Clinical management of tumour volume changes in VMAT head & neck radiation treatment

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Abstract. The impact of changing anatomy due to tumour shrinkage was assessed for a VMAT head & neck plan optimized according to our centre’s planning protocol. A custom-built wax phantom accommodating ion chamber, MOSFET, EBT3 film and Fricke-xylene orange-gelatin (FXG) gel dosimeters and a variable size bolus ‘tumour’ was used in the investigation. Results indicate that the practice of initiating a patient re-scan and verification plan is appropriate when a change in external body contour greater than 1 cm compared to the original anatomy is observed.

1. Introduction
Radiation treatment of head and neck cancers often involves significant tumour volume shrinkage over the course of treatment, particularly in the parotid, oral cavity and neck regions. At our centre, when daily cone beam computed tomography (CBCT) imaging of a head and neck patient on treatment indicates a change in external body contour greater than 1 cm compared to the planning CT anatomy, the oncologist may decide to initiate a new planning CT and have the treatment plan calculated and verified for target coverage and organ-at-risk (OAR) sparing on the new CT anatomy. If the dose distribution is acceptable, then treatment continues as before; if not, a re-plan is initiated.

The purpose of this work is to develop a head-and-neck phantom that can accommodate different types of dosimeters and perform an end-to-end validation of this clinical process step by evaluating the 3D dosimetry [1] of a variable volume tumour in the head-and-neck region. In this investigation, the dosimetric impact of a shrinking tumour is assessed for a VMAT head-and-neck plan using ion chamber, MOSFET, EBT3 Gafchromic film, and Fricke-xylene orange-gelatin (FXG) gel dosimeters incorporated into a custom-built wax head and neck phantom.

2. Materials and Methods

2.1. Phantom Design
A plaster cast of a Rando phantom (figure 1a) was used to create a wax head and neck phantom (figure 1b) that could accommodate different dosimeters (figure 1c). The phantom included a cavity for insertion of either i) a gel dosimeter or ii) a wax-filled jar with a hole for ion chamber insertion. A slot was also cut for placement of EBT3 film on an axial plane within the region of the target volume (figure 1b). A representative ‘tumour’ was made in two parts that fit together to form a single tumour conforming to the neck region below the ear of the wax phantom (figures 1a,b). Each part of the wax
tumour measured a maximum thickness of approximately 1.3 cm near the location of the slot for film insertion for a combined total maximum tumour thickness of approximately 2.6 cm.

Figure 1. (a) Rando phantom used to create wax phantom, (b) two part wax bolus ‘tumour’, (c) Photo showing all four dosimeters used in the study: FXG gel jar fitting in an interior cavity, ion chamber in wax-filled jar in the same interior cavity, EBT3 film inserted in slot through ‘tumour into wax Rando neck, and MOSFET dosimeter affixed to phantom surface. (d) Head and neck mask used for wax Rando immobilization with custom wax bolus on mask to bring full dose to target volume surface. (e) VMAT plan delivered to wax Rando with ion chamber insert, with red dotted line showing location of film on the coronal plane (lower left window).

2.2. Delivery Validation
The dosimetry tools used for delivery validation in this investigation were: a) a single point ion chamber (PR-05P 0.07 cc, Capintec, Ramsey, NJ), b) a MOSFET (TN-502RDM-H, Thomson Nielson, Division of Best Medical Canada Ltd, Ottawa, ON) c) 2D Gafchromic EBT3 film (ISP, Wayne, NJ), and c) 3D FXG gel dosimeter with optical CT readout [2]. CT scans of the two phantom geometries (gel insert and ion chamber insert) were acquired according to our centre’s standard head and neck imaging protocol (120kV, 2mm slice thickness, 2 mm spacing) using a Philips Brilliance Big Bore CT scanner (Philips Medical Systems, Cleveland, OH). The phantom was immobilized in a thermoplastic mask (figure 1d) on a Type-S Overlay head and neck board (Civco Medical Solutions, Coralville, IA) during CT planning and treatment delivery.

For VMAT planning, dual coplanar clockwise/counterclockwise 6MV 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. A RapidArc™ VMAT plan was optimized and calculated in Eclipse™ v.10 (Varian Medical Systems, Palo Alto, CA) on the 2 mm slice thickness scan of the wax phantom containing the
ion chamber wax jar insert. This plan was then re-calculated (but not re-optimized) on the CT dataset containing a gel dosimeter jar. The optimized plan was normalized to a prescription of 1.8 Gy to accommodate the optimal range for FXG gel dose readout accuracy. A screen capture of the ion chamber plan is shown in figure 1e.

All treatment plans were delivered on a Varian Trilogy 2100iX linear accelerator (Varian Medical Systems, Palo Alto, CA) with Advanced OBI™ imaging cone beam CT (CBCT) setup verification. Each dose measurement was compared against calculated Eclipse treatment planning system dose using software appropriate for that QA tool. EBT3 film measurements were acquired using an in-house built CCD-lightbox film scanner and analyzed using the Film Dosimetry Analysis tool in 3D Slicer [3]. The reconstructed, calibrated gel dose data from the Vista™ optical CT scanner (Modus Medical Devices Inc., London, ON) was compared to Eclipse dose in 3D Slicer [4] (www.slicer.org).

3. Results

3.1. Dosimeter-Plan Dose Comparison

Results for the dosimeters used in this work are summarized in Table 1. The first value in the point dose difference column compares the measurement to the Eclipse calculated value on the associated full/half/no tumour anatomy. The second (bracketed) value is the comparison of the Eclipse calculated dose on the full tumour anatomy to the measurement delivered to the half/no tumour anatomy.

| Dosimeter | Tumour | Prescription (Gy) | Point Dose Difference (%) | % Gamma ≤1 (3%/3mm) |
|-----------|--------|-------------------|---------------------------|---------------------|
| Ion Chamber | Full | 1.8 | -1.2 | - |
| Ion Chamber | Half | 1.8 | -1.5 (-0.5) | - |
| Ion Chamber | No | 1.8 | -1.4 (+1.1) | - |
| MOSFET | Full | 1.8 | -1.0 | - |
| MOSFET | Half | 1.8 | -2.6 (+6.6) | - |
| MOSFET | No | 1.8 | -3.5 (+6.4) | - |
| EBT3 Film | Full | 1.8 | 78.9 | - |
| EBT3 Film | Half | 1.8 | 83.2 | - |
| EBT3 Film | No | 1.8 | 60.7 | - |
| FXG Gel | Full | 1.8 | 98.5 | - |
| FXG Gel | Half | 1.8 | 87.8 | - |
| FXG Gel | No | 1.8 | 56.1 | - |

Figure 2. (a) Eclipse screen capture of the gel plan with red and blue dashed lines showing the location of profile measurements for the (b) FXG gel and (c) EBT3 film deliveries.
4. Discussion & Conclusions
The ion chamber results in Table 1 indicate good agreement between Eclipse and delivery measurement at depth for all anatomies studied. And, as MOSFETs have a greater uncertainty, the MOSFET measurements (located 1 cm superior to isocentre at tumour surface) suggest good agreement between calculation and measurement at the tumour surface, albeit at only one point. The ion chamber readings at depth increased as expected when the half/no tumour measurements were compared to the calculated Eclipse values on the full tumour anatomy. The MOSFET results for the half/no tumour anatomies are surprisingly high given the gap between the tumour surface and the bolus placed in the exterior of the mask (figure 1d). If these single point results were the only measurements available, they would suggest that the surface and depth dose coverage is adequate and that treatment could continue as per normal even with an external body contour reduction on the order of 2 cm.

To provide an additional surface dose measurement, a 3.5 cm x 5 cm piece of film was placed in a slot on an axial plane within the tumour (figure 1b). The analysis for the full tumour film measurement shows reasonable agreement with Eclipse at depth, but lower agreement than expected near the surface (Table 1, figure 2c), affecting the gamma comparison results. Note that the gamma comparison was limited on all three anatomies to the region within the phantom/tumour. For the half/no tumour anatomy, the film dose at depth again agrees with Eclipse, but severe underdosing on the order of 20% is observed in the measurement near the surface. The underdose is likely related to the accuracy of Eclipse calculations within and a short distance downstream of air cavities [5]. There is a small gap between the tumour surface and mask bolus, creating a cavity in the full tumour anatomy upstream of the tumour volume. As the bolus tumour layers are removed for the half/no tumour anatomy, the size of the upstream air cavity increases, which could be the source of the discrepancy between Eclipse calculation and surface film measurement underdose. This does not explain the good agreement between Eclipse and surface MOSFET measurements, so further investigation is warranted.

Looking at the gel results, the 3%,3mm gamma agreement between Eclipse (full tumour anatomy) and measurement is 87.8% for the half tumour anatomy (max. tumour shrinkage ~1.3 cm) and 56.1% for the no tumour anatomy (max. tumour shrinkage ~2.6 cm), neither of which would be clinically acceptable at our centre. The location of the ion chamber measurement is closer to the left side of the profile in figure 2b, at a deeper depth in phantom where better agreement is observed between Eclipse and the gel dosimeter delivery data. This indicates that the practice at our centre of having a 1 cm change in external body contour being the point of initiating a patient re-scan, verification of the original plan on the new planning CT anatomy and possible re-plan is therefore quite reasonable.

While not discussed, the design/manufacture of a suitable phantom incorporating different dosimeter types at appropriate locations was a significant challenge of critical importance. Also, the development of proper tools for registering/analyzing multiple types of dosimetry data [3, 4] was a key element in enabling a clinically meaningful end-to-end validation of the treatment process step in question. Both of these challenges are perhaps understated in the 3D dosimetry literature.

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6. References
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