in-fill PLA and 100% in-fill StoneFil terracotta composite filaments for tissue and bone, respectively.

Agreement between measurements and calculations has been strong at surface, but not at depth, presumably due to uncertainty in material modelling (e.g., non-water-equivalence of film).

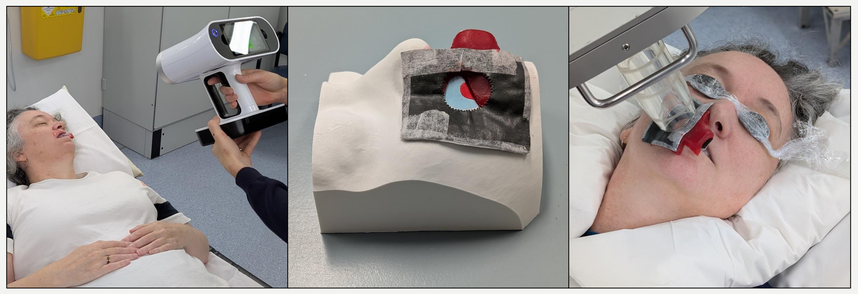

Figure 1. Optical scanning is used to acquire a 3D model of a patient, which is then 3D printed to allow the fabrication of a shielding device for treatment delivery[2].

Figure 2. Dose grid definition and beam arrangement using the OrthoPlan software[1].

Figure 3. 3D-printed phantom, printed to facilitate film measurements using the WOmed T-300 unit. Note that film has been placed on the surface of the phantom, as well as in a transverse plane between phantom pieces.

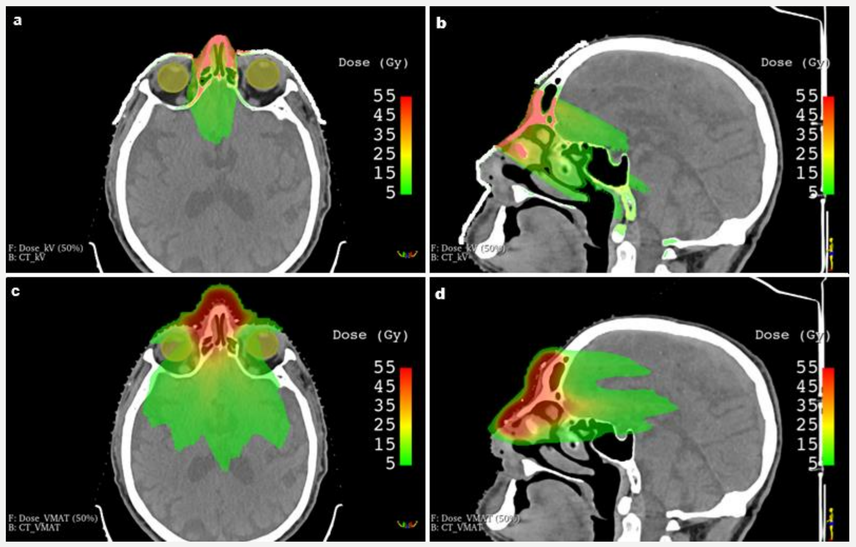

Figure 4. Comparison of dose distributions achievable with superficial (a, b) and VMAT (c,d) modalities. Dose to the eyes (contoured in yellow) would be reduced by at least 5 Gy over the course of treatment for this case. Note that the VMAT treatment requires the use of bolus to increase skin dose.

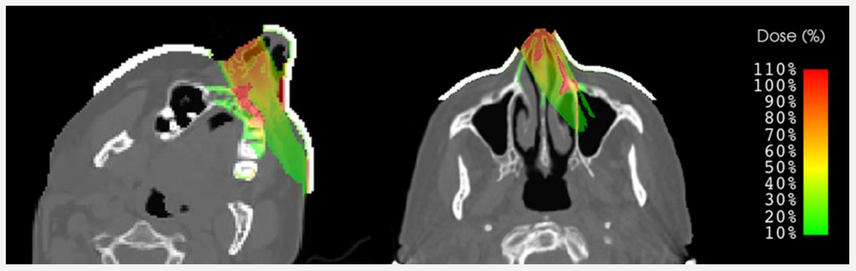

Figure 5. Two additional nasal dose calculation examples achieved with superficial radiotherapy beams.

EDUCATIONAL RESOURCE

An example dose calculation for a nasal bridge basal cell carcinoma patient is shown with a comparison VMAT plan in Figure 4. This treatment was planned for delivery with a 100 kV, 2.9 mm Al HVL beam and 5 cm applicator. A substantial reduction in ocular dose was achieved with the use of superficial radiotherapy.

The handbook currently features 15 retrospective dose calculations, covering the nose, cheek, canthus, ears, forehead and chest, shown alongside diagnosis, prescription and treatment information, photographs of treatment areas, dose quality metrics (such as surface dose homogeneity), and dose distributions optimised for other modalities where available. Two additional nose treatments are shown in Figure 5.

Notes describing uncertainties in Monte Carlo modelling and calculation, including dose grid resolution, voxelization and volume averaging, tissue composition, treatment set-up, and use of dose-to-medium, are also included.

FURTHER WORK

Validation of dose calculations outside of water-equivalent tissue is challenging, particularly for kilovoltage radiotherapy where the photoelectric effect is dominant for high-Z materials. Uncertainty in the assignment of materials according to HU, and in volume averaging at surface need investigation.

The dose to bone can be five times higher than surrounding dose to tissue (this is not visible in Figures 4 and 5, which have been clipped to 110% of prescription). This is due to high-Z bone mineral content. The biological impact of this dose, and the communication of calculated dose, are both topics for future investigations.

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