Surface dose accuracy in VMAT head and neck radiation treatment using bolus

KM Alexander1, J Gooding2, LJ Schreiner1,2 and T Olding1,2
1Department of Physics, Queen’s University, Kingston, Ontario, Canada, K7L3N6
2Cancer Centre of South Eastern Ontario at Kingston Health Sciences Centre, 76 Stuart Street, Kingston, ON, Canada K7L 2V7

E-Mail: kevin.alexander@kingstonhsc.ca

Abstract. The accuracy of Eclipse™-calculated head and neck VMAT plan dose delivery was assessed in the situation when there is a gap between placed bolus on a head and neck thermoplastic mask and the body surface. GafchromicEBT3 film dosimetry was used for dose delivery validation. The results from 3%, 3 mm 2D gamma comparison indicate better than 95% agreement between measured film dose and calculated plan dose for gap widths up to 25 mm between placed bolus and body surface.

1. Introduction

Radiation treatment (RT) of head and neck cancers often involves the decision of whether or not to treat the planning target volume (PTV) of the high risk disease to the skin surface. At some cancer centres, no additional effort is made to compensate for the photon dose build-up region and bring full prescription dose to the surface of the skin. At our centre, radiation oncologists occasionally request the use of bolus on the surface of the head and neck mask to ensure full surface build-up to the treated volume.

A previous study examined the deviation from calculated plan in the case of significant tumour volume shrinkage over the course of treatment [1]. The standard practice at our centre was to initiate a CT re-scan when the daily cone beam computed tomography (CBCT) imaging of a head & neck patient at time of treatment indicated a change in external body contour greater than 1 cm compared to the planning CT anatomy. The treatment approved plan was then calculated and verified for target coverage and organ-at-risk (OAR) sparing on the new CT anatomy. If the resultant dose distribution was acceptable, then the treatment would continue as before, else a re-plan was initiated. A custom-built wax head and neck phantom incorporating gel, Gafchromic EBT3 film (ISP, Wayne, NJ), ion chamber and MOSFET dosimeters was used for the evaluation. The overall conclusion from the previous study was that a 1 cm change in external body contour was an appropriate point to initiate a re-scan and potential re-plan. There was some discrepancy between the MOSFET and film surface dose results, indicating a slight overdose and significant underdose (up to 20% compared to the calculated plan dose) respectively. This reported difference was significant enough in its implications to warrant further investigation.

The purpose of this work is to assess the accuracy of the treatment planning surface dose calculations at our centre for head and neck RT in the case where there is a gap between the bolus placed on the immobilization mask and the body surface (see figure 1a). Given that this type of 3D dose delivery had been validated at depth using gel and ion chamber dosimeters in the previous study, the focus is shifted in this work to ensuring the accuracy of the dose at target (skin) surface. EBT3 film is well-suited to this type of measurement and was selected for use in this investigation.
2. Materials and Methods

2.1. Phantom Design
A multi-purpose cylindrical acrylic phantom [2] was used for surface dose evaluations, along with Superflab (Mick RadioNuclear, Mount Vernon, NY) bolus with clinically validated dosimetric properties. This phantom has two possible coronal planes for incorporation of EBT3 film in a well-determined fixed geometry which simplifies the measurement dose-to-plan dose registration process. Film was placed in the more anterior plane (see figure 1c). Layers of bolus were affixed to the surface of the cylinder to simulate a tumour (total bolus thicknesses of 10 mm, 15 mm, 20 mm and 25 mm) and a thermoplastic mask was fitted to the phantom. A large cut piece of bolus was taped in place on the surface of the mask, sufficient in size to ensure full dose build-up to the “tumour” volume.

![Figures 1(a)-1(e)]

Figure 1. (a) Multi-purpose cylindrical acrylic phantom, (b) phantom showing the film placement, and (c) axial CT image showing the 15 mm tumour anatomy (pink contour), where the dashed red line indicates the film position. (d) Eclipse screen capture of the “no tumour” anatomy showing overlaid plan isodose with dashed line again showing film position, and (e) Eclipse screen capture of the full 25 mm tumour plan, windowed to show target dose coverage.

2.2. Delivery Validation
CT scans of the cylindrical phantom (with bolus and mask, see figure 1a) were acquired according to our centre’s standard head and neck imaging protocol (120 kV, 2 mm slice thickness, 2 mm spacing) using a Philips Brilliance Big Bore CT scanner (Philips Medical Systems, Cleveland, OH). The phantom
was immobilized on a Type-S Overlay head and neck board (Civco Medical Solutions, Coralville IA, USA) during CT planning and treatment delivery.

A RapidArc™ VMAT plan was optimized and calculated in Eclipse™ v.13.6 (Varian Medical Systems, Palo Alto, CA) using the Analytical Anisotropic Algorithm (AAA) for each of the phantom anatomies with various gaps. PTV targets were contoured to the phantom “tumour” surface on each CT anatomy. For VMAT planning, dual coplanar clockwise/counterclockwise 6 MV partial arcs were employed, extending from just beyond midline anteriorly to 180 degrees posteriorly (figure 1e). The collimator angle on the two arcs was set to ± 30 degrees to minimize overlap of multi-leaf collimator (MLC) leakage. The optimized plan was normalized to a prescription of 2.0 Gy. Screen captures of plans on different anatomies are shown in figures 1d and 1e, with one showing isodose lines to visualize the full dose distribution and the other showing dose color wash to visualize target dose coverage and uniformity. Full sheets of Gafchromic EBT3 film (20.3 cm x 25.4 cm) were cut into 7 cm x 12.7 cm pieces (long edge cut in half) and placed in a coronal plane, as shown in figure 1b.

All treatment plans were delivered on a Varian TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA) with cone beam CT (CBCT) setup verification. EBT3 film dose readout measurements were acquired using an in-house built CCD-lightbox film scanner [3]. A calibration set of 6 MV 10x10 cm² films were delivered under machine reference conditions to doses spanning the range of 0-4.5 Gy. The calibrated film dose data was compared to Eclipse dose in 3D Slicer (www.slicer.org) using the Film Dosimetry Analysis extension [4].

3. Results

3.1. Dosimeter-Plan Dose Comparison

Dosimetric results comparing film measurements against Eclipse planned are shown in figure 2 for the various stages of bolus thicknesses. Excellent agreement was found between film dosimeter measurements and Eclipse calculated doses, with gamma pass rates of > 95% within the PTV contour for each bolus thickness.

![Figure 2](image-url)

Figure 2. (a)-(e) Dose profiles about the central axis (profile direction shown in (f)) comparing the Eclipse dose measurement and EBT3 film measurements for various bolus thicknesses.
3.2. Film Edge Effects
After initial film dosimeter analysis, a systematic discrepancy in film measurements at the tumour surface was observed for dose measurements for all cases where an original manufacturer edge (non-cut edge) was positioned at the tumour surface. The experiment was repeated by irradiating two films simultaneously (one film with a cut edge at the surface, a second film with a manufacturer edge at the surface). This repeat experiment confirmed the discrepancies (within the first 1 cm of the tumour) for films with the manufacturer edge at the surface. Up to 12% surface dose difference was observed across all film irradiations, as shown in figure 3.

![Figure 3](image.png)

Figure 3. Dose profile comparing Eclipse and film measurement for a film irradiated with a manufacturer film edge at the tumour surface with a (a) 15 mm bolus, and (b) 25 mm bolus. Gamma dose comparisons for films irradiated with a manufacturer film edge at the surface for each of the (c) 15 mm bolus (gamma agreement of 86.5%), and (d) 25 mm bolus (gamma agreement of 83.7%).

4. Discussion & Conclusions
Accurate surface dose measurements are difficult to perform. MOSFETs are frequently used for surface dose measurements, but they are not tissue equivalent and are sensitive to positioning errors. While a 3D gel dosimeter measurement is desirable due to its tissue equivalence and high-resolution readout, optical CT measurements are degraded within 5 mm of the gel jar surface due to refraction and other optical artifacts. Based on our past experience [1] we chose to use EBT3 film, as it is tissue equivalent and enables a high-resolution 2D dose measurement.

As shown in figure 2, film dose measurements were shown to be in good agreement for air gaps of up to 25 mm between the bolus on the mask and the body surface. While the mask bolus was removed and replaced after each film irradiation, we note that the minor variations in bolus placement does not significantly affect dose measurements. The clinical practice of placing bolus on the mask to act as a beam spoiler was confirmed to accurately deliver full dose to the skin surface due to the generation of secondary electrons by the mask-placed bolus. No further bolus material is needed beneath the mask to
ensure full dose buildup. Placement of bolus material under the mask can be awkward and somewhat variable on a day-to-day basis, so avoidance of this practice is preferred.

Small non-uniformity across radiochromic film is reported in the literature [5], however the drop in response at the edge of the manufacturer film edge was unexpected. As presented, a significant dose difference of up to 12% at the tumour surface was found when irradiating films with a manufacturer film edge at the tumour surface. This discrepancy is likely inherent to the manufacturer’s film coating process. Disagreement within the first 1 cm may also help to explain some of the discrepancy in the dose measurements previously reported [1].

While this phantom lacks the anthropomorphic geometry used in Alexander et al. 2017, it was chosen to realize a more robust setup which allows for better localization of the film dosimeter plane for precise registration with the planning CT and Eclipse calculated dose volume.

Overall, this investigation reassures us that air gaps between bolus and the body surface are accurately considered in the Eclipse treatment planning algorithms.

5. Acknowledgements
This work was funded by the Canadian CIHR funding agency, project MOP-115101.

6. References
[1] Alexander K M et al 2017 J. Phys.: Conf. Ser. 847 012038
[2] Olding T et al 2013 J. Phys.: Conf. Ser. 444 012052
[3] Lalonde M et al. 2016 Med. Phys. 43 4938
[4] Alexander KM et al. 2017 J. Phys.: Conf. Ser. 847 012061
[5] Micke A et al 2011 Med. Phys. 38 2523