Development of an automated routine for the calibration of multi-point scintillation detectors for advanced dosimetry applications

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Abstract. Multi-point scintillation dosimeters have the advantage to allow real-time measurements of dose with a good spatial resolution, but these detectors must be accurately calibrated to perform precise dose measurements. This study demonstrates, by means of simulations and an experimental validation, that when the calibration dataset is well chosen, it is possible to perform an automated calibration of such dosimeters, with an accuracy on the measured output factors reaching $(0.5 \pm 0.1)\%$.

1. Introduction
Scintillation dosimetry is taking advantage of the properties of plastic scintillators to convert ionizing radiation into visible light. This technology has the advantage to allow real-time measurements of dose with a good spatial resolution (i.e. submillimeter), due to the small size scintillators can have. In addition, plastic scintillation detectors also have the advantage of being water-equivalent (Beddar et al. 1992a, 1992b), which make them well suited for advanced dosimetry applications. To perform accurate dose measurements with such detectors, they must be precisely calibrated, however the calibration process can be long and tedious.

The goal of this study is to develop an automated calibration routine, using a translation module controlled by a computer, to enhance the calibration of multi-point scintillation dosimeters used with external radiation therapy photon beams. The module must allow the user to easily perform the required measurements for the calibration of the dosimeter when used under a photon beam delivered by a linac. Therefore, the calibration dataset conducting to the most accurate dose measurements with the dosimeter must first be determined.

2. Methods and materials
The principle of scintillation detectors is based on the collection of the light produced within a plastic scintillator using a waveguide; the collected light is thereafter measured by a photodetector. Plastic optical fiber is usually used as a waveguide to conduct the light from the scintillators to the photodetector without introducing non-water equivalent material. When more than one scintillating element is present, the detector is said to be “multi-point”. Figure 1 shows an example of a multi-point scintillation detector (mPSD). Because the light produced by every scintillator travels the same unique waveguide, a hyperspectral approach has been proposed to separate the light coming from each scintillator...
(Archambault et al. 2012, Therriault-Proulx et al. 2012). However, this method requires the pure spectra of each spectral component present within the total measured signal to be accurately known, which is a difficult task to perform with the high energy photon beam delivered by a linac because of the Cherenkov radiation light that is produced within the fiber. The method developed here aims at calibrating the mPSD without the prior knowledge of the pure spectra of the scintillators, using only a set of measurements that can be performed at the linac.

The detector used for this study is a 3-point scintillation detector, and the scintillators used are BCF-10, BCF-12 and BCF-60. In order to know what kind of measurements should be performed for the calibration of the mPSD at the linac, many calibration datasets have been simulated from the pure spectra of the scintillators and from the stem spectrum generated within the clear fiber. Measurements under a highly collimated kilovoltage photon beam at which there is no Cherenkov light emission produced within the optical fiber have been first acquired and are considered as the reference spectra for the scintillators, while the stem spectrum is measured at the linac using a subtraction method. Using a simple mPSD homemade simulator, coded in Python, allowing to simulate the measured dose under given experimental conditions with a calibrated mPSD, the calibration datasets have been classified according to their accuracy for subsequent dose measurements. For helping to choose the best calibration datasets for the mPSD, Principal Component Analysis (PCA) is performed on the data, using the pure spectra to build the Principal Components space. The transformed data is thereafter plotted in a simplex formed by the pure spectra composing the signal for a better visualization of the calibration datasets relative to the pure spectra.
Once the best calibration dataset has been determined by the simulations, using the representation of the data in the Principal Components space, a preliminary experimental validation is performed. The device used experimentally to measure the light produced by these scintillators is the HYPERSCINT scintillation dosimetry research platform (Medscint inc., Québec, Canada) allowing for both intensity and spectral measurements. An acquisition software linked to the translation module is used to measure the spectrum of the light coming from the fiber and to automatically control the translation module during the calibration. The translation module can therefore be programmed for performing the required irradiations for the calibration, in order to have an automated calibration routine. Lead blocks are also used into the setup to create a narrow slit of 5 mm into which the photon beam can pass through and get to the detector, while the detector, on the translation module, can move under this slit for the calibration. Once the calibration of the detector is performed, irradiations of the detector at different field sizes are performed in order to plot the output factors for the three scintillators and compare them to the reference. A schematic representation of the experimental setup is shown in figure 2, and figure 3 shows the real experimental setup, under the photon beam delivered by the linac.

![Figure 3. Experimental setup at the linac.](image)

3. Results
The results obtained from the simulations showed that the best dosimetric results are obtained when the mPSD is calibrated with a dataset for which every points of measurement are situated near the corners of the simplex formed by the pure spectral components in the Principal Components space, which means that the scintillation light from each component of the signal has to be maximised for each measure of the dataset. The simulations also showed that it is not necessary to have a lot of measures in the calibration dataset, as long as the measures are well chosen. An example of a simulated calibration dataset, represented in the Principal Components space and which can be reproduced experimentally with a 3-points mPSD, is shown in figure 4 (a). Figure 4 (b) shows the experimental calibration dataset measured using the translation module and the lead blocks to maximise the scintillation light for each measurement, which is in good agreement visually with what has been done in simulations. Using this calibration dataset to calibrate the mPSD, the output factors obtained, both in simulations and at the linac, are shown in figure 5. The average error on the output factors, compared to the reference, is (0.5 ± 0.1)%, while this error was (0.09 ± 0.04)% in simulations.
Figure 4. (a) Calibration dataset that gives the most precise dose measurements for the mPSD simulated with the homemade simulator. (b) Calibration dataset acquired at the linac, reproducing the best dataset obtained in simulations.

Figure 5. Output factor curves obtained with the three scintillators, at the linac and in simulations.

4. Conclusion
This study demonstrates that the translation module developed, along with its software, makes it possible to calibrate a multi-point scintillation detector with a high-energy photon beam. Furthermore, the use of the translation module facilitates greatly the calibration process, preventing the user from having to move the mPSD between each calibration measurement. While it is possible to make very small steps with the translation module (lesser than 1 mm if desired), it is not possible to move the jaws of the linac with steps as small as 1 mm, making the module and the lead blocks necessary for acquiring many measures around the scintillating elements of the mPSD in order to get calibration points near the corners of the simplex in the Principal Components space for the calibration. A further dosimetric validation could be done experimentally in order to verify the limits of the calibration of the mPSD with such a dataset for the calibration.

5. References
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