Application of the PTW microDiamond in small field dosimetry on different accelerators: Comparative measurements and Monte Carlo calculations

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Introduction

- Literature data on PTW microDiamond (mD) in small fields are in fairly good agreement down to about 1 cm field size, while controversial results are reported for very small fields: for 5 mm field sizes correction factors ranges from -4% to + 2%.

- Reasons for discrepancies are still not clear, they could include:
  - variability of individual detector properties
  - differences in beams produced by different linacs
  - issues of detector modelling in Monte Carlo simulations
  - differences in measurement protocol

- In this work, an investigation of the mD response has been carried out with purpose:
  - To evaluate variability of dosimetric properties among individual mD detectors
  - To assess influence of accelerator type and collimation system on the mD response
  - To check consistency of Monte Carlo calculation of mD output correction factors for three different linacs.
Materials and Methods

- **NDw** measurement in Co-60 beam and $k_Q$ determination in accelerator beams for ten mD detectors

- Monte Carlo calculation of $m_D$ and Ediode $k_{Q_{\text{clin}},Q_{\text{msr}}}$ factors for the beams actually used

- Validation of $k_{Q_{\text{clin}},Q_{\text{msr}}}$ calculation for the mD by comparison of field factor measurements by mDs and Ediodes

<table>
<thead>
<tr>
<th>Accelerator type</th>
<th>$TPR_{20,10}$</th>
<th>Collimation system</th>
<th>Nominal field size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CyberKnife</td>
<td>0.640</td>
<td>Fixed collimators</td>
<td>5 to 60 diameter</td>
</tr>
<tr>
<td>Varian DHX</td>
<td>0.670</td>
<td>Jaws</td>
<td>6 to 100 square side</td>
</tr>
<tr>
<td>Elekta Synergy</td>
<td>0.683</td>
<td>Jaws and MLC</td>
<td>6 to 100 square side</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Detector type</th>
<th>Number of detectors</th>
<th>Diameter (mm)</th>
<th>Thickness (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mD PTW 60019</td>
<td>10</td>
<td>2.2</td>
<td>1</td>
</tr>
<tr>
<td>Ediode PTW 60017</td>
<td>2</td>
<td>1.1</td>
<td>30</td>
</tr>
</tbody>
</table>
Results: calibration coefficients and $k_Q$

- $N_{Dw}$ average value
  $1.06 \text{ Gy/nC} \pm 6.5\% \ (k=1)$
  with maximum spread about 25%

- Sensitivity variations are consistent with an active volume thickness
  $1 \mu m \pm 0.06 \mu m \ (k=1)$
  and a maximum deviation from nominal thickness ($1 \mu m$)
  $\sim 250 \text{ nm}$
  These variations have negligible effects on output correction factor calculation

- High reproducibility of $k_Q$ values among ten mDs in three linac beams

<table>
<thead>
<tr>
<th>measured $k_Q^{(*)}$, 6 MV beams</th>
<th>CyberKnife</th>
<th>Elekta</th>
<th>Varian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average value</td>
<td>0.982</td>
<td>0.978</td>
<td>0.978</td>
</tr>
<tr>
<td>st. dev. (%)</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

(*)Type A uncertainty 0.5% (k=1)
Results: MC output correction factors

\[
k_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}} = \frac{D_{w, Q_{\text{clin}}}^{f_{\text{clin}}}}{D_{w, Q_{\text{msr}}}^{f_{\text{msr}}}} \cdot \frac{D_{\text{det}, Q_{\text{clin}}}^{f_{\text{clin}}}}{D_{\text{det}, Q_{\text{msr}}}^{f_{\text{msr}}}}
\]

- mD correction factors are between +0.7% and -1.4%
- The behaviour of mD correction factor at smaller field sizes originates from a trade-off between perturbation and volume averaging effects
- Ediode correction factor monotonically decreases with field size (correction is around 6% for the smallest fields)

Type A uncertainties ≤0.3% (k=1)
Results: Field factors

\[
\Omega_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}} = \frac{M_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}}}{M_{Q_{\text{msr}}}^{f_{\text{msr}}}} \cdot k_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}}
\]

- Agreement between \( \langle \Omega_{MD} \rangle \) and \( \langle \Omega_{Ediode} \rangle \) is generally well within 1%
- Taking into account difference in beam size (\( \sim 0.1 \) mm) between mDs and Ediodes irradiations the odd 1.6% difference reduces to 0.8%
- In case of fixed collimators agreement is better than 0.3%

- SD of field factor values is generally below 0.5%
- The smallest SD values are found for beams shaped by fixed collimators
- Larger SD values at smaller field sizes are related to a lower reproducibility of small beams shaped by jaws or multi leaf collimators
Discussion

- The good agreement obtained between mD and Ediode field factors provides a validation of the mD Monte Carlo modelling.

- Output correction factors show similar qualitative and quantitative behaviour in three linacs with different collimator systems.

- A best fit function of all data allows to reproduce within ±0.5% $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ values specifically calculated for each linac beam.
Conclusions

• Homogeneous results have been obtained from ten mD detectors, indicating a good reproducibility of their fabrication process.

• The Monte Carlo simulation of microDiamond is proved to be capable of providing reliable output correction factors

• A unique set of mD output correction factors can be applied in beams shaped by different collimation systems according to the actual beam size

• mD output correction factors are lower than 1.5% down to 5 mm beam diameter