Investigation of lung tumour peripheral doses using normoxic polymer gel and film dosimetry techniques

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Abstract. This paper describes the investigation of lung tumour peripheral doses for 6MV, 6MV FFF, 10MV FFF and 15MV conformal arc therapy (CAT) beams calculated in the Monaco® TPS and delivered using a flattening filter free capable Elekta® Agility™ linac. Two independent high resolution dosimetry techniques were used for investigations. Measurements were performed using the normoxic PAG polymer gel dosimeter and GAFchromic™ EBT3 film and compared against the calculated dose plane from the Monaco treatment planning system. Both measurement methodologies indicate that Monaco is overestimating the lung tumour peripheral dose for the beams investigated in this study. It is shown that when using 10MV FFF in lung for arc deliveries, there is a dosimetric compromise compared with 6MV and 6MV FFF.

1. Introduction

Radiotherapy has progressed rapidly over the last few years with technologies such as flattening filter free (FFF), stereotactic ablative body radiotherapy (SABR), dynamic conformal arc therapy (DCAT) and volumetric modulated arc therapy (VMAT) with 4D image guidance (4D-IGRT). While these treatments provide a significant improvement in the quality of patient care and outcomes [1-3], the consequences of misadministration can be severe. Mainstream quality assurance tools are often utilised for measuring dosimetric and geometric accuracy to a homogenous medium or phantom. Such 2D methods provide partial-reassurance to the clinical physicist that the patient will receive the intended dose [4]. However, estimating delivered dose within patient target volumes under circumstances such as lung SABR is challenging. Confidence must be placed in the planning system’s commissioning and capability to calculate and predict dose accurately within tight dosimetric and geometric tolerances in non-homogenous medium. The advantages of treating high dose regimes with FFF is clear, with significant delivery time savings which leads to less chance of intra-fraction motion. In our clinic, there has been a desire to use 10MV FFF for lung SABR due to its 2200 MU/min nominal dose rate, compared to 1400MU/min for 6MV FFF and 470MU/min for 6MV. However, there is concern with using higher energies to treat lung tumours due to the extended build-up region in the tumour periphery [5]. This phenomenon is investigated closely for the range of photon beams available in our clinic. Regions of electronic disequilibrium are often too challenging for many dosimeters to provide accurate
measurements. Monaco by default calculates dose to medium and applies human equivalent tissue density mapping. Modern day dosimetric phantoms, such as plastic water and end-to-end phantoms, mimic electron-densities of human equivalent tissue while their composition varies significantly from that of human tissue composition. This can become problematic particularly when electron densities vary significantly from a relative electron density of unity [6-8]. Radiation oncologists expect tight dose margins as shown in Figure 1, but can we be sure this is realistic and delivered accordingly in low density media? In this study, water based, non-homogenous medium is used in an attempt to replicate and mimic human equivalent tissue as close as possible. This study utilises the unique high resolution characteristics of gel dosimeters to encapsulate doses [9-12] in critical treatment regions such as the periphery of lung tumours. Film dosimetry techniques were also employed to provide additional validation of our findings and are reported here within this paper. Investigations continue with other dosimetry tools but are not discussed here.

2. Methods and Materials

2.1. Lung-tumour simulation

To simulate lung tissue, a car washing sponge of similar size to human lung with a 47 mm diameter hole drilled out from its central core was used. The unladen sponge weighed 40 grams, and through experimentation it was determined that with a water retention weight of 640 grams the CT HU of the sponge was equivalent to that of average human lung tissue. To simulate the lung tumour [13], oxygen proof polyethylene terephthalate (PET) vials of 47 mm dia. x 150 mm hgt. filled with gelatine were used and placed within the sponge as per Figures 2 and 3.

Figure 2. Sponge and PET vial.

Figure 3. CT of lung-tumour (left) with wet sponge and gelatine filled vial simulating lung-tumour.
2.2. Polymer gel method
Normoxic PAG polymer gel dosimeters were manufactured using methods and techniques described elsewhere [14-20], with a composition of 5% gelatine, 3% acrylamide, 3% N, N’-Methylenebisacrylamide, 2mM hydroquinone, 5 mM tetrakis phosphonium chloride and 89% de-ionised water with a resistivity of 17MΩ. A total of 9 PET vials were filled with this gel, 4 used for the lung-tumour irradiations, 4 used for calibration and 1 used for simulation and treatment planning.

2.3 Film method
One PET vial was filled with a mixture of 95% H₂O and 5% gelatine. A thin slit was cut halfway through the vial in the transverse plane where a square strip of EBT3 film could be slotted into the vial. With the vial in place in the sponge, a small insertion was made in the sponge to place the film inside the vial.

![Figure 4. Film inserted in gelatine avoiding edge cutting effects in the critical dosimetric region.](image)

2.4 Treatment planning
CT images of the wet sponge with the gelatine filled PET vial were exported to the Monaco TPS. Four conformal arc treatment (CAT) plans were generated for each energy, all having the same field size (4.8 cm x 4.8 cm) and calculated with 450 MU. The central axis transverse dose plane was exported for comparison with the measurements.

![Figure 5. Conformal arc treatment plan in Monaco.](image)

2.5 Irradiation
Before each irradiation the sponge was weighed to ensure water retention consistency. The sponge with each dosimeter were located at the isocentre of the linac and irradiated according to the conformal arc treatment plan. To generate the R₂-dose response calibration curve, three calibration vials were irradiated end on in a water tank using 6MV with a range of monitor units under TRS-398 conditions. The centre of each vial was placed at the reference depth of 10 cm as shown in Figure 6. One vial remained un-irradiated to acquire the background.
2.6 Polymer gel readout
The polymer gels were imaged 12 hours post-irradiation using a Siemens Avanto 1.5T clinical MRI scanner with head coil. A multi-echo pulse sequence with 16 echoes, echo spacing of TE = 40 ms, slice thickness of 5 mm, pixel spacing of 1 x 1 mm² and with 128 phase encoding steps was used to generate $T_2$ maps [21]. The arc distributions were imaged on the central transverse axis and the calibration vials were imaged at the centre of the vial and at ±5 cm where known doses were delivered.

2.7 Film readout
The EBT3 films were readout using a method developed in-house on an EPSON® V850 scanner with a scanning resolution of 75 dpi. A calibration curve was generated for each energy extending up to 10Gy.

2.8 Analysis
Data analysis between the TPS, polymer gel dosimeters and films were performed using MATLAB™ [22]. The film data was symmetrised by “flipping” the image over to create a full circle as only half the dose distribution was captured on the film squares. This is based on the assumption that the dose distribution is symmetric due to the delivered field being a conformal arc. Absorbed dose was used for each dosimetry method; however, profile scaling was applied to match profiles to the central region of the Monaco profile to allow a more effective analysis of the build-up region.

3. Results and Discussion

3.1. $R_2$-dose response
Figure 7 shows the $R_2$-dose response curve with an $R_2$-dose sensitivity of 0.26 s⁻¹Gy⁻¹ in the linear region extending up to 5Gy. The maximum absorbed dose in the gel phantoms was less than 5.5 Gy as delivered by the conformal arc plan.

3.2. Gel and film measurement compared to TPS
Figure 9 shows the profile comparisons taken in the vertical direction of the dose maps as, shown in Figure 8, for each energy studied. While the film and polymer gel measurements do not match exactly, they both indicate that Monaco is overestimating the dose in the build-up peripheral region of tumour equivalent tissue in
lung. The overestimation of the TPS compared with measurement is of similar magnitude for each energy. This finding was not anticipated and is of concern, in consideration of the tight dose margins required by radiation oncologists (as per Figure 1) when using high dose fractionation regimes, especially when a tumour under-dose rapidly leads to a reduction in the tumour control probability. This indicates Monaco may not be correctly modelling regions where a state of electronic disequilibrium exists. Simulating and measuring doses accurately under such conditions, in regions of steep dose gradients is challenging and many dosimeters are not suitable for this purpose. While polymer gel dosimeters are ideal for a study of this complexity, investigations will continue with other dosimetry techniques and methods to characterise this finding in greater detail.

Figure 8. 6MV FFF dose maps showing the peripheral build-up ring.

Figure 9. Comparison of polymer gel and film profiles against the TPS for each photon energy.
3.3. Gel profiles – energy evaluation in lung tumours

Figure 10 shows a comparison of the absorbed dose profiles for each energy in the polymer gel phantoms. This shows that 6MV and 6MV FFF are comparable in terms of absorbed dose and build-up. On the Elekta system, the PDDs for 6MV and 6MV FFF are matched (at 10 cm deep in water for 10 x 10 cm² field), yielding similar beam qualities, but have different energy spectrums. The profiles in the polymer gel show that 6MV and 6MV FFF can be used interchangeably without compromising the peripheral regions of a lung tumour. The higher energy 10MV FFF exhibits a slightly lower maximum dose for equivalent monitor units and clearly shows a lower dose contribution in the periphery as might be expected. To make up this difference and to expand the iso-dose lines, a higher total dose needs to be delivered, potentially compromising organs at risk and therefore, careful consideration should be given to its use. While 10MV FFF provides an efficiency dividend, it comes with a dosimetric expense. For equivalent monitor units, 15MV shows a lower total dose and a significantly lower dose contribution to the periphery and hence; should not be considered for use under such circumstances.

4. Conclusion

Two independent dosimetry techniques suggest the Monaco TPS is overestimating dose in the build-up peripheral region of tumour equivalent tissue in lung. Further investigations will be performed to fully characterise this finding and quantify the extent of overestimation. The use of 10MV FFF in lung tumours should be considered carefully, while there is an efficiency gain that can lead to a geometric gain, there is a dosimetric compromise compared with 6MV and 6MV FFF.

5. References

[1] Prendergast B et al 2012 J. Appl. Clin. Med. Phys. 14 64-71
[2] Xing L et al 2005 Med. Dosim. 31 91-112
[3] Folkert M and Timmerman R 2017 Adv. Drug Del. Rev. 109 3-14
[4] Vial P et al 2008 Med. Phys. 35 4362-74
[5] Wang L et al 2002 J. Appl. Clin. Med. Phys. 3 51-9
[6] Andreo P 2015 Phys. Med. Biol. 60 309-37
[7] Liu H and Keall P et al 2002 Med. Phys. 29 922-4
[8] Chetty I J et al 2007 Med. Phys. 34 4818-53
[9] Baldock C et al 2010 Phys. Med. Biol. 55 R1-R63
[10] Hurley C et al 2006 Nucl. Instrum. Meth. A 565 801-11
[11] Mather M L et al 2003 Phys. Med. Biol. 48 N269-75
[12] Baldock C 2009 J. Phys.: Conf. Ser. 164 012002
[13] Venning A J et al 2005 Phys. Med. Biol. 50 3875-88
[14] De Deene Y et al 2002 Phys. Med. Biol. 47 2459-70
[15] De Deene Y et al 2002 Phys. Med. Biol. 47 3441-63
[16] De Deene Y 2004 J. Phys.: Conf. Ser. 3 34-57
[17] Baldock C et al 1998 Phys. Med. Biol. 43 695-702
[18] De Deene Y et al 2006 Phys. Med. Biol. 51 653-73
[19] De Deene Y and Baldock C 2002 Phys. Med. Biol. 47 3117-41

Figure 10. Combined gel profiles for all energies.
[22] Murry P et al 2000 Austral. Phys. Eng. Sci. Med. 23 44-51