Investigation of target dose conformity using normoxic polymer gel dosimetry techniques: A clinical example of 12th thoracic vertebrae SBRT treatment with VMAT

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Abstract. This paper describes the 3D dosimetry verification of a 24Gy in 3 fractions VMAT SBRT treatment delivery to the 12th thoracic vertebrae (T12). With this fractionation regime, the critical isodose value is 17.5Gy to the outer edge of the spinal cord and must not be exceeded. This is a high-risk treatment that could result in severe injury to the patient unless administered precisely. With the use of 3D normoxic polymer gel dosimetry techniques, using MRI readout, a clinical example is presented which shows that the Mid North Coast Cancer Institute’s paraspinal program is capable of delivering complex distributions with high doses to within very tight tolerances. This also demonstrates the strength of normoxic polymer gel as a 3D dosimeter.

1. Introduction
With advances in radiotherapy delivery techniques and image guidance, the Mid North Coast Cancer Institute (MNCCI) has recently developed a paraspinal SBRT program. A common treatment delivery regime is 24Gy in 3 fractions to spinal metastases. With this fractionation, a hard dose constraint is placed on the spinal cord which must not be violated, and the PTV, GTV and CTV coverage is compromised, if necessary, to achieve this. Modern commercially available dosimeters do not offer true 3D delivery verification capabilities [1,2]. Patient quality assurance tools, such as the ArcCheck™ which are routinely used in the clinical environment do not measure dose to high precision. Furthermore, for SBRT patient QA, most of the dose is delivered to the centre of the ArcCheck where there is only located a 0D dosimeter such as an ionisation chamber. With QA devices, such as the ArcCheck, all the dose information is captured at the periphery and the complexities of the volumetric dose distributions around the isocentre are ignored. Using 3D normoxic polymer gel dosimetry techniques with MRI readout [3-10], this study presents a 3D dosimetric analysis of a 12th thoracic vertebrae (T12) VMAT SBRT treatment. While the gel does not have the same radiological tissue equivalence of bone, it does have the same radiological tissue equivalence of soft tissue, providing accurate dose calculation and dose information capture [11]. Figure 1 below, shows the treatment case which is presented in this study.
2. Methods and Materials

2.1. Phantom

The gel vial simulating the spine was irradiated in a phantom designed for another concurrent study assessing lung tumour doses [12,13]. This phantom was used due to its human tissue equivalent electron densities as it predominately consists of water. The phantom was made of foam wrapped in 1cm thick Superflab Bolus (NL-Tec Pty Ltd) to simulate chest wall, and the foam was soaked in water to simulate lung tissue electron densities. The correct retention of water was established to be equivalent to that of average human lung tissue electron density. A 47 mm diameter hole drilled out from its central core was used to hold the gel dosimeter firmly in position. The gel container was oxygen proof polyethylene terephthalate (PET) vials of 47 mm dia. x 150 mm hgt.

2.2. Polymer gel method

Normoxic PAG dosimeters were manufactured using techniques described elsewhere [4-6,8,14], with a composition of 5% gelatine, 3% acrylamide, 3% N, N’-methylenebisacrylamide, 2mM hydroquinone, 5 mM tetrakis phosphonium chloride and 89% de-ionised water. A total of 4 PET vials were filled with this gel, 3 used for $R_2$-dose calibration and 1 used for the T12 treatment plan measurement.

2.3 Treatment planning

CT images of the wet foam with a water filled PET vial were exported to the Monaco TPS. In the TPS, the patient’s dataset and phantom were fused together such that the spinal cord and PTV contours could be transferred onto the PET vial and the plan isocentre could be established. The patient’s bi-arc VMAT treatment plan was copied onto the CT data set and recalculated at 1mm voxel with 1% STD, retaining MLC beam shapes. As per protocol, for paraspinal SBRT treatments delivered in 24Gy/3# must meet the hard dose constraint on the spinal cord of 17.5Gy and must not be exceeded [15]. In these cases, the PTV, CTV and GTV are to be compromised to achieve this. However, for this dosimetry study, the plan was scaled down as 24Gy in 3 fractions leads to a single fraction dose that would saturate the gel.
dosimeter. The scaled isodose line of interest in this study that was shaped around the spinal cord was 5Gy as shown in figure 3.

2.4 Irradiation
The phantom was located at the isocentre of the linac with a PET vial filled with water and a cone beam CT was performed and then position matched to the reference data using HexaPOD™. The PET vial with water was then carefully replaced with a vial filled with polymer gel and irradiated as per the scaled VMAT SBRT treatment plan. Using 3 vials the $R_2$-dose calibration curve was generated using the PDD method and a 6MV beam under TRS-398 reference conditions in water as shown in figure 4.

![Figure 3. Image fusion (left). Critical isodose (centre). Phantom treatment plan (right).](image)

![Figure 4. Reference data matching using HexaPOD and irradiation.](image)

2.5 Polymer gel readout
The polymer gels were imaged 5 days post-irradiation using a Siemens Magnetom Vida 3T clinical MRI scanner with head coil. A multi spin-echo pulse sequence with 16 echoes, echo spacing of TE = 40 ms, pixel size of 1 x 1 mm$^2$ and with 128 phase encoding steps was used to generate $T_2$ maps [3]. The calibration vials were imaged with single transverse slice at different known dose deposition locations with a slice thickness of 5mm. The gel irradiated according to the T12 treatment plan was imaged in the transverse orientation with 20 adjacent 2mm slice thicknesses (4mm centres) using an interleaved sequence that covered the irradiated volume of the gel dosimeter. As a note, this slice thickness leads to a reduced signal to noise ratio and subsequently produces noisy images. This is due to a limiting time constraint. Ideally, image averaging would be performed but this comes at a significant time efficiency loss.

2.6 Analysis
The MRI DICOM images were processed using MATLAB™ [16]. $R_2$ maps were generated for each of the 20 slices and converted to dose maps using the $R_2$-dose calibration curve. A 3D dose matrix was created from the individual dose maps and the 5Gy isodose line was plotted in 3D in MATLAB™ using the isosurface function. The patient’s CT dataset was imported into MATLAB™ and the spinal cord contour surrounded by the T12 vertebra was extracted from the dataset. From the fused images of the patient’s dataset and the gel phantom, the position of the PET vial that encompassed both the PTV and spinal cord contours was established. The key assessment criteria for this study was to observe if the
5Gy isodose line was shaped around the spinal cord and hence the treatment delivery did not violate the hard 5Gy isodose line constraint in this case.

3. Results and Discussion

3.1. $R_2$-dose response

Figure 5 shows the $R_2$-dose response curve with an $R_2$-dose sensitivity of 0.19 s$^{-1}$Gy$^{-1}$ in the linear region.

3.2. Gel isosurface and spinal cord

Figure 6 shows the 5Gy (red) isodose sphere of interest wrapped around the spinal cord (blue). At no point does the 5Gy isodose line enter or impinge upon the spinal cord along its length of the treatment region. The 5Gy isodose line is adjacent to the spinal cord to within 1 mm at its closest point which is reassuring in consideration of how tight the radiation oncologist is pushing the major isodose line of consideration as in figure 3 above. This shows, that the full treatment chain is capable of safely delivering complex dose distributions, and means there can be a greater level of confidence in dose escalation and planning high dose fractionation regimes close to critical organs at risk. There is no other dosimeter available that could record dose to such high precision under these circumstances in 3-dimensions. While the gel dosimeter doesn’t represent the high density bone of the T12 vertebrae, this shows that when some inhomogeneous regions are introduced, such as lung and patient chest wall, the planning system and delivery systems are capable of achieving a safe outcome.

4. Conclusion

The Mid North Coast Cancer Institute has recently commenced an SBRT paraspinal treatment program. Using VMAT with high doses near to critical serial organs at risk is complex and requires validation using 3-D dosimeters. True 3-D dosimeters are not commercially available, but with the use of an in-house polymer gel dosimetry program this study enables a greater level of confidence in delivery and allows the paraspinal SBRT program to safely advance its treatment options. This study found that the full delivery chain, from end-to-end can safely deliver a high dose fractionation regime to complex and tight margins, ultimately resulting in better patient outcomes.
Figure 6. 5Gy isodose sphere (red) with spinal cord (blue) inside the gel filled PET vial.

5. References
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