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

Whole Breast Irradiation (WBI) → Accelerated Partial Breast Irradiation (APBI) → Stereotactic Partial Breast Irradiation (SPBI or Breast SBRT)

From WBI to APBI:

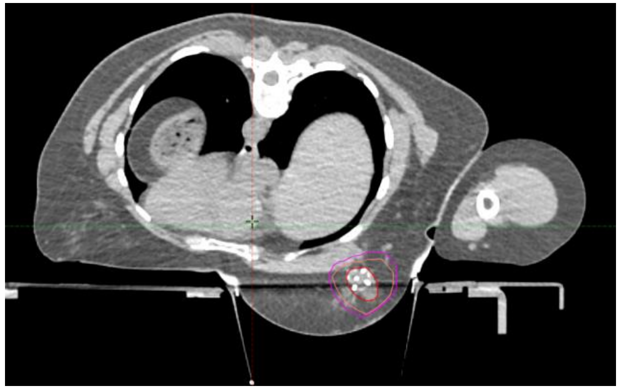
- Partial volume irradiation --- less acute toxicity
- Accelerated treatment course --- convenience to patients, cost effectiveness
- Comparable to slightly worse local control*
- Increase in moderate late toxicity and adverse cosmesis* (From BID?)

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

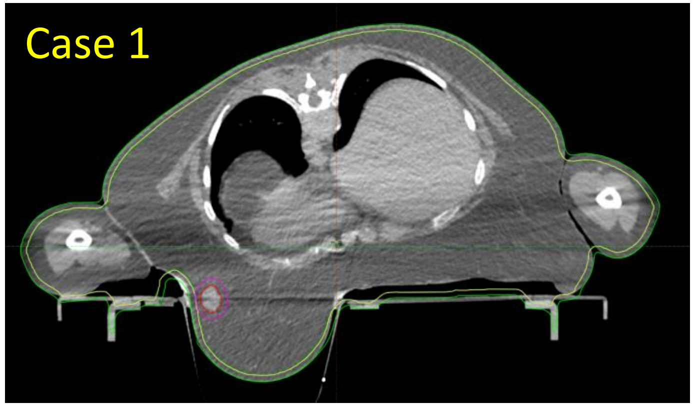


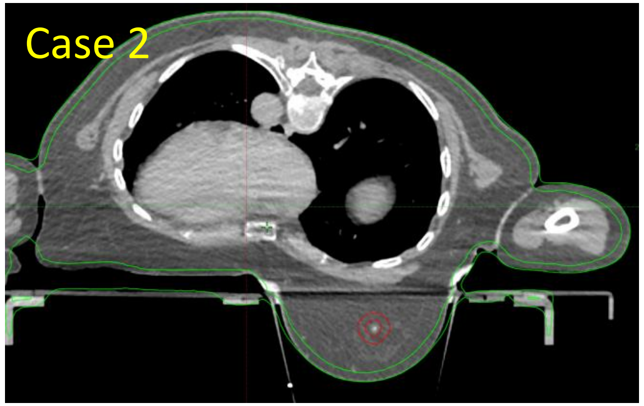
Post-operative (surgery) radiotherapy is the norm:

--- 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

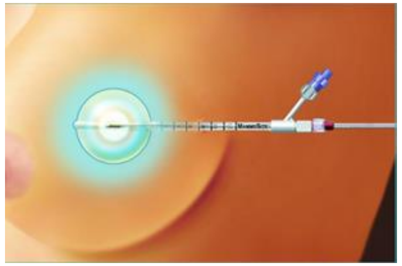




Background - Delivery techniques for breast APBI/SBRT

C-arm LINAC

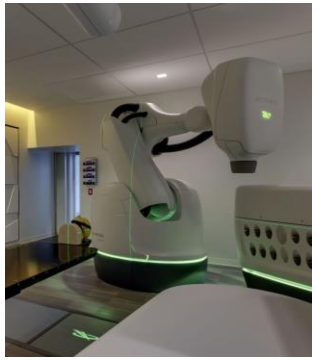
Brachytherapy



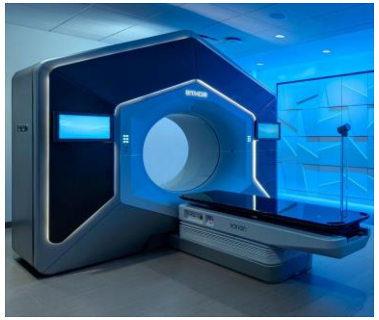
Proton

GammaPod

Cyberknife



Ethos



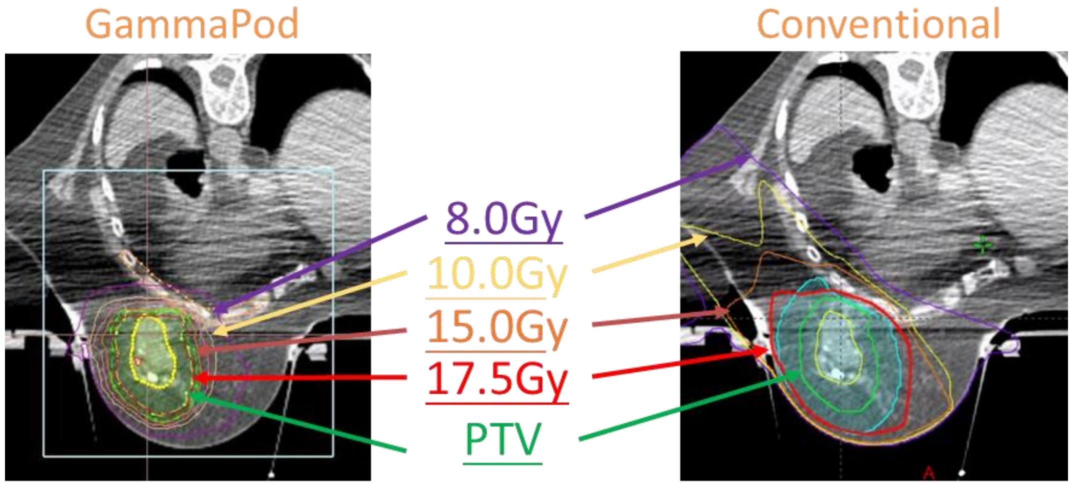
Unity MR-LINAC

What we are using at UTSW for breast SBRT

Background - GammaPod for breast SBRT

GammaPod:

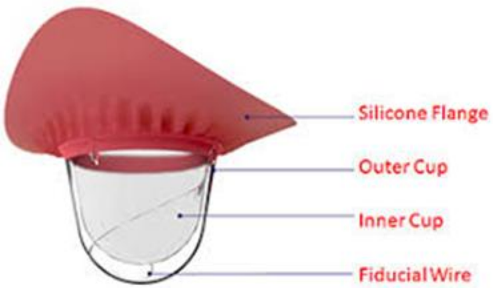
- Dedicated, noninvasive breast SBRT treatment
- Our first-line modality (better dosimetry)
- Vacuum-assisted breast immobilization
- Same-day imaging, contouring, planning
  and treatment for each fraction (adaptive in nature)



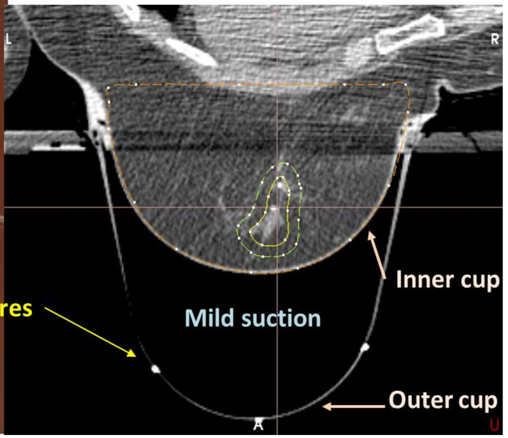
GammaPod - Basic workflow and design

For each treatment fraction,

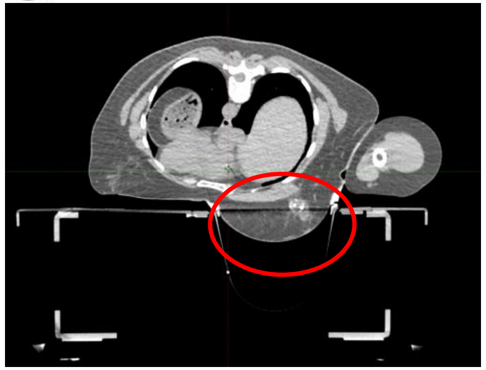
Breast cup fitting + vacuum fixation → Prone CT scan →



CT scan showing breast within cup system



Breast cup holder



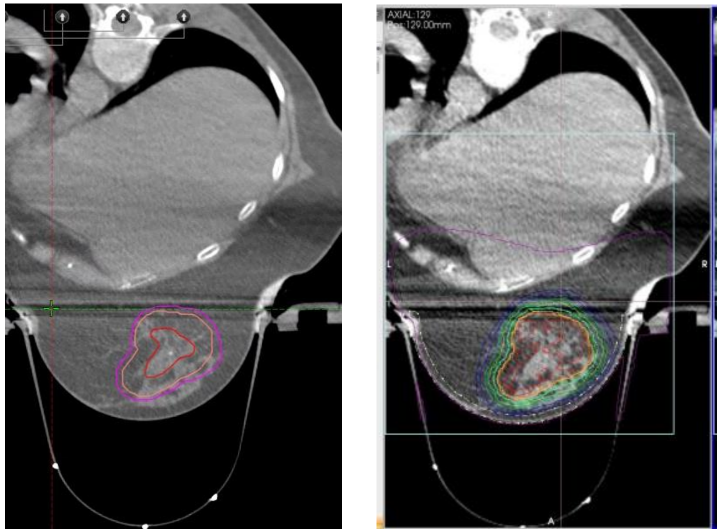
Vacuum + prone set-up:

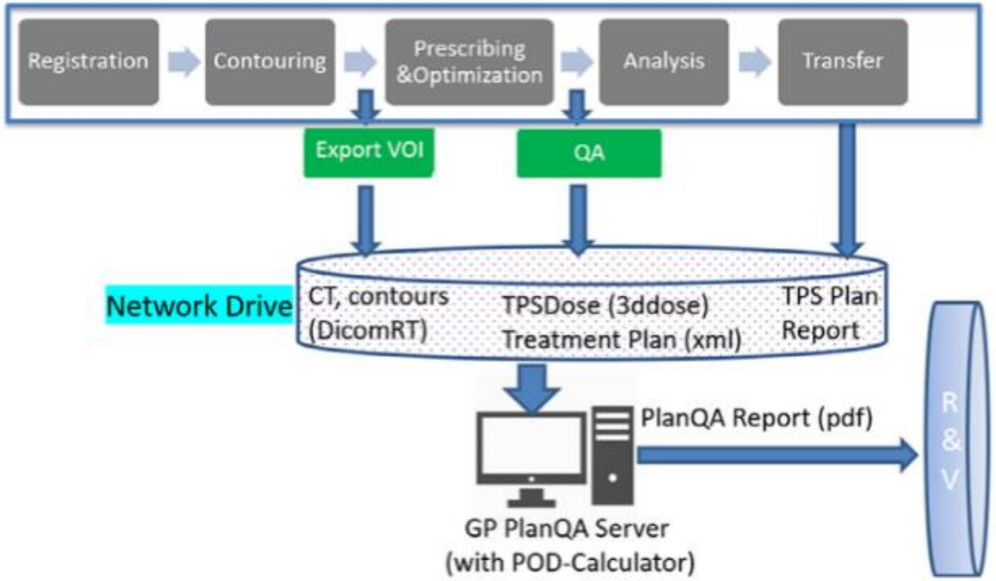
Minimizes intra-fractional motion!

GammaPod - Basic workflow and design

Contouring + treatment planning

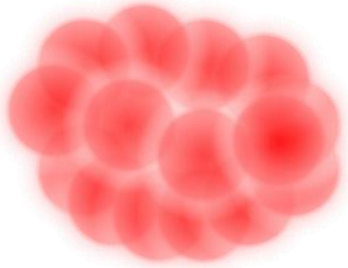
Monte-Carlo based 2^{nd} dose calculation QA

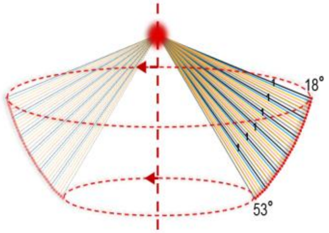


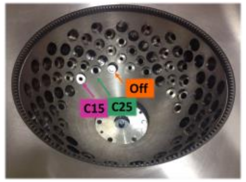


GammaPod - Basic workflow and design

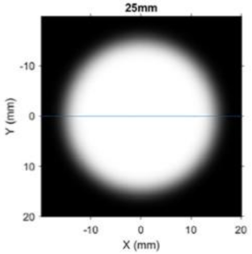
On-board loading + delivery

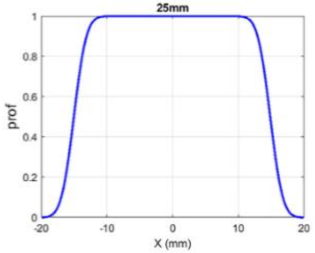




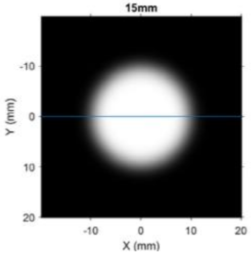


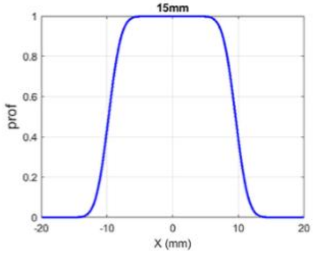
25 mm collimator





15 mm collimator

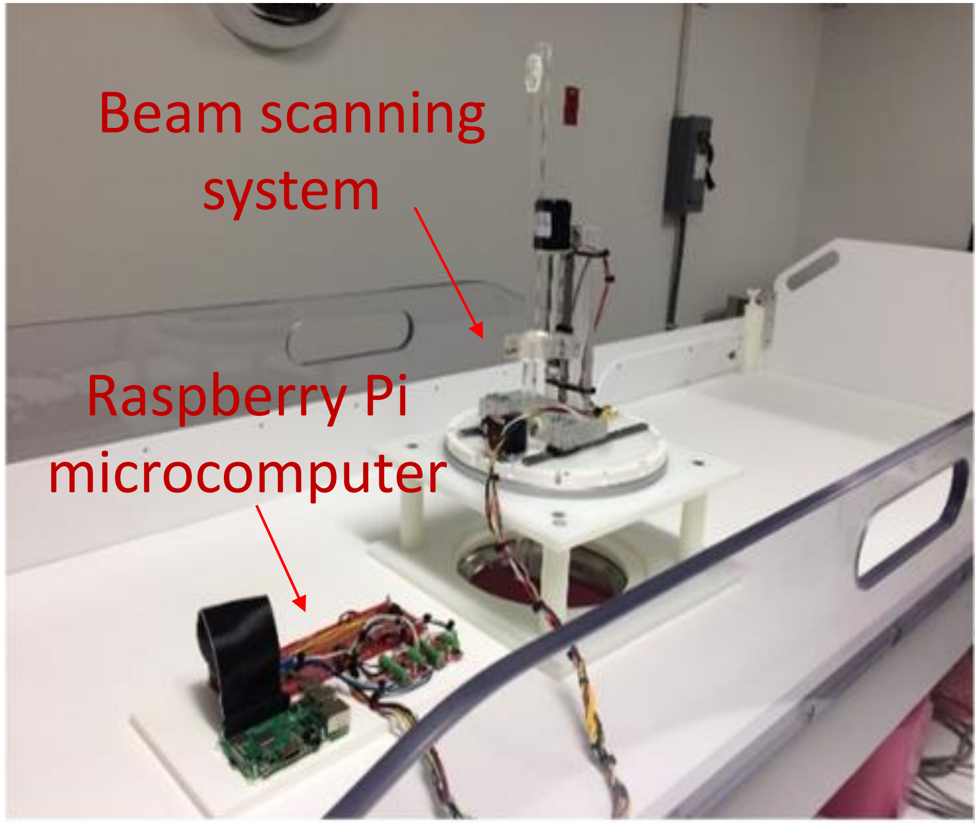




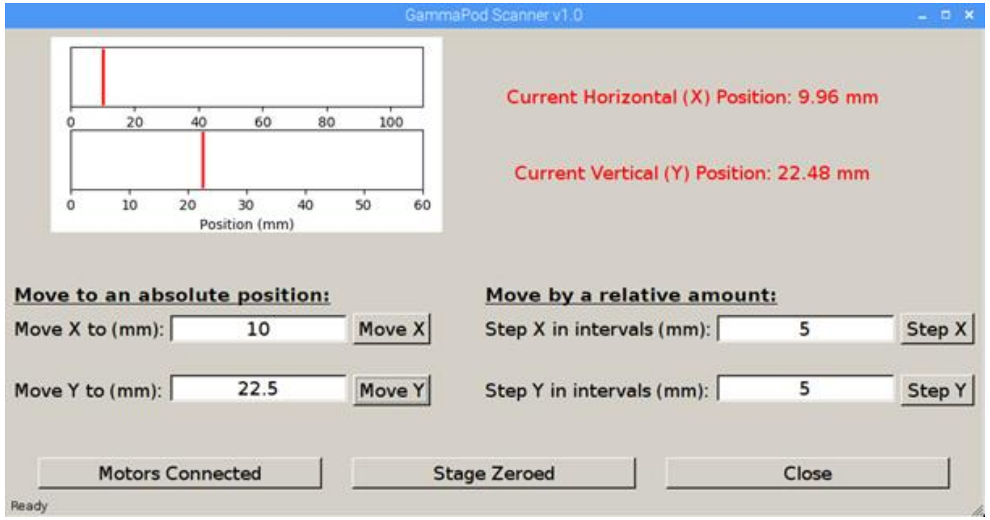
- 25 rotating sources: non-coplanar, conically shaped beams (15 mm or 25 mm collimator settings)
- Moving couch for dose painting

GammaPod - Commissioning at UTSW

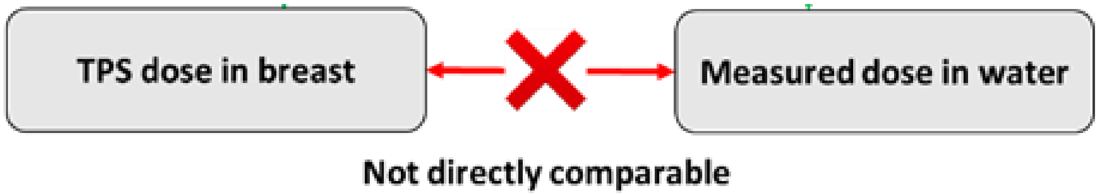
- System commissioned in 2019
- No 3D beam scanning system available for GammaPod
- Manual point-by-point scanning laborious and time-consuming



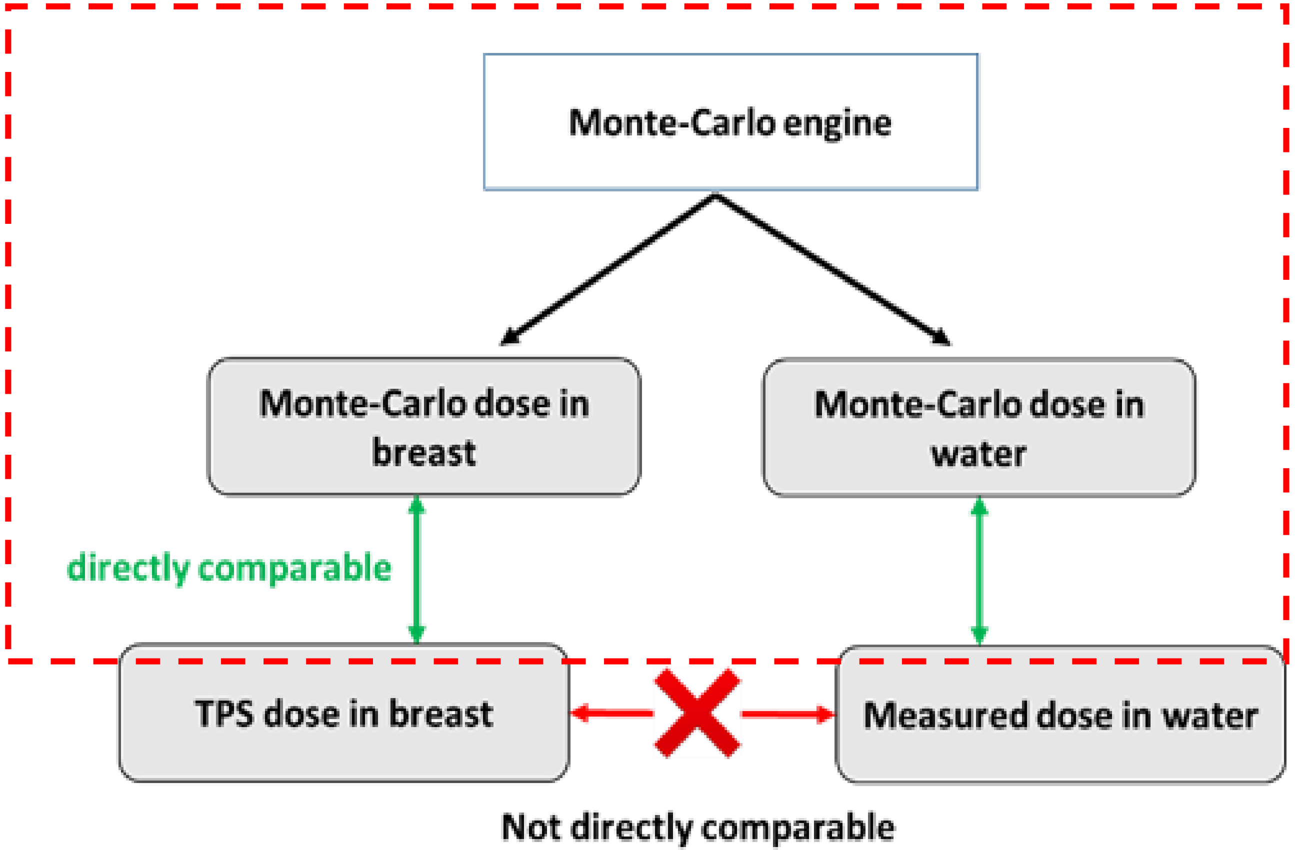
- We developed an in-house beam scanning system for automatic profile acquisition
- Shorten profile acquisition from weeks to 2 days



GammaPod - Commissioning at UTSW

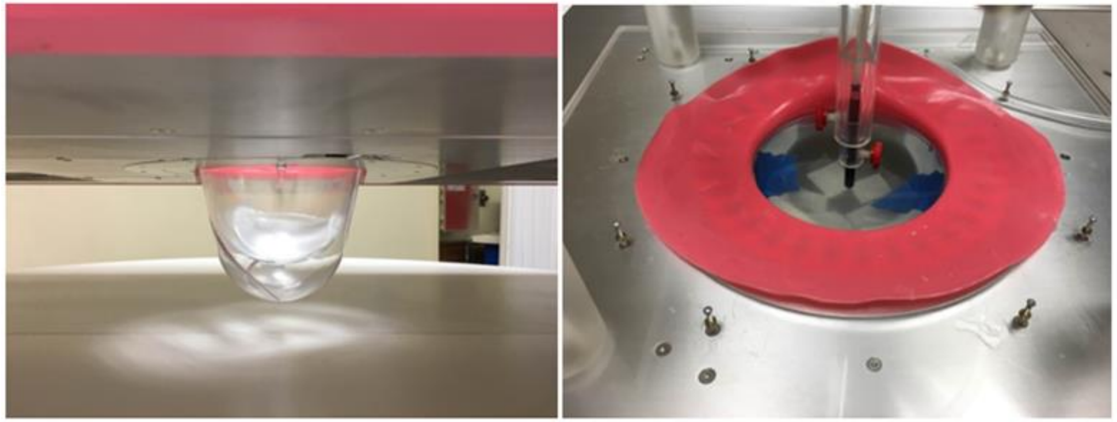


- GammaPod TPS reports dose to breast tissue
- We measure dose to water
- Not directly comparable



- We developed an in-house Monte-Carlo package to allow indirect comparison between TPS dose and measured dose.

GammaPod - Commissioning at UTSW



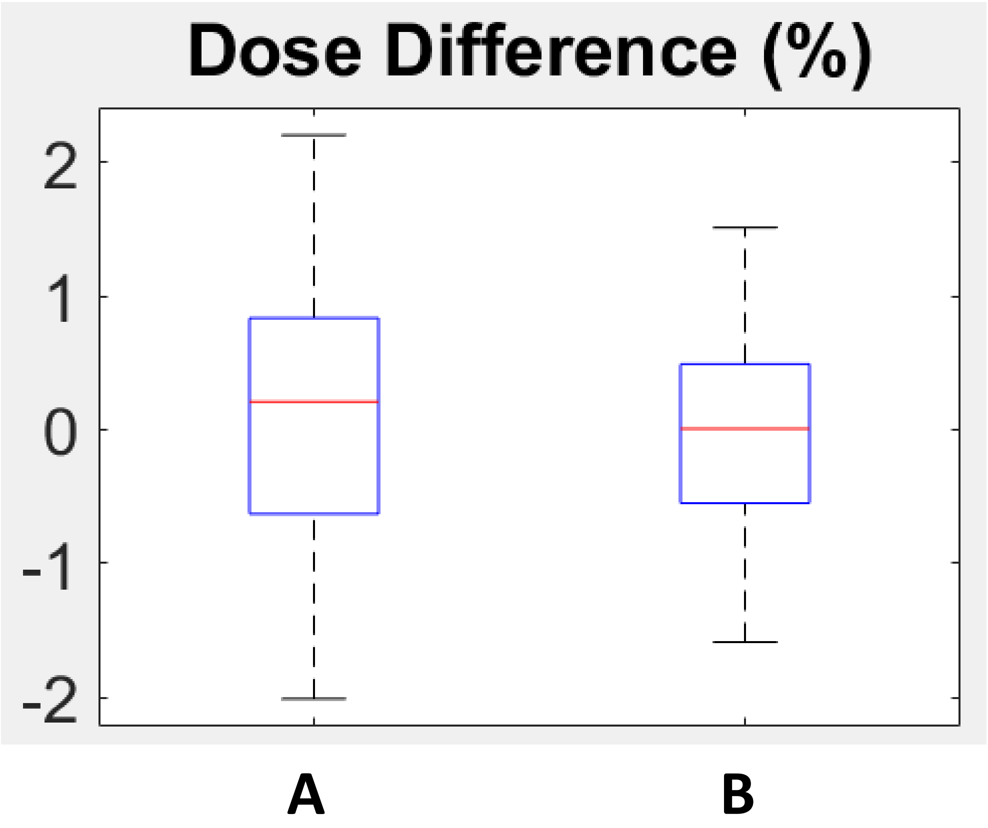
Absolute dosimetry:

- In-water chamber measurement

Relative dosimetry:

- SRS mapcheck + custom-made insert for plane dose verification

GammaPod - Commissioning at UTSW

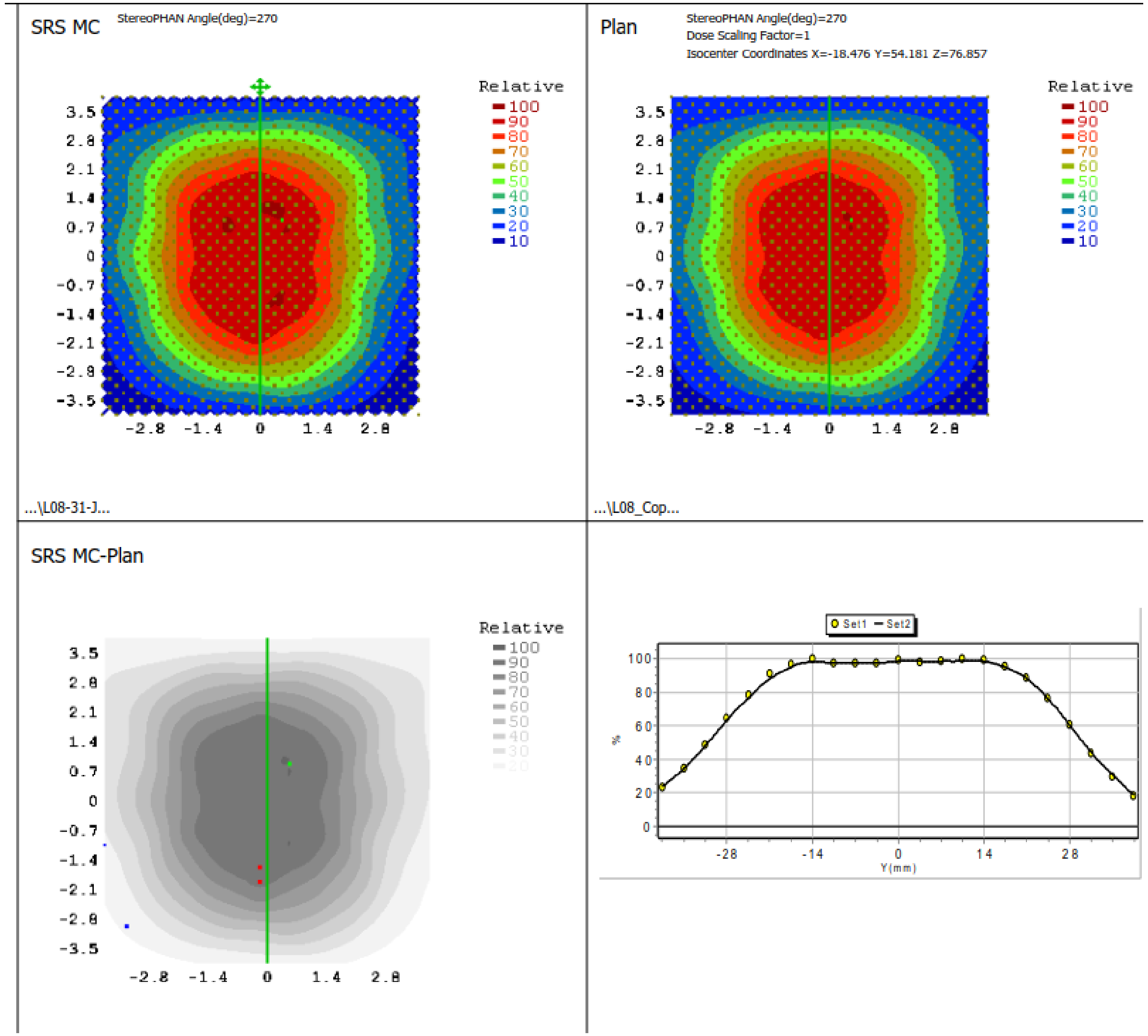


- 56 plans of different target sizes, locations and breast cup sizes measured and evaluated.

Dose Diff Metrics	A	B
Min	-2.01%	-1.59%
Max	2.20%	1.51%
Mean	0.04%	-0.02%

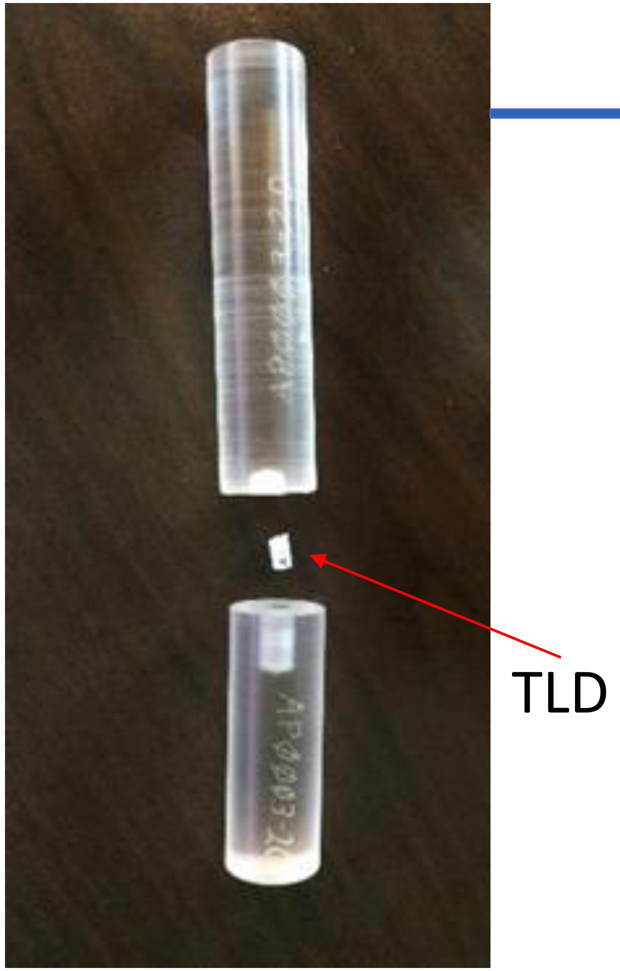
A: Monte-Carlo vs. Measurement (in water)
B. Monte-Carlo vs. TPS (in breast)

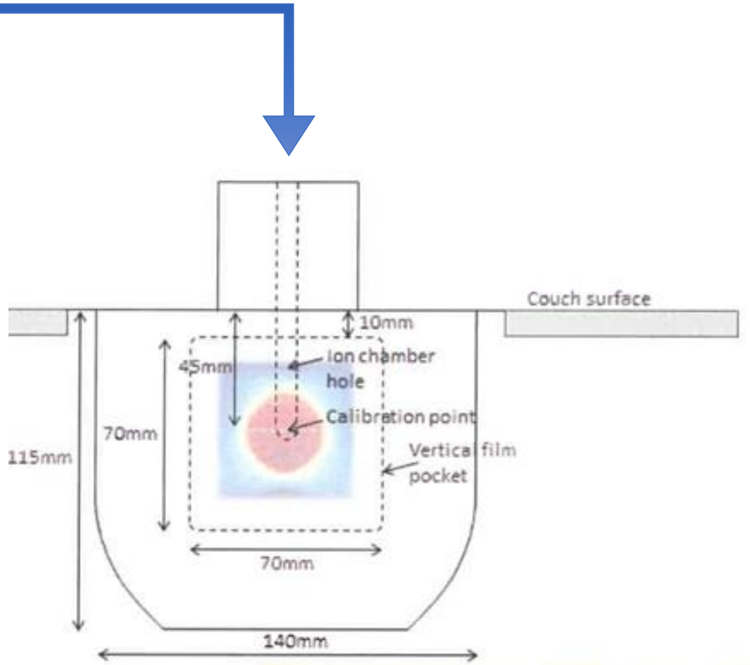
GammaPod - Commissioning at UTSW



- 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

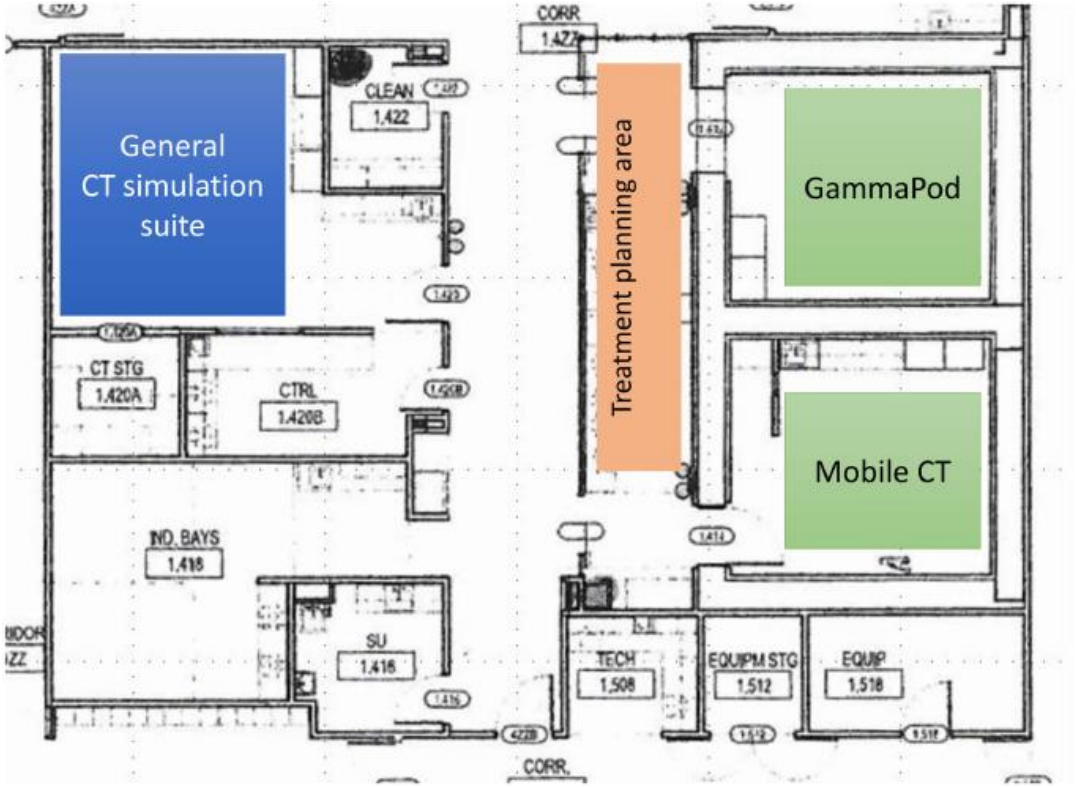




TLD jig inside PMMA slot holder for absolute dose calculation, two TLDs measured for <5% uncertainty at >90% confidence level

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

GammaPod - Operations at UTSW: clinical trials

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)*

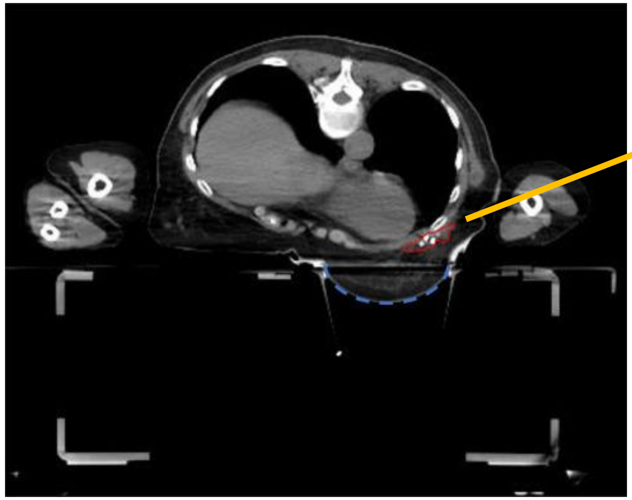
❑ currently at the 34 Gy/Fx (to CTV) dose level

Level	Dose	No. of Patients
-1*	26.5 Gy	7-15
1	30 Gy	7-15
2	34 Gy	7-15
3	38 Gy	7-15

* 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

GammaPod - Operations at UTSW: contouring

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:

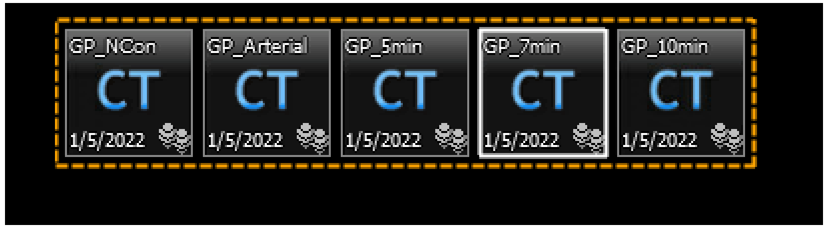
For 5x post-op --- CTV: GTV + 10 mm; PTV: CTV + 3 mm;
For 1x post-op (boost only) --- CTV: GTV + 5 mm; PTV: CTV + 3 mm.

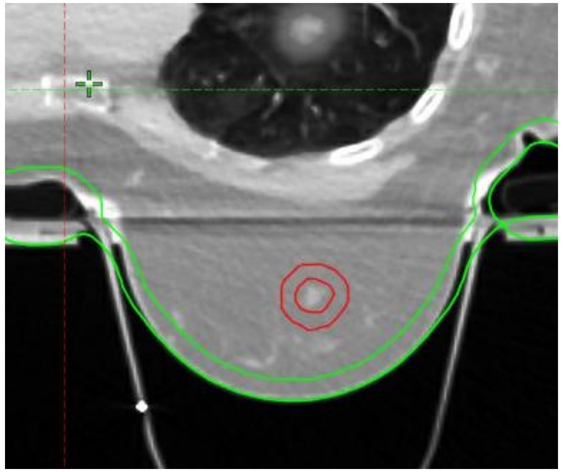
CTV 6 mm from skin surface; PTV 5 mm from skin surface; both excluding chest wall

GammaPod - Operations at UTSW: contouring

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

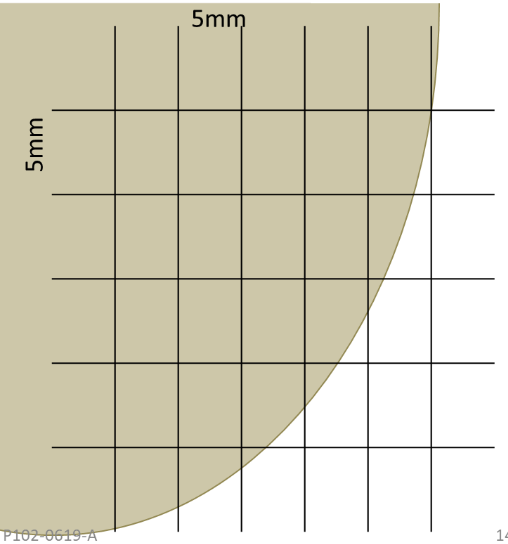
GammaPod - Operations at UTSW: treatment planning

Kernel based dose engine:

1. Monte Carlo simulation for various locations of shots for all cups.

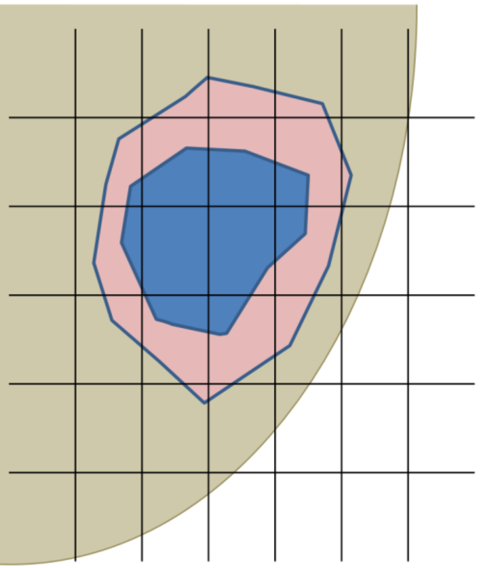
2. Kernel spacing -- 5 mm

3. Cups are cylindrical symmetric.

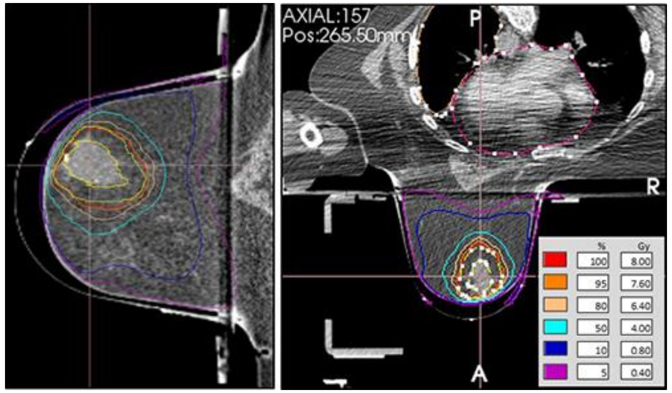


7/8/2022 P102-0619-A 14

- **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



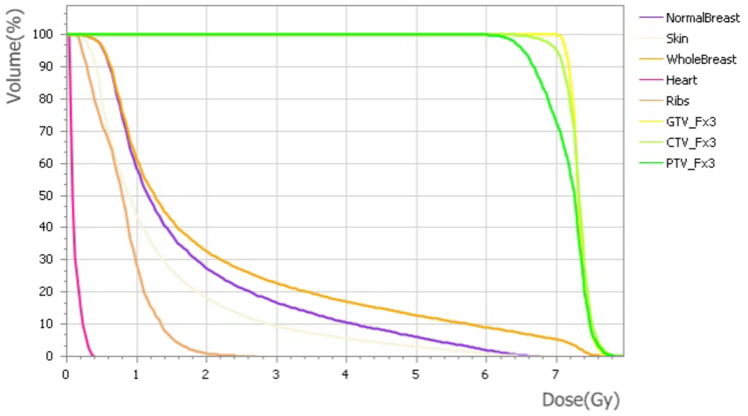
Courtesy of Xcision Medical Systems, LLC



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

- 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

GammaPod - Operations at UTSW: plan evaluation



UTSW Post-op 5Fx Protocol

UT SOUTHWESTERN MEDICAL CENTER

Dose Statistics of UTSW GammaPod Partial Breast Irradiation Treatment

Patient Name:	**Patient Name**	MRN:	**ID**	Study ID:	**1**
Fraction Dose (Gy):	**8.00**	# of Fractions:	**1**	R_x Dose:	**8.00**
Attending Rad. Onc.	**Rad Onc**	Physicists:	**physicist**	Date:	
Plan Name:					

Contouring Compliant ?	Organ	Goal	Targeted Value	Unit	Current Value	Compliant ?
Yes	Heart	$V_{5\%}$ <	50%			Yes
Yes	Skin	D_{max}<	7.9	Gy		Yes
Yes	Ipsilateral breast	$V_{50\%Rx}$ <	40%			Yes
Yes	Ipsilateral breast	V_{Rx} <	20%			Yes
Yes	Rib	D_{max}<	8.6	Gy		Yes
	Optional:(Fat Necrosis Constraint on Whole breast)	$V_{7.5Gy}$<	115.0	cc		Yes
		V_{8Gy}<	100.0	cc		Yes
		$V_{8.5Gy}$<	50.0	cc		Yes
		V_{9Gy}<	20.0	cc		Yes
		$V_{9.5Gy}$<	1.0	cc		Yes
		D_{max}<	9.6	Gy		Yes
		PTV	100	cc		Yes

Target Coverage and High Dose Spillage

Evaluation	Organ/volume	Goal	Targeted Value	Unit	Current Value	Compliant ?
Location of Max Dose Point	Irradiation volume	Max. dose point	within CTV			0.00%
percentage CTV volume receiving Rx	CTV	V_{Rx} >	95%			No
Minimum dose	CTV	$D_{99\%}$ >	90%Rx	Gy		No

UTSW Post-op Boost Protocol

UT SOUTHWESTERN MEDICAL CENTER

Dose Statistics of UTSW GammaPod Partial Breast Irradiation Treatment

Patient Name:		MRN:		Study ID:	
Fraction Dose (Gy):	8.00	# of Fractions:	1	R_x Dose:	8.00
Attending Rad. Onc.		Physicists:		Date:	
Plan Name:					

Contouring Compliant ?	Organ	Goal	Targeted Value	Unit	Current Value	Compliant ?
Yes	Skin surface	Maximum dose <	7.60	Gy		Yes
Yes	Chest Wall	Maximum dose <	8.00	Gy		Yes
Yes	Rib	Maximum dose <	6.00	Gy		Yes
Yes	Lung	Maximum dose <	6.00	Gy		Yes
Yes	Heart	Maximum dose <	6.00	Gy		Yes

Target Coverage and High Dose Spillage

Evaluation	Organ/volume	Goal	Targeted Value	Unit	Current Value	Compliant ?
Location of Max Dose Point	Irradiation volume	Max. dose point	within CTV			Yes
percentage PTV volume receiving Rx	PTV	V_{Rx} >	95%			No
Maximum dose	PTV	<	9.60	Gy		Yes
Minimum dose	PTV	>	7.60	Gy		No
Maximum dose	PTV	between	[9.6 10.4]	Gy		No
Minimum dose	PTV	between	[7.44 7.6]	Gy		Yes
Maximum dose	PTV	>	10.40	Gy		No
Minimum dose	PTV	<	7.44	Gy		Yes

GammaPod - Operations at UTSW: plan evaluation

UTSW pre-op 1Fx Protocol

UT SOUTHWESTERN MEDICAL CENTER

Dose Statistics of UTSW GammaPod Partial Breast Irradiation Treatment

Patient Name:		MRN:		Study ID:	1
Fraction Dose (Gy):	34.00	# of Fractions:	1	R_x Dose:	34.00
Attending Rad. Onc.		Physicists:		Date:	
Plan Name:	1 fx pre-op (new protocol)				

3% Rx =	
5% Rx =	
10% Rx =	
20% Rx =	
30% Rx =	
130% Rx=	

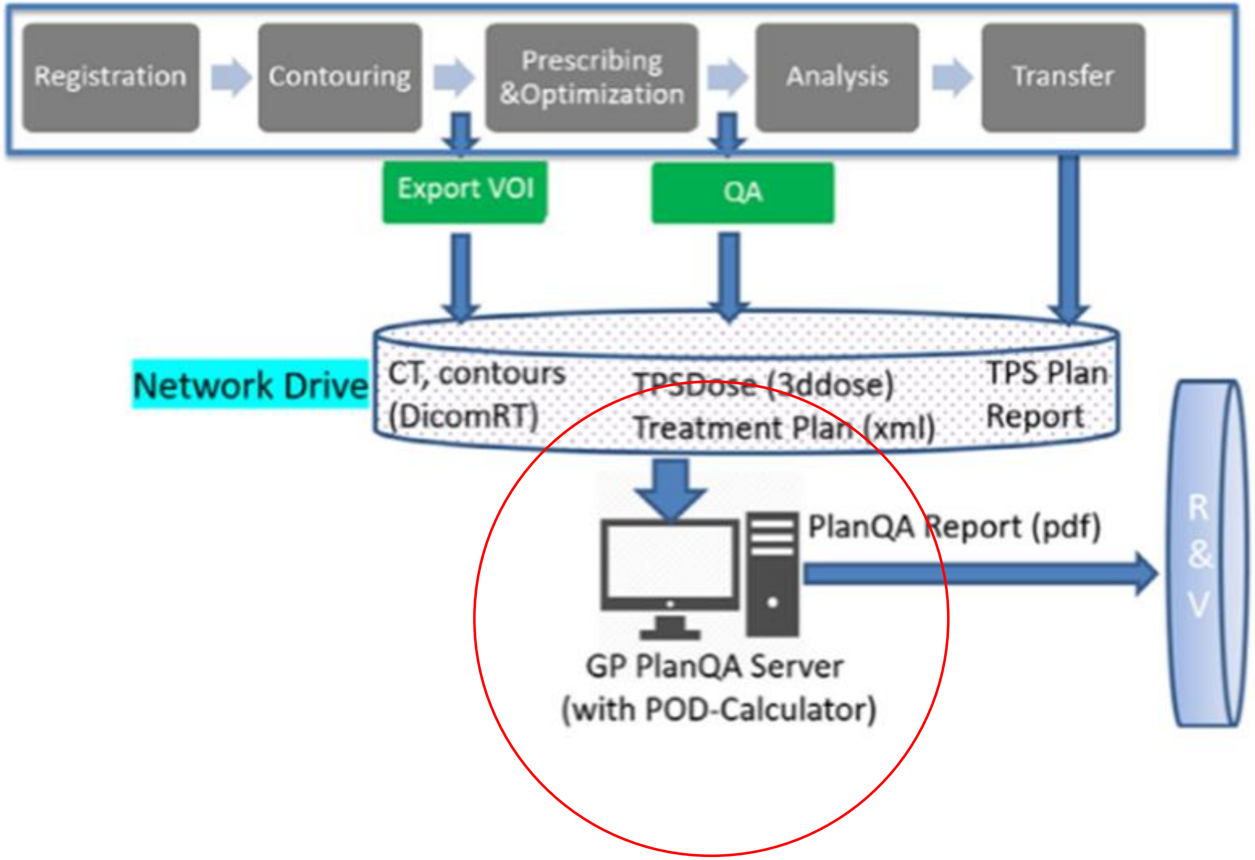
Contouring Compliant ?	Organ	Goal	Targeted Value	Unit	Current Value	Compliant ?	Comments
Yes	Skin	D_{max} <	27.50	Gy		Yes	
		D_{10cc} <	25.50	Gy		Yes	
Yes	Ipsilateral breast	$V_{50\%Rx}$ <	40%			Yes	
		V_{Rx} <	20%			Yes	
Yes	Rib	D_{max} <	33.00	Gy		Yes	
		D_{5cc} <	28.00	Gy		Yes	
Yes	Heart	D_{max} <	22.00	Gy		Yes	
		D_{15cc} <	16.00	Gy		Yes	

Target Coverage and High Dose Spillage

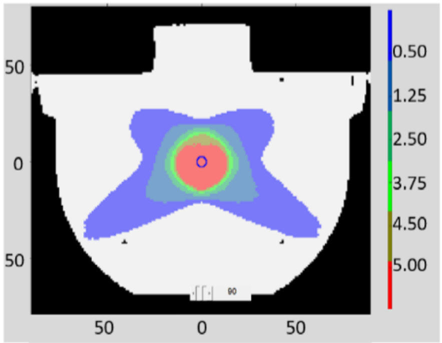
Evaluation	Organ/volume	Goal	Targeted Value	Unit	Current Value	Compliant ?	
Location of Max Dose Point	Irradiation volume	Max. dose point	within PTV			0.00%	Plan normalization
Maximum dose	PTV	<	44.20	Gy		Yes	
percentage CTV/GTV volume receiving 93%Rx	CTV/GTV=31.62Gy	$V_{93\%Rx}$ >	99%			No	The percentage CT
percentage PTV volume receiving 27 Gy	PTV=27Gy	V_{27Gy} >	95%			No	No Deviation
percentage PTV volume receiving 27 Gy	PTV=27Gy	V_{27Gy} >	90%			No	Minor deviation

GammaPod - Operations at UTSW: plan QA

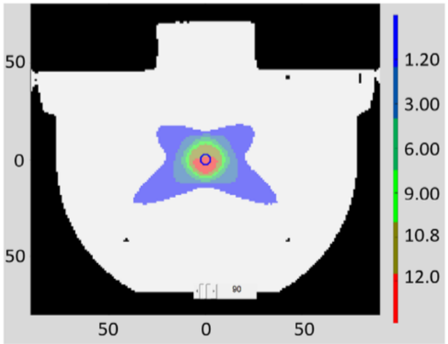
Patient-specific plan QA (for each case using Monte-Carlo based 2nd dose calculation)



- 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



MC 25 mm cone

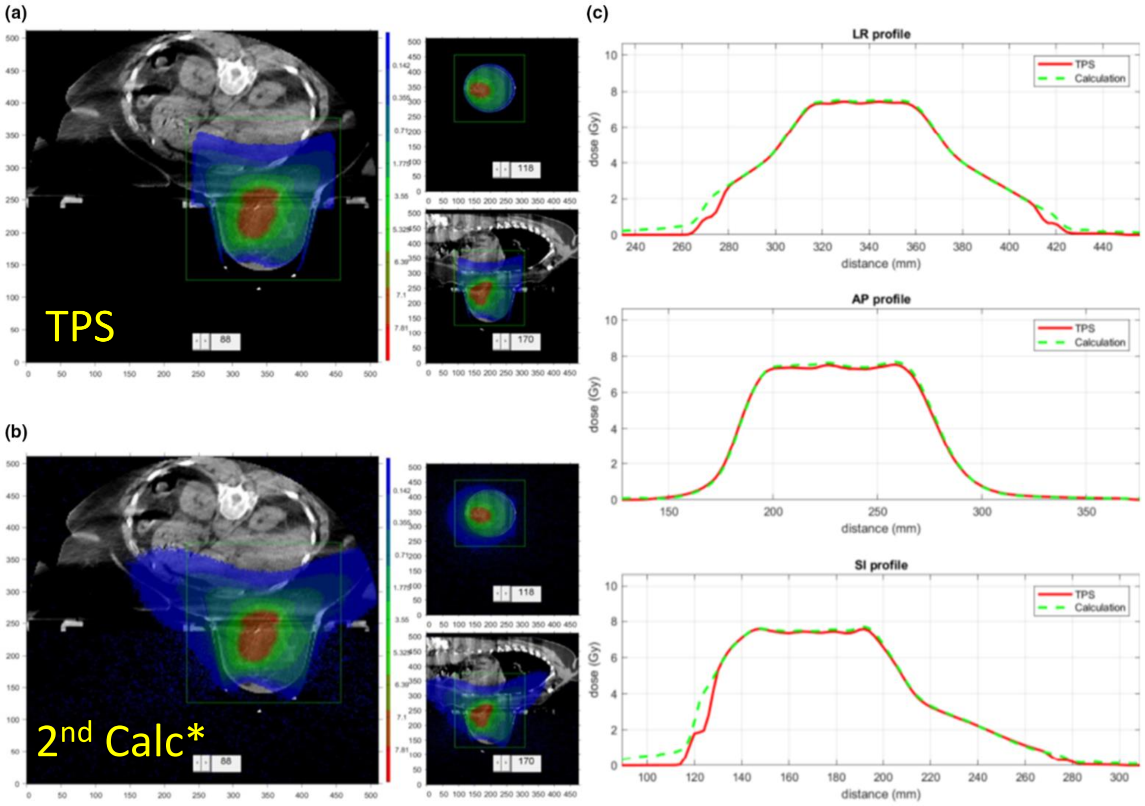


MC 15 mm cone

David Parsons et al., Medical Physics, 2020

GammaPod - Operations at UTSW: plan QA

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



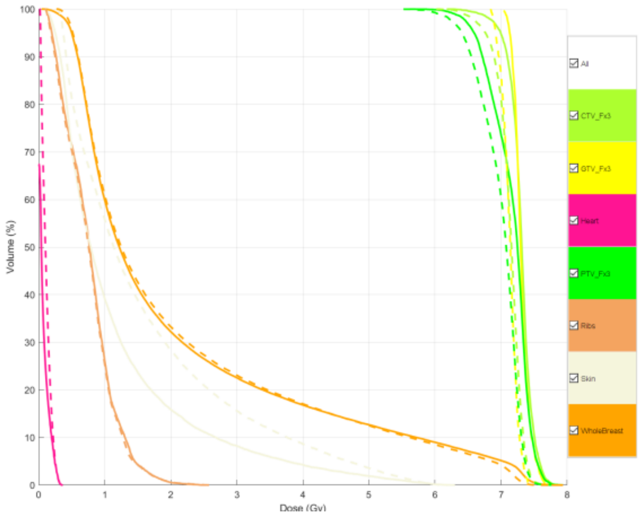


Figure 2.1. Dose Volume Histogram (solid: TPS, dashed: Calculation)

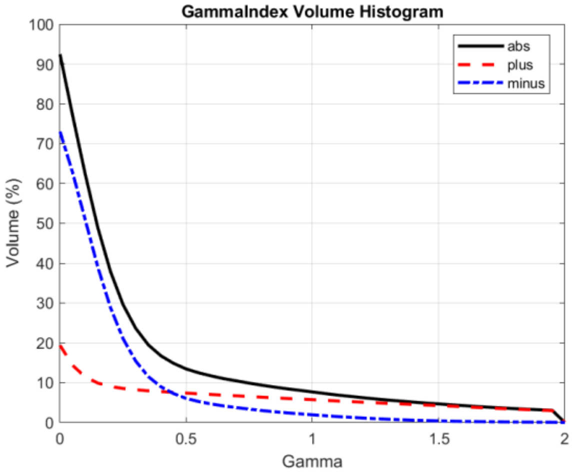


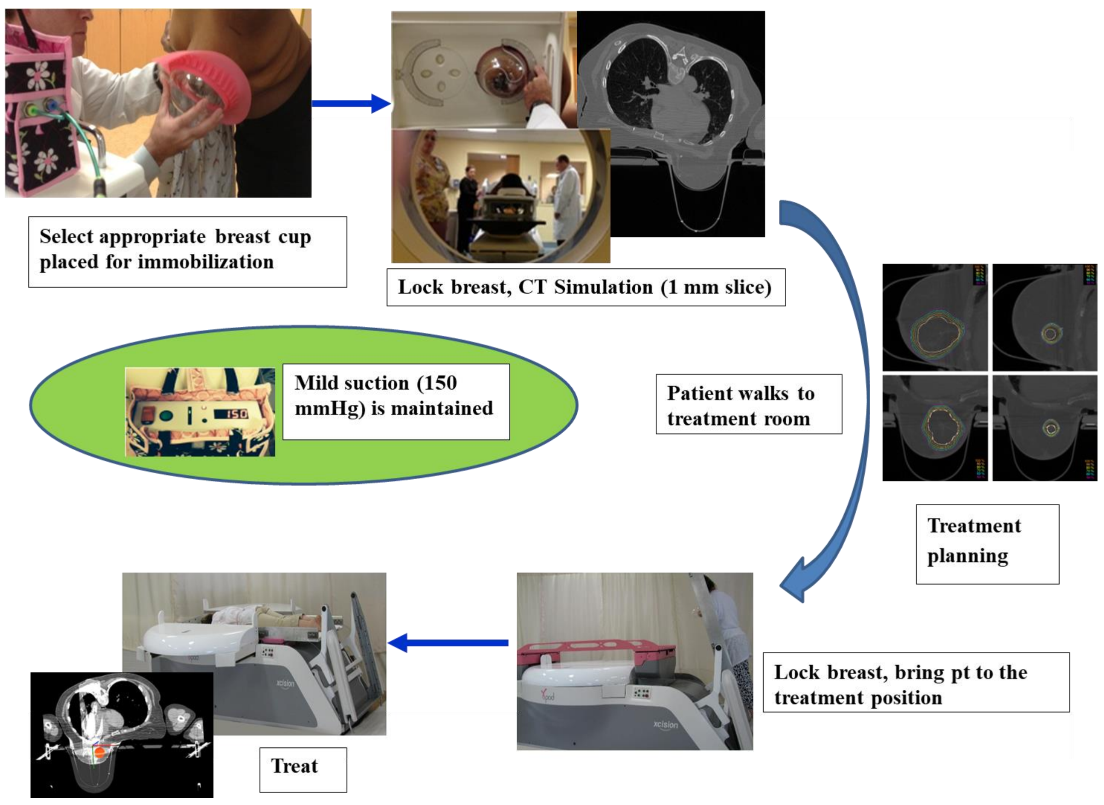
Figure 2.8. WholeBreast GammaIndex Volume Histogram (criteria:2%,2mm. GammaPass=94.1858%)

*GPU-based, ~ 3 min

David Parsons et al., Medical Physics, 2020

GammaPod - Operations at UTSW: delivery summary

Overall workflow revisit



Courtesy of Xcision Medical Systems, LLC

	Time, min				
Procedure	Minimum	Maximum	Mean	SD	Median
Cup fitting	5	110	22	17	17
CT scan	3	90	14	10	10
Planning	20	125	55	18	53
Treatment delivery	10	70	33	9	32
Total	75	226	124	27	120

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

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

Elizabeth Zhang-Velten et al., Prac. Rad. Onc., 2022

GammaPod - Summary

The GammaPod system:

- uses unique system design for highly-focused breast SBRT;
- maintains breast immobilization through a Vaccum 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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