# Feasibility of Soft Robot Assisted 4π Supine Breast Radiotherapy

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## Purpose

- We recently developed a novel soft robot (BreastBot) device for breast radiotherapy.
- BreastBot shows the potential to create the "prone geometry" in the supine patient position (setup position) by supporting and immobilizing the breast via inflated air chambers.
- In this study, we aim to determine the dosimetric benefit of treating the patient in the setup position vs. standard prone position.

## Methods

**Collision Maps**

The collision-free beam angles for the simulated BreastBot supine position and the prone position, respectively, were determined based on the patient and machine CAD model. The prone geometry with supine patient position created by BreastBot was simulated by rotating the prone setup breast patient CT.

**Treatment Planning**

Two 4π treatment plans, each with 20 non-coplanar beams selected from the collision-free beams, were created for setup position and prone position, respectively. The non-coplanar beam selection and fluence map optimization problem was formulated as a group sparsity problem that can be solved using a Fast Iterative Shrinkage Thresholding Algorithm (FISTA).
Problem formulation:

$$\underset{x}{argmin} \quad \frac{1}{2}\|(Ax-d)\|_2^2 + \gamma\|Dx\|_1^{(\mu)} + \sum_{b=1}^{B}\omega_b\|x_b\|_2 \qquad \textit{Subject to } x \geq 0$$

$A$: dose-calculation matrix for the planning target volume
B: number of candidate beams
$d$: dose to PTV and OARs
$x_b$: the vector of beamlet intensities for beam $b$
$x$: the concatenation of the vector $x_b$
$Dx$: a list of intensity differences between adjacent beamlets
$\gamma\|Dx\|_1^{(\mu)}$: smoothness
$\sum_{b=1}^{B}\omega_b\|x_b\|_2$: group sparsity

**Dosimetry Comparison**

Twenty partial breast patients initially simulated in the prone position were included in the study. Wilcoxon signed-rank tests were conducted on the maximum and mean doses of all OARs and PTV between the setup position and prone position. The study includes the following OARs: left lung, heart, and normal ipsilateral breast tissue excluding the PTV.

## Results

- Figure 1 shows the BreastBot, a soft robot with air chambers as actuator for supporting the soft tissue organ breast without interfering with the dosimetry.
- Figure 2 shows repeatability when BreastBot is applied to a deformable breast phantom.
- Figure 3 and Figure 4 shows the 196 and 351 collision-free candidate beams for one patient in the prone and simulated setup positions, respectively.
- Figure 5 and Figure 6 show the DVH and isodose colorwash for the simulated supine setup and prone position plans for a representative patient. Table 1 shows PTV and OARs dose statistics. Statistical analysis showed a significant ($p<0.05$) improvement in PTV dose conformity, $R_{50}$, $D_{95}$, $D_{98}$, and $D_{99}$ in the simulated supine setup. The PTV homogeneity for the plans in both positions were comparable, while the integral dose, maximum dose and mean dose delivered to left lung, heart, and normal breast tissue in the treated breast were significantly reduced in the simulated supine BreastBot plans compared with the standard prone position.

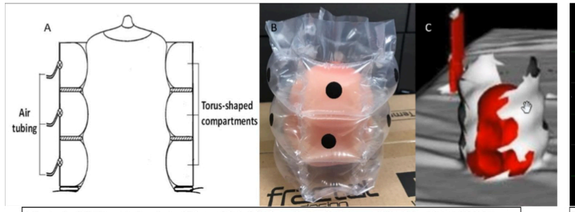

Figure 1: (A) The mechanism of BreastBot. (B) Breast phantom immobilized by BreastBot. The black dots are for optical tracking (C) The soft robot 3D surface captured using 3D camera and the breast phantom surface generated from CT.

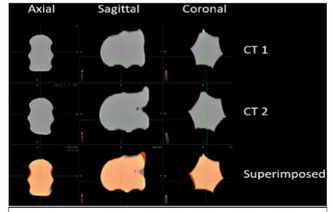

Figure 2: Two repeated application of BreastBot and CT images.

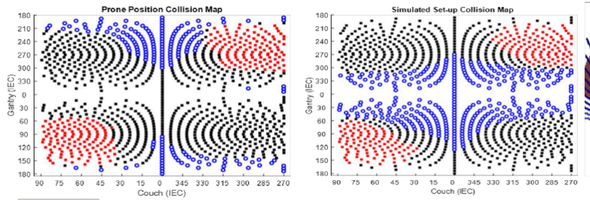

Figure 3: Beam collision maps of prone plan and simulated setup plan.

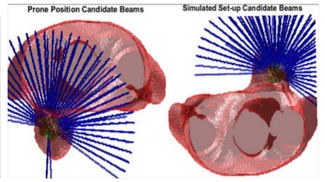

Figure 4: Candidate beams of prone plan and simulated setup plan.

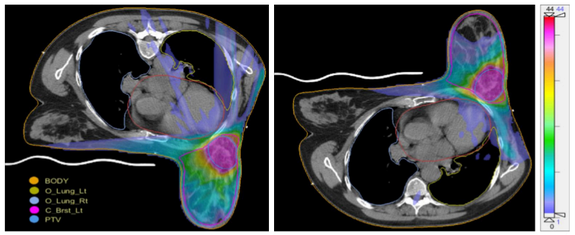

Figure 6: Isodose colorwash, (A) simulated set-up position plan, (B) prone position plan.

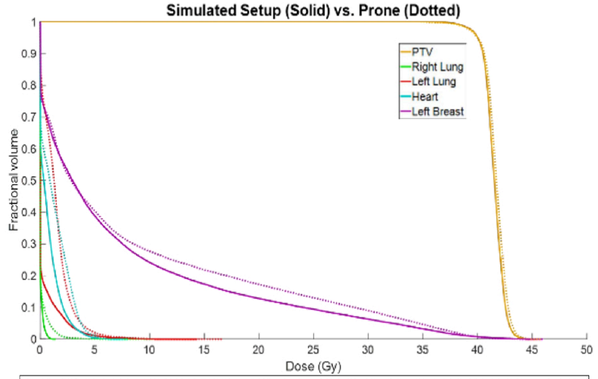

Figure 5: Dose volume histogram (DVH) comparison, prone position (solid), simulated set-up position (dotted)

| Statistics | p- value | Mean | | STD | |
|---|---|---|---|---|---|
| | | Prone | Simulation | Prone | Simulation |
| PTV Homogeneity | 0.25 | 0.94 | 0.94 | 0.01 | 0.01 |
| PTV Conformity | 6.17E-05 | 0.63 | 0.66 | 0.04 | 0.03 |
| $R_{50}$ | 4.78E-05 | 2.25 | 1.70 | 0.45 | 0.16 |
| Integral Dose (Gy*L) | 4.78E-05 | 26.60 | 19.90 | 11.16 | 7.72 |
| $D_{95}$ (Gy) | 6.97E-05 | 38.87 | 39.03 | 0.35 | 0.28 |
| $D_{98}$ (Gy) | 8.74E-05 | 38.24 | 38.46 | 0.53 | 0.45 |
| $D_{99}$ (Gy) | 5.55E-05 | 37.77 | 38.01 | 0.66 | 0.56 |
| $D_2$ (Gy) | 0.302 | 41.78 | 41.76 | 0.16 | 0.18 |
| Left Lung $D_{max}$ (Gy) | 5.58E-05 | 3.59 | 2.77 | 2.76 | 2.53 |
| Left Lung $D_{mean}$ (Gy) | 4.78E-05 | 0.76 | 0.45 | 0.72 | 0.51 |
| Heart $D_{max}$ (Gy) | 4.78E-05 | 3.15 | 2.28 | 2.28 | 1.81 |
| Heart $D_{mean}$ (Gy) | 4.78E-05 | 0.63 | 0.49 | 0.59 | 0.48 |
| Left Breast $D_{max}$ (Gy) | 6.5E-05 | 33.41 | 32.18 | 3.50 | 3.68 |
| Left Breast $D_{mean}$ (Gy) | 3.18E-04 | 7.05 | 6.56 | 2.22 | 2.18 |

Table 1. Wilcoxon signed-rank test of prone plans and simulated setup plans for the PTV and OAR statistics in 4π 20-beam plans.

## Conclusions

Significantly improved OAR sparing and partial breast target dosimetry were observed in the prone geometry in the supine position using the BreastBot compared with the standard prone position.