PhD Thesis title: 'The use of proton radiography to reduce uncertainties in proton treatment planning'

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ABSTRACT:
The availability and demand for proton therapy is rapidly expanding across the globe. One of the key decisions that must be made in the procurement process by all new centers is which proton treatment planning system (TPS) to purchase. The first topic of this thesis is therefore to evaluate the performance of three different proton TPSs in the planning of ten meningioma patients. The comparison is built upwards from the beam commissioning and attempts are made to make as many variables as possible consistent between systems. Few statistically significant differences were found between the plans, although differences between the systems (such as layer spacing and spot positioning) are discussed. It is hoped this work will be of general use to the whole proton physics community and will encourage further development of proton TPSs from vendors.

One of the major sources of range uncertainty in current proton treatment planning is due to the necessary conversion of the patient's X-ray computed tomography (CT) dataset from CT numbers to relative stopping powers (RSPs). The remainder of the thesis looks to address this. The stoichiometric procedure is considered the most accurate method to generate the X-ray CT to RSP calibration curve. In the third chapter of the thesis an investigation is made into the errors of this procedure: specifically, the theoretical calculation of the RSP, step four of the process. The impact of these errors on the proton beam range is calculated for both phantom and patient cases.

It has been suggested that proton radiography could offer a solution to the uncertainty in this calibration curve. The fourth chapter of the thesis therefore looks at a novel method of proton radiography, which involves taking the dose ratio of two pristine Bragg peaks. The investigation proceeds with a theoretical analysis of the application limits of the technique, together with an experimental validation of the theoretical approach.

The fifth chapter of the thesis demonstrates an approach that uses proton radiography to improve the calibration curve. Assuming the information in the proton radiograph to be correct, the calibration curve can be optimized by comparison with a digitally reconstructed radiograph through the X-ray CT. The function of this optimizer is validated on synthetic datasets and its application is demonstrated with real measurements on plastic and real tissue phantoms. The

technique is also shown to offer an improvement in the water-equivalent path length prediction at a therapeutic depth.

References to author publications that relate specifically to the dissertation:

P Doolan, G Royle, A Gibson, H-M Lu, D Prieels, E H Bentefour, "Dose ratio proton radiography using the proximal side of the Bragg peak" Med. Phys. 42 (4) 1871-1883 (2015)

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P Doolan, J Alshaikhi, I Rosenberg, C G Ainsley, A Gibson, D D'Souza, E H Bentefour, G Royle, "A comparison of the dose distributions from three proton treatment planning systems in the planning of meningioma patients with single-field uniform dose pencil beam scanning" J. Appl. Clin. Med. Phys. 16 (1) 86-99 (2015)