Clinical Applications of Surface Guided Radiation Therapy and the Future

Ryan Foster, PhD
Chief Physicist
Atrium Health/LCI NorthEast

Objectives

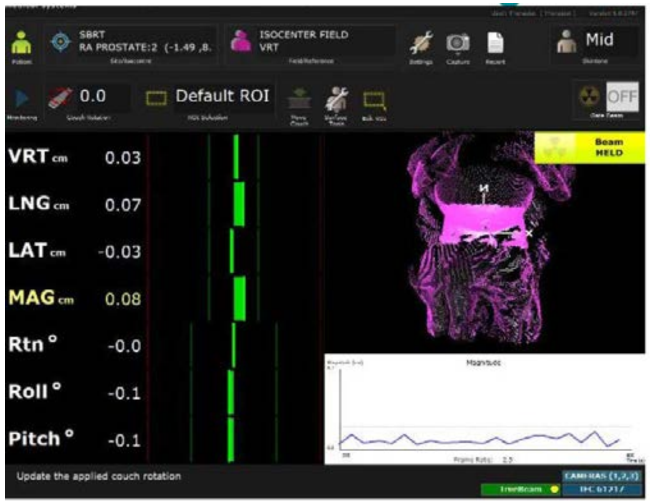
- Understand the clinical uses of SGRT
- Understand the advantages and disadvantages of SGRT for various treatment sites
- FMEA Analysis for potential failure modes for SGRT
- Provide a quick overview of upcoming TG302

Overview of SGRT Options

- AlignRT by VisionRT
- Catalyst by C-RAD
- Identify by humediQ

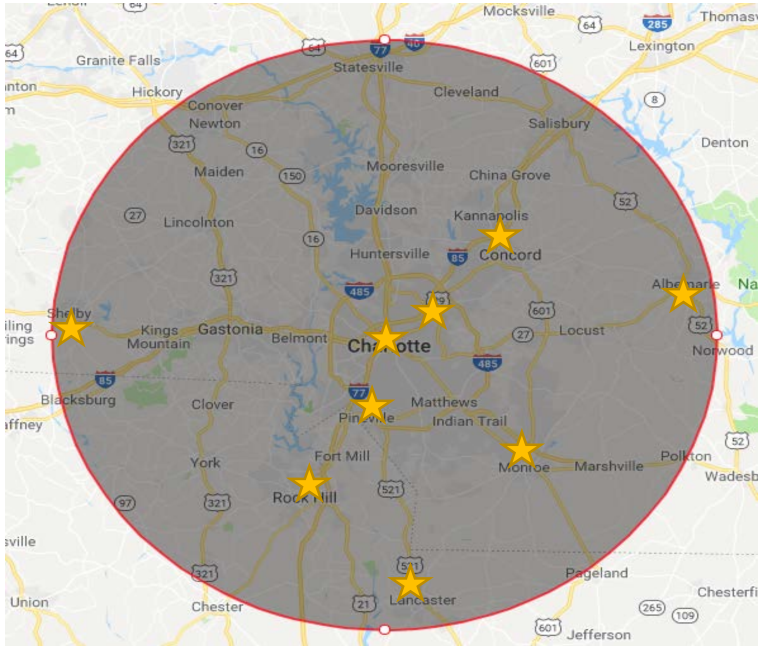
What are the advantages of SGRT?

- Sub-millimeter accuracy
- Can automatically gate the linac beam
- Non-invasive
- Non-ionizing



Background on Atrium Health & Levine Cancer Institute

- Serves the Charlotte, NC Metro Area
- More than 40 hospitals and 900 care locations
- More than 65,000 employees
- Largest health system in all of North and South Carolina
- 9 radiation oncology clinics with 13 linacs, 10 with SGRT
- Treating 360+ patients per day



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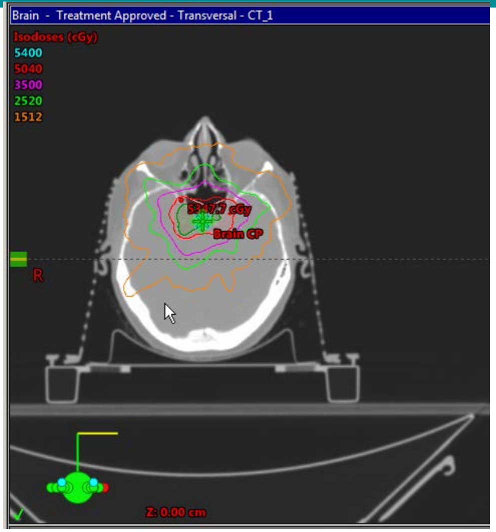
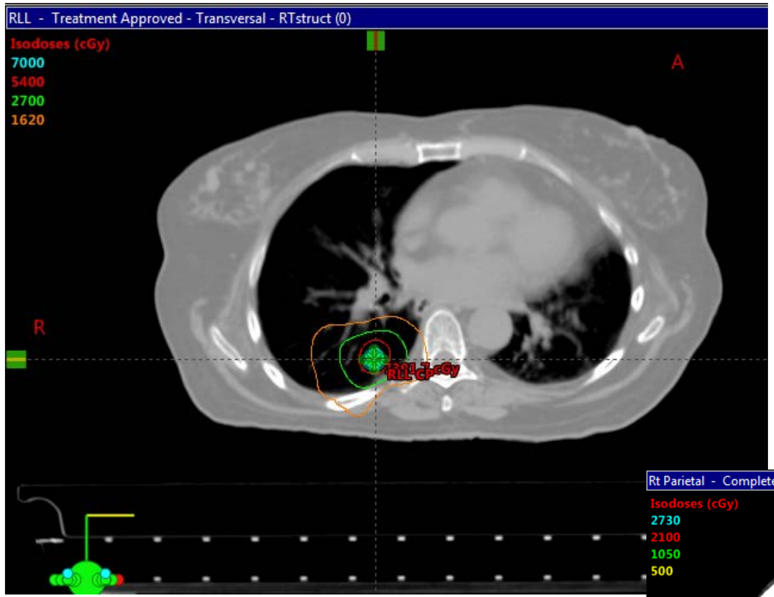
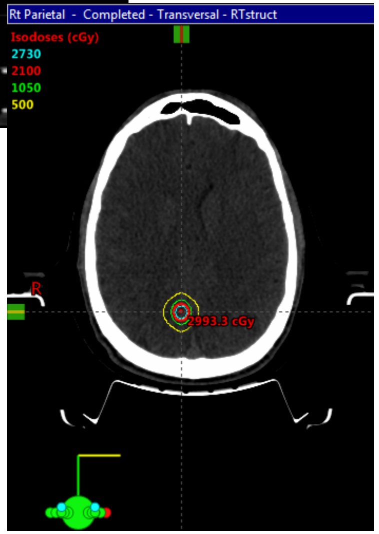
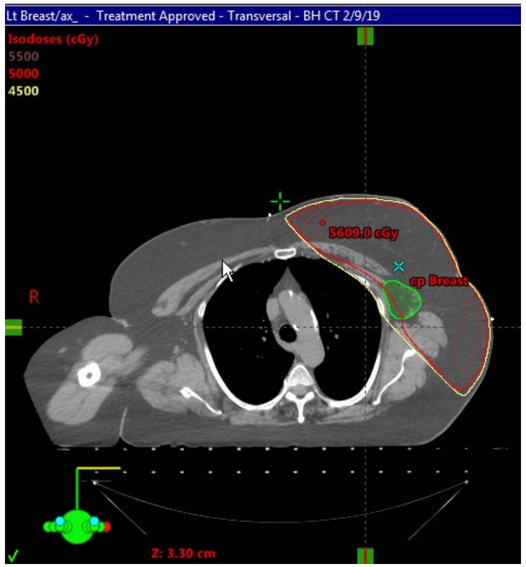
Disease sites with published/presented data

- Breast
- H&N
- SRS
- SBRT
- Thorax/abdomen
- Extremities
- Pelvis









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Patient Setup

Comparison of initial patient setup accuracy between surface imaging and three point localization: A retrospective analysis

Dennis N. Stanley[1] | Kristen A. McConnell[1] | Neil Kirby[1] | Alonso N. Gutiérrez[1,2] | Nikos Papanikolaou[1] | Karl Rasmussen[1]

- Stanley et al. JACMP 2017
- Initial setup using lasers or SGRT, followed by CBCT
- Evaluated pelvis/lower extremities, abdomen, chest/upper extremities and breast
- 6000 total fractions – 600 – 900 per treatment site per method

TABLE 1 Summary of post-CBCT 3D corrections calculated averages and standard deviations for a traditional three point localization with subcutaneous tattoos and surface imaging techniques.

	Three point localization		Surface imaging	
	Average(cm)	σ(cm)	Average(cm)	σ(cm)
Pelvis/lower extremities	0.9	0.4	0.6	0.3
Abdomen	1.0	0.5	0.5	0.3
Chest/upper extremities	0.9	0.6	0.5	0.3
Breast	1.4	0.7	0.6	0.2

This study shows that the overall 3D shift corrections for patients initially aligned with the C-RAD CatalystHD were significantly smaller than those aligned with subcutaneous tattoos. Surface imaging systems should be considered a viable option for initial patient setup and may be preferable to permanent marks for specific clinics and patients.

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Breast

- Why breast radiation therapy?
- Most widely published disease site for SGRT use
- Allows monitoring of breast shape and position
- Facilitates deep inspiration breath hold (DIBH) for cardiac sparing during left breast RT
- Partial breast irradiation setup without daily imaging

Whole Breast Setup

Clinical evaluation of interfractional variations for whole breast radiotherapy using 3-dimensional surface imaging

Amish P. Shah PhD*, Tomas Dvorak MD, Michael S. Curry MS, Daniel J. Buchholz MD, Sanford L. Meeks PhD

Department of Radiation Oncology, MD Anderson Cancer Center Orlando, Orlando, Florida

- Shah et al. PRO 2013
- Evaluated SGRT vs skin marks for setup
- Performed dosimetric evaluation

Table 1 Mean setup errors detected by the surface-based imaging system relative to alignment based on skin marks and lasers for all patients (n = 50)

	No. of treatment fractions	Vertical (mm)	Longitudinal (mm)	Lateral (mm)	3D vector (mm)
Average displacement (including nature of displacements)	1258	0.08	−0.20	−0.62	6.35
Average displacement (absolute value)	1258	4.09	2.67	2.59	6.35
Maximum individual average (absolute value)	1258	11.99	6.88	5.31	13.22
Minimum individual average (absolute value)	1258	0.91	0.82	0.80	2.76

Average values given as mean of individual means. Maximum and minimum values given as individual means of each patient.
3D, 3-dimensional.

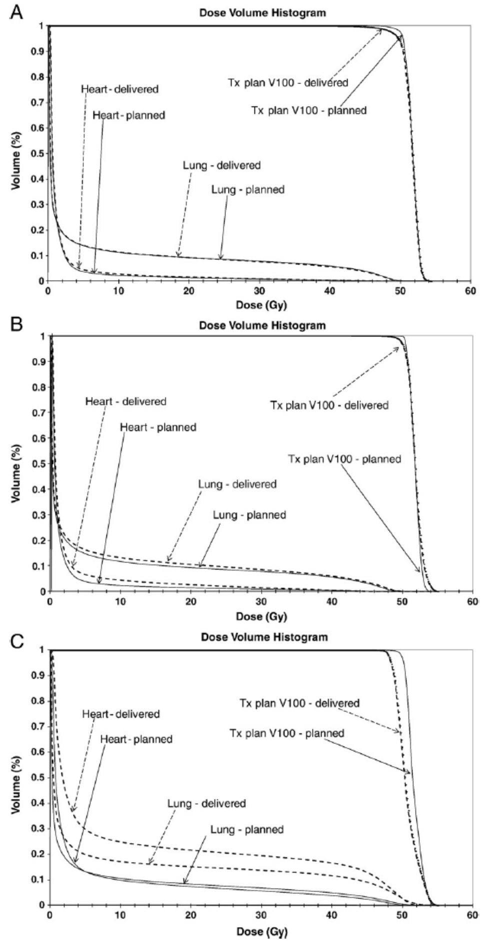

Figure 5 Planned and delivered dose-volume histograms of heart, lung, and volume of prescription isodose line from the treatment plan for (A) patient (No.7) with moderate AlignRT offsets from skin marks; (B) patient (No. 32) with excessive AlignRT offsets from skin marks (data displayed in Fig 3); and (C) left-sided breast cancer patient's treatment (Tx) plan, combined with a separate patient's daily offsets in order to display a possible "worst-case" scenario from daily laser and skin mark alignments with large systematic error.

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APBI

CLINICAL EXPERIENCE WITH A 3D SURFACE PATIENT SETUP SYSTEM FOR ALIGNMENT OF PARTIAL-BREAST IRRADIATION PATIENTS

Christoph Bert, M.S.,*† Katherine G. Metheany, B.S.,† Karen P. Doppke, M.S.,† Alphonse G. Taghian, M.D., Ph.D.,† Simon N. Powell, M.D., Ph.D.,† and George T.Y. Chen, Ph.D.†

*Abteilung Biophysik, Gesellschaft für Schwerionenforschung, Darmstadt, Germany; and †Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, MA

- Bert et al. IJROBP 2006
- Free breathing
- Evaluated SGRT for setup for accelerated partial breast irradiation (APBI)
- Compared to lasers and port films

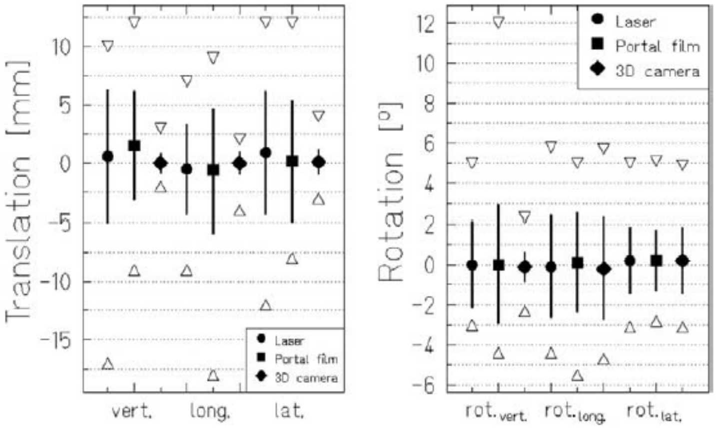

Fig. 7. Mean ± standard deviation with minimum (Δ) and maximum (∇) of the couch shift required to bring the corresponding surface model back to reference. Data are from 9 patients, and 44 fractions were analyzed.

Table 1. Three-dimensional displacement (in mm) as recommended by the alignment procedure

Surface model	Mean	Standard deviation	Minimum	Maximum
Laser	7.3	4.4	1	17.6
Treatment	7.6	4.2	1.7	19.3
Virtual 3D alignment	1	1.2	0	4.2

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APBI

Video surface image guidance for external beam partial breast irradiation

Albert J. Chang MD, PhD [a], Hui Zhao PhD [a], Sasha Hyatt Wahab MD [b], Kevin Moore PhD [a], Marie Taylor MD [a], Imran Zoberi MD [a], Simon N. Powell MD, PhD [c], Eric E. Klein PhD [a,*]

[a]*Department of Radiation Oncology, Washington University, St Louis, Missouri*
[b]*Radiation Oncology Services, Riverdale, Georgia*
[c]*Department of Radiation Oncology, Memorial Sloan Kettering Cancer Center, New York, New York*

- Chang et al. PRO 2012
- Initial setup with tattoos followed by orthogonal kV images and then SGRT
- Verification orthogonal kV imaging matching the chest wall and SGRT performed
- Evaluated laser, orthogonal imaging of the chest wall and SGRT

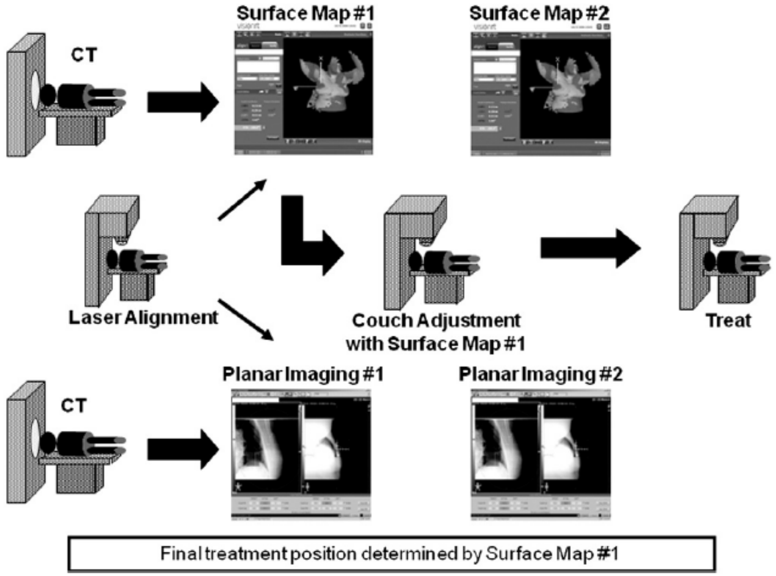

Figure 1 Workflow demonstrating setup, imaging, and analysis. Patients underwent computed tomography (CT) simulation. Digitally reconstructed radiographs and a reference surface map were reconstructed from the CT dataset. For each treatment, patients were initially set up by the laser-based system. Video surface mapping and orthogonal planar imaging were performed. Shifts were made based on video surface mapping referenced to surface map for the CT dataset. Video surface mapping and orthogonal planar imaging were performed again, but no shifts were made. Treatment was then delivered.

Table 2 Residual setup error

Technique	Anterior/ Posterior (mm)	Superior/ Inferior (mm)	Right/Left Lateral (mm)	Vector Spatial Deviation (mm)
Video surface mapping	1.9 ± 2.2	1.8 ± 1.9	1.8 ± 2.1	4.0 ± 2.3
Orthogonal imaging	3.2 ± 2.9	4.2 ± 3.5	4.7 ± 5.3	8.3 ± 3.8
Laser	3.9 ± 3.7	4.6 ± 3.9	4.3 ± 4.5	8.8 ± 4.2

Table 3 Impact of residual setup error on prescription coverage

Prescription coverage	Plan	On board imaging	Video surface map
V100	95.4 ± 0.1	89.3 ± 0.2	96.0 ± 0.1
V95	99.9 ± 0.003	99.7 ± 0.01	98.6 ± 0.01

Prone breast

- Our clinic images one field every day for prone breast patients
- For initial set-up, we are alternating SGRT and laser/skin marks
- Compare shifts between SGRT and skin marks for initial set up
- Preliminary data indicates SGRT results in smaller shifts upon imaging

DIBH

- Why use DIBH?
- Marks et al. found that RT caused perfusion defects in approximately 40% of patients within 2 years of treatment*

Respiratory gating techniques

Respiratory gating techniques afford the opportunity to deliver radiation to the breast/chest wall only during specific portions of the respiratory cycle. Because the heart is displaced inferiorly with deep inspiration, one

- Severity of these defects was hotly debated
- Darby** et al. reported that the rate of major coronary events increased linearly with mean heart dose by 7.4% per Gy

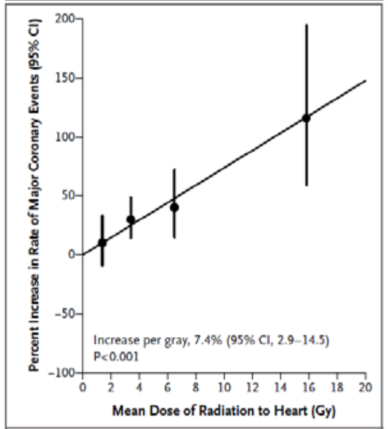

Figure 1. Rate of Major Coronary Events According to Mean Radiation Dose to the Heart, as Compared with the Estimated Rate with No Radiation Exposure to the Heart.

*Marks et al. IJROBP 2005 **Darby et al. NEJM 2013

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DIBH

Using surface imaging and visual coaching to improve the reproducibility and stability of deep-inspiration breath hold for left-breast-cancer radiotherapy

Laura I Cerviño, Sonia Gupta, Mary A Rose, Catheryn Yashar and Steve B Jiang

Department of Radiation Oncology, University of California San Diego, 3855 Health Sciences Dr, La Jolla, CA 92037-0843, USA

- Cerviño et al. PMB 2009
- Evaluated reproducibility and stability of DIBH to develop an optimal coaching protocol
- Investigate usefulness of visual coaching

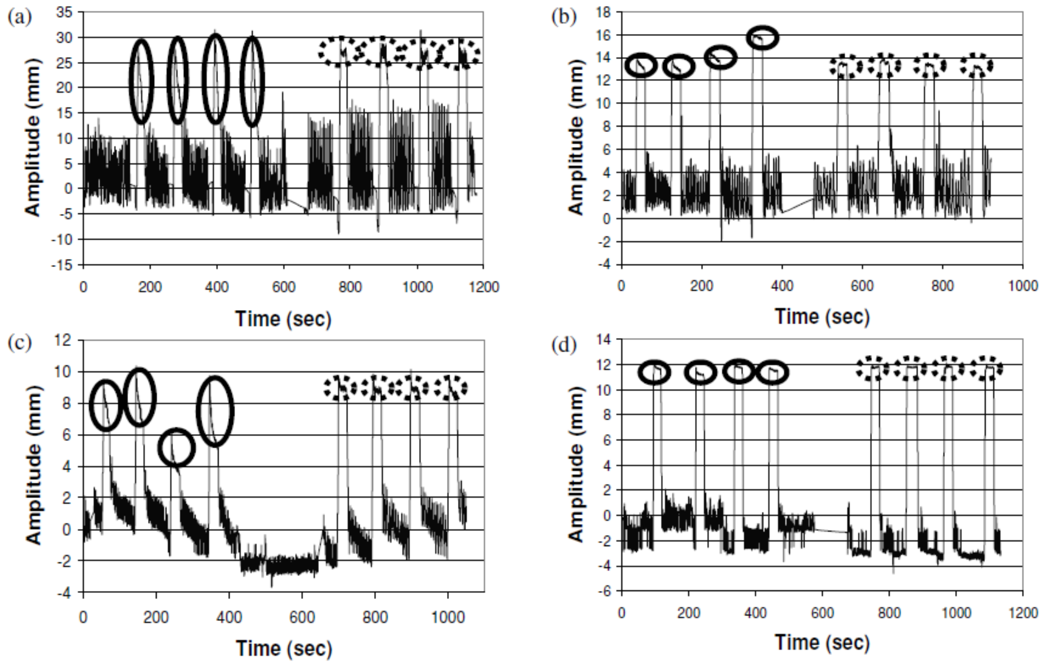


Figure 6. DIBH without and with visual feedback in four different subjects. Without visual feedback (marked in solid-line circles): subjects with poor stability (a), poor reproducibility (b), poor reproducibility and stability (c), and good reproducibility and stability (d). All achieve a good reproducibility and good stability with visual coaching (marked with dotted-line circles).

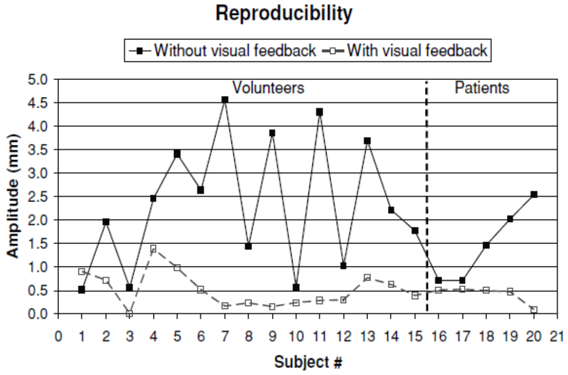


Figure 7. Reproducibility curve of all the patients and volunteers without visual feedback (solid line) and with visual feedback (dashed line). Reproducibility amplitude is lower with visual feedback for all except for one individual, indicating an improvement with respect to the non-coached DIBH.

Table 2. Stability averages by groups of stability improvement.

Stability improvement	Number of subjects (volunteers/patients)	Stability without visual feedback (mm)	Stability with visual feedback (mm)
No improvement	4 (20%) (2/2)	0.4	0.7
<2 mm	13 (65%) (10/3)	1.4	0.7
>2 mm	3 (15%) (3/0)	3.7	0.6

DIBH

A Voluntary Breath-Hold Treatment Technique for the Left Breast With Unfavorable Cardiac Anatomy Using Surface Imaging

David P. Gierga, PhD,*,† Julie C. Turcotte, MS,* Gregory C. Sharp, PhD,*,†
Daniel E. Sedlacek, BA,* Christopher R. Cotter, BS,*
and Alphonse G. Taghian, MD, PhD*,†

**Department of Radiation Oncology, Massachusetts General Hospital and †Harvard Medical School, Boston, Massachusetts*

- Gierga et al. IJROBP 2012
- Reported their experience using SGRT for DIBH left breast patients with unfavorable cardiac anatomy

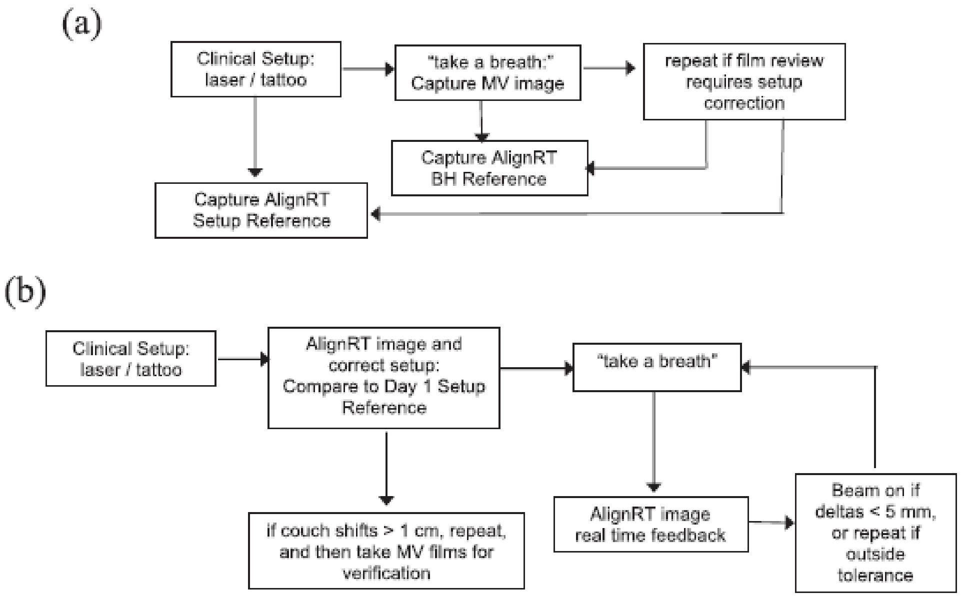


Fig. 1. Imaging protocol for the first treatment day (a) and subsequent treatment days (b). (BH = breath hold; MV = megavoltage.)

Table 2 Systematic (μ, σ) and random (σ) errors for initial patient setup using lasers

	Systematic errors (mm)		Random errors (mm)
Direction	Mean (μ)	SD (σ)	σ
VRT	2.0	2.6	3.5
LNG	1.2	2.9	3.3
LAT	0.3	3.5	3.8
3D	7.8	1.9	2.9

Abbreviations: 3D = 3-dimensional; LAT = latitudinal; LNG = longitudinal; VRT = vertical couch shifts.

Table 3 Summary of breath-hold results

Treated BH fields			BH out of tolerance			
Mean Real-time delta (mm)			Mean Real-time delta (mm)	Maximum Real-time delta (mm)	Percent BH out of tolerance	Mean number of additional reference images
VRT	LNG	LAT	All directions	All directions	Mean (SD, range)	
2.2	2.3	2.0	6.3	8.8	22 (11,7-41)	1.3

Abbreviations: BH = breath hold; LAT = latitudinal; LNG = longitudinal; VRT = vertical couch shifts.

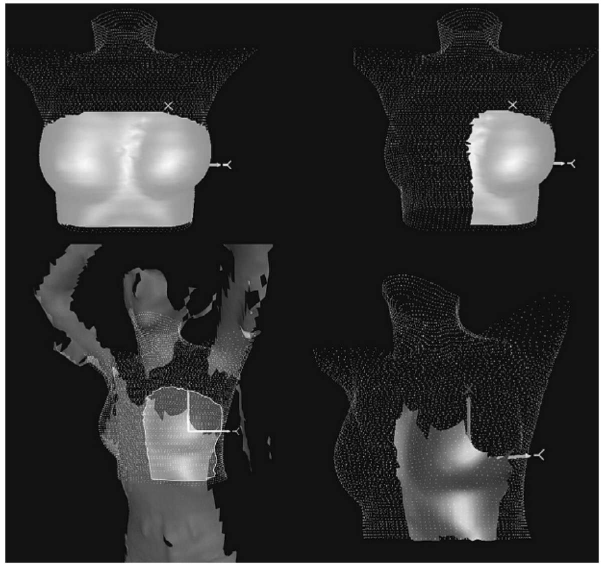
DIBH

Accuracy Evaluation of a 3-Dimensional Surface Imaging System for Guidance in Deep-Inspiration Breath-Hold Radiation Therapy

Tanja Alderliesten, PhD, Jan-Jakob Sonke, PhD, Anja Betgen, MSc, Joeri Honnef, MSc, Corine van Vliet-Vroegindeweij, PhD, and Peter Remeijer, PhD

Department of Radiation Oncology, The Netherlands Cancer Institute—Antoni van Leeuwenhoek Hospital, Amsterdam, The Netherlands

- Alderliesten et al. IJROBP 2013
- Compared SGRT setup to CBCT
- Captured surface images concurrently with CBCT acquisition
- CBCT matched to ribs and sternum
- Looked at SGRT ROIs consisting of both breasts or only left



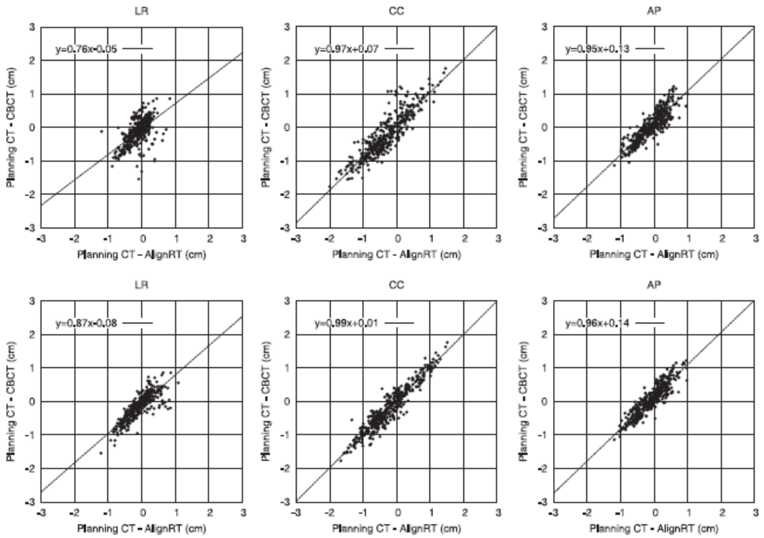


Fig. 2. Scatterplots with regression lines of the translational part of the setup errors derived from computed tomography (CT)-AlignRT registration vs setup errors derived from CT-cone beam computed tomography (CBCT) registration. Above, region of interest comprising both sides. Below, region of interest comprising left side.

We do not recommend solely the use of surface imaging for setup verification and monitoring. When only surface data are available, it is harder to distinguish whether a setup error in the AP direction is caused by anatomic changes or by a change in BH.

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DIBH – Clinical Results

Utility of Deep Inspiration Breath Hold for Left-Sided Breast Radiation Therapy in Preventing Early Cardiac Perfusion Defects: A Prospective Study

Timothy M. Zagar, MD,* Orit Kaidar-Person, MD,* Xiaoli Tang, PhD,† Ellen E. Jones, MD,* Jason Matney, MS,* Shiva K. Das, PhD,* Rebecca L. Green, MS,* Arif Sheikh, MD,‡ Amir H. Khandani, MD,§ William H. McCartney, MD,§ Jorge Daniel Oldan, MD,§ Terence Z. Wong, MD, PhD,§ and Lawrence B. Marks, MD*

*Departments of *Radiation Oncology, and §Radiology, University of North Carolina, Chapel Hill, North Carolina; †Memorial Sloan Kettering Cancer Center, West Harrison; and ‡Department of Radiology, Columbia University; New York, New York*

- Zagar et al. IJROBP 2017
- Prospective trial evaluating utility of DIBH for preventing cardiac perfusion defects
- 20 patients evaluated

Table 2 Radiation doses and target volumes

Characteristics	No. of patients
Total prescribed dose (cGy)* (fraction number)	
4272 (16)	10
4600 (23)	6
5000 (25)	4
Prescribed boost dose (cGy)† (fraction number)	
1000 (5)	11
1200 (6)	2
1600 (8)	6
Internal mammary chain RT (superiorly placed nodes)	7
Supraclavicular RT field	5
Whole axillary RT field	0

* To whole breast/chest wall

† Tumor bed/scar. In 18 patients an electron boost was used; in 1 patient photon boost was used.

Table 3 Dosimetric parameters of radiation therapy (RT) plans

Parameters	No. (range)
Median % D95 tumor bed*	100.8 (92.3-102.4)
Median mean heart dose (cGy)	94 (56-200)
Median heart $V25_{Gy}$	0 (0-0.1)
Median ipsilateral lung $V20_{Gy}$	15 (4-31)

* Minimum dose to the "hottest" 95% of the tumor bed, in patients with intact breast.

By the use of early imaging changes after RT as a surrogate marker for RT-associated heart injury, the present study suggests that DIBH with conformal cardiac blocking is an effective means to mitigate cardiac injury. At 6 months post RT, none of the patients in this study had a new RT-associated perfusion or wall motion defects on cardiac SPECT. This rate of cardiac perfusion abnormalities after RT is lower than the 27% rate reported by Marks et al (9) (used as our historical control during protocol design) and is also lower than the rates reported by others (8, 11, 12).

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Breast SGRT Review

- DIBH has been shown to reduce cardiac perfusion defects
- DIBH should be monitored
- Patients who are imaged weekly could benefit from SGRT on non-imaging days

H&N

Migration from full-head mask to "open-face" mask for immobilization of patients with head and neck cancer

Guang Li,[1a] D. Michael Lovelock,[1] James Mechalakos,[1] Shyam Rao,[2]
Cesar Della-Biancia,[1] Howard Amols,[1] and Nancy Lee[2]
Department of Medical Physics[1] and Department of Radiation Oncology,[2]
Memorial Sloan-Kettering Cancer Center, New York, NY, USA
lig2@mskcc.org

- Li et al. JACMP 2013
- Evaluated open-face mask immobilization using SGRT using 10 volunteers
- Compared kV imaging and SGRT during localization of 121 fractions for 5 patients

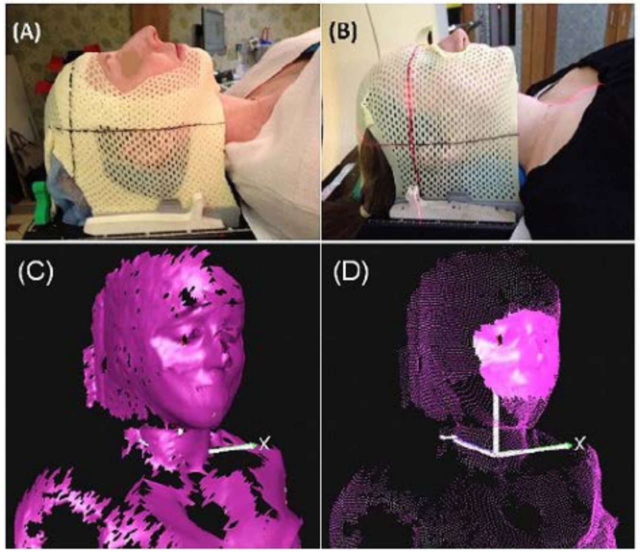

Fig. 1. An open-face mask and a conventional full-head mask molded on two volunteers. An arbitrary alignment point was marked on the masks. For the open-face mask (a), the open area was set to be the region of interest for AlignRT motion monitoring. For the conventional mask (b), the nose area was open, allowing alignment between a skin mark and the room laser in a forced motion test. A raw reference image (c), where the open area is clearly seen; the ROI (d) drawn on the reference image.

Table 3. Head motion of five claustrophobic patients monitored with AlignRT in real time during treatment, and with both AlignRT and orthogonal kV imaging in pre- and post-treatment (P&P). The average motion of these patients is similar to that of the volunteers. The X-ray P&P data fall between two sets of AlignRT P&P data (OSI-1 and OSI-2) using different reference images. Note: both OSI-1 and OSI-2 show P&P differences, quantifying head motion during treatment, although OSI-1 is more reliable since it does not carry residual head rotation at setup.

				Translation (mm)					*Rotation (degree)*			
				RTD		*P&P X-ray*			*RTD*		*P&P*	
Patient	*Sex*	*Age*	*fx/Fx*[a]	*Mean*	*St dev*	*OSI-1*[b]	*OSI-2*[c]	*kV*	*Mean*	*St dev*	*OSI-1*	*OSI-2*
1	M	65	16/30	1.2	0.6	1.3	2.3	1.7	0.5	0.2	0.6	1.1
2	F	72	11/20	0.7	0.1	0.9	1.5	1.0	0.3	0.1	0.3	1.2
3	M	59	16/33	0.6	0.3	0.5	1.4	1.2	0.3	0.1	0.2	0.6
4	M	76	4/5	0.5	0.2	1.3	1.0	1.1	0.6	0.2	0.8	0.2
5	F	55	14/33	0.9	0.4	1.1	1.6	1.4	0.4	0.2	0.4	0.8
Average		65	12/24	0.8	0.3	1.0	1.6	1.4	0.4	0.2	0.5	0.8
St dev				0.3		0.4	0.5	0.5	0.2		0.3	0.4

[a] fx/Fx refers to the number of fractions (fx) for which AlignRT was applied for motion monitoring over the total number of treatment fractions (Fx).
[b] OSI-1 uses the on-site AlignRT image as the registration reference image, for pre- and post-treatment registration.
[c] OSI-2 uses the CT external contours as the registration reference image, for pre- and post-treatment registration.

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H&N

A prospective evaluation of open face masks for head and neck radiation therapy

David Wiant PhD*, Sarah Squire MD, Han Liu PhD, Jacqueline Maurer PhD, T. Lane Hayes MS, Benjamin Sintay PhD

Cone Health Cancer Center, Greensboro, North Carolina

- Wiant et al. PRO 2016
- Prospective evaluation of open face masks for H&N RT
- Monitored intra-fraction motion for open-face masks using SGRT

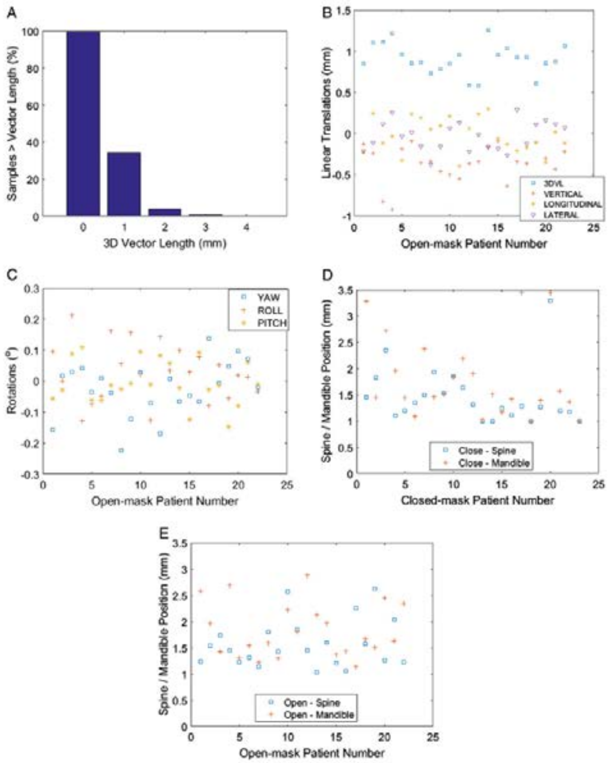

Figure 2 (A) Percent of 568 total monitored fractions with 3-dimensional vector length (3DVL) greater than the listed value for the open-mask group. Mean values for the open-mask group over all fractions for (B) 3DVL and (C) rotations. Mean spinal canal and mandible contour expansions that covered the structures in the (D) closed-mask group and (E) open-mask group.

Table 2 Intrafraction motion group mean values

	3DVL	Vertical	Longitudinal	Lateral	Yaw	Roll	Pitch
Mean (mm)	0.9	-0.4	0.0	0.0	0.0	0.0	0.0
1 SD (mm)	0.5	0.5	0.7	0.5	0.3	0.3	0.2
Range (mm)	0.1 to 3.5	-3.0 to 1.7	-2.7 to 3.5	-2.2 to 3.0	-1.3 to 1.3	-1.8 to 1.4	-0.9 to 1.1
Range of means (mm)	0.6 to 1.3	-0.9 to -0.1	-0.4 to 0.3	-0.4 to 0.3	-0.2 to 0.1	-0.1 to 0.2	-0.1 to 0.1

3DVL, 3-dimensional vector length; SD, standard deviation.

Why use SGRT for SRS and SBRT?

- Treatments with small margins and sharp dose gradients
- Allow smaller margins?
- Benign conditions or pediatric patients – reduce imaging dose
- Pediatrics or non-compliant patients – reduce margins and eliminate need for anesthesia
- Facilitate breath hold lung SBRT

SRS

- Li et al. Med Phys 2011
- SGRT used to verify setup at treatment angles and for motion monitoring
- CBCT used as standard for IGRT
- Compared frame-based SRS with frameless

Motion monitoring for cranial frameless stereotactic radiosurgery using video-based three-dimensional optical surface imaging

Guang Li,[a] Åse Ballangrud, Li Cheng Kuo, Hyejoo Kang, Assen Kirov, and Michael Lovelock
Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, 1275 York Avenue, New York, New York 10065

Yoshiya Yamada
Department of Radiation Oncology, Memorial Sloan-Kettering Cancer Center, 1275 York Avenue, New York, New York 10065

James Mechalakos and Howard Amols
Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, 1275 York Avenue, New York, New York 10065

TABLE I. Average head motion for frame-based SRS patients at all treatment couch angles using AlignRT surface imaging. Motion magnitude is defined as $\sqrt[2]{x_m^2 + y_m^2 + z_m^2}$ (m = translation or rotation).

Treatment	Patient	Number of lesions	Age	Sex	Translational magnitude (mm)	SD[a]	Rotational magnitude (°)	SD[a]
Frame-based SRS	1	3	59	F	0.36	0.23	0.28	0.23
	2	2	48	F	0.29	0.16	0.19	0.14
	3	2	65	M	0.29	0.19	0.20	0.18
	4	1	53	F	0.20	0.14	0.23	0.15
	5	2	56	F	0.25	0.15	0.14	0.11
	6	2	67	F	0.33	0.20	0.16	0.13
	7	1	70	M	0.19	0.12	0.18	0.11
	8	1	45	M	0.29	0.15	0.16	0.10
	9	3	74	M	0.32	0.21	0.43	0.37
	10	1	33	F	0.19	0.14	0.18	0.16
	11	1	64	F	0.13	0.07	0.08	0.05
	Average	1.7	58		0.3	0.2	0.2	0.2
	SD[a]	0.8	12		0.1	0.1	0.1	0.1
	RMS[b]	1.9	59		0.3	0.2	0.3	0.2

FIG. 2. The noninvasive head immobilization (PinPoint®) system used in this frameless SRT/SRS procedure. (1) A carbon-fiber couch board with a head support, (2) a patient-specific head mold, (3) a patient-specific mouthpiece, (4) an adjustable, rigid connector, and (5) a metal arch, which is locked to a couch board (1).

TABLE II. Setup verification and head motion of frameless SRT/SRS patients averaged at all treatment couch angles using AlignRT surface imaging. Motion magnitude is defined as $\sqrt[2]{x_m^2 + y_m^2 + z_m^2}$ (m = translation or rotation).

					Setup verification		Near-real-time motion monitoring			
Treatment	Patient	Fraction number	Age	Sex	Translation difference[a] (mm)	SD[b]	Translation magnitude (mm)	SD[b]	Rotation magnitude (°)	SD[b]
Frameless SRT	1	1	68	F	0.9	0.3	0.25	0.16	0.20	0.12
		2			0.8	0.3	0.19	0.08	0.10	0.05
		3			1.1	0.7	0.35	0.24	0.17	0.15
	2	1	48	F	0.7	0.2	0.32	0.21	0.10	0.05
		2			0.8	0.6	0.15	0.08	0.12	0.06
		3			0.4	0.2	0.37	0.17	0.19	0.09
		4			1.1	0.2	0.52	0.30	0.19	0.12
		5			1.1	0.2	0.28	0.12	0.18	0.10
Frameless SRS	1	1	71	M	0.9	0.1	0.51	0.26	0.37	0.23
	2	1	38	F	0.8	0.3	0.37	0.20	0.29	0.14
	Mean				0.9	0.3	0.3	0.2	0.2	0.1
	SD[b]				0.2	0.2	0.1	0.1	0.1	0.1
	RMS[c]				0.9	0.4	0.4	0.2	0.2	0.1

[a]Setup verification: the values (in mm) are absolute vector distances calculated using Eq. (2) and averaged at all couch angles.
[b]SD, standard deviation.
[c]RMS, root mean square.

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SRS

Initial clinical experience with a frameless and maskless stereotactic radiosurgery treatment

Laura I. Cerviño PhD*, Nicole Detorie PhD, Matthew Taylor BS, Joshua D. Lawson MD, Taylor Harry BS, Kevin T. Murphy MD, Arno J. Mundt MD, Steve B. Jiang PhD, Todd A. Pawlicki PhD

Department of Radiation Oncology, University of California San Diego, La Jolla, California

- Cerviño et al. PRO 2012
- Frameless and maskless SRS monitored with SGRT – 23 patients
- Evaluated CBCT – SGRT agreement for setup
- Interrupted treatment if intra-fraction motion exceeded 1 – 2 mm (margin dependent)

Figure 1 An example of a patient-specific head mold made out of expandable foam that conforms to the patient's head (CDR Systems, Inc, Calgary, Alberta, Canada).

Shifts calculated based on CBCT after the initial setup with AlignRT were −0.8 mm, 1.8 mm, and 0.0 mm in the lateral, anterior-posterior (AP), and superior-inferior (SI) directions, respectively. For our first patient, the shifts

Eight patients needed repositioning during the treatment. In most of these cases, repositioning was required when a treatment field included a couch rotation. In 3 cases, patients fell asleep and also needed repositioning during treatment.

beam hold was initiated at least once for 15 patients. In most cases, the patient movement would naturally return back under the movement threshold value. The worst cases were the 2 patients who fell asleep, where the treatment was interrupted 10 and 14 times. Although the average number

SRS Clinical Outcomes

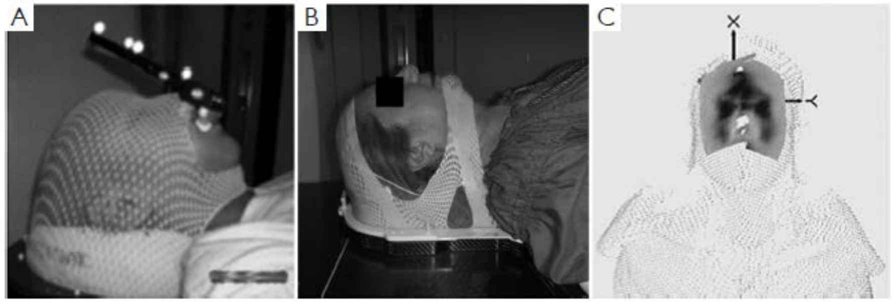
Frameless, real-time, surface imaging-guided radiosurgery: update on clinical outcomes for brain metastases

Nhat-Long L. Pham, Pranav V. Reddy, James D. Murphy, Parag Sanghvi, Jona A. Hattangadi-Gluth, Grace Gwe-Ya Kim, Laura Cervino, Todd Pawlicki, Kevin T. Murphy

Department of Radiation Medicine and Applied Science, University of California, San Diego, La Jolla, CA 92093, USA

Correspondence to: Kevin T. Murphy, MD. Department of Radiation Medicine and Applied Science, University of California, San Diego, La Jolla, California, 3960 Health Sciences Dr., MC0865, La Jolla, CA 92093, USA. Email: kevinmurphy@ucsd.edu.

- Pham et al. Trans Canc Res 2014
- Reported clinical outcomes for frameless SGRT guided SRS
- 163 patients with 490 lesions and 45 post-op cavities



findings that SIG-RS for treating brain metastases can produce clinical outcomes comparable to those for conventional frame-based and frameless SRS techniques. At the same time, SIG-RS setup provides better comfort with an open-faced mask, and allows continuous non-ionizing tracking during the treatment delivery time.

Table 2 Comparison of local control and survival rates in retrospective studies of brain metastases treated with radiosurgery reporting kaplan-meier data[a]

Study	Treatment system	Patients, n	Crude LC, %	Actuarial 1-yr LC, %	Actuarial 1-yr OS, %
Schomas *et al*. (19) [2005]	Frame-based LINAC	80	91	89	33
Bhatnagar *et al*. (18) [2006]	Frame-based Gamma Knife	205	***	71	37[b]
Brenenman *et al*. (6) [2009]	Frameless LINAC	53	***	80	44
Nath *et al*. (7) [2010]	Frameless LINAC	65	88	76	40
Pan *et al*. (17) [2012]	Frameless, surface-imaging guided LINAC	44	85	76	38
Present series	Frameless, surface-imaging guided LINAC	163	85	79	56

[a], LC indicates local control; LINAC, linear accelerator; ***, not reported; [b], estimated from Kaplan-Meier curve.

SRS

Orthogonal image pairs coupled with OSMS for noncoplanar beam angle, intracranial, single-isocenter, SRS treatments with multiple targets on the Varian Edge radiosurgery system

Jasmine A. Oliver PhD, Patrick Kelly MD, Sanford L. Meeks PhD, Twyla R. Willoughby PhD, Amish P. Shah PhD*

UF Health Cancer Center — Orlando Health, Department of Radiation Oncology, Orlando, Florida

- Oliver et al. Adv Rad Onc 2017
- Assessed kV imaging against SGRT for single iso multi-target SRS
- Evaluated couch-rotation induced shifts

Table 2 kV/kV and OSMS image pair couch rotation—induced shifts (ie, difference between shift at angle and shift at 0)

	CR 45°	CR 315°	CR 30°	CR 330°	CR 15°	CR 345°
kV/kV Image Pairs						
Vrt (mm)	0.25 (0.00-0.50)	0.14 (0.00-0.40)	0.29 (0.10-0.60)	0.25 (0.10-0.40)	0.24 (0.00-0.40)	0.24 (0.00-0.80)
Lng (mm)	0.30 (0.10-0.60)	0.21 (0.00-0.40)	0.17 (0.00-0.40)	0.23 (0.00-0.40)	0.17 (0.00-0.70)	0.21 (0.00-1.00)
Lat (mm)	0.49 (0.30-0.90)	0.71 (0.30-1.10)	0.31 (0.00-1.00)	0.22 (0.00-0.50)	0.12 (0.00-0.20)	0.63 (0.20-1.10)
Yaw (°)	0.16 (0.00-0.40)	0.50 (0.20-1.10)	0.13 (0.00-0.30)	0.19 (0.00-0.50)	0.17 (0.10-0.40)	0.26 (0.00-0.60)
Pitch (°)	0.54 (0.00-1.00)	0.11 (0.00-0.40)	0.39 (0.00-0.90)	0.34 (0.10-0.60)	0.32 (0.00-0.60)	0.22 (0.00-0.50)
Roll (°)	0.31 (0.00-0.70)	0.44 (0.00-1.00)	0.50 (0.20-0.80)	0.48 (0.10-1.00)	0.38 (0.10-1.10)	0.62 (0.00-1.40)
OSMS						
Vrt (mm)	0.03 (0.10-0.50)	0.10 (0.00-0.10)	0.40 (0.10-0.70)	0.10 (0.10-0.20)	0.20 (0.00-0.30)	0.40 (0.10-0.70)
Lng (mm)	0.40 (0.10-0.60)	0.10 (0.00-0.30)	0.40 (0.30-0.40)	0.10 (0.00-0.30)	0.30 (0.00-0.60)	0.10 (0.00-0.10)
Lat (mm)	0.30 (0.10-0.60)	0.90 (0.70-1.10)	0.20 (0.10-0.30)	0.10 (0.10-0.20)	0.20 (0.20-0.20)	0.70 (0.50-0.80)
Yaw (°)	0.58 (0.40-0.80)	0.06 (0.00-0.10)	0.48 (0.30-0.60)	0.14 (0.00-0.40)	0.32 (0.20-0.40)	0.16 (0.00-0.40)
Pitch (°)	0.50 (0.40-0.60)	0.18 (0.10-0.30)	0.38 (0.30-0.50)	0.20 (0.10-0.40)	0.28 (0.20-0.40)	0.06 (0.00-0.10)
Roll (°)	0.24 (0.10-0.40)	0.24 (0.10-0.40)	0.36 (0.30-0.40)	0.10 (0.00-0.20)	0.08 (0.00-0.10)	0.28 (0.10-0.50)

CR, couch rotation; Lat, lateral; Lng, longitudinal; OSMS, Optical Surface Monitoring System; Vrt, vertical.

Extremities

Analysis of setup uncertainties for extremity sarcoma patients using surface imaging

David P. Gierga PhD [a,b,*], Julie C. Turcotte MS [a], Long W. Tong BS [a], Yen-Lin E. Chen MD [a,b], Thomas F. DeLaney MD [a,b]

[a]Department of Radiation Oncology, Massachusetts General Hospital, Boston, Massachusetts
[b]Harvard Medical School, Boston, Massachusetts

- Gierga et al. PRO 2014
- Evaluated usefulness of SGRT for extremity sarcoma patients
- MV images first fx and every 5 fx thereafter

Table 1 Patient characteristics

Characteristic	Total
No. patients	16
Thigh	6
Leg	5
Arm	3
Other (buttock, inguinal)	2
Supine	15
Prone	1

Table 2 Intrafraction errors, in millimeters: group mean error μ, systematic error (Σ), and random error (σ)

Direction	Systematic errors (mm)		Random errors (mm)
	Mean (μ)	SD (Σ)	σ
VRT	−0.9	0.6	1.1
LNG	0.2	0.7	1.1
LAT	−0.2	0.8	1.1
3D	2.1	0.9	1.3

3D, 3 dimensional; LAT, latitudinal; LNG, longitudinal; VRT, vertical.

Table 4 Interfraction errors when using a reference surface generated from the planning computed tomography (SurfRef-CT), in millimeters: group mean error μ, systematic error (Σ), and random error (σ)

Direction	Systematic errors (mm)		Random errors (mm)
	Mean (μ)	SD (Σ)	σ
VRT	1.3	3.6	3.1
LNG	−0.4	7.9	4.6
LAT	0.3	4.1	3.3
3D	9.5	5.1	4.1

3D, 3 dimensional; LAT, latitudinal; LNG, longitudinal; VRT, vertical.

Intrafraction motion is small for sarcoma extremity patients with custom-made immobilization. Interfraction motion can exceed typical PTV margins and daily imaging should be utilized to reduce setup variations. Surface imaging may reduce setup errors and is a feasible technique for daily image guidance.

Pelvis

Three-dimensional surface and ultrasound imaging for daily IGRT of prostate cancer

Marco Krengli[1,2*], Gianfranco Loi[3], Carla Pisani[1,2], Debora Beldì[1], Giuseppina Apicella[1], Valentina Amisano[1,2] and Marco Brambilla[3]

- Krengli et al. Radiat Onc 2016
- Compared ultrasound and SGRT for prostate patient set up, followed by MV imaging
- Over 1300 fractions recorded

Table 1 Descriptive statistic (mean, standard deviation, maximum and minimum values) of positioning errors (mm) along the three main axes by the two IGRT modalities, AlignRT and Clarity

	AP		CC		LL	
	AlignRT	Clarity	AlignRT	Clarity	AlignRT	Clarity
Mean	1.8	0.6	3.1	0.6	0.7	-0.0
SD	3.3	5.0	4.4	5.1	2.6	4.9
Max	12.0	20.5	21.2	18.2	10.5	24.3
Min	-9.1	-23.8	-18.1	-49.1	-9.4	-17.6

Table 2 Descriptive statistic (mean, standard deviation, maximum and minimum values) of the daily displacement differences (mm)

	AP	CC	LL
Mean	-1.2	-2.6	-0.7
SD	4.9	6.4	5.0
Max	18.0	15.9	22.1
Min	-25.8	-48.8	-22.5

Conclusions

Daily variations detected by 3D-surface and 3D-US imaging in our series are in the range of the literature data. The error distributions for both imaging modalities were asymmetric, suggesting a systematic component with significant differences between the two imaging modalities. The systematic errors detected by 3D-surface and 3D-US imaging were significantly different only in the LL direction, possibly related to the difficulty in precise definition the lateral edge of the prostate by US. The differences between the random errors detected by the two IGRT modalities were not statistically significant, meaning that AlignRT measurements can be predictive of Clarity displacements after adjustment for systematic errors, given a constant bladder filling as verified in our study by 3D-US imaging. These findings suggest that the two techniques could be used as complementary QA methods in addition to weekly x-rays/cone beam imaging and could represent a daily "low-cost" and non-invasive IGRT modality for prostate cancer patients.

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Thorax/Abdomen

- External – Internal Correlation?
- Glide-Hurst et al. Med Phys 2011
- Coupled SGRT with on-board flouro

Coupling surface cameras with on-board fluoroscopy: A feasibility study

Carri K. Glide-Hurst
Department of Radiation Oncology, Henry Ford Health Systems, Detroit, Michigan 48202

Dan Ionascu
Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, Michigan 48073

Ross Berbeco
Department of Radiation Oncology, Dana-Farber/Brigham and Women's Cancer Center and Harvard Medical School, Boston, Massachusetts 02115

Di Yan
Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, Michigan 48073

TABLE I. Tracking performance of the motion platform as measured by on-board kV fluoroscopy and surface imaging.

	Period (s)		Amplitude (cm)	
Expected	Surface imaging Mean ± Stdev	Fluoroscopy Mean ± Stdev	Surface imaging Mean ± Stdev	Latency (s)
3.33	3.33 ± 0.07	3.31 ± 0.08	1.00 ± 0.01	0.62
4.00	4.00 ± 0.04	3.97 ± 0.10	1.01 ± 0.00	0.66
5.00	4.99 ± 0.07	4.98 ± 0.15	1.00 ± 0.00	0.63
				0.64 ± 0.02

TABLE III. Patient-specific correlations between abdominal surface motion and superior–inferior internal motion (tumor and diaphragm) are presented. The internal structures were measured using fluoroscopy whereas external abdominal motion was measured via surface imaging cameras.

		Abdomen–diaphragm		Abdomen–tumor		Diaphragm–tumor	
Patient	Treatment timepoint	Pearson r	RMSE (mm)	Pearson r	RMSE (mm)	Pearson r	RMSE (mm)
1	Pre	0.94	1.19	0.90	1.91	0.95	1.35
	Post	0.92	1.04	0.96	1.02	0.95	1.13
2	Pre	0.99	0.73	0.96	1.01	0.95	1.15
	Post	0.98	0.93	0.93	1.34	0.93	1.35
3	Pre	0.96	2.99	0.83	3.37	0.87	2.95
	Post	0.85	5.01	0.73	1.43	0.91	0.86

TABLE II. The internal (measured via fluoroscopy) to external (measured via surface imaging cameras) correlation (the Pearson correlation coefficient) before and after latency correction for three patient breathing traces simulated with the motion platform. All latency-corrected correlations were statistically significant ($p < 0.001$).

			Latency-corrected	
Breathing trace	Scaled tumor excursion (Mean ± Stdev, cm)	Uncorrected Pearson r	Pearson r	RMSE (mm)
Trace 1	0.69 ± 0.65	0.47	0.97	0.48
Trace 2	0.24± 0.73	0.44	0.97	0.82
Trace 3	0.58 ± 0.67	0.13	0.97	0.42

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Thorax/Abdomen

Assessment of two novel ventilatory surrogates for use in the delivery of gated/tracked radiotherapy for non-small cell lung cancer

Simon Hughes [a,b,*], James McClelland [c], Segolene Tarte [c], David Lawrence [d], Shahreen Ahmad [b,e], David Hawkes [c], David Landau [a,b,e]

[a] Division of Imaging Sciences, King's College London, London, UK
[b] Department of Radiotherapy, Guy's & St Thomas' Hospitals NHS Trust, London, UK
[c] Centre for Medical Image Computing, University College London, London, UK
[d] Cancer Research UK & UCL Cancer Trials Centre, University College London, UK
[e] National Institute for Health Research (NIHR), Biomedical Research Centre, Guy's & St. Thomas' NHS Foundation Trust and King's College London, London, UK

- Hughes et al. Radiother Oncol 2009
- Assessed correlation of surface-derived ventilatory signals with spirometry-derived signals
- Evaluated surface-derived point and surface-derived volume against spirometry

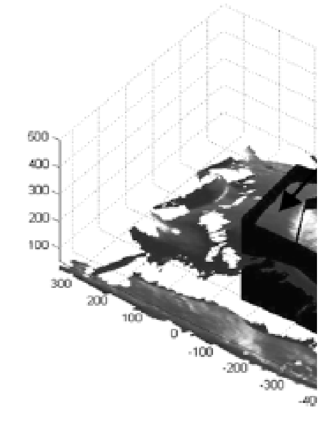

Fig. 3. The Global, thoracic and
VisionRT-derived surface. The tho
mated to form a global bounding

Table 3
Correlation and linear regression analyses.

Subject	Correlation with spirometry		…ip with spirometry (R^2)			
					Multivariate analysis	
	VRT-TP				VRT-TP	VRT-SDV
1	0.80				0.76	0.91
2	0.68				0.76	0.79
3	0.82				0.90	0.93
4	0.93				0.90	0.92
5	0.82				0.68	0.76
6	0.84	0.86	0.71	0.74	0.90	0.93
7	0.86	0.95	0.74	0.91	0.76	0.92
8	0.92	0.94	0.85	0.89	0.86	0.90
9	0.62	0.72	0.39	0.51	0.45	0.60
10	0.84	0.92	0.70	0.85	0.73	0.89
11	0.96	0.97	0.92	0.94	0.92	0.94
Mean	0.83	0.87	0.69	0.77	0.78	0.86

Conclusion

Both the VRT-TP and VRT-SDV have potential applications in ventilatory-gated radiotherapy, tracked radiotherapy, and in providing a ventilatory signal for sorting 4DCT images. They can also be used as parameters to drive 4DCT single- [26] and multi-parameter motion models [27]. This proof of concept study has paved the way for future research utilising both fluoroscopy and cine-CT techniques with implanted fiducial markers to determine the relationship between VRT-derived ventilatory signals and actual tumour location during the ventilatory cycle.

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Thorax/Abdomen

3D surface imaging for monitoring intrafraction motion in frameless stereotactic body radiotherapy of lung cancer

Tanja Alderliesten, Jan-Jakob Sonke, Anja Betgen, Corine van Vliet-Vroegindeweij, Peter Remeijer *

Department of Radiation Oncology, The Netherlands Cancer Institute – Antoni van Leeuwenhoek Hospital, Amsterdam, The Netherlands

- Alderliesten et al. Radiother Oncol 2012
- Captured SGRT surfaces during CBCT acquisition for lung SBRT
- Investigated accuracy of intrafraction motion detection by SGRT
- Found a difference between male and female patients with better agreement for females
- Only had single camera pod

with a ROI comprising both sides of the patient. Retrospectively, we derived that in 24% of the fractions tumor movement >4 mm occurred. The AlignRT system would have detected this correctly in 20% of the fractions (i.e. not in 4% of the fractions). After warning notification, a new CBCT scan will be acquired for setup verification.

Conclusion

In conclusion, the accuracy found for the 3D surface imaging system is sufficient for monitoring intrafraction tumor motion purposes in frameless SBRT of lung cancer for female patients. Further research in a larger group of male patients is needed before solid conclusions regarding male patients can be drawn.

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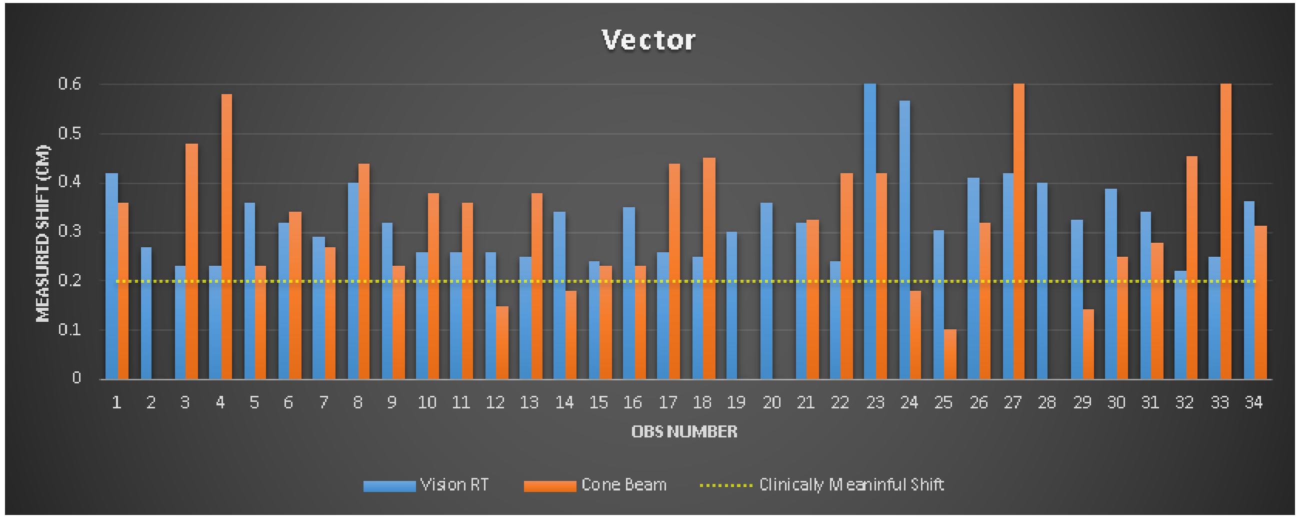
Thorax/Abdomen

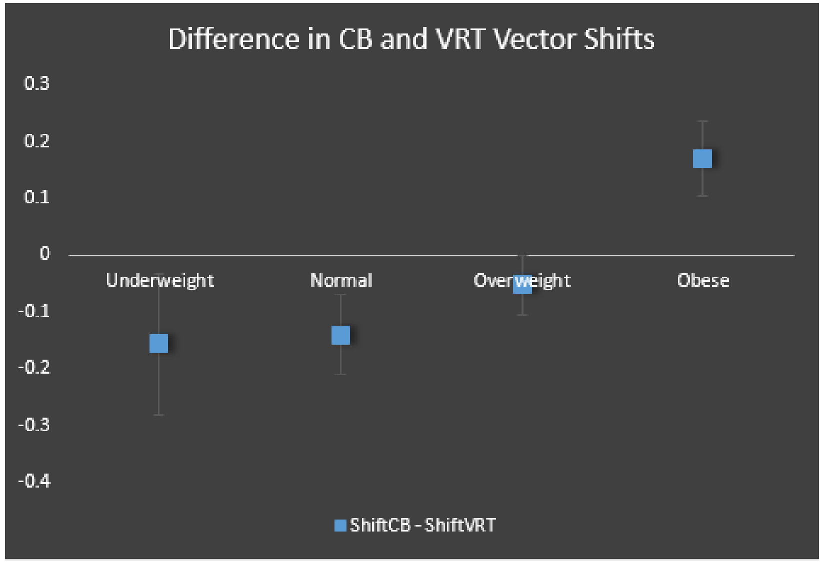
Use of 3D Optical Surface Mapping for Quantification of Interfraction Set up Error and Intrafraction Motion during Stereotactic Body Radiation Therapy Treatments of the Lung and Abdomen

CrossMark

J.H. Heinzerling,[1,2] C.J. Hampton,[2] M. Robinson,[3] M. Bright,[2] J.T. Symanowski,[3] B.J. Moeller,[1,2] K. Mileham,[2] S.H. Burri,[2,4] and R.D. Foster[2]; [1]*Southeast Radiation Oncology Group, Levine Cancer Institute, Carolinas HealthCare System, Charlotte, NC,* [2]*Levine Cancer Institute: Carolinas HealthCare System, Charlotte, NC,* [3]*Department of Biostatistics, Levine Cancer Institute, Carolinas Healthcare System, Charlotte, NC,* [4]*Southeast Radiation Oncology Group, Levine Cancer Institute, Charlotte, NC*

- Heinzerling et al. ASTRO 2017 abstract
- Manuscript under review
- Intra-fraction monitoring of SBRT patients
- 2 mm/2° tolerance – Intra-fraction CBCT





*Adjusting for PTV and ITV

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FMEA Analysis – DIBH CW with bolus

Steps in the Process	Potential Failure Mode	Potential Cause of Failure	Potential Effects of Failure
Bolus capture taken during DIBH daily	Patient moves when bolus placed	Patient not ready (no warning, cold), physical pressure of trying to get bolus flush	Patient not treated accurately
Bolus capture taken during DIBH daily	Bolus capture taken with incorrect surface chosen in Vision RT	Unfamiliar process/nomenclature, labels incorrect/confusing, lack of attention, in hurry, bolus surface resembles chest wall	No effect on current tx, subsequent fxs not accurately treated
Bolus capture taken during DIBH daily	Use incorrect surface to set up patient	Unfamiliar process/nomenclature, labels incorrect/confusing, lack of attention, in hurry, bolus surface resembles chest wall	Patient not treated accurately
Bolus capture taken during DIBH daily	Shift patient based on bolus surface discrepancy rather than using patient surface	Unfamiliar process/nomenclature, labels incorrect/confusing, lack of attention, in hurry, bolus surface resembles chest wall	Patient not treated accurately
Bolus capture taken during DIBH daily	Bolus ROI not adequate	Shiny, slope, cameras blocked or not functioning, other material in capture	Positioning not accurate
Bolus capture taken during DIBH daily	System crashes during/after bolus capture	No ROI drawn before monitoring, clicking too quickly	Delay--patient moves/gets tired, no tx that day

Steps in the Process	Potential Failure Mode	Detection Method-Current Controls (prevent, detect, moderate)
Bolus capture taken during DIBH daily	Patient moves when bolus placed	Explain to patient what to expect on first tx, visual inspection, try to drape only
Bolus capture taken during DIBH daily	Bolus capture taken with incorrect surface chosen in Vision RT	Visual inspection, timeout with physics for bolus patients
Bolus capture taken during DIBH daily	Use incorrect surface to set up patient	Visual inspection, timeout with physics for bolus patients, table tolerances
Bolus capture taken during DIBH daily	Shift patient based on bolus surface discrepancy rather than using patient surface	Visual inspection, timeout with physics for bolus patients, table tolerances
Bolus capture taken during DIBH daily	Bolus ROI not adequate	Visual inspection, timeout with physics for bolus placement
Bolus capture taken during DIBH daily	System crashes during/after bolus capture	Click slowly, reboot system daily, remember to draw ROI before monitoring

Courtesy of Megan Bright, M.S. Presented at 2018 SGRT User Meeting.

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FMEA Analysis - SRS

Failure mode and effects analysis and fault tree analysis of surface image guided cranial radiosurgery

Ryan P. Manger,[a] Adam B. Paxton, Todd Pawlicki, and Gwe-Ya Kim
Department of Radiation Medicine and Applied Sciences, University of California, San Diego, La Jolla, California 92093 and Moores Cancer Center, 3855 Health Sciences Drive, La Jolla, California 92093

- Manger et al. Med Phys 2015
- Of top 25 failure modes, only 1 directly related to use of SGRT

TABLE V. Top five SIG-specific failure modes ranked by RPN.

Rank	Step	Potential failure modes	Potential cause of failure	Potential effects of failure	O	S	D	RPN
8	84. Monitor SIG indicated offsets to ensure patient position is within tolerance	SIG system fails to detect patient movement	SIG system failure	Geometric miss	3	8	8	192
26	84. Monitor SIG indicated offsets to ensure patient position is within tolerance	Not done	Inattention	Geometric miss	4	8	4	128
26	61. Ensure surface imaging cameras are within tolerance	Not checked	Inattention	System may be out of tolerance	6	4	4	96
26	84. Monitor SIG indicated offsets to ensure patient position is within tolerance	Not all metrics were monitored	Mental lapse	Patient position out of tolerance on the unmonitored axis	4	6	4	96
30	84. Monitor SIG indicated offsets to ensure patient position is within tolerance	SIG system indicates movement, yet patient did not move	SIG system isocenter drift	Prolong treatment to investigate movement	10	3	3	90

5. CONCLUSIONS

Based on the FMEA performed in this work, the use of surface imaging for monitoring intrafraction movement in Linac-based SRS does not greatly increase the risk of the Linac-based SRS process. In some cases, SIG helps to reduce the risk (e.g., verifying couch shifts with the SIG system). FMEA is dependent on the process being analyzed, so the failure mode and their RPNs may change if SIG-RS is implemented differently than in this work; however, the general findings of this FMEA should be similar. It is

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TG302 Update

Charges:

To review current use of non-ionizing surface imaging functionality and commercially-available systems.

To provide clinically relevant technical guidelines that include recommendations for the clinical indications of use for general patient positioning, breast DIBH, and frameless brain SRS, including potential pitfalls to avoid when implementing this technology.

To provide commissioning and on-going quality assurance requirements of surface image guided systems, including implementation of risk or hazard assessment of surface image guided radiotherapy as a part of total QM program (e.g., TG-100).

To discuss emerging clinical applications of SI and associated QA implications based on evaluation of technology and risk assessment.

Unofficial Outline

I. Introduction

II. Background

II. A. Evolution of SI systems

II.B. Summary of SI theory and applications

III. Current clinical applications with workflow recommendations

III.A. Types of reference surfaces and implications for registration and positioning accuracy

III.B. Region-of-interest selection and implications for registration accuracy and temporal resolution

III.C. Beam-hold threshold selection as a function of SI and clinical application

III.D. Workflows for general positioning/monitoring

III.E. Workflow for CT simulation/motion management

III.F. Workflow for motion tracking/gating

IV. Commissioning and QA implications for SI

IV.A. Brief summary of TG-147 recommendations

IV.B. Phantom selection for SI

IV.C. Incorporating SI into existing QA program including other imaging modalities

IV.D. QA issues unique to SI

V. Risk Assessment (TG-100)

V.A. Role of SI for risk assessment

V.B. Example of risk assessment for DIBH treatment using SI

VI. Emerging clinical applications and associated QA considerations

VI.A. Emerging applications

VI.B. Emerging clinical workflows

VII. Key recommendations

VIII. Conclusions

Timeline: Finalized Draft 1/1/2020

Courtesy Alonso Gutierrez, PhD.

Atrium Health Levine Cancer Institute

SGRT Textbook

- Coming 2019?
- Publisher: Taylor & Francis Group/CRC Press
- Editors: Hoisak, Paxton, Waghorn and Pawlicki

Future Directions

- SGRT only for initial patient set up – eliminate tattoos (some places have done this already)
- Patient identification applications
- Use intra-fraction motion data to determine margins

Disadvantages of SGRT

- Require patient surface to be visible – could limit types of immobilization used
- Gantry, imaging arms etc can block the camera's view of the patient
- Surfaces without much variation can be challenging to track
- Surface is not always a reliable surrogate for internal tumor position
- Potential mismatches in surfaces generated from a CT dataset and that reconstructed by SGRT

Conclusions

- SGRT is an attractive option for patient set-up and intra-fraction monitoring
- Can be used for almost any treatment site
- Uses visible light – no additional dose to the patient
- Sub-millimeter accuracy is achievable
- Surface – internal correlation is still under investigation