Pre- and Post-Operative Breast SBRT using GammaPod

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Disclosure

There is nothing to disclose regarding the conduct and presentation of this study.
Background - Stereotactic body radiation therapy for breast

From WBI to APBI:
- Partial volume irradiation --- less acute toxicity
- Accelerated treatment course --- convenience to patients, cost effectiveness
- Comparable to slightly worse local control*
- Increase in moderate late toxicity and adverse cosmesis* (From BID?)

From APBI to Breast SBRT:
- Further dose escalation --- potentially better local control?
- Normal tissue sparing with stereotactic target localization --- potentially less toxicity?
- Every other day treatments --- potentially better cosmesis?

*Frank Vicini et al, Lancet, 2019; & Timothy Whelan et al, Lancet, 2019
Background - Pre- and post-op breast radiotherapy

Post-operative (surgery) radiotherapy is the norm:
--- Reduce local-regional recurrence
--- Define targets based on cavity/seroma and surgical clips

Pre-operative Breast SBRT is an emerging technique:
--- Usually smaller targets than post-operative breast SBRT
--- Irradiated tissue could be removed during surgery to minimize late effects
--- Radiobiological response can be tracked at time of surgical pathology
--- Reduce/Mitigate the need of post-operative radiotherapy
--- 21 Gy x 1 Fx deemed safe in previous trials, while further dose escalation study is warranted
--- Targets contoured post-contrast, usually with fiducials to help

Case 1

Case 2
Background - Delivery techniques for breast APBI/SBRT

- C-arm LINAC
- Brachytherapy
- Proton

GammaPod
Cyberknife
Ethos
Unity MR-LINAC

What we are using at UTSW for breast SBRT
Background - GammaPod for breast SBRT

GammaPod:
- Dedicated, noninvasive breast SBRT treatment
- Our first-line modality (better dosimetry)
- Vacuum-assisted breast immobilization
- Same-day imaging, contouring, planning and treatment for each fraction (adaptive in nature)
GammaPod - Basic workflow and design

For each treatment fraction,

Breast cup fitting + vacuum fixation

Prone CT scan

Vacuum + prone set-up: Minimizes intra-fractional motion!
GammaPod - Basic workflow and design

Contouring + treatment planning

Monte-Carlo based 2nd dose calculation QA
GammaPod - Basic workflow and design

On-board loading + delivery

- 25 rotating sources: non-coplanar, conically shaped beams (15 mm or 25 mm collimator settings)
- Moving couch for dose painting
GammaPod - Commissioning at UTSW

- System commissioned in 2019
- No 3D beam scanning system available for GammaPod
- Manual point-by-point scanning laborious and time-consuming

- We developed an in-house beam scanning system for automatic profile acquisition
- Shorten profile acquisition from weeks to 2 days
GammaPod - Commissioning at UTSW

- GammaPod TPS reports dose to breast tissue
- We measure dose to water
- Not directly comparable

- We developed an in-house Monte-Carlo package to allow indirect comparison between TPS dose and measured dose.
Relative dosimetry:
• SRS mapcheck + custom-made insert for plane dose verification

Absolute dosimetry:
• In-water chamber measurement
A: Monte-Carlo vs. Measurement (in water)
B. Monte-Carlo vs. TPS (in breast)

- 56 plans of different target sizes, locations and breast cup sizes measured and evaluated.

<table>
<thead>
<tr>
<th>Dose Diff Metrics</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>-2.01%</td>
<td>-1.59%</td>
</tr>
<tr>
<td>Max</td>
<td>2.20%</td>
<td>1.51%</td>
</tr>
<tr>
<td>Mean</td>
<td>0.04%</td>
<td>-0.02%</td>
</tr>
</tbody>
</table>
GammaPod - Commissioning at UTSW

- 56 plans of different target sizes, locations, and breast cup sizes measured and evaluated;
- For both x-y and z-y planes;
- 2%/1mm criteria with 10% RX threshold;
- >90% pass rates for all cases.
GammaPod - Commissioning at UTSW

TLD jig inside PMMA slot holder for absolute dose calculation, two TLDs measured for <5% uncertainty at >90% confidence level

| Institutional chamber measurement (TG 21) | 6.43 cGy |
| IROC TLD reading | 6.47 cGy |
| Difference | - 0.6% |
GammaPod - Operations at UTSW: clinic layout

- Close proximity to CTs allows streamlined imaging and planning experience
- It also reduces the need of patient in-clinic travel (and the chance of Vacuum cup suction lost)

Elizabeth Zhang-Velten et al., Prac. Rad. Onc., 2022
Post-op:
- 5 Fx treatment
  - 8 Gy/Fx to CTV
  - Or 7 Gy/Fx to CTV (if CTV > 100 cc (fat necrosis limit) or skin dose limit)
  - Both using 6 Gy/Fx to PTV
- 1 Fx treatment (for boost only)
  - 8 Gy/Fx to PTV

Pre-op:
- 1 Fx treatment (dose escalation study)
  - currently at the 34 Gy/Fx (to CTV) dose level

<table>
<thead>
<tr>
<th>Level</th>
<th>Dose</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1*</td>
<td>26.5 Gy</td>
<td>7-15</td>
</tr>
<tr>
<td>1</td>
<td>30 Gy</td>
<td>7-15</td>
</tr>
<tr>
<td>2</td>
<td>34 Gy</td>
<td>7-15</td>
</tr>
<tr>
<td>3</td>
<td>38 Gy</td>
<td>7-15</td>
</tr>
</tbody>
</table>

* Fall back to level -1 if significant toxicity
GammaPod - Operations at UTSW: cavity/target check

The use of GP may be contraindicated in some scenarios:

1. Tumor too posterior (out of reach by dose deposition)
2. Tumor too large (cannot satisfy normal breast constraint)
3. Tumor too close to skin
4. Tumor difficult to see in CT (for pre-op cases)

We do a pre-check CT scan with cup fitting/suction (cavity/target check CT) to:

1. Check the tumor location/size to determine its fit for GammaPod
2. In some pre-op cases, to do a pre-plan to evaluate the dosimetric feasibility
3. For the GammaPod team to practice cup fitting on each patient to expedite treatments
GammaPod - Operations at UTSW: contouring

Daily CT

Eclipse TPS: physician contouring
GTV/CTV/PTV

GammaPod TPS: physicist contouring
OARs (skin, heart, ribs)

Export → Merge → Full structure set

* Usually the most time-consuming step
We have different breast physicians covering GammaPod each day of a week:

To maintain the consistency of target contouring for 5-Fx cases,
1. We propagate Fx 1’s contours to following Fxs as reference through image registration
2. Physicians use some basic QA metrics like PTV volume etc.
3. The surgical clips also help to improve the consistency

Margin recipes used:

For 5x post-op --- CTV: GTV + 10 mm; PTV: CTV + 3 mm;
For 1x post-op (boost only) --- CTV: GTV + 5 mm; PTV: CTV + 3 mm.

CTV 6 mm from skin surface; PTV 5 mm from skin surface; both excluding chest wall
For pre-op cases, to enhance the tumor visibility, we administer iodinated contrast:
1. We acquire a series of images (w/o contrast, immediately after (arterial), 5 min, 7 min and 10 min)
2. Physician reviews images and contours one with the best tumor contrast

Margin recipes used:

For 1x pre-op --- CTV = GTV; PTV: CTV + (3-10 mm, usually 5 mm)

CTV/PTV excluding skin and chest wall
GammaPod - Operations at UTSW: treatment planning

Kernel based dose engine:
1. Monte Carlo simulation for various locations of shots for all cups.
2. Kernel spacing -- 5 mm
3. Cups are cylindrical symmetric.

- Dose kernels pre-computed via Monte-Carlo
- We use full-optimization directly
- Semi-automatic plan optimization/generation in a couple of minutes

---- Target/OAR importance weighting can be customized via sliding bars

24 available sizes of inner cups, i.e., breast geometries are predetermined in TPS
Each inner cup size corresponds a pre-calculated set of Monte-Carlo generated kernels, i.e. corresponding various positions of isocenter within the cup
Breast tissue density = 0.935; no heterogeneity correction

**Weight Optimization**
- A DVH will be displayed to allow the user to assess the prescription

**Full Optimization**
- Takes into account the physical characteristics of the machine (speed, range of motion, etc.)
- Optimizes the path to achieve an uniform distribution
- A large amount of potential paths are created then evaluated

Courtesy of Xcision Medical Systems, LLC
GammaPod - Operations at UTSW: plan evaluation

UTSW Post-op 5Fx Protocol

UTSW Post-op Boost Protocol
### GammaPod - Operations at UTSW: plan evaluation

#### Dose Statistics of UTSW GammaPod Partial Breast Irradiation Treatment

<table>
<thead>
<tr>
<th>Patient Name</th>
<th>MRN</th>
<th>Study ID</th>
<th>3% Rx</th>
<th>5% Rx</th>
<th>10% Rx</th>
<th>20% Rx</th>
<th>30% Rx</th>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>Fraction Dose (Gy)</th>
<th># of Fractions</th>
<th>Rx Dose</th>
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<tbody>
<tr>
<td>34.00</td>
<td>1</td>
<td>34.00</td>
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**Attending Rad. Onc.**

<table>
<thead>
<tr>
<th>Plan Name</th>
<th>1 fx pre-op (new protocol)</th>
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**Contouring Compliant?**

<table>
<thead>
<tr>
<th>Organ</th>
<th>Goal</th>
<th>Targeted Value</th>
<th>Unit</th>
<th>Current Value</th>
<th>Compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td></td>
<td>27.50</td>
<td>Gy</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>25.50</td>
<td>Gy</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Ipsilateral breast</td>
<td></td>
<td>40%</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20%</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Rb</td>
<td></td>
<td>33.00</td>
<td>Gy</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28.00</td>
<td>Gy</td>
<td></td>
<td>Yes</td>
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<tr>
<td>Heart</td>
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<td>22.00</td>
<td>Gy</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>16.00</td>
<td>Gy</td>
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<td>Yes</td>
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</tbody>
</table>

#### Target Coverage and High Dose Spillage

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Organ/volume</th>
<th>Goal</th>
<th>Targeted Value</th>
<th>Unit</th>
<th>Current Value</th>
<th>Compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of Max Dose Point</td>
<td>Irradiation volume</td>
<td>Max. dose port within PTV</td>
<td>0.00%</td>
<td>Plan normalization</td>
<td></td>
<td></td>
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<tr>
<td>Maximum dose</td>
<td>PTV</td>
<td>&lt;</td>
<td>44.20</td>
<td>Gy</td>
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<tr>
<td>percentage CTV/GTV volume</td>
<td>CTV/GTV=31.62Gy</td>
<td>V_{95 Gy} &gt;</td>
<td>99%</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>percentage PTV volume</td>
<td>PTV=27Gy</td>
<td>V_{95 Gy} &gt;</td>
<td>95%</td>
<td>No</td>
<td></td>
<td></td>
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<tr>
<td>receiving 27 Gy</td>
<td></td>
<td>V_{85 Gy} &gt;</td>
<td>90%</td>
<td>No</td>
<td></td>
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</table>

UTSW pre-op 1Fx Protocol
**GammaPod - Operations at UTSW: plan QA**

Patient-specific plan QA (for each case using Monte-Carlo based 2nd dose calculation)

- In-house Monte-Carlo engine developed during system commissioning
- Takes images and plan files to compute dose and analyze via comparison with GP TPS doses

David Parsons et al., Medical Physics, 2020
Patient-specific plan QA (for each case using Monte-Carlo based 2\textsuperscript{nd} dose calculation)

*GPU-based, ~ 3 min

David Parsons et al., Medical Physics, 2020
Overall workflow revisit

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
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<tbody>
<tr>
<td>Cup fitting</td>
<td>5</td>
<td>110</td>
<td>22</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>CT scan</td>
<td>3</td>
<td>90</td>
<td>14</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Planning</td>
<td>20</td>
<td>125</td>
<td>55</td>
<td>18</td>
<td>53</td>
</tr>
<tr>
<td>Treatment delivery</td>
<td>10</td>
<td>70</td>
<td>33</td>
<td>9</td>
<td>32</td>
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<tr>
<td>Total</td>
<td>75</td>
<td>226</td>
<td>124</td>
<td>27</td>
<td>120</td>
</tr>
</tbody>
</table>

*Abbreviations: CT = computed tomography; SD = standard deviation.*

**Table 1.** Time from cup fitting to end-of-fraction for 93 patients treated at UTSW

Courtesy of Xcision Medical Systems, LLC

Elizabeth Zhang-Velten et al., Prac. Rad. Onc., 2022
The GammaPod system:

- uses unique system design for highly-focused breast SBRT;
- maintains breast immobilization through a Vacuum cup system;
- provides high dosimetric accuracy to match measurements and Monte-Carlo calculations;
- offers excellent dosimetric benefits in OAR sparing and tumor targeting;
- serves well for treating both pre- and post-op breast SBRTs;
- can be further improved to enable MR-compatible imaging, auto contouring, more secured cup fitting etc.
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