Toward Tattooless/Markerless SGRT for Multiple Treatment Sites

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SGRT Meeting, May 12, 2023

MSK Commitment to SGRT

AlignRT-equipped TrueBeam or Ethos Systems account for 88%

1). 26 AlignRT Advanced systems

2). 2 AlignRT inBore systems

3). Uniform clinical procedures in 8 clinical centers

4). Started tattooless SGRT since 2022

SGRT physics team and RTT champion team

A. Bi-weekly clinical research meeting for future SGRT development

B. Bi-weekly clinical meeting to cover clinical SGRT issues

C. Worked closely with RTT team and chiefs and provided in-services, etc.

D. Worked closely with VRT to handle new client-server issues

One-weekend system upgrade, and data backup, user feedback, etc.

OUTLINE

- Background of Tattooless SGRT
  - Patients' demand: prefer no tattoos for cancer treatment
  - Availability of commercial Optical Surface Imaging (OSI)
- Tattooless SGRT at different disease sites
  - Accelerated partial breast irradiation (APBI) for early-stage cancer
  - VMAT treatment for locally-advanced breast cancer
  - Hypo-fractional SRS and SRT for Brain cancer
- Remaining challenges ahead
  - Site-specific studies before clinical implementation
  - Beyond superficial to infer internal organ motion

BACKGROUND

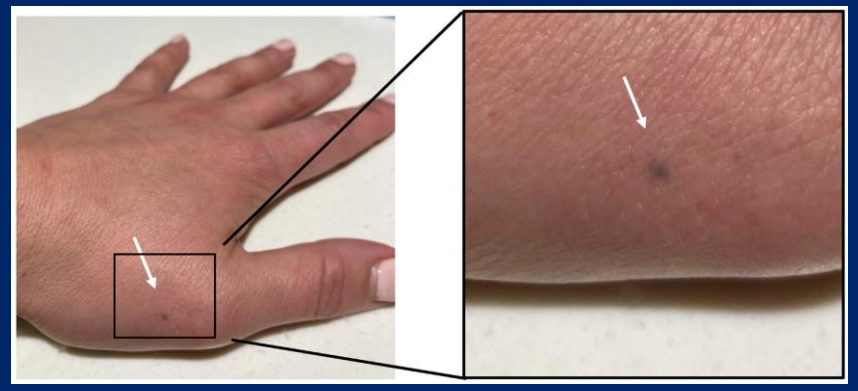
Patients' demands for tattooless with various reasons:

1). A permanent reminder of a cancer diagnosis

2). Worry tattoos being seen and try to cover

3). Not comfortable at beach or gym

4). Culture and religious reasons



Availability of commercial OSI systems

A. AlignRT Advanced system from VisionRT

- The best system available

B. Catalyst+ HD from C-RAD

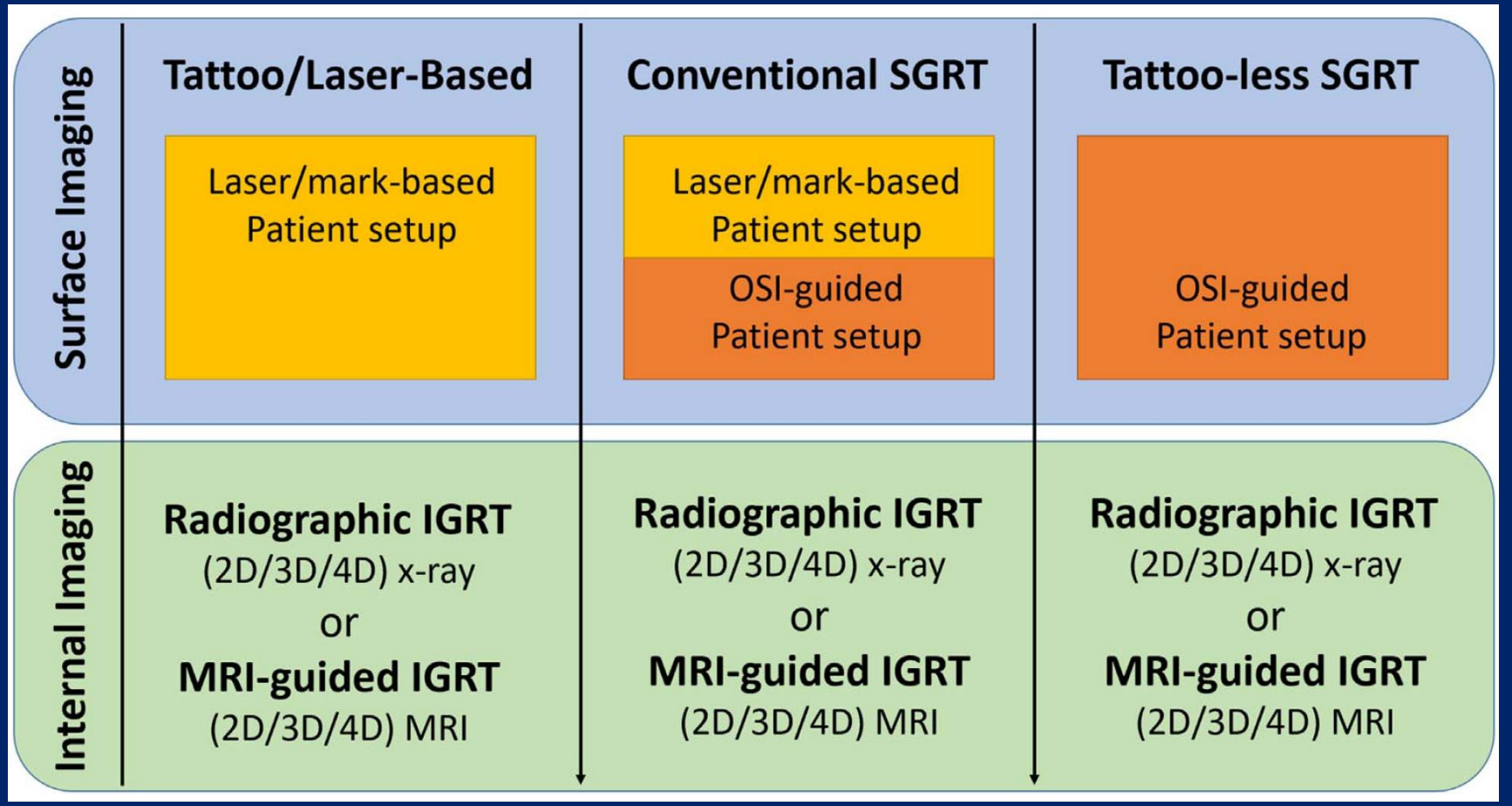
C. IDENTIFY system from Varian

- Li G, Advances and potentials of optical surface imaging in radiotherapy, *Phys Med Biol*, **2022**, 67, 1-22.

SGRT – Surface-guided Radiotherapy

- Tattoo-laser-based
- Conventional SGRT
- Tattooless SGRT

- **SGRT ≠ IGRT**
  (for IGRT & SBRT X-ray imaging is still required)



- Li G. **2022**, Advances and potentials of optical surface imaging in radiotherapy. *Phys Med Biol*. **67**(16TR02):1-22.

SGRT Patient Setup

Conventional tattoo-laser-based patient setup – A vital procedure

- Established since the beginning of radiotherapy
- Successfully implemented in radiotherapy for decades
- Patient setup affects clinical workflow: simulation, planning, and treatment

Tattoo-less SGRT patient setup – An emerging new vital procedure

We proceed with tattooless SGRT cautiously with IGRT confirmation

1). Simulation: No permanent skin markers, but IGRT markers

2). Planning: BBs' may still be needed to determine the ISO

Setup instruction and a backup strategy (native anatomic landmarks)

3). Treatment: SGRT patient setup and motion monitoring

IGRT to confirm and finalize the setup with light field for bolus placement.

Tattooless SGRT Studies – APBI (Early Stage)

Accelerated partial breast irradiation (APBI)

Ground Truth: 2DkV on surgical clips or CTOR on surgical cavity

1. MGH group (R Jimenez, et al), 2019, JACMP, 2DkV

   20 patients in 2 groups: SGRT system error = (2.3, 0.5, 1.4)mm & random error=0.7mm

   Tattoo system error = (1.4, 0.3, 0.8)mm & random error=1.5mm

2. Utah group (H Zhao, et al), 2019, Med Phys, CTOR

   12 patients test consecutively: Conv→SGRT→CTOR: mean vector shift:4.6mm SGRT and 5.9mm tattoo

   But, 9/12 patients: >5mm and 2/12 patients: >10mm

3. MSK group (B Mueller, et al), 2023, ARO, 2DkV

   43 patients (356 fractions) in alternate fractions between tattoo (174) and SGRT (182) setups

   SGRT mean |error| = (3.1, 2.3, 2.6)mm and Tattoo mean |error| = (3.4, 3.1, 3.4)mm

   SGRT variance is smaller, comparing with conventional setup.

Tattooless Studies – APBI (MSK Study)

- Mueller B, Song Y, et al. “Accuracy and Efficiency of Patient Setup Using Surface Imaging versus Skin Tattoos for Accelerated Partial Breast Irradiation”. Adv Radiat Oncol. 2023;8(3):101183.

Two cohorts of same patients:

- Tattoo-based in odd fx
- SGRT setup in even fx

So, more direct comparison.

Table 1 Comparison of translational shifts and timing between tattoo-based and AlignRT-based setup techniques

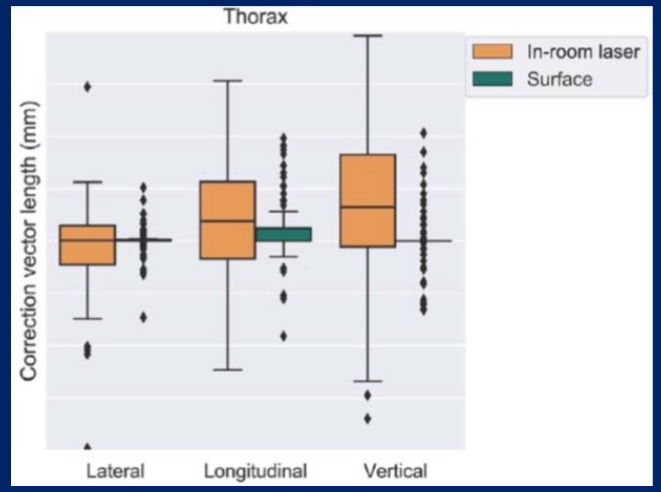
	Tattoo (N = 43, f = 174)	AlignRT (N = 43, f = 182)	Difference (N = 43)	*P* value
Average in-room time (min)				.005
Mean (SD)	17.32 (4.02)	15.62 (3.32)	−1.69 (3.45)	
Median (Ql, Q3)	17.25 (14.73, 19.67)	15.42 (13.17, 17.50)	−1.08 (−3.92, 0.58)	
Min-max	9.50-26.00	9.80-22.55	−8.67 to 5.50	
Average setup time (min)				<.001
Mean (SD)	13.46 (4.02)	11.50 (3.58)	−1.96 (3.55)	
Median (Ql, Q3)	13.00 (10.66, 15.56)	11.12 (8.98, 13.89)	−2.01 (−4.50, −0.17)	
Min-max	5.66-21.60	5.58-19.95	−9.42 to 5.61	
Absolute vertical axis shift (cm)				.154
Mean (SD)	0.44 (0.35)	0.34 (0.19)	−0.10 (0.33)	
Median (Ql, Q3)	0.34 (0.23, 0.53)	0.31 (0.20, 0.44)	−0.02 (−0.21, 0.08)	
Min-max	0.05-1.98	0.08-0.82	−1.35 to 0.36	
Absolute lateral axis shift (cm)				.059
Mean (SD)	0.39 (0.31)	0.29 (0.18)	−0.10 (0.36)	
Median (Ql, Q3)	0.31 (0.23, 0.48)	0.23 (0.16, 0.42)	−0.06 (−0.21, 0.08)	
Min-max	0.09-1.84	0.05-0.86	−1.71 to 0.59	
Absolute longitudinal axis shift (cm)				.021
Mean (SD)	0.40 (0.25)	0.28 (0.16)	−0.13 (0.32)	
Median (Ql, Q3)	0.34 (0.22, 0.52)	0.26 (0.16, 0.36)	−0.09 (−0.28, 0.03)	
Min-max	0.08-1.25	0.02-0.72	−1.16 to 0.38	
Magnitude shift (cm)				<.001
Mean (SD)	0.86 (0.39)	0.62 (0.23)	−0.23 (0.41)	
Median (Ql, Q3)	0.80 (0.59, 1.01)	0.59 (0.45, 0.75)	−0.20 (−0.34, −0.02)	
Min-max	0.27-2.13	0.30-1.31	−1.49 to 0.40	

Tattooless SGRT Studies – Breast VMAT

Volumetric-Modulated Arc Therapy (VMAT) – advanced patients

Ground Truth: 2DkV on the anterior bony landmarks

1. Haraldsson A, et al. JACMP, 2020 & Carl G et al 2018 TCRT 2018



All Values in mm	Mean Value	95% CI	SD	Range
Thorax				
Catalyst lat.	−0.13	[−0.55; 0.30]	±4.67	−18.1; 15.3
Laser lat.	−0.21	[−0.58; 0.16]	±4.06	−18.7; 15.1
Catalyst long.	−1.14	[−1.57; −0.71]	±4.66	−15.6; 16.8
Laser long.	−0.65	[−0.98; −0.31]	±3.65	−11.2; 12.6
Catalyst vert.	−0.01	[−0.44; 0.41]	±4.64	−18.9; 14.0
Laser vert.	0.22	[−0.16; 0.61]	±4.18	−19.7; 14.1

2. A UK group (J Rigley and L Scattergood), 2020, Radiography

3. MSK group (B. Mueller, Y Song, et al), 2023, ARO

Mueller B, Song Y, Chia-Ko W, et al. Accuracy and Efficiency of Patient Setup Using Surface Imaging versus Skin Tattoos for Accelerated Partial Breast Irradiation. Adv Radiat Oncol. 2023;8(3):101183.

Tattooless Approach at MSK

Tattooless SGRT changes in Simulation, Planning, and Treatment

Simulation

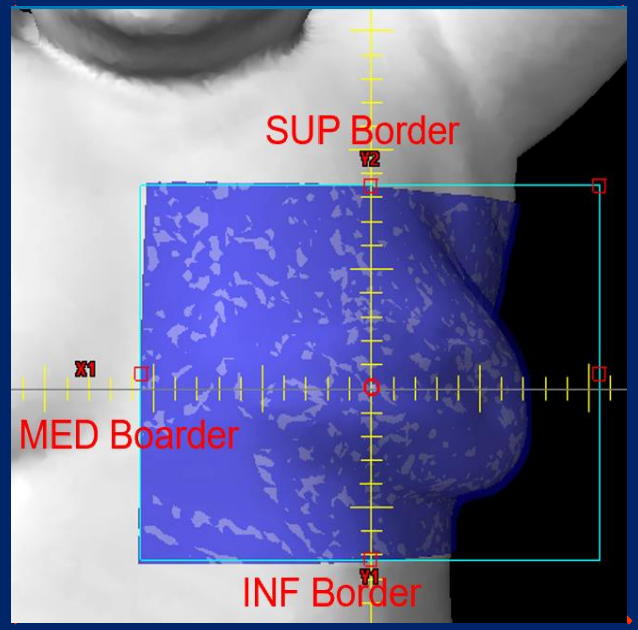
~~4 tattoos~~

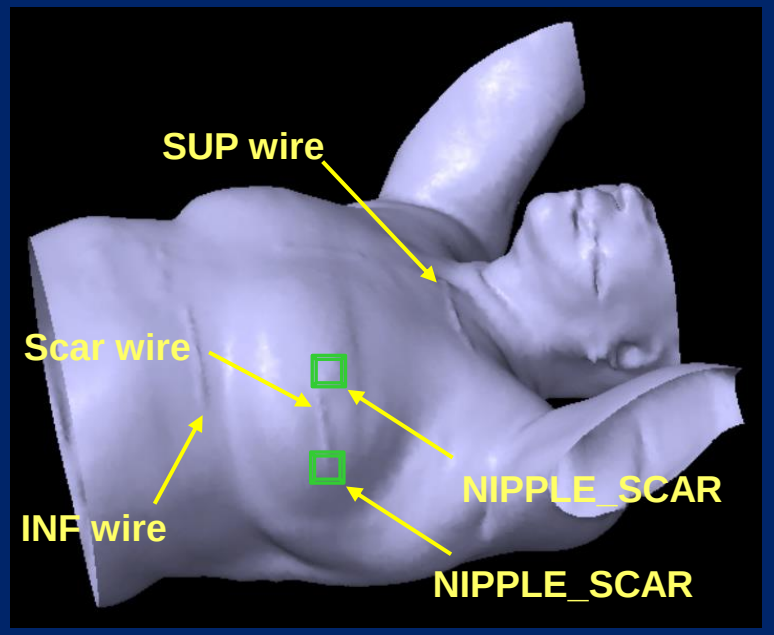
- 3 wires
- backup

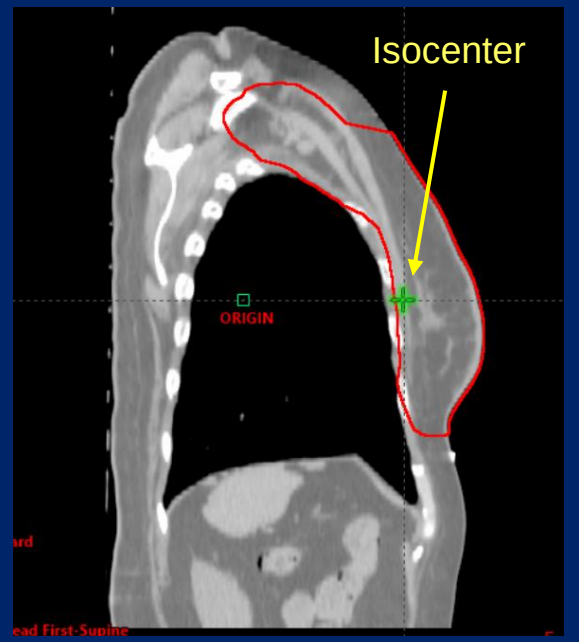
Planning

- AlignRT

Treatment







- Straight out the patient at the setup, then AlignRT, and 2DkV verification
- Bolus placement: use the light fields to define the edges
- Backup method: nipple or lateral end of the scar as landmarks

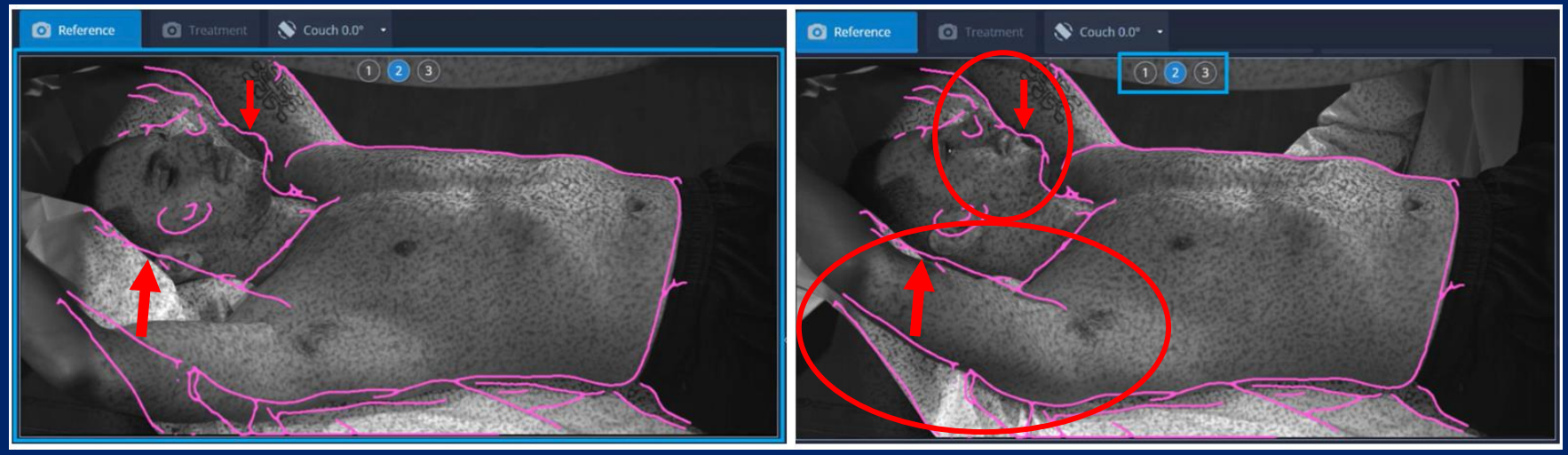
SGRT Advantages: 2-Step Setup at Free Breathing

First to align the arm/chin *with large FOV, then breast ROI*

Different arm positions from SIM may cause

1. breast deformation
2. location changes of the local lymph nodes

AlignRT postural video: To view DICOM outlines and on-site surface to guide patient arm/chin adjustment in real time.



- Li G, **2022**, Advances and potentials of optical surface imaging in radiotherapy, *Phys Med Biol*, **67**, 1-22.

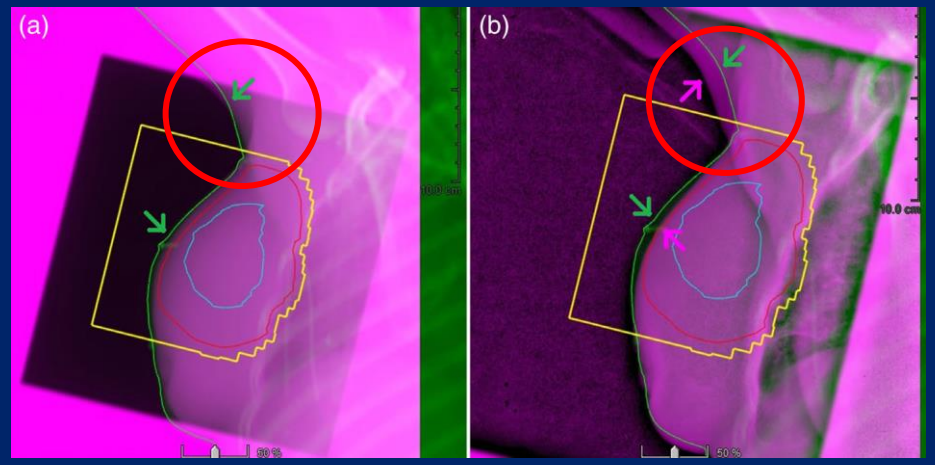
2-Step SGRT Setup for Better Reproducibility

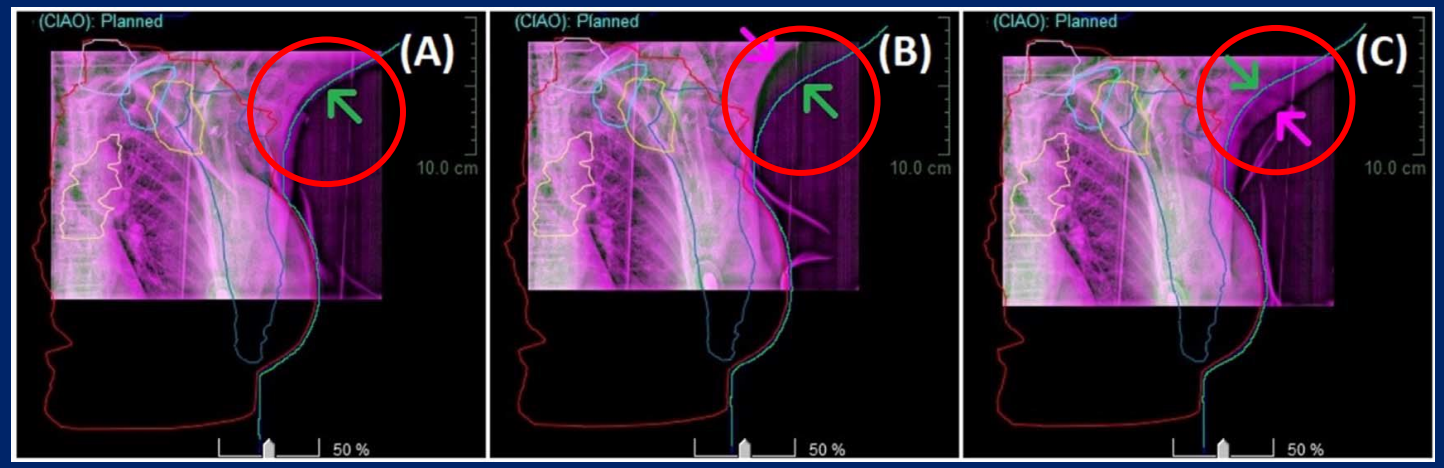
OSI has the largest FOV, allowing to align the arm/chin

- Reproduce of the breast shape – minimizing deformation
- Reproduce the position of local lymph nodes.

Potential clinical problems without aligning the arm/chin first

1. breast deformation
2. location changes of the local lymph nodes





Li G, Lu W, O'Grady K, et al. **2022**, A uniform and versatile surface-guided radiotherapy procedure and workflow for high-quality breast deep-inspiration breath-hold treatment in a multi-center institution. *J Appl Clin Med Phys*.**23**(3):e13511.

WARNING: Chest-only ROI May NOT Work for DIBH

Chest-only ROI is good for 85% breast patients with T-DIBH

- ~15% patients are abdominal-driven A-DIBH with VCE≤5mm

  Therefore, the default chest-only ROI does not work.

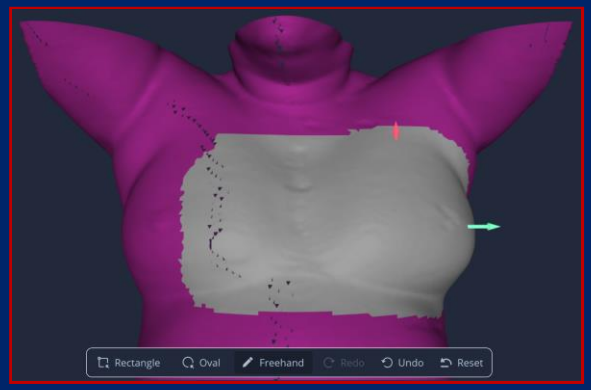
  • Another study shows 27% patients have A-DIBH

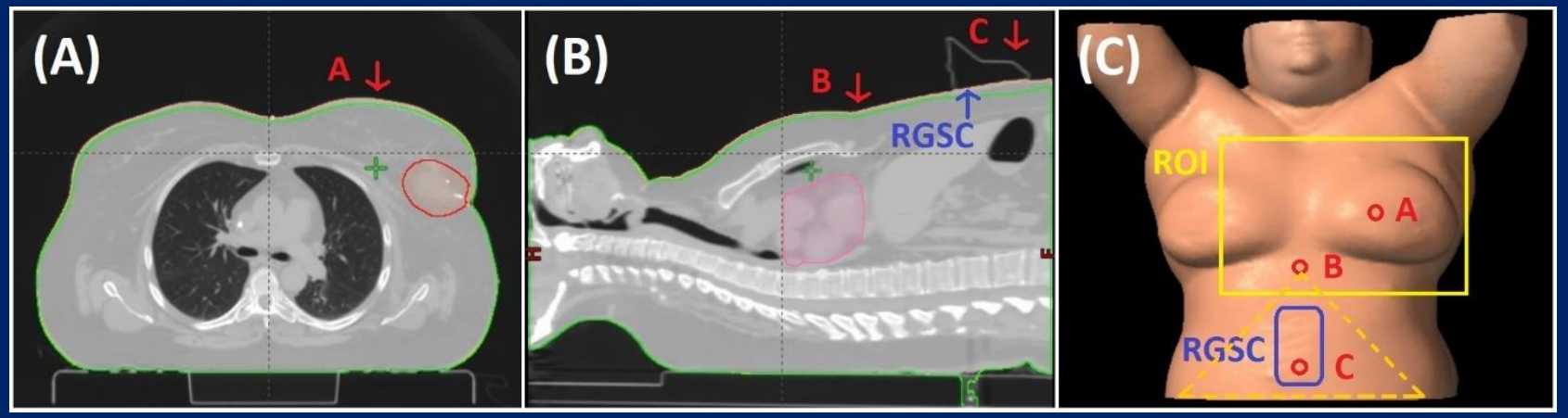
  - Zhao et al, Radio Onc, 2018

- Need a new ROI to accurately monitor A-DIBH for heart sparing.

  • Add new Abd. ROI

  • Use RPM at Abd.



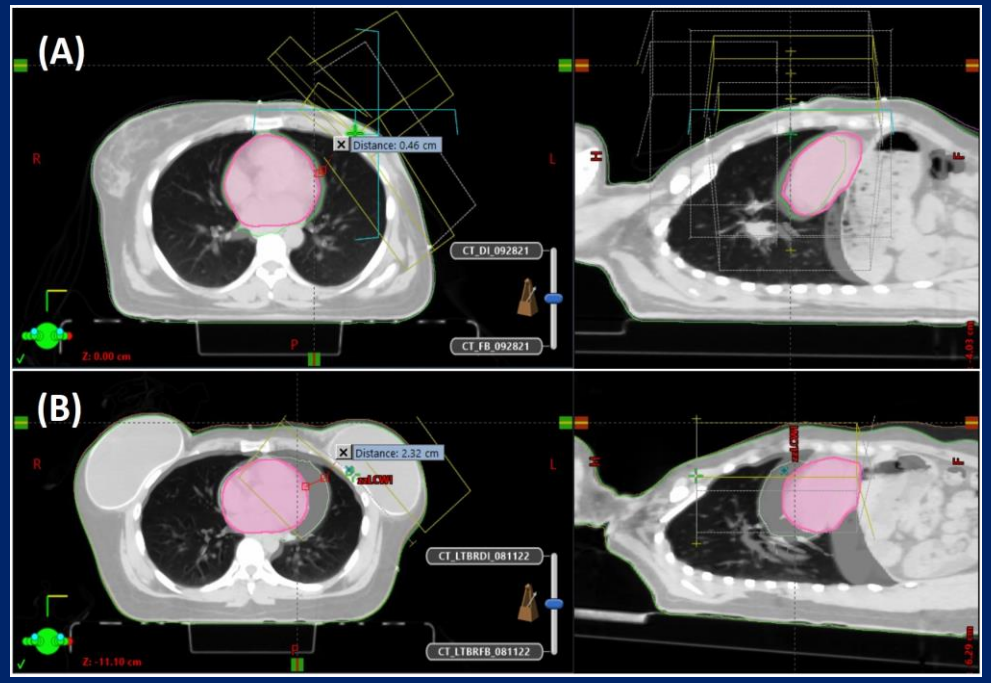


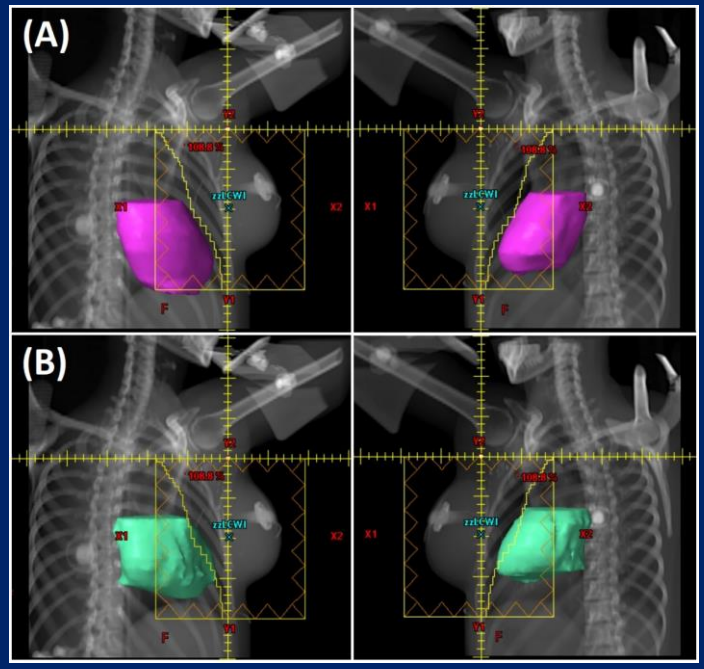
- C. Zeng, Q. Fan, et al, *Adv Rad Onc* **2023** (under review with minor revision)

WARNING: Accurate Monitoring A-DIBH for Heart-Sparing

Abdominal-driven DIBH (A-DIBH) can have lower heart dose

- Two studies: A-DIBH spares heart more than T-DIBH: But only 15% patients
- One study: 20 out of 120 patients could NOT differentiate A-DIBH and T-DIBH





Preserve Patients' Native Breathing Behavior for better reproducibility

- C. Zeng, Q. Fan, et al, *Adv Rad Onc* **2023** (under review with minor revision)

SURROGATE: A Better ROI for Abdomen DIBH Treatment

Use an appropriate ROI to infer and reproduce diaphragm position

1. Chest elevation → AP motion
2. Abdomen rise → Diaphragm motion
   → SI motion

- ROI-1 & ROI-2: One rectangle shape
- ROI-3 & ROI-4: 2x triangles on the ribs
- ROI-5 & ROI-6: The central triangle

- ROI definition is critical for what you can get from SGRT setup.

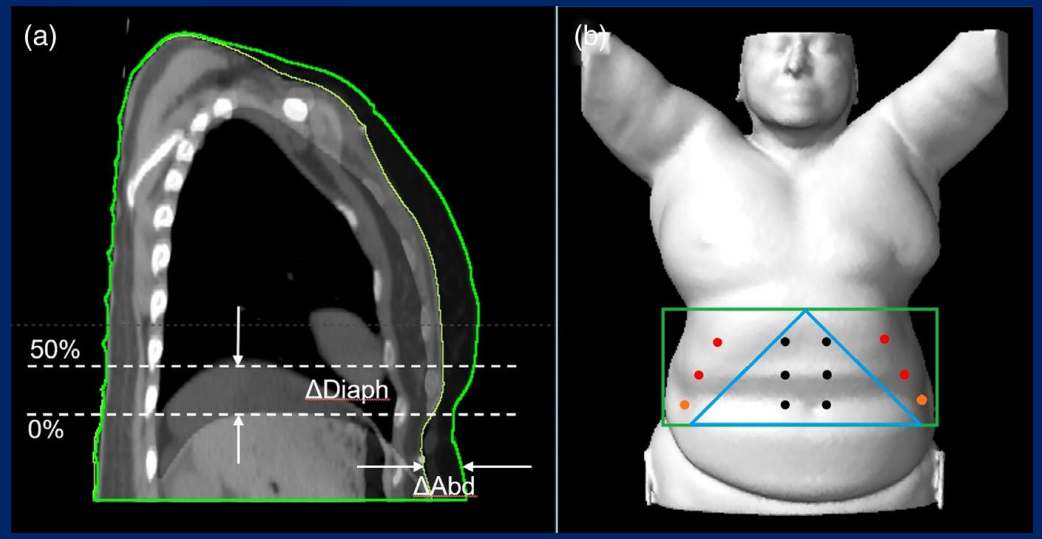


TABLE 1 Six regions of interest (ROIs) and their composition of points of interest (POIs), shape, and correlation with the diaphragmatic motion

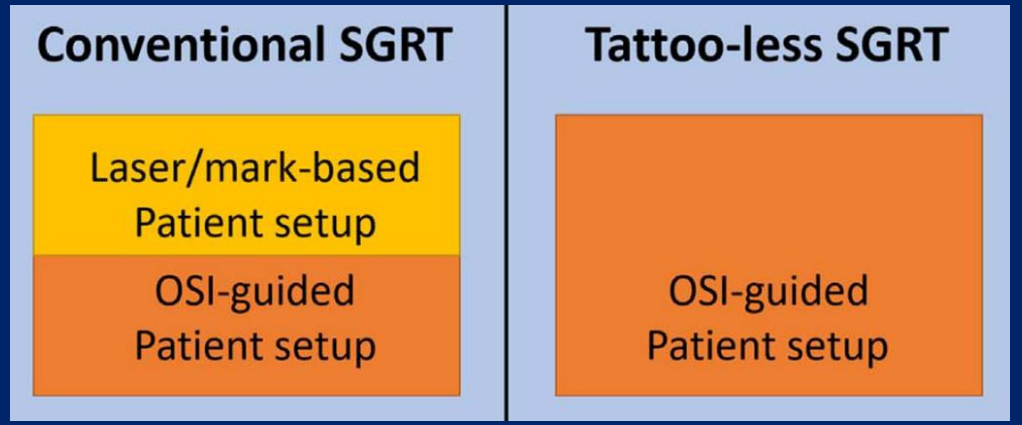
ROI	Number of POIs			Simplified topographic shape	Surrogate of diaphragm		
	Total	Central	Lateral		Correlation	Slope	R^2
ROI-1	12	6	6	□	0.61	0.18	0.37
ROI-2	8	4 (inferior)	4 (inferior)	□	*0.67*	0.24	0.45
ROI-3	6	0	6	∇∇	0.50	0.13	0.25
ROI-4	4	0	4 (superior)	∇∇	0.28	0.06	0.08
ROI-5	8	6	2 (inferior)	Δ	*0.64*	0.24	0.41
ROI-6	10	6	4 (inferior)	⌓	*0.63*	0.20	0.40

- Y. Song, W Lu, et al, **2022** *J Appl Clin Med Phys*, doi.org/10.1002/acm2.13748

Markerless SGRT for Brain SRS/SRT

Brain SRS/SRT SGRT setup, using marker-based setup as backup

1. Direct SGRT for initial setup
2. Use marker as a backup
3. No change in other workflow
4. SGRT setup within 30 seconds



New marker-less SGRT setup procedure

1. Use the nose and tragus to align the head, putting ISO inside the brain
2. Use AlignRT postural video to provide visual guidance and then shifts.
3. Minimize head rotation by adjusting the patient (~1˚ in pitch/roll/yaw).
4. Apply the mask to patient with care for rotation changes.
5. Correct translational couch shifts (<1mm), ready for CBCT setup.

- SK Lee, et al, **2021**, Accuracy of surface-guided patient setup for conventional radiotherapy of brain and nasopharynx cancer, *J Appl Clin Med Phys*, DOI: 10.1002/acm2.13241

Markerless Brain SRS/SRT

(1) Postural Video
- Visual guide
- Shift guide

(2) <30 seconds

(3) This is recorded during the first trial by an RTT.

(4) The couch is moved far away as the worst-case scenario.

Tattooless SGRT Studies – 2F/3F/4F Breast Treatments?

SGRT setup for conventional breast 2F/3F/4F treatments?

SGRT would be the Final Setup: No clinical daily 2DkV

1. A UK group (J Rigley and L Scattergood), 2020, Radiography

   43 patients in 2 groups: Mean uncertainty=7.6mm (Tattoo) vs. 4.6mm (Tattooless)

2. We are investigating the accuracy of SGRT patient setup using the Tattooless patient data we have collected so far.

Billing/Reimbursement of non-IGRT SGRT setup

- SGRT in bundled with IGRT; so 2F/3F/4F are non-IGRT setup
- So, it is a question on how to proceed with tattooless SGRT setup
- This is common for all non-IGRT cases, such as partial brain and HN.

Other Disease Sites for Potential Tattooless SGRT

Patient setup with very large treatment region

- Requires 2x 2DkV to cover the entire treatment area (PTV)

  Case 1. Groin with leg and pelvis

  Case 2. Whole abdomen

- Manages neck curvature for SBRT of multiple recurrence HN lesions

  Case 3. Head and neck (markerless)

- Patient setup for extremity with 3DP bolus and 3DM immobilization

  Case 4. Extremity

Clinical trials to setup nasal patients with en-face electron beam

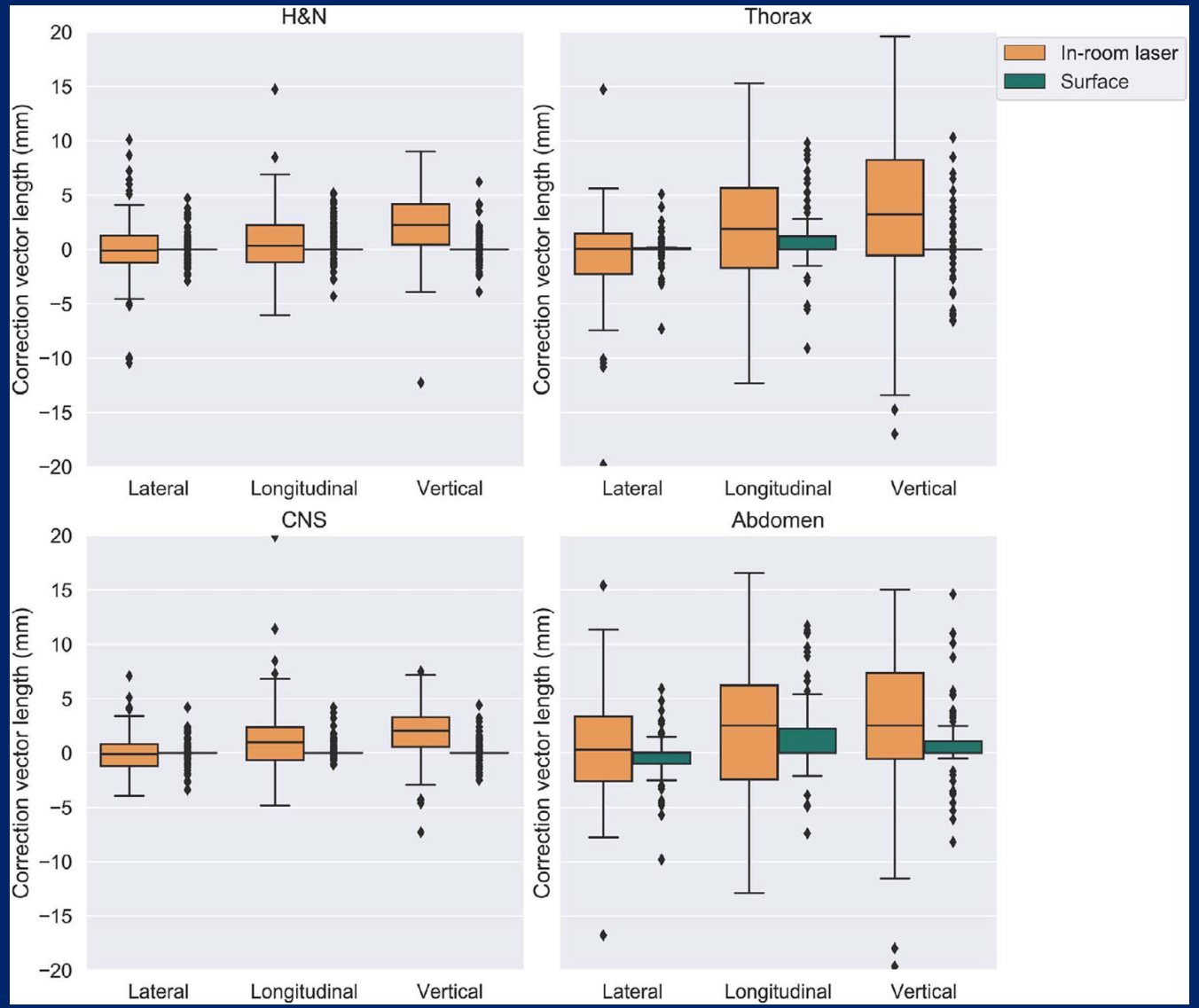
- Aims to reduce the physician weekly on-stie light-field checks

Tattoos vs. SGRT Study (1)

Demonstration of residual setup uncertainties and error ranges in 3DOFs between tattoo/laser-based and OSI-based patient setups, using **MVCT** reference in 16,835 fractions (894 patients).

Four anatomical sites are studied, illustrating better SGRT accuracy and precision in patient setups.

- HN and CNS
- Thorax
- Abdomen



- Haraldsson A, et al. **2020** Surface-guided tomotherapy improves positioning and reduces treatment time: a retrospective analysis of 16 835 treatment fractions *J. Appl. Clin. Med. Phys*. **21** 139–48

Tattoos vs. SGRT Study (2)

Demonstration of residual setup uncertainties and 95% CI in 3DOFs between tattoo/laser-based and OSI-based patient setups, using **CBCT reference** in 1902 fractions (110 patients).

Four anatomical sites are studied, illustrating better SGRT accuracy and precision in patient setups.

- HN
- Thorax
- Abdomen
- Extremity

Similar setup accuracy but significant timesaving

Table 1. Catalyst and Spatial Laser Deviations Sorted by Region.

All Values in mm	Mean Value	95% CI	SD	Range
Catalyst deviations sorted by therapeutic regions				
Head				
Catalyst lat.	−0.21	[−0.37; −0.05]	±2.14	−15.4; 11.8
Laser lat.	−0.18	[−0.31; −0.06]	±1.71	−5.3; 5.1
Catalyst long.	0.17	[0.02; 0.33]	±2.11	−9.7; 9.1
Laser long.	0.29	[0.14; 0.43]	±1.89	−29.6; 8.0
Catalyst vert.	0.13	[−0.08; 0.35]	±2.88	−11.0; 15.3
Laser vert.	−0.03	[−0.20; 0.14]	±2.27	−10.1; 8.6
Thorax				
Catalyst lat.	−0.13	[−0.55; 0.30]	±4.67	−18.1; 15.3
Laser lat.	−0.21	[−0.58; 0.16]	±4.06	−18.7; 15.1
Catalyst long.	−1.14	[−1.57; −0.71]	±4.66	−15.6; 16.8
Laser long.	−0.65	[−0.98; −0.31]	±3.65	−11.2; 12.6
Catalyst vert.	−0.01	[−0.44; 0.41]	±4.64	−18.9; 14.0
Laser vert.	0.22	[−0.16; 0.61]	±4.18	−19.7; 14.1
Abdomen				
Catalyst lat.	−0.46	[−0.84; −0.08]	±4.85	−16.6; 12.9
Laser lat.	−0.06	[−0.37; 0.26]	±4.03	−13.8; 11.2
Catalyst long.	1.99	[1.58; 2.40]	±5.25	−15.2; 23.0
Laser long.	1.56	[1.23; 1.89]	±4.18	−29.1; 22.5
Catalyst vert.	−0.59	[−1.03; −0.16]	±5.58	−18.8; 19.8
Laser vert.	0.68	[0.37; 0.98]	±3.93	−10.5; 13.8
Extremities				
Catalyst lat.	1.71	[0.55; 2.87]	±6.50	−17.1; 16.5
Laser lat.	1.18	[0.18; 2.19]	±5.63	−12.5; 14.4
Catalyst long.	0.18	[−0.96; 1.32]	±6.38	−17.4; 16.9
Laser long.	0.96	[0.26; 1.66]	±3.90	−10.4; 11.2
Catalyst vert.	−1.57	[−2.52; −0.62]	±5.34	−16.6; 10.9
Laser vert.	−1.20	[−1.80; −0.59]	±3.38	−14.0; 6.0

Abbreviations: CI, confidence interval; SD, standard deviation; lat., lateral; long., longitudinal; vert., vertical.

- Carl G et al **2018** Optical surface scanning for patient positioning in radiation therapy: a prospective analysis of 1902 fractions *Technol. Cancer Res. Treat*. **17** 1533033818806002

Challenges in Tattooless SGRT

- Remaining challenges ahead with a lot of studies
  - Site-specific studies are still needed: Accuracy and workflow
  - The DICOM reference vs. on-site new references…
  - At MSK, we want to produce the results to convince ourselves
- Beyond superficial anatomy alignment and motion monitoring
  - Abdominal DIBH setup: define an ROI to infer diaphragm position
  - AlignRT has the potential to demonstrate external-internal correlation
- Engaging SGRT for intra-fractional motion monitoring
  - Beyond rigid anatomy in motion management
  - Motion monitoring for Thoracic and Abdominal SBRT treatments?

Summary

We have implemented tattoo-less breast PBI and VMAT SGRT

1. First pilot tattooless studies and then clinical implementation
2. All tattooless SGRT setups come with IGRT verifications so far
3. Tattooless workflow is different in simulation, planning, and treatment
4. Benefits: reduced workload and accelerated setup at better accuracy.

We have implemented markerless brain SGRT for SRS/SRT

We have several ongoing studies to extend the initial successes

1. SGRT accuracy for breast setup (2F/3F/4F) without IGRT verification
2. SGRT for extremity, HN (c-spine curvature control), and abdomen
3. SGRT is bundled as IGRT, so facing a reimbursement issue…

Thank You!

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Any Questions?