PhD Thesis title: 'Novel 3D radiochromic dosimeters for advanced radiotherapy techniques'

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ABSTRACT:
During the last few decades, radiotherapy treatment delivery techniques have been developed into an extremely valuable modality for delivering high curative or palliative doses of ionising radiation for the treatment of cancer in a way that is safer and more accurate than ever before. However, one major hurdle with respect to the planning and delivery of radiotherapy is the preservation of normal tissue while still ensuring the effective targeting of tumour cells and eradication of tumours. Hence, the radiation dose delivery to the target is limited by the tolerance of non-tumour cells to minimise toxicity to normal, healthy surrounding tissues. As a quality assurance tool, three dimensional (3D) polymer dosimeters were developed as part of the process of monitoring and improving dose delivery. Conceivably, one of the most significant developments in 3D dosimetry over the past decade was the introduction of the PRESAGE® dosimeter. The PRESAGE® dosimeter is a unique 3D radiochromic dosimeter with great potential for clinical applications. Although the majority of studies have focused on clinical applications of the PRESAGE® dosimeter, few studies have focused on the optimisation of the main components of the PRESAGE® dosimeter to suit specific dosimetric situations.

An emerging strategy to target tumours and enhance radiotherapy involves the utilisation of metal nanomaterials, such as gold nanoparticles (AuNPs). From a therapeutic perspective, free radicals generated by heavy metals such as gold when combined with low energy ionising radiation have been shown to enhance radiation effects. Although the idea of using metal nanoparticles to enhance radiation effects is gaining acceptance, one major limitation to date has been the lack of an independent dosimetric method that reveals the way in which the nanoparticles interact with ionising radiation and the 3D spatial dose distributions of the dose enhancement. Thus, there is an urgent need to develop an independent experimental approach to answer these questions.

Therefore, this thesis had two major aims: (1) to carry out a series of PRESAGE® dosimeter component-specific investigation studies with an ultimate goal of developing a novel suite of formulations for different clinical applications, and (2) to develop and characterise novel 3D radiochromic dosimeters for nanoparticle-enhanced radiotherapy dosimetry.

Results for the first aim show that the sensitivity, stability and radiological properties of the PRESAGE® dosimeter could be customised by using different concentrations or types of its typical component, or by the inclusion of novel chemical components in the dosimeter formulation. In brief, a range of novel and optimised PRESAGE® dosimeters were fabricated as part of this research, which are expected to find specific and general dosimetric applications.

The second aim was achieved through the development of a novel 3D radiochromic dosimeter referred to as the Sensitivity-Modulated Advanced Radiation Therapy (SMART) dosimeter, which can be used as an independent method for nanoparticle-enhanced radiotherapy dosimetry and verification. This research represents the first documented experimental confirmation and 3D visualisation of the nanoparticle-enhanced radiotherapy effect, as demonstrated using AuNPs as an initial example. Furthermore, the SMART dosimeter provides a generalised approach for investigating the influence of nanomaterial composition, size, morphology and surface chemistry on metal nanoparticle-radiation interactions. Although AuNPs have been touted as the ideal radiation-enhancing candidates, studies with the SMART dosimeter have shown that cheap and non-toxic bismuth-based nanoparticles are promising alternatives for improving the efficacy of radiotherapy, and approximately double the deposited dose of radiation.

References to author publications that relate specifically to the dissertation:

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