Dosimetry and Uncertainty Analysis in Gynecologic Brachytherapy

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Dosimetry and Uncertainty Analysis in Gynecologic Brachytherapy

The intracavitary brachytherapy consists in treating tumors located in natural body cavities such as the uterus and vagina by placing one or more sealed radioactive sources.
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1. Introduction

Allows to administer high dose to the tumor with a significant dose reduction to the adjacent healthy tissues and organs\(^1,2\) (Fig.1) as opposed to EBRT (Fig.2).

Fig.1 - Axial slice showing a vaginal brachytherapy dose distribution.

Fig.2 - Axial slice showing an external beam dose distribution of a gynecologic pathology.

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1. Introduction

Is still common that brachytherapy dose distribution is based on radiographic images (Fig.3) instead of CT images.

![Fig.3 – AP image on the left side and lateral image on the right side for a gynecologic application.](image)

Is frequent not to use dose calculation algorithms that account for the interaction of radiation with tissues and applicators (Fig. 4)³.

![Fig.4 – Dose distribution using a shielded rectal applicator calculated with Acuros® Algorithm (left side) vs TG-43 (right side).](image)
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1. Introduction

Uncertainties in the constituent materials of the gynecologic applicator\textsuperscript{4,5} and in the source positioning lead to uncertainties in dose calculation received by the tumor and surrounding tissues and organs.

Objectives:

- To determine the accuracy of dose calculation based on TG-43\textsuperscript{6} formalism obtained by the Treatment Planning System (TPS) Brachyvision\textsuperscript{®}.
- To assess the influence of source position uncertainties in dose calculation received by the rectum and bladder.

Monte Carlo PENELLOPE\textsuperscript{®7} simulation program
I. Validation of the $^{192}$Ir geometry (Varisource IX®) and the model implemented in Monte Carlo PENELLOPE simulation program.

a) Measurements using a cylindrical phantom and the ionization chamber Farmer® 0.6cm$^3$ (Fig. 5).

Fig.5 – Experimental setup: a) setup 1; b) setup 2; c) setup 3; d) setup 4. For each setup the ionization chamber (blue wire) is inserted into a different hole of the phantom. The source is inserted in the central hole.
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b) Implementation of the experimental model in the Monte Carlo PENELLOPE simulation program.

Fig.7 - Geometry obtained by PENELLOPE program for "setup 1" (display x and z axis)

Fig.8 - Geometry obtained by PENELLOPE program for "setup 2" (display y and z axis)

Legend:
- Material 1 – $^{192}$Ir
- Material 2 – NITINOL
- Material 3 – Air
- Material 4 – Aluminium
- Material 5 – Graphite
- Material 6 – PMMA
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Fig.9 - Geometry obtained by PENELOPE program for "setup 3" (display x and z axis)

Fig.10 - Geometry obtained by PENELOPE program for "setup 4" (display y and z axis)

Legend:
- Material 1 – $^{192}$Ir
- Material 2 – NITINOL
- Material 3 – Air
- Material 4 – Aluminium
- Material 5 – Graphite
- Material 6 – PMMA

3. Results

4. Final Considerations

5. Bibliographical References
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**c) Comparison of the experimental results with Monte Carlo simulations.**

**Graphic 1** - Dose values (cGy) obtained by PENELope and experimentally for "setup 1" depending on the source position with its statistical uncertainty.

**Graphic 2** - Dose values (cGy) obtained by PENELope and experimentally for "setup 2" depending on the source position with its statistical uncertainty.

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Graph 3 - Dose values (cGy) obtained by PENELOPE and experimentally for "setup 3" depending on the source position with its statistical uncertainty.

Graph 4 - Dose values (cGy) obtained by PENELOPE and experimentally for "setup 4" depending on the source position with its statistical uncertainty.
In conclusion:

The relative deviation between the measurements and the values obtained by Monte Carlo PENELPOE simulation program was less than 5% for most of the points, therefore the model was considered validated.
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II. Compare a brachytherapy dose distribution obtained with the TPS and with Monte Carlo simulations.

a) Dose distribution was calculated by the TPS through the use of 2 radiographic images following the ICRU38 recommendations. The intention was to get 5.5Gy in the prescription points considering a 3 cm diameter cylinder (Fig. 11).

Fig.11 - Dose distribution obtained by TPS for a vaginal BT treatment in the axial plane (left image) and coronal (right image). The source positions are represented in the center of the distribution (A).
b) Implementation of the geometry and materials of the source with and without the applicator in the Monte Carlo PENEOPE simulation program (Fig. 12). For each geometry were created five input files for each source position.

The values obtained were converted to absorbed dose considering the activity, the emitted photons and the time that the source spent in each position.
III. Construction of a voxel phantom from a sequence of CBCT images (Fig. 13-14) with ImageJ® program. This phantom was used to calculate the absorbed dose in organs at risk using the main program PenEasy®.

Fig. 13 - Axial, coronal and sagittal slices of a CBCT sequence of a patient who held conventional brachytherapy.

Fig. 14 - Axial, coronal and sagittal slices of the anthropomorphic voxel phantom obtained from the CBCT images.
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TPS dose distribution vs. Monte Carlo simulations

Without applicator, the relative differences in the calculated dose between the PENELOPE simulated values and the TPS ones were below 3% (Table 1).

Table 1 - Dose values obtained at 2 cm away from the source center with TPS and with PENELOPE, for the geometry without the applicator.

<table>
<thead>
<tr>
<th>Central source position (cm)</th>
<th>TPS Dose (Gy)</th>
<th>Dose and PENELOPE uncertainty (Gy)</th>
<th>Relative deviation(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.595</td>
<td>5.51</td>
<td>5.44 (0.26)</td>
<td>-1.27</td>
</tr>
<tr>
<td>10.095</td>
<td>5.5</td>
<td>5.44 (0.27)</td>
<td>-1.09</td>
</tr>
<tr>
<td>9.595</td>
<td>5.55</td>
<td>5.41 (0.26)</td>
<td>-2.52</td>
</tr>
<tr>
<td>9.095</td>
<td>5.58</td>
<td>5.47 (0.26)</td>
<td>-1.97</td>
</tr>
<tr>
<td>8.595</td>
<td>5.36</td>
<td>5.28 (0.25)</td>
<td>-1.49</td>
</tr>
</tbody>
</table>
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With the applicator, the corresponding relative deviation was on average -9.4% (Table 2).

Table 2 - Dose values obtained at 2 cm away from the source center with TPS and with PENELope, for the geometry with the applicator.

<table>
<thead>
<tr>
<th>Central source position (cm)</th>
<th>TPS Dose (Gy)</th>
<th>Dose and PENELope uncertainty (Gy)</th>
<th>Relative deviation(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Source with applicator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.595</td>
<td>5.51</td>
<td>5.05 (0.24)</td>
<td>-9.11</td>
</tr>
<tr>
<td>10.095</td>
<td>5.5</td>
<td>4.97 (0.25)</td>
<td>-10.66</td>
</tr>
<tr>
<td>9.595</td>
<td>5.55</td>
<td>5.10 (0.25)</td>
<td>-8.82</td>
</tr>
<tr>
<td>9.095</td>
<td>5.58</td>
<td>5.15 (0.25)</td>
<td>-8.35</td>
</tr>
<tr>
<td>8.595</td>
<td>5.36</td>
<td>4.87 (0.23)</td>
<td>-10.06</td>
</tr>
</tbody>
</table>
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3. Results

Source position uncertainties in dose calculation received by the rectum and bladder

- The anterior-posterior variation contributed to a relative deviation of +6.6% in the average dose to the bladder (Graphic 6).

- The cranio-caudal variation contributed to a relative deviation of +6.6% in the average dose to the rectum (Graphic 7).

Graphic 6- Average dose received by the bladder when performing a deviation of 1 mm in the source position for the various directions.

Graphic 7- Average dose received by the rectum when performing a deviation of 1 mm in the source position for the various directions.
Validation of the computational models

The model of the gynecologic applicator has not been validated experimentally due to the geometric limitations of the phantom.

TPS dose distribution vs. Monte Carlo simulations

The current available calculation model TG-43 overestimates the dose in clinical points.

Compromise treatment outcome

It is important the introduction of more sophisticated algorithms that consider different densities
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Source position uncertainties in dose calculation

The used voxel phantom was a useful tool that provided detailed information of the different tissues.

Uncertainty in the source position is a relevant factor influencing the uncertainty in the dose calculation in gynecologic brachytherapy.

- Source position verification before each treatment
- Methods to verify the position of the source during treatment

Results vary:
- Type of applicator
- Inter and intra observer variability contouring the phantom
- Sequence used represents the anatomy of only one patient

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5. Gerardy I; Evaluation d’un système de planification pour un traitement de brachythérapie gynécologique en utilisant des techniques Monte Carlo et des mesures expérimentales; Tesis Doctoral, May 2011.