A novel multi-point plastic scintillation detector for in vivo dosimetry and quality assurance in radiation therapy

Innovation/Impact: This is the first demonstration of a multi-point plastic scintillation detector (mPSD) using a single optical guide. Current plastic scintillation detectors (PSDs) require one fiber per scintillating element. Multi-point applications are therefore cumbersome or even impossible when space is limited (e.g. inside catheters). The maturation of mPSDs will facilitate the development of 1D, 2D, and 3D detectors. The use of a spectrometry setup led the way to the implementation of an innovative hyperspectral calibration approach. This allowed for simultaneous dose measurements at multiple positions from a single light spectrum, while accounting for Cerenkov and other contamination signals. Three scintillating elements were used here, but there is no theoretical limit to this number. This study shows mPSDs can accurately be used with both external beam radiation therapy and HDR brachytherapy. Along with all the advantages of plastic scintillation detectors (water equivalence, small size, fast response, independence to energy, temperature and pressure), an mPSD with a single optical guide is a very promising avenue for both pre-treatment quality assurance and on-line in vivo dosimetry in radiation therapy.

Fig.1 Details of the construction of the mPSD used in this study.

Description of the technique: The physical characteristics of the multi-point plastic scintillation detector (mPSD) are detailed in Figure 1. The challenge for such a dosimeter is that the signal reaching the photodetector is a superposition of multiple light-emitting components. In this study, a linear superposition of the different light emission spectra was assumed, whether it is light coming from scintillation or stem effect (e.g. Cerenkov). Equations 1 through 4 detail the approach used in this study for decomposition of the signal in its components and accurate dose measurement at each scintillating element. Experimentally, this was performed using a spectrometry setup composed of a spectrograph combined to a CCD camera. The spectrum of each light emitting component was acquired separately and normalized to its area under the curve. The scintillating elements spectra \( S_{BCFXX}(\lambda) \) were acquired through irradiation of a lead-collimated, Cerenkov-free, 125 kVp x-ray beam on each individual scintillating fiber. The stem effect spectrum \( S_{Stem}(\lambda) \) was acquired by irradiation of the bare fiber prior to the assembly. The use of a highly over-determined system (up to 1024 different wavelengths \( \lambda_1 \) to \( \lambda_{1024} \) for 4 unknowns) allows for a precise calculation of each light component's contribution \( C_X \) through equation 3. Finally, knowing the dose \( D_{X,\text{Calib.}} \) for a minimum of one calibration condition per scintillating element enables subsequent dose measurements \( D_X \) to each element with a single-spectrum acquisition \( S_{\text{Tot}} \) (see equation 4).

\[
S_{\text{Tot}} = C_{BCF60} \cdot S_{BCF60} + C_{BCF12} \cdot S_{BCF12} + C_{BCF10} \cdot S_{BCF10} + C_{Stem} \cdot S_{Stem} \tag{1}
\]

\[
\begin{bmatrix}
S_{\text{Tot}}(\lambda_1) \\
S_{\text{Tot}}(\lambda_2) \\
\vdots \\
S_{\text{Tot}}(\lambda_N)
\end{bmatrix} =
\begin{bmatrix}
S_{BCF60}(\lambda_1) & S_{BCF12}(\lambda_1) & S_{BCF10}(\lambda_1) & S_{Stem}(\lambda_1) & C_{BCF60} \\
S_{BCF60}(\lambda_2) & S_{BCF12}(\lambda_2) & S_{BCF10}(\lambda_2) & S_{Stem}(\lambda_2) & C_{BCF12} \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
S_{BCF60}(\lambda_N) & S_{BCF12}(\lambda_N) & S_{BCF10}(\lambda_N) & S_{Stem}(\lambda_N) & C_{BCF10}
\end{bmatrix}
\tag{2}
\]

\[
C = (S_{\text{comp}}^{T} \cdot S_{\text{comp}})^{-1} \cdot S_{\text{comp}}^{T} \cdot S_{\text{Tot}} \tag{3}
\]

\[
D_X = D_{X,\text{Calib.}} \cdot (C_X/C_{X,\text{Calib.}}) \tag{4}
\]
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Results: Different irradiations were performed using a 6 MV photon beam and mPSD measurements were in good agreement with the ion chamber. The profile (see Figure 2a) and depth-dose of a 10 cm x 10 cm field, and the profile of a 45 degree wedge were measured with both detectors. A summary of the relative difference between these measurements is provided in Table 1 for each scintillating element. The hyperspectral approach effectively separated the various components of the total emitted light spectra (bottom of Figure 2a). The most accurate results were obtained from scintillating element #3, which was the closest to the photodetection setup, and was therefore less subject to attenuation from crossing multiple interfaces. The mPSD compared advantageously to previous studies using single-point PSDs. The average accuracy of the mPSD depth-dose measurement, (0.9±0.6)%, was within the 1.5% and 1.6% reported by Lambert et al. and Lacroix et al., respectively. The mPSD was also shown to be accurate for in-phantom HDR Ir-192 brachytherapy measurements. Measurements at radial distances (r) of 1 cm and 2 cm are shown in Figure 2b as a function of the source-to-detector longitudinal position (z). The average accuracy was (4.6±1.0)% per dwell-position and (2.1±1.0)% per catheter.

<table>
<thead>
<tr>
<th>Scint.</th>
<th>Profile (d=10 cm)</th>
<th>Depth dose</th>
<th>45 degrees wedge</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>(2.1 ± 1.4)%</td>
<td>(1.3 ± 1.4)%</td>
<td>(3.9 ± 2.4)%</td>
</tr>
<tr>
<td>#2</td>
<td>(1.6 ± 1.1)%</td>
<td>(1.1 ± 0.5)%</td>
<td>(2.1 ± 1.1)%</td>
</tr>
<tr>
<td>#3</td>
<td>(0.3 ± 0.2)%</td>
<td>(0.2 ± 0.1)%</td>
<td>(0.6 ± 0.3)%</td>
</tr>
</tbody>
</table>

Table 1 - Summary of the measurements done with the 3-points PSD in comparison to measurements from an ion chamber.

Fig. 2 – Measurement with the mPSD of a) dose profile of a 6 MV photon beam and contribution from each light-emitting component, and b) dose along the catheter for Ir-192 HDR brachytherapy.

Reference: