Effect of Prostatic Calcifications on dosimetry in I-125 Brachytherapy

Brad Oborn¹perimental, Stacy Miller², Joe Bucci³

¹Illawarra Cancer Care Centre, Wollongong Hospital
²Centre for Medical Radiation Physics, University of Wollongong
³St George Cancer Care Centre, Kogarah NSW
Background

- Prostatic calcifications are present to some degree in a lot of cases.

- The calcium acts to absorb some of the I-125 x-rays (high cross section for absorption).

CT scan with I-125 seeds

Ultrasound
Background cont.

- **Chibani & Williamson, 2005**
  - Simulated presence of calcification in the prostate by assigning 1, 2, and 5% of CT voxels the density of calcification.
  - "The presence of calcification, even at 1% level, produces a significant impact on dose distribution."

- **Carrier et al, 2006 & 2007**
  - Used Monte Carlo simulation to study the impact of interseed attenuation and tissue composition.
  - Systematic dose overestimation of 2.6 Gy +/- 4% due to tissue composition.

- **Youseff et al, 2008**
  - Clinical study of one patient with significant calcification
  - Area of underdosage on either side of the calcification ranging from 0-35% with most attenuation occurring at the center of the gland.
CT images may in fact show “artefacts” due to the calcification.

Preliminary histology study showed that regions of calcification reflect lots of “small beads” of dense deposits.

Hence knowledge of the exact structure/density/composition of calcifications is limited.

In this study we have assume a contoured volume contains calcium-like material.
Aims

- To use Geant4 simulations to estimate the dose changes to the prostate due to calcification material
  - generate common dose metrics such as Dose-volume-histograms
  - examine several patient-based cases with varied calcification extent
Methods

- Geant4.9.3
- Voxelized phantom from CT scan
- Voxels removed where seeds located
- Voxels replaced with calcification material
- In-house Matlab based GUI used to convert contoured calcification regions to different materials
- I-125 seed from manufacturer’s specifications
- Source fired from surface of Silver rod
- 3 patient cases examined, calcification boundary expanded by +1 mm and +2 mm to see effect
Geant4 setup: CT phantom

- default approach would be read DICOM images and assign voxels to each pixel (regular navigation, parameterized volumes etc...)
- What about I-125 seeds x 100?
  - these would overlap!
- Soln: custom approach...
  - read all pixels, place all as voxels EXCEPT ones which would contain the seeds
  - use Matlab GUI to contour the seeds: Boolean arguments to identify seed regions (lots of background things done in Matlab first!!)
  - set background/world to water
  - read in and place seeds from Variseed export of seed centroids
  - these should fall inside the missing voxel gaps
  - what is empty space will be water anyway...
- OR: Gamos idea
Simulating materials and interactions in parallel geometries

In any case, Geant4 can navigate in the parallel geometries, but the materials are never taken into account. This means that a track never interacts on a parallel geometry volume. We have developed in GAMOS an utility that allows to have interactions in both geometries at the same time, that is to have real overlapping geometries. This maybe useful for example to simulate the real geometry of brachytherapy seeds or ionisation chambers inside a phantom. This utility is based on making a copy of the parallel geometry in the mass geometry. When a particle is going to enter the parallel geometry volume its position is shifted to the border of its copy in the mass geometry and when a particle exits the parallel volume copy its position is shifted back to the border of the parallel geometry. To activate this utility you just have to use the command.

/gamos/geometry/copyParallelToMassGeom VOL_NAME_1 VOL_NAME_2 ... VOL_NAME_N DISP_X DISP_Y DISP_Z

where VOL_NAME_1 VOL_NAME_2 ... VOL_NAME_N is the list of volumes in a parallel geometry that will be copied and DISP_X DISP_Y DISP_Z are the values of the displacement vector.

The user should check that the copy of the parallel geometry volumes in the mass geometry are inside the user-defined world volume, and also that they do not overlap with any of the preexisting mass geometry volumes. GAMOS will check that these two conditions are satisfied, but only a warning message will be sent. We also recommend that the copy is placed far from the rest of the mass geometry volumes. If this is not done, it may happen that some particles navigating in the mass geometry will enter the copy, what is a non-physical situation. Alternatively, the user can take care of killing the particles that approach the copy, for example by using the user action GmKillAtSteppingActionUA with the corresponding filters.
The Matlab GUI

- This version is showing the dose overlayed.
- Default version would show native CT slices with contour lines.
Geant4 setup: the I-125 seeds

- create single seed (logical volume) and place (physical volume) multiple times according to VariSeed export on seed positions
- setup random x-rays to fire from a seed at the centroid (but don’t fire): just like in G4 Brachytherapy example
- loop through all seeds placed and fire identical x-ray, but position shifted to match each seed location
- run ~ 100 mill = 10 billion total
G4 setup: Dose scoring

- Custom read-out-geometry
- energy not captured in seeds
- dose grid matches CT resolution (512x512x no_slices)
G4 setup: calcium-like material

- The CT material composition comes from the 24 materials listed in Table 6 of the paper "Correlation between CT numbers and tissue parameters needed for Monte Carlo simulations of clinical dose distributions", PMB 45(2000). These are related to the CT numbers. The density of each material will come from Figure 9 of this same work - the value at the centre of the bin.

- Regions of calcification where binned to 15 density levels

- density = 1.5202*g/cm3;
- G4Material* ct_material_15 = new G4Material(name="ct_material_15",density , ncomponents=9);
- ct_material_17->AddElement( elH, 5.60 *perCent);
- ct_material_17->AddElement( elC, 26.50 *perCent);
- ct_material_17->AddElement( elN, 3.60 *perCent);
- ct_material_17->AddElement( elO, 40.50 *perCent);
- ct_material_17->AddElement( elNa, 0.10 *perCent);
- ct_material_17->AddElement( elMg, 0.20 *perCent);
- ct_material_17->AddElement( elP, 7.30 *perCent);
- ct_material_17->AddElement( elS, 0.30 *perCent);
- ct_material_17->AddElement( elCa, 15.90 *perCent);
# Results: Cases

<table>
<thead>
<tr>
<th>Patient</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prostate Volume (cc)</strong></td>
<td>51.24</td>
<td>28.59</td>
<td>38.10</td>
</tr>
<tr>
<td><strong>Calcification Volume (cc)</strong></td>
<td>0.95 (1.7%)</td>
<td>0.69 (2.4%)</td>
<td>1.00 (2.6%)</td>
</tr>
<tr>
<td><strong>Calcification Volume + 1mm</strong></td>
<td>1.96 (3.8%)</td>
<td>1.08 (3.8%)</td>
<td>1.87 (4.9 %)</td>
</tr>
<tr>
<td><strong>Calcification Volume + 2mm</strong></td>
<td>3.45 (6.7%)</td>
<td>1.66 (5.8%)</td>
<td>2.90 (7.6%)</td>
</tr>
</tbody>
</table>
Patient #1

V100 Goal:
- >90: good
- >80: fair
- <80: poor

D90 Goal: 130-180 Gy

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>V100 (%)</th>
<th>D90 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no calc</td>
<td>91.2</td>
<td>149</td>
</tr>
</tbody>
</table>
**Patient #1**

**Integral DVH - Patient: 1**

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>V100 (%)</th>
<th>D90 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no calc</td>
<td>91.2</td>
<td>149</td>
</tr>
<tr>
<td>with calc</td>
<td>64.3</td>
<td>111</td>
</tr>
</tbody>
</table>

**D90 Goal:** 130-180 Gy

**V100 Goal:**
- >90: good
- >80: fair
- <80: poor
Patient #1

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>V100 (%)</th>
<th>D90 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no calc</td>
<td>91.2</td>
<td>149</td>
</tr>
<tr>
<td>with calc</td>
<td>64.3</td>
<td>111</td>
</tr>
<tr>
<td>calc + 1mm</td>
<td>61.9</td>
<td>106</td>
</tr>
<tr>
<td>calc + 2mm</td>
<td>55.2</td>
<td>96</td>
</tr>
</tbody>
</table>

**V100 Goal:**
- >90: good
- >80: fair
- <80: poor

**D90 Goal:** 130-180Gy

Diagram showing integral DVH for Patient 1 with various dose results for different conditions.
Patient #1

No Calcification

With Calcification
Patient #2

V100 Goal: >90: good
       >80: fair
       <80: poor

D90 Goal: 130-180 Gy

<table>
<thead>
<tr>
<th></th>
<th>V100 (%)</th>
<th>D90 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no calc</td>
<td>99.4</td>
<td>211</td>
</tr>
<tr>
<td>with calc</td>
<td>65.8</td>
<td>110</td>
</tr>
<tr>
<td>calc + 1 mm</td>
<td>27.7</td>
<td>69</td>
</tr>
<tr>
<td>calc + 2 mm</td>
<td>32.3</td>
<td>70</td>
</tr>
</tbody>
</table>
Patient #2

No Calcification

With Calcification
Patient #2

No Calcification

With Calcification + 2mm
Patient #3

V100 Goal:
>90: good
>80: fair
<80: poor

D90 Goal: 130-180 Gy

<table>
<thead>
<tr>
<th>Patient 3</th>
<th>V100 (Gy)</th>
<th>D90 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no calc</td>
<td>94.2</td>
<td>159</td>
</tr>
<tr>
<td>with calc</td>
<td>89.4</td>
<td>145</td>
</tr>
<tr>
<td>calc + 1mm</td>
<td>88.5</td>
<td>142</td>
</tr>
<tr>
<td>calc + 2mm</td>
<td>87.3</td>
<td>140</td>
</tr>
</tbody>
</table>
Patient #3

**V100**

**D90**

<table>
<thead>
<tr>
<th>Patient 3</th>
<th>V100 (Gy)</th>
<th>D90 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no calc</td>
<td>94.2</td>
<td>159</td>
</tr>
<tr>
<td>with calc</td>
<td>89.4</td>
<td>145</td>
</tr>
<tr>
<td>calc + 1mm</td>
<td>88.5</td>
<td>142</td>
</tr>
<tr>
<td>calc + 2mm</td>
<td><strong>87.3</strong></td>
<td><strong>140</strong></td>
</tr>
</tbody>
</table>

V100 Goal:

- >90: good
- >80: fair
- <80: poor

D90 Goal: 130-180 Gy
Patient #3

No Calcification

With Calcification
Summary

- For 2 of the 3 patients, calcification had a significant, negative impact on dosimetry.
  - Minimal impact on normal tissue exposure

- Most impact on patient #2
  - Smallest gland
  - Calcification with largest surface area

- Least impact on patient #3
  - Only patient with 1mm slice CT
    - Possible impact of voxel size
Discussion

- The Monte Carlo simulation is only as accurate as the materials defined.

- Calcifications are not well represented by CT scan.

- Current results indicate clinically significant differences.

- Further Monte Carlo studies should be performed with improved knowledge of the calcification density and composition.

- Pre-implant Monte Carlo analysis may be desirable in certain cases where calcifications are significant.