PhD Thesis Title: Reference dosimetry of static, nonstandard radiation therapy fields: application to biology-guided radiotherapy and cranial radiosurgery generators

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ABSTRACT:

In radiotherapy, radiation field sizes smaller than 3 × 3 cm^2 have been widely used; however, the dosimetry of small fields is very complex. It requires calibration methodologies that are different than the calibration methodologies used for the radiotherapy machines with a conventional field size. To provide recommendations on the dosimetry of small fields, a working group was formed by the International Atomic Energy Agency (IAEA) in collaboration with the American Association of Physicists in Medicine (AAPM). In 2017, the working group published a new Code of Practice (COP) and termed it the "IAEA-AAPM Technical Report Series (TRS) No. 483 (TRS-483)." The TRS-483 defines a formalism for the dosimetry of static small and nonstandard fields used in radiotherapy and introduces the correction factor $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ for calibration purposes.

One example of the use of small and nonstandard fields in radiotherapy is the Leksell Gamma Knife®(LGK). The LGK is a cranial radiosurgery generator containing 192 ^{60}Co sources arranged in a cone section configuration which delivers small radiation fields with the maximum field size of 16 mm diameter (Perfexion model). The $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ values for calibration of LGK are tabulated in TRS-483. However, these data are limited to a few chamber types, a single orientation of the chamber, and only two phantom materials. Moreover, the $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ values in TRS-483 have not been validated experimentally for the LGK.

The first aim of this thesis was to provide the data for the reference dosimetry of LGK for different chamber types, phantoms and orientations of chambers. First, the $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ values for nine common ionization chamber types and six phantom materials were used in the calibration of the LGK Perfexion model, then calculated using Monte Carlo (MC). A relationship was derived between the $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ values and the electron density of the phantom material. Therefore, the $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ for any phantom material type with a known electron density can be determined. Secondly, the calculated $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ factors for the calibration of the LGK unit were experimentally validated. The TRS-483 with the aforementioned correction factors was compared to two other calibration protocols of the LGK. Applying the $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ values to the measured dose rates using the LGK unit resulted in dose rates that were consistent within 0.4%.

A second radiation therapy unit that uses nonstandard fields is the recently developed RefleXion™ biology-guided radiotherapy (BgRT) machine, which combines stereotactic radiotherapy with positron-emission tomography (PET) and computed tomography (CT) imaging systems. The closest possible field size to a reference field in this system is 10 × 2 cm^2 or possibly 10 × 3 cm^2 at the

isocenter. The BgRT is a new machine and there is no available data on its reference dosimetry. The calibration of this machine is challenging and the TRS-483 cannot be directly applied.

The goal of this thesis in chapters 5 and 6 was therefore to provide a methodology for reference dosimetry of machines with fields as small as 10 × 2 cm^2 and to provide the data for calibration of BgRT. We extended the TRS-483 methodology to 10 × 2 cm^2 field size and provided two calibration methods. We recommended using the first approach; however, if the $k_{Q_A,Q_0}^{f_A,f_{ref}}$ values are not available, the second calibration method can be used to predict the $k_{Q_A,Q_0}^{f_A,f_{ref}}$ factors. But, the second methodology should not be used for chambers with electrode materials of high atomic number *Z*. Next, we provided the data for calibration of the BgRT using the two methodologies. The $k_{Q_A,Q_0}^{f_A,f_{ref}}$ values calculated using the two approaches were within ±0.27% for all chambers except the IBA CC01, which has an electrode made of high *Z* material. We provided the $k_{Q_A,Q_0}^{f_A,f_{ref}}$ values as a function of the beam quality specifier at the BgRT for six chamber types.

The first part of this thesis provided data for the reference dosimetry of the LGK. The second part provided two calibration approaches and data for the BgRT. Overall, this work has contributed to the improved accuracy in the reference dosimetry of nonstandard beams.

References to author publications that relate specifically to the dissertation:

1. **Mirzakhanian, L.,** Bassalow, R., Zaks, D., Huntzinger, C., and Seuntjens, J. "IAEA-AAPM TRS-483-based reference dosimetry of the new RefleXion biology-guided radiotherapy (BgRT) machine." Medical Physics 48.4 (2021): 1884-1892. https://doi.org/10.1002/mp.14631

2. **Mirzakhanian, L.,** Sarfehnia, A., and Seuntjens, J. "Experimental validation of recommended msr-correction factors for the calibration of Leksell Gamma Knife® Icon^{tm} unit following IAEA TRS-483." Physics in Medicine & Biology 65.6 (2020): 065003. DOI: 10.1088/1361-6560/ab6953

3. **Mirzakhanian, L.,** Bassalow, R., Huntzinger, C., and Seuntjens, J. "Extending the IAEA-AAPM TRS-483 methodology for radiation therapy machines with field sizes down to 10× 2 cm^2." Medical Physics 47.10 (2020): 5209-5221. https://doi.org/10.1002/mp.14325

4. **Mirzakhanian, L.,** Benmakhlouf, H., Tessier, F., and Seuntjens, J. "Determination of $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ factors for ion chambers used in the calibration of Leksell Gamma Knife Perfexion model using EGSnrc and PENELOPE Monte Carlo codes." Medical physics 45.4 (2018): 1748-1757. https://doi.org/10.1002/mp.12821