Further investigation of lung tumour peripheral doses using normoxic polymer gel dosimetry techniques

A Venning1, M Mundayadan Chandroth1, C Morgan2 and M Roberts2
1Mid-North Coast Cancer Institute, Port Macquarie Base Hospital, Port Macquarie, NSW, Australia
2Mid-North Coast Diagnostic Imaging, Highfields Circuit, Port Macquarie, NSW, Australia

Email: anthony.venning@health.nsw.gov.au

Abstract. This work builds upon previous investigations of lung tumour peripheral doses for 6 MV, 6 MV FFF, and 10 MV FFF conformal arc therapy beams calculated in the Monaco® TPS and delivered using an Elekta® Agility™ linac. An improved patient lung phantom is developed with measurements using the normoxic PAG gel dosimeter and compared against dose planes from the TPS. The gel dosimeter measurements indicate that the TPS is overestimating the secondary build-up in the lung tumour peripheral region. It has been determined that in lung tumours, 6 MV FFF is the optimal beam energy for peripheral dose coverage and that there is a dosimetric compromise using 10 MV FFF.

1. Introduction
In recent years, radiation therapy has made significant technological advances with the introduction of treatment techniques like volumetric modulated arc therapy (VMAT), stereotactic radiotherapy (SRT), and flattening filter free beams (FFF). These treatment techniques, while enhancing patient outcomes and care [1-3], come with significant consequences if misadministration occurs. Accurately determining delivered dose within tight margins to an inhomogeneous treatment volume, as in lung tumours, using complex delivery techniques, is extremely difficult and demanding. Therefore, a high level of confidence needs to be placed in the ability of the treatment planning system (TPS) to correctly calculate both dosimetrically and geometrically within the patient volume. For high dose fractionation regimes, beam geometry is of high importance, and as such, the delivery time is an important factor for a non-static treatment site, like the lung. With longer delivery times, geometric errors increase due to patient motion. At our treatment centre, radiation oncologists prefer to use 10 MV FFF due to its higher dose rate compared to 6 MV and 6 MV FFF, to minimise treatment time and motion during delivery. Clinical physicists are concerned though, that the higher energy extends the secondary build-up region in lung tumours, reducing the dose to the tumour periphery [4]. This is an important factor to consider, as an under dose rapidly leads to a loss of tumour control. This phenomenon was previously investigated [5] for the photon beams available in our clinic, and this current work utilises the unique, tissue equivalent, high-resolution properties [6,7] of gel...
dosimeters to build upon previous findings using an improved phantom design.

2. Methods and Materials

2.1. Lung-tumour phantom
The phantom was created from foam and cut to the size of a typical human thorax. A hole of 47 mm dia. was drilled out of the foam centre to hold the dosimeter. The foam was wrapped in 1 cm thick Bolus (NL-Tec Pty Ltd) to simulate the chest wall. The foam was soaked in water with the correct retention determined to be equivalent to that of the electron density of lung. Plastic (PET) vials of 47 mm dia. x 150 mm hgt. filled with 5% gel and 95% water were inserted into the foam as shown in figure 2.

![Figure 2. CT of lung-tumour phantom showing the equivalent lung electron density.](image)

2.2. Gel dosimeter manufacture
Manufacturing of the normoxic PAG dosimeter is well described elsewhere [8-16]. The composition used was 5% gel, 89% de-ionised water, 3% acrylamide, 3% N,N´-Methylene-bis-acrylamide, 2 mM hydroquinone and 5 mM tetrakis phosphonium chloride. Seven normoxic PAG gel filled vials were used in this study, 3 for calibration, 3 for lung tumour irradiation and 1 for PDD simulation.

2.3 Treatment planning
The lung phantom with gel insert was CT scanned and the data set sent to the TPS. Conformal arc beams of 360° were created using 6 MV, 6 MV FFF and 10 MV FFF beam energies, all with a field size of 4.8 cm², 450 MUs and calculated at 1%/1 mm resolution. The transverse central axis dose plane was exported for comparison with the gel dosimeter measurement.

2.4 Gel irradiation

The lung phantom was placed on the treatment couch, a cone beam CT was performed and then position matched to the reference data using HexaPOD™. Gel filled vials were carefully inserted and irradiated with the conformal arc plans. The calibration curve was generated using the PDD method in water. One vial was irradiated side-on at the surface with 6 MV to assess the dosimeter in the build-up region compared to the TPS and beam reference data.

![Figure 3. Conformal arc treatment plan in Monaco.](image)
2.5 MRI readout

Five days after irradiation, the gels were imaged using a clinical 3T MRI scanner in a head coil to enhance the signal-to-noise ratio. To generate $T_2$ maps, a multi-echo sequence with imaging parameters; echoes = 16, TE = 40 ms, FOV = 128 mm$^2$, matrix size 128 mm$^2$ and slice thickness of 5 mm was used. The vials were imaged on the central transverse plane for the open field 360° arc deliveries and at various known dose deposition positions along the calibration vials.

![Figure 5. PDD irradiation.](image)

2.6 Beam profile analysis

The MRI images were processed and compared against the TPS using MATLAB$^\text{TM}$ [17]. $T_2$ maps were converted to dose maps; however, the profiles were normalised to match the central region of the TPS profiles so an effective assessment of the peripheral build-up region could be made.

3. Results and Discussion

3.1. $R_2$-dose response curve

The $R_2$-dose response curve in figure 6 has an $R_2$-dose sensitivity of 0.19 s$^{-1}$Gy$^{-1}$ in the linear region.

![Figure 6](image)

3.2. Gel measurements versus TPS

Figure 7 shows the dose distribution for the three different beam energies and it is shown that for equivalent MUs there is higher dose deposition for 6 MV FFF. Figure 8 shows profile comparisons of the dose maps, indicating the TPS is overestimating the dose in the tumour peripheral region, which agrees with previous findings [5]. This is concerning considering the requirement of the tight dose margins when using high dose fractionation regimes.
To verify the gel dosimeters correctly measure the build-up region, the gel PDD was plotted against the reference beam data and also compared against the TPS as shown in the left plot in figure 9. These results show an underestimation between gel dosimeter and ion chamber (5% at the surface) and Monaco (10% at the surface), which contrasts with the lung tumour profiles in figure 8 above.

3.3. Energy evaluation in lung tumours

A comparison of the dose profiles is shown in figure 9 for each energy used in the gel dosimeters. The 6 MV FFF beam shows the higher absorbed dose while 10 MV FFF shows a lower absorbed dose for equivalent MUs. 6 MV FFF also shows a higher dose deposition at the tumour periphery. While 6 MV also shows a higher peripheral dose compared to 10 MV FFF, the authors suggest that 6 MV FFF is the optimal energy to use for lung tumours, providing greater coverage and peripheral dose. If using 10 MV FFF in lung, a higher total dose needs to be delivered to expand the Rx iso-dose line, potentially compromising organs at risk and therefore, careful consideration should be given to its use.
4. Conclusion
This study builds upon work previously performed by the lead authors by developing a lung phantom that improves patient inhomogeneity lung simulation. Further to the previous study, the build-up region of the gel dosimeter has been examined for a 6 MV beam and found to closely represent ion chamber measurements. It was also found that the Monaco TPS is over estimating the peripheral lung tumour dose when compared with gel dosimeters. The recommended beam energy in lung tumours is 6 MV FFF followed by 6 MV. Using 10 MV FFF in lung tumours requires careful consideration, as there is found to be a dosimetric compromise compared with 6 MV and 6 MV 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] Wang L et al 2002 J. Appl. Clin. Med. Phys. 3 51-9
[5] Venning et al 2019 J. Phys.: Conf. Ser 1305 012003
[6] Baldock C et al 2010 Phys. Med. Biol. 55 R1-R63
[7] Venning A J et al 2005 Med. Phys. 32 1047-53
[8] Venning A J et al 2004 J. Phys.: Conf. Ser. 3 155-8
[9] Venning A J et al 2005 Phys. Med. Biol. 50 3875-88
[10] Hill B et al 2002 Phys. Med. Biol. 47 4233
[11] De Deene Y et al 2002 Phys. Med. Biol. 47 2459-70
[12] De Deene Y et al 2002 Phys. Med. Biol. 47 3441-63
[13] De Deene Y 2004 J. Phys.: Conf. Ser. 3 34-57
[14] Baldock C et al 1998 Phys. Med. Biol. 43 695-702
[15] De Deene Y et al 2006 Phys. Med. Biol. 51 653-73
[16] De Deene Y and Baldock C 2002 Phys. Med. Biol. 47 3117-41
[17] Murry P et al 2000 Austral. Phys. Eng. Sci. Med. 23 44-51