PhD Thesis Title: Demonstration of x-ray acoustic computed tomography as a radiotherapy dosimetry tool

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ABSTRACT:

Dosimetry is a crucial process in radiation therapy to ensure that radiation dose is accurately delivered to patients. A number of different dosimetry protocols are used at all stages of the external beam radiation therapy workflow. Recent advancements in radiation therapy delivery have posed a dosimetry challenge due to the use of highly modulated radiation fields and large dose per treatment fraction. Therefore, there is a need for novel accurate dosimetry techniques that are volumetric, non beam-perturbing, and near real-time. X-ray acoustic computed tomography (XACT) is an emerging imaging modality that detects the acoustic waves generated in an object via the thermoacoustic effect following a single pulse of x-ray irradiation. By using these transducer signals, an image of the differential pressure build-up can be reconstructed. Since XACT images can be related to radiation dose, it has been proposed that XACT could be a valuable tool for radiotherapy dosimetry.

The goal of this thesis was to demonstrate the feasibility of using XACT for relative water tank and *in vivo* dosimetry applications in photon external beam radiation therapy. First, the properties of the acoustic waves induced following the irradiation of metal blocks were systematically investigated through experimental measurements. Simultaneously, a simulation workflow capable of modelling the induction and propagation of acoustic waves following a pulse of clinical linear accelerator (linac) radiation was developed and validated using the experimental metal block measurements. This study established the relationships between the properties of radiation-induced acoustic waves and the deposited dose distribution. Next, the ability to detect radiation-induced acoustic waves in a homogeneous water tank and image the deposited dose distribution was demonstrated. XACT images of dose distributions of a variety of shapes and sizes were formed and compared to ion chamber and film measurements to verify the linear relationship between XACT image magnitude and deposited radiation dose. In addition, the acquisition of XACT images was extensively characterized, and the repeatability, sensitivity, and required imaging dose were found to be promising for relative water tank dosimetry applications. The final portion of this thesis comprises a simulation study to investigate XACT as a tool for *in vivo* dosimetry. The acoustic waves induced in a prostate patient during irradiation with static rectangular fields or a volumetric modulated arc therapy plan were modelled to simulate the signal detected by a transducer placed at the perineum. It was observed that the position of dose distribution gradients in the patient could be inferred by back-projecting the transducer signal onto a computed tomography (CT) or ultrasound image of the patient.

This work demonstrates that XACT has great promise as a radiotherapy dosimetry technique, particularly for relative water tank and *in vivo* applications. Future work in the field should focus on the improvement of transducer technology and image reconstruction to enhance the sensitivity of the technique. Ultimately, XACT could be used as a tool for rapid volumetric water tank dosimetry of

complex treatment fields and be combined with anatomical ultrasound imaging for near real-time *in vivo* dosimetry and treatment monitoring.

References to author publications that relate specifically to the dissertation:

1) **S. Hickling,** L. Xiang, K. C. Jones, K. Parodi, W. Assmann, S. Avery, M. Hobson, I El Naqa, "Ionizing radiation-induced acoustics for radiotherapy and diagnostic radiology applications," Med. Phys. **45**(7), 707-721 (2018). DOI: https://doi.org/10.1002/mp.12929

2) **S. Hickling,** M. Hobson, I. El Naqa, "Characterization of x-ray acoustic computed tomography for applications in radiotherapy dosimetry," IEEE Trans. Rad. Plas. Med. Sci **2**(4), 337-344 (2018). DOI: 10.1109/TRPMS.2018.2801724

3) **S. Hickling,** H. Lei, M. Hobson, P. Léger, X. Wang, I. El Naqa, "Experimental evaluation of x-ray acoustic computed tomography for radiotherapy dosimetry applications," Med. Phys. **44**(2), 608-617 (2017). DOI: https://doi.org/10.1002/mp.12039

4) **S. Hickling**, P. Léger, I. El Naqa, "On the detectability of acoustic waves induced following irradiation by a radiotherapy linear accelerator," IEEE Trans. Ultrason. Ferroelectr. Freq. Control **63**(5), 683-690 (2016). DOI: 10.1109/TUFFC.2016.2528960