Video-Based Positioning for Breast Radiotherapy

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Disclosures

- I am employed by the University of Chicago.
- I receive royalties from the University of Chicago for software licensed for computer aided detection of breast cancer.

Learning Objective

- Discuss the use of video-based surface imaging (SI) of breast cancer patients for:
  - Initial positioning
  - Real-time tracking during deep-inspiration breath hold (DIBH) treatments

Outline

- Clinical rationale: Cardiac dose
- DIBH techniques: ABC, RPM, Surface Imaging (SI)
- Verifying DIBH: MV ports, MV cine, CBCT
- Absolute versus relative positioning with SI
- Real-time tracking with SI: Surveillance, DIBH
- Clinical issues for DIBH with SI: Patient selection, Field matching, Reconciling with x-ray
- Challenges when using SI for breast RT
- Example workflows of SI for breast RT
- Future Directions of SI

Clinical Rationale

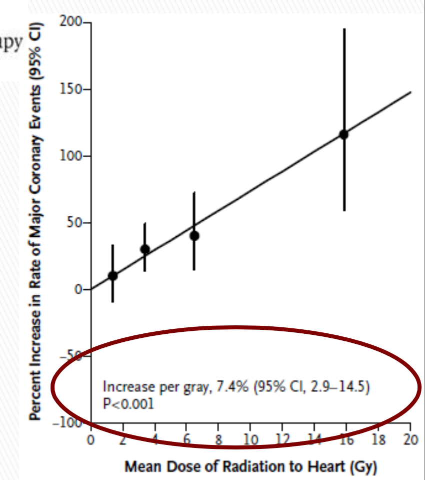
Cardiac Dose

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 MARCH 14, 2013 VOL. 368 NO. 11

Risk of Ischemic Heart Disease in Women after Radiotherapy for Breast Cancer

- Population-based study in Sweden & Denmark
- Breast RT from 1958-2001:
  - 963 major coronary events
  - 1205 controls
- Heart dose estimated:
  - "CT scan of a woman with typical anatomy"



NSABP B-51 Sets De Facto Standard

Ipsilateral lung:

- **Arm 1/Group 1A:**
  - $\leq$ 15% of the ipsilateral lung should receive $\geq$ 20 Gy
  - $\leq$ 35% of the ipsilateral lung should receive $\geq$ 10 Gy
  - $\leq$ 50% of the ipsilateral lung should receive $\geq$ 5 Gy
- **Arm 2/Groups 2A and 2B:**
  - $\boxed{\leq \text{30\% of the ipsilateral lung should receive} \geq \text{20 Gy}}$
  - $\leq$ 50% of the ipsilateral lung should receive $\geq$ 10 Gy
  - $\leq$ 65% of the ipsilateral lung should receive $\geq$ 5 Gy

Contralateral lung:

- $\leq$ 10% of the contralateral lung should receive $\geq$ 5 Gy

Heart:

- **Arm 1/Group 1A**
  - $\leq$ 5% of the whole heart should receive $\geq$ 20 Gy for left-sided breast cancers, and 0% of the heart should receive $\geq$ 20 Gy for right-sided breast cancers
  - $\leq$ 30% of the whole heart should receive $\geq$ 10 Gy for left-sided breast cancers, and $\leq$ 10% of the heart should receive $\geq$ 10 Gy for right-sided breast cancers
  - $\boxed{\text{Mean heart dose should be} \leq \text{400 cGy}}$
- **Arm 2/Groups 2A and 2B**
  - $\leq$ 5% of the whole heart should receive $\geq$ 25 Gy for left-sided breast cancers, and 0% of the heart should receive $\geq$ 25 Gy for right-sided breast cancers
  - $\leq$ 30% of the whole heart should receive $\geq$ 15 Gy for left-sided breast cancers, and $\leq$ 10% of the heart should receive $\geq$ 15 Gy for right-sided breast cancers
  - $\boxed{\text{Mean heart dose should be} \leq \text{400 cGy}}$

Cardiac dose reduction strategies

1. Increase distance from target to heart:
   - Prone positioning
   - Exploit advantages of breathing cycle
2. Reduce dose to heart
   - IMRT/VMAT
   - Proton

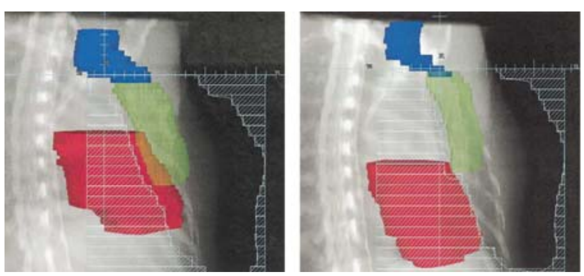
Shah et al, *Radioth & Oncol*, 112:9–16, 2014.

DIBH Techniques

ABC, RPM, SI

Advantages of DIBH

- Freeze organ/tumor motion
- Separate heart from target (breast, IMN)
- Increase total lung volume



Remouchamps et al, *IJROBP*, 55(2): 392–406, 2003.

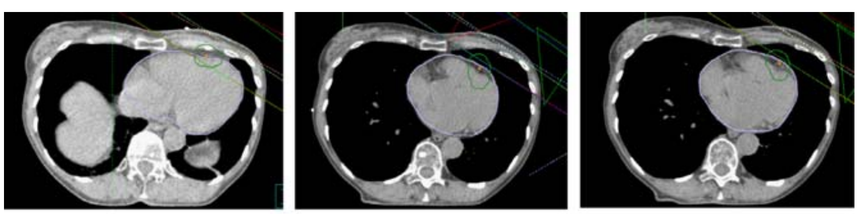
Active Breathing Control (ABC) with Spirometer at William Beaumont

- Largest U.S. institutional experience:
  - 87 patients with ≤T2 disease
  - 50% treated with simple tangents only (FIF)
  - Median dose of 46Gy + 16Gy boost
- Compared to free-breathing (FB), moderate DIBH significantly *decreased*:
  - Mean heart dose (4.23Gy vs. 2.54Gy)
  - Mean left lung dose (9.08Gy vs. 7.86Gy)
  - All dosimetric parameters (V5, V10, V15, V20) for lung/heart

Swanson et al, *Am J Clin Oncol.* ,36(1): 24–30, 2013.

Voluntary Breath Hold vs. ABC

- 23 patients receiving 40 Gy in 15 fractions:
  - Randomized to v_DIBH or ABC_DIBH for 7 fractions & vice versa
  - Daily portal imaging & CBCT for 6 fractions
- No significant Δ: setup errors, normal tissue doses
- *Patients & therapists significantly preferred v_DIBH!*

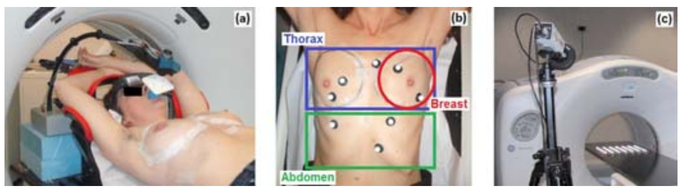


Free breathing v_DIBH ABC_DIBH

Bartlett et al, *Radiother Oncol*,, 108 :242–247, 2013.

Breast/Chest Wall Surface vs. ABC

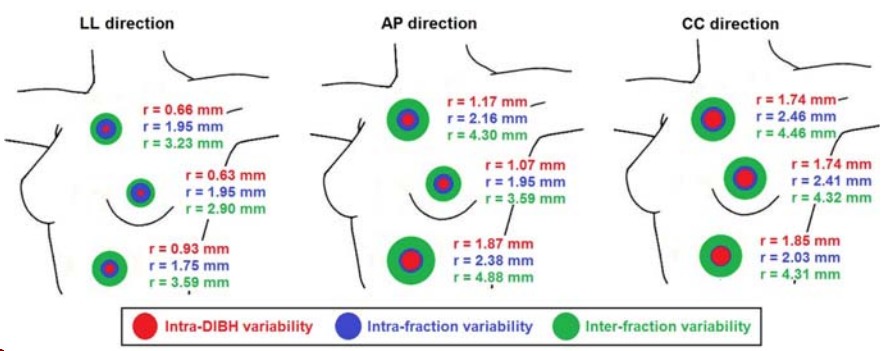
- Surface displacement studied in 7 patients with IR markers:
  - During a single DIBH
  - Intra-fraction (between DIBH/same treatment)
  - Inter-fraction



Fassi et al, *J Appl Clin Med Phys*, 15(1): 130-140, 2014.

Breast/Chest Wall Surface vs. ABC

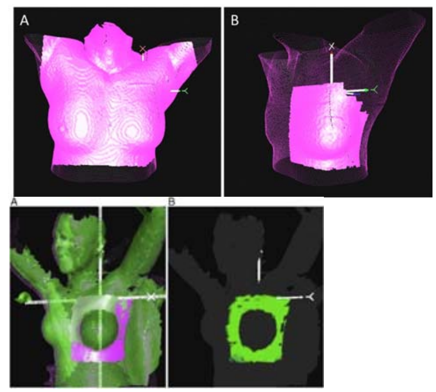
- "Spirometer-based control does not guarantee a stable and reproducible position of the external surface in left-breast DIBH"



Fassi et al, *J Appl Clin Med Phys*, 15(1): 130-140, 2014.

Surface Imaging (SI) for Breast Cancer

- Advantages:
  - 3D modality
  - Real-time monitoring
  - No radiation dose
- Disadvantages:
  - Variations with ROI used for registration
  - Tissue deformation can lead to low correlation with MV films
  - Results difficult to interpret



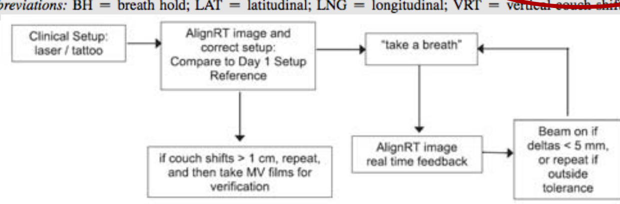
Cervino et al, *PMB* 54, 2009.
Shah et al, *PRO* 3: 16-25, 2013.
Tang et al., *PRO* 4: e151-e158: 2014.
Padilla et al, JACMP 15: 4921, 2014.

Voluntary DIBH with AlignRT

- Surface variability (2-3 mm) comparable to spirometry-controlled in 20 patients
- 7/20 did not require additional reference surfaces

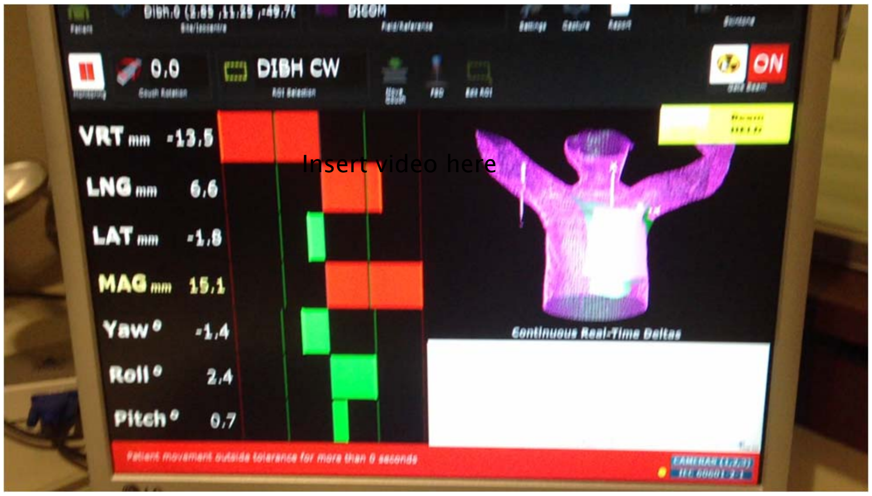
Treated BH fields			BH out of tolerance		
Mean Real-time delta (mm)			Mean Real-time delta (mm)	Maximum Real-time delta (mm)	Percent BH out of tolerance
VRT	LNG	LAT	All directions	All directions	Mean (SD, range)
2.2	2.3	2.0	6.3	8.8	22 (11,7-41)

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



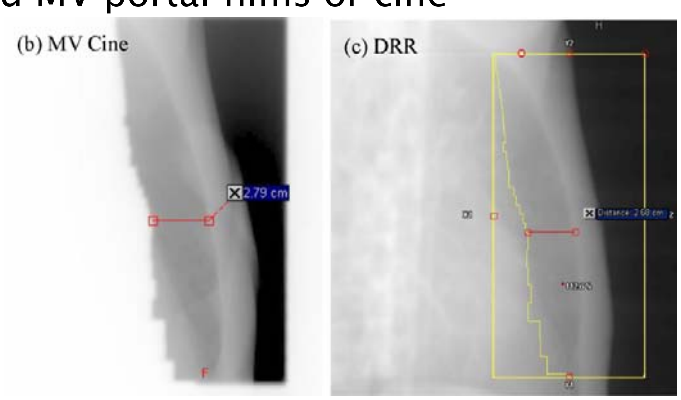
Gierga et al, *IJROBP*, 84(5), 2012.

Voluntary DIBH with AlignRT (8th fraction)



Real-Time Position Management (RPM) vs. AlignRT

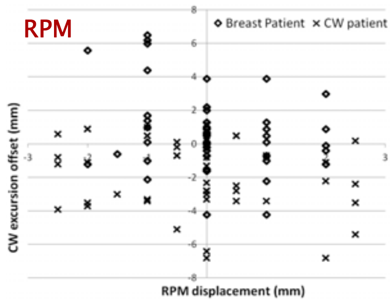
- Chestwall excursion offset between DRRs and MV portal films or cine

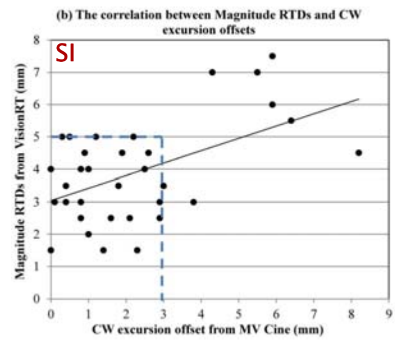


Rong et al, *PLOS ONE*, 9(5), 2014.

Real-Time Position Management (RPM) vs. AlignRT

- Chestwall excursion & RPM: no correlation
- Chestwall excursion & SI: correlation = 0.52



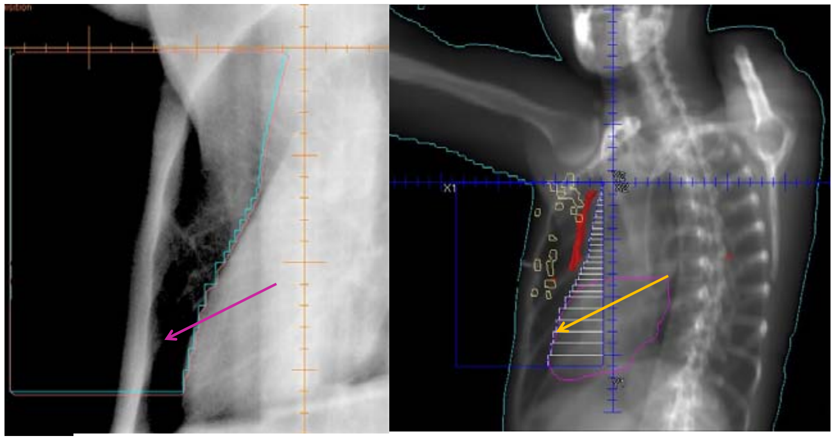


Rong et al, *PLOS ONE*, 9(5), 2014.

Verification of DIBH

Using Surface Imaging

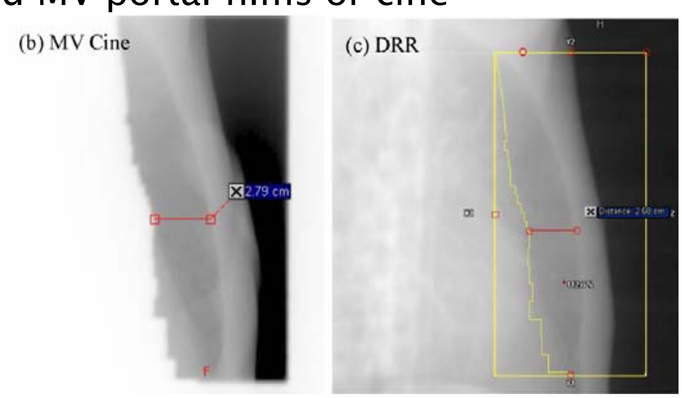
Comparison of MV Port Films to DRR



Mean heart dose reduced from 4.8 Gy (FB) to 1.2 Gy (vDIBH)

Comparison of MV Cine to DRRs

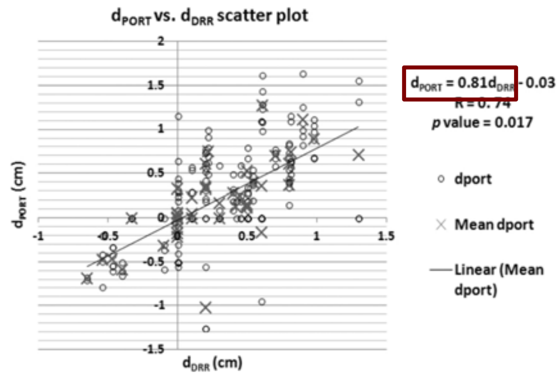
- Chestwall excursion offset between DRRs and MV portal films or cine



Rong et al, *PLOS ONE*, 9(5), 2014.

Consistent Differences Between MV Port and DRRs

- Inherent differences in image resolution?
- More dose to the heart than planned?



Tang et al., *PRO* 4: e151–e158: 2014.

CBCT vs. SI: Geometric Uncertainty of Heart

- Planning OAR margins recommended when setting up to surface: 1.1mm (LR), 6.7mm (CC), 2.5mm (AP)
- SI: "Harder to distinguish whether a setup error …is caused by anatomic changes or by a change in BH"

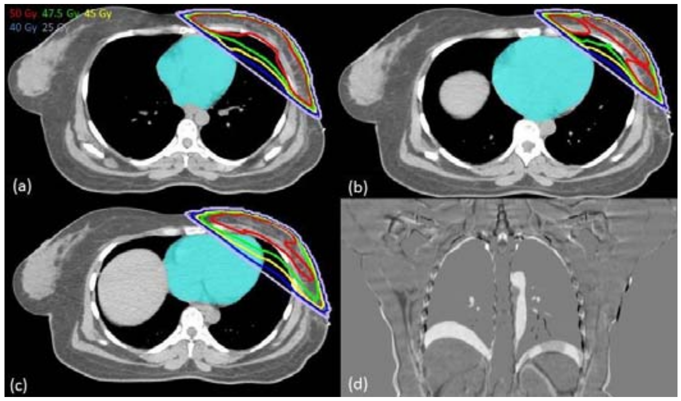
Table 2 The mean and maximum dose for the heart and left coronary artery averaged over all patients for planning, offline, and online protocol situations

	Dose (Gy)			p value (Wilcoxon Signed-rank Test)		
	Planned	Offline	Online	Planned vs. Offline	Planned vs. Online	Offline vs. Online
Heart D_{mean}	1.9	2.3	2.1	0.04	0.71	0.02
Heart D_{max}	40.2	36.2	35.5	0.02	0.01	0.26
Left coronary artery D_{mean}	6.5	7.5	7.1	0.05	0.53	0.02
Left coronary artery D_{max}	26.6	25.9	25.0	0.37	0.09	0.13

Abbreviations: D_{max} = maximum dose; D_{mean} = mean dose.
For offline and online protocols, the dose was first accumulated over all breathing phases and then over all fractions. Wilcoxon signed-rank test was calculated to determine statistical significance dose difference between the protocols.

Topolnjak et al, *IJROBP*, 82(4):e6470e655, 2012.
Alderliesten et al, *Radiother Oncol*, 109:442-447, 2013.

ΔDose Between Breath-Holds



	DIBH1	DIBH2	FB
Heart Mean Dose (Gy)	1.8	2.5	8.7
Lung V20 (%)	24%	29%	39%

Surface Imaging for Breast RT

- Using Video-Based Systems

Absolute vs. Relative Positioning?

- Absolute:
  - Register to same reference surface
  - Reduce systematic errors?
  - Reduce frequency of filming?
- Relative:
  - Capture new reference surfaces
  - Reduce intra-fraction errors?
  - Relies on use of "other" IGRT modality

Relative Positioning Workflow

- "If there was a discrepancy between the patient position determined by surface and MV imaging, then a new set of initial setup and/or BH reference surfaces was generated and used for subsequent treatments."

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
VRT	LNG	LAT	All directions	All directions	Mean (SD, range)
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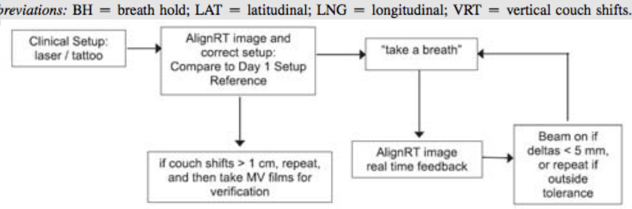
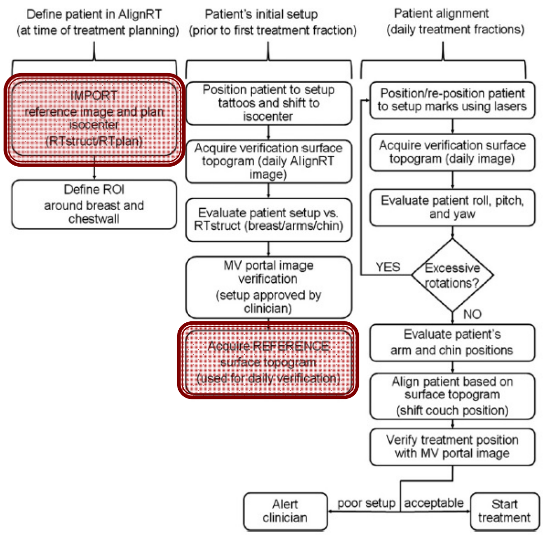


Gierga et al, *IJROBP*, 84(5), 2012.

Semi-Absolute Positioning Workflow



Shah et al, *PRO* 3: 16-25, 2013.

Implementing SI for Breast RT/DIBH

- Patient selection:
  - Compliance
  - Breast size or pendulous shape
  - Dosimetric threshold for use of DIBH?
- Technical:
  - Field matching during DIBH
  - Bolus placement obstructs surface
  - Dependencies of registration on ROI selection
  - Reconciling discrepancies between SI and MV/kV?
- Training:
  - Steep learning curve/difficult to interpret SI

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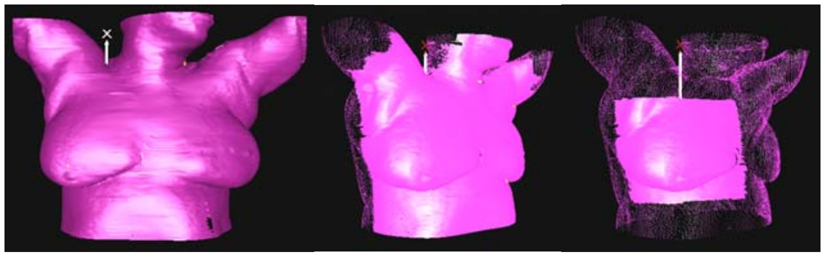
Surface Imaging with AlignRT

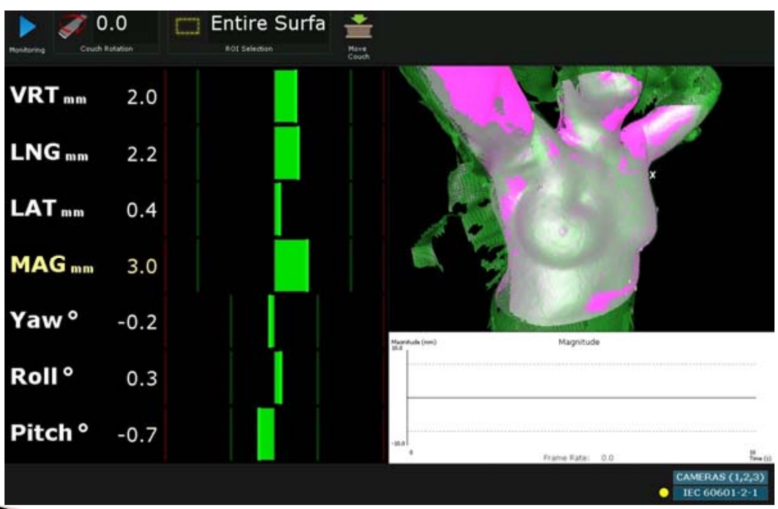
Functionality

Reference Surface & ROIs for Registration



3D Surface from CT data | 'Entire' ROI | 'Breast' ROI

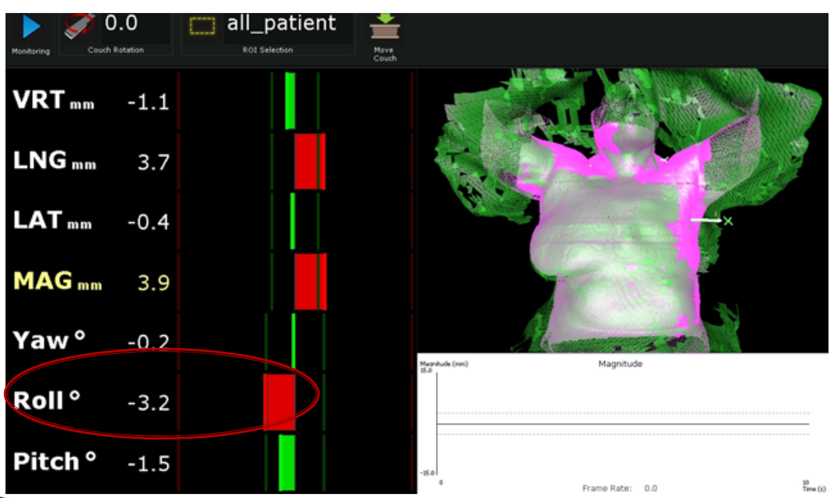
Rigid Registration Yields Translations & Rotations



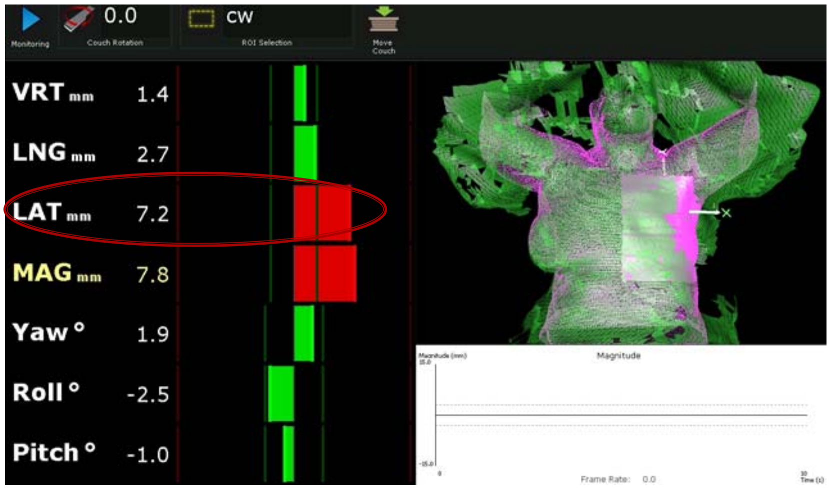
Surface Imaging with AlignRT

- Registration Variations with ROI Selection

Registration of 'Entire' ROI Identifies Roll



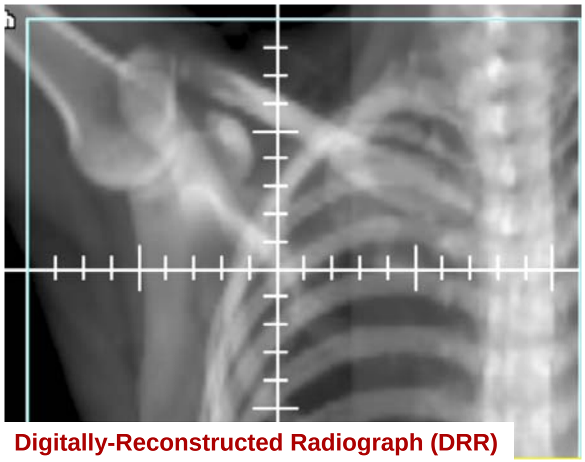
Registration of ‘CW’ ROI Misinterprets Roll as LAT shift



Surface Imaging with AlignRT

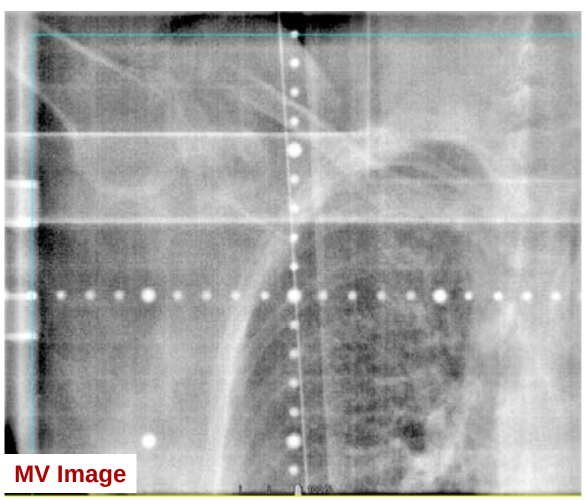
- Reconciling SI with kV/MV

Verification with Weekly MV Imaging



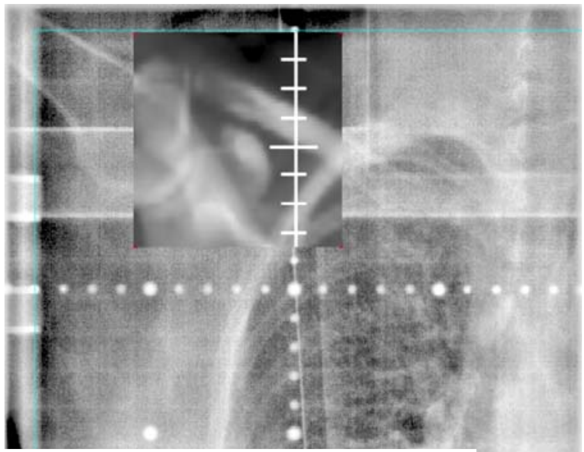
Digitally-Reconstructed Radiograph (DRR)

Verification with Weekly MV Imaging



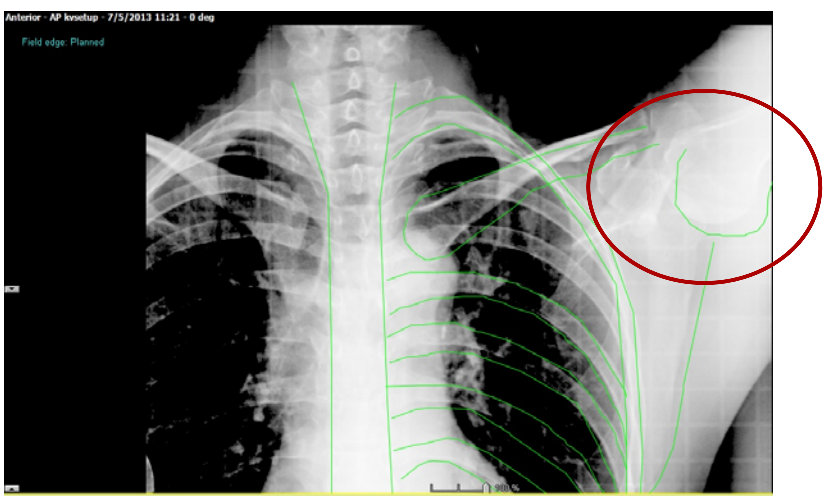
MV Image

Verification with Weekly MV Imaging

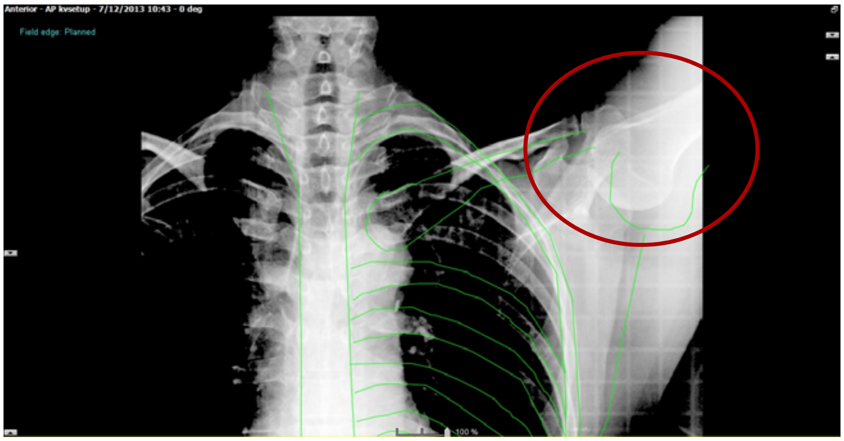


Landmark Matching of DRR & MV Image

Following Adoption of kV Imaging

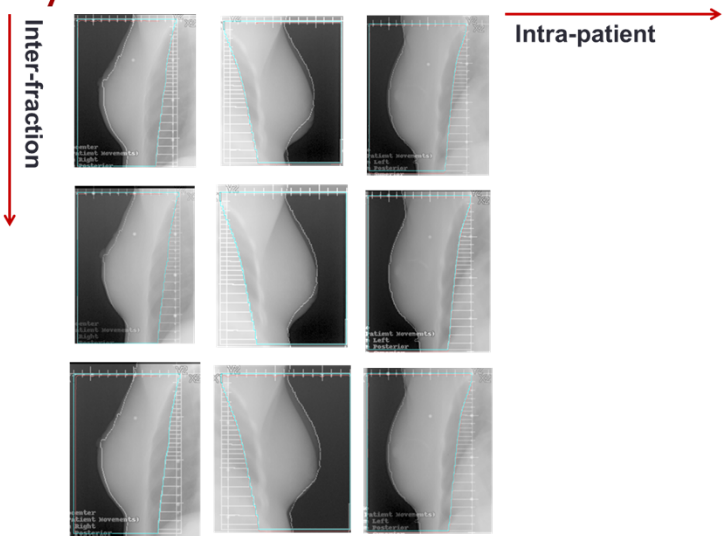


Following Adoption of kV Imaging



kV Orthogonal Films

Breast Surface & Bony Anatomy Do Not Always Correlate



Padilla et al, JACMP 15: 4921, 2014.

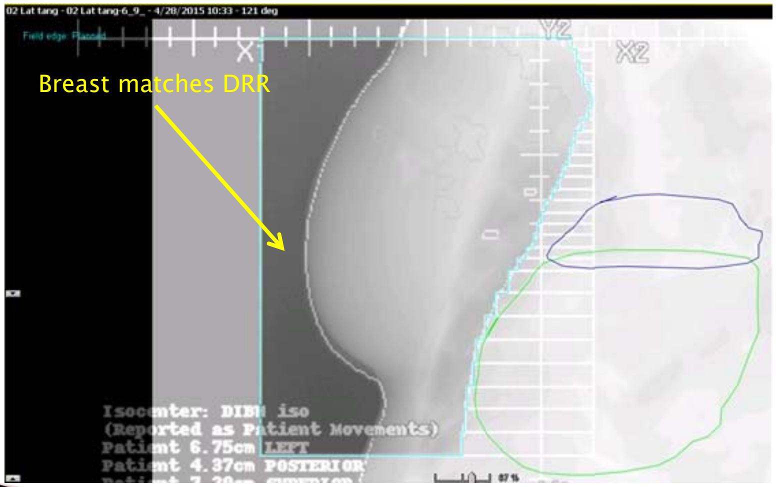
Surface Imaging with AlignRT

- Steep Learning Curve

WBRT Example: Setup Variability Day 7

WBRT Example: AlignRT Detects ↑ Pitch & VRT on Day 7

WBRT Example: Setup Variability Day 8



WBRT Example: AlignRT No Pitch or VRT on Day 8

Surface Imaging with AlignRT

Challenges/Pitfalls

Potential Clinical Challenges

- Changes in patient surface
  - Tissue deformation: swelling, shrinking seroma
  - Skin darkening during throughout treatment
- Non-specific topography
  - Male vs. female
  - Post-matectomy chestwall vs. intact breast
- Accuracy of surface generation from CT
  - Use of slow CT acquisition for FB
  - HU threshold to create DICOM reference surface
- Detecting changes in breathing pattern

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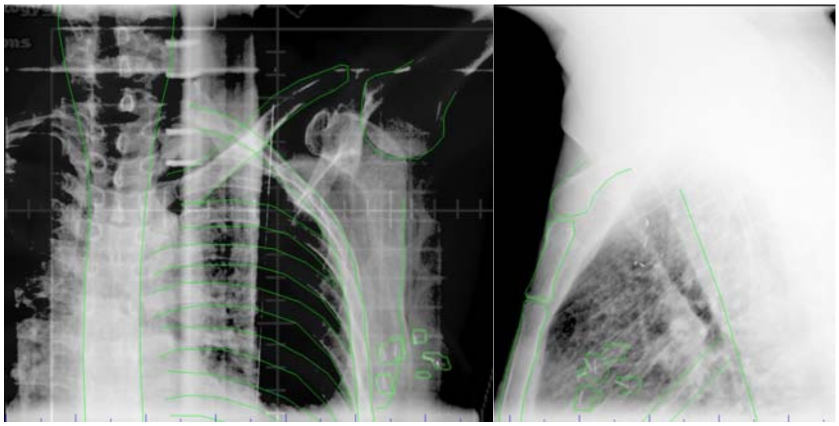
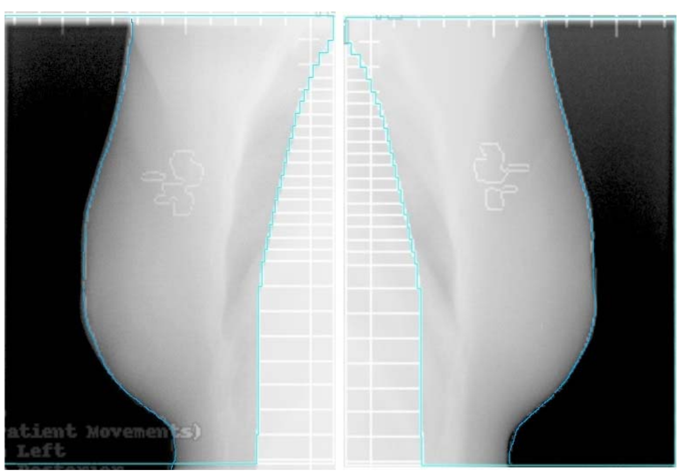
Surface Imaging with AlignRT

» Tissue Deformation

WBRT Example: First Day Orthogonal kV Films

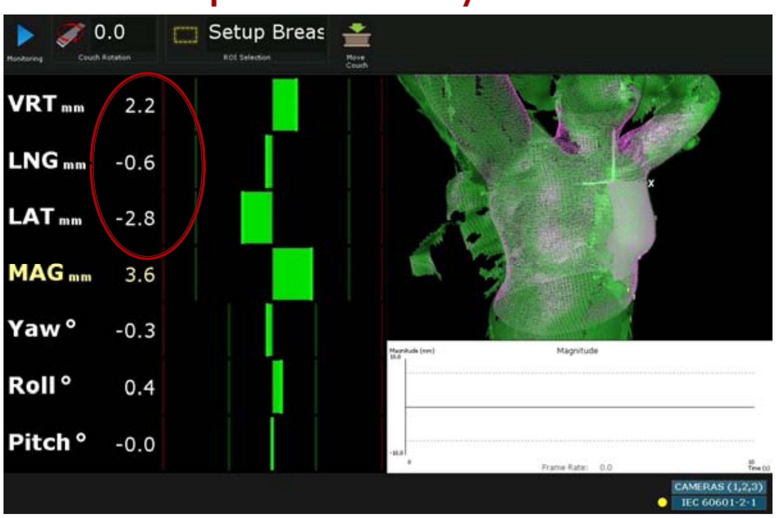


WBRT Example: First Day Tangent MV Films

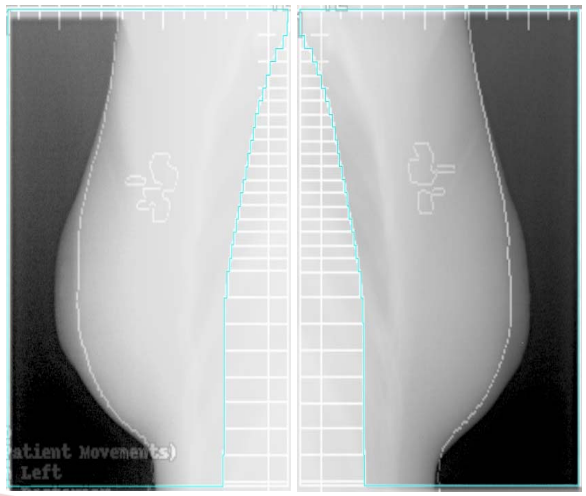


WBRT Example: First Day ‘Entire’ ROI

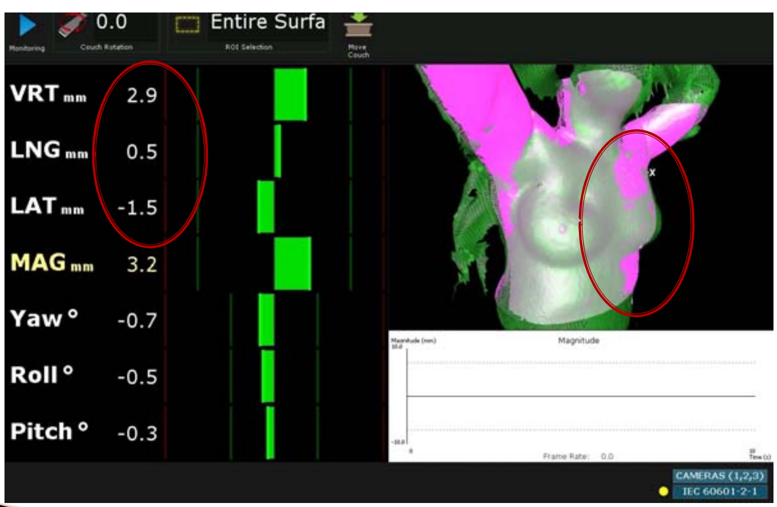
WBRT Example: First Day ‘Breast’ ROI



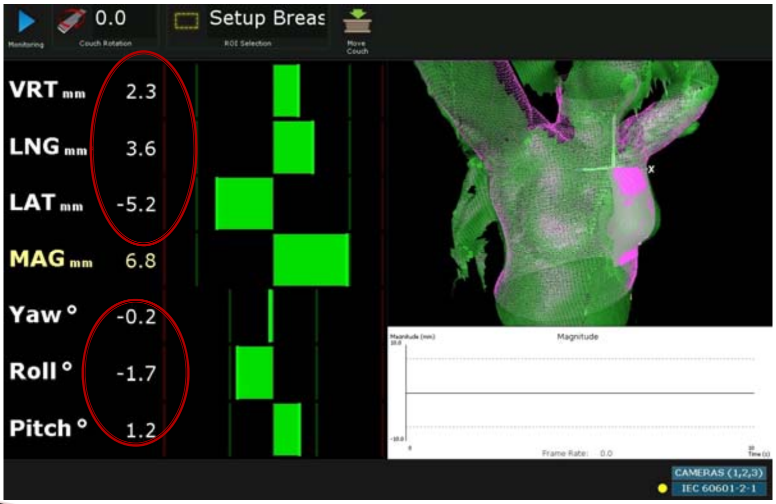
WBRT Example: 24th Treatment Tangent Films



WBRT Example: 24^{th} Fraction 'Entire' ROI



WBRT Example: 24th Fraction ‘Breast’ ROI

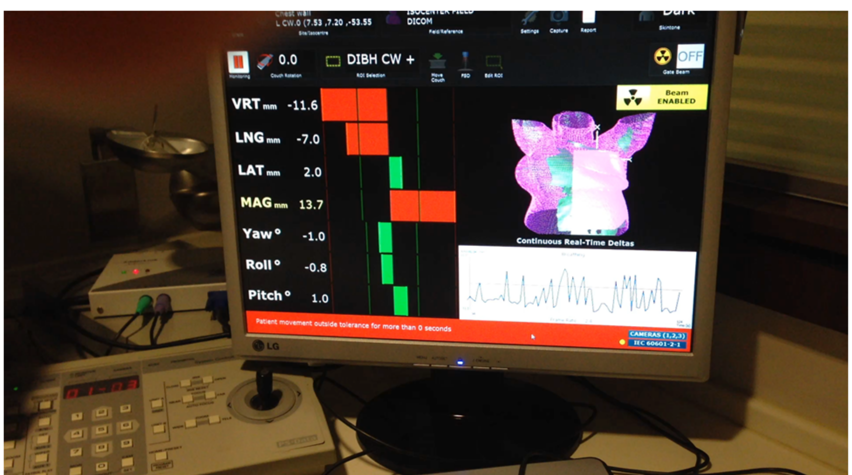


Surface Imaging with AlignRT

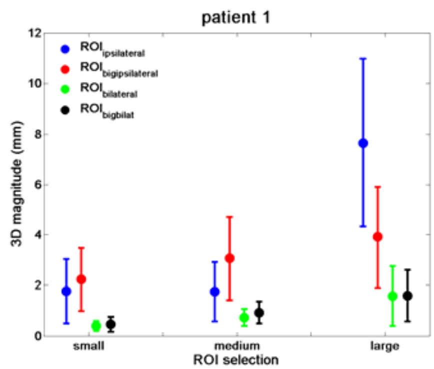
» Skin Darkening

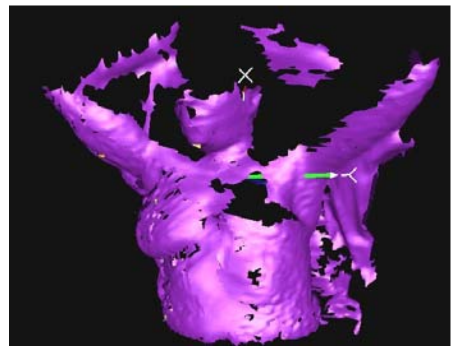
Skin Darkening Degrades SI Quality

Skin Darkening Due to Bolus Causes Registration Instability



Skin Darkening Degrades SI Quality

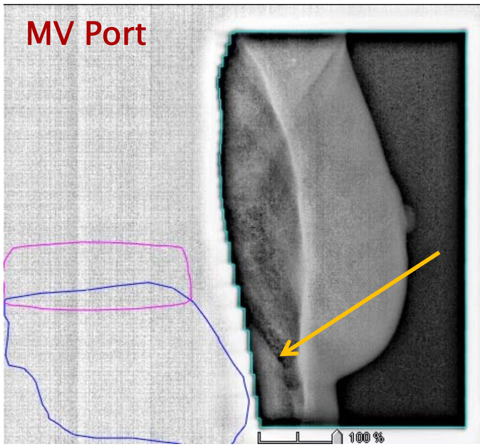


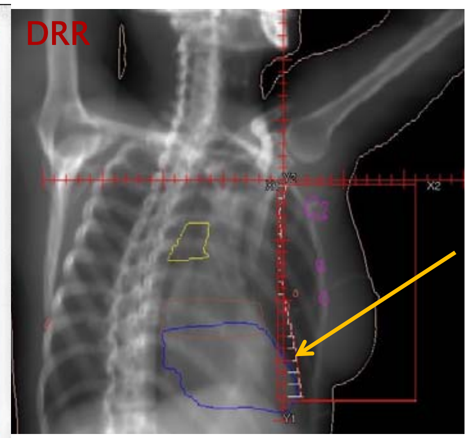


Surface Imaging with AlignRT

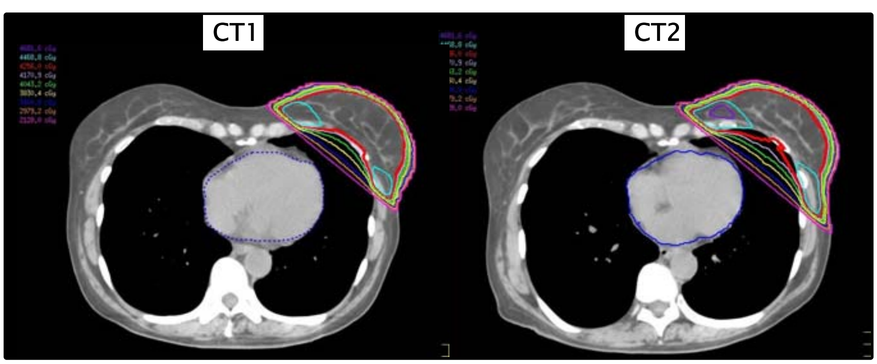
Changes in Breathing Pattern

Heart Position Mis-Match Detected

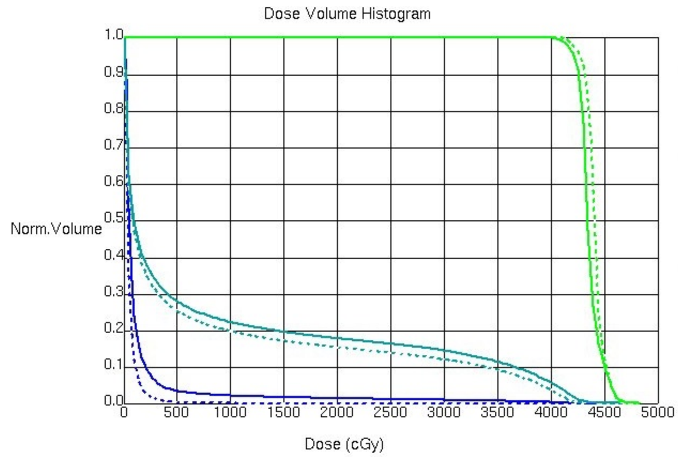




Repeat CT Simulation Following Changes in Breathing Pattern

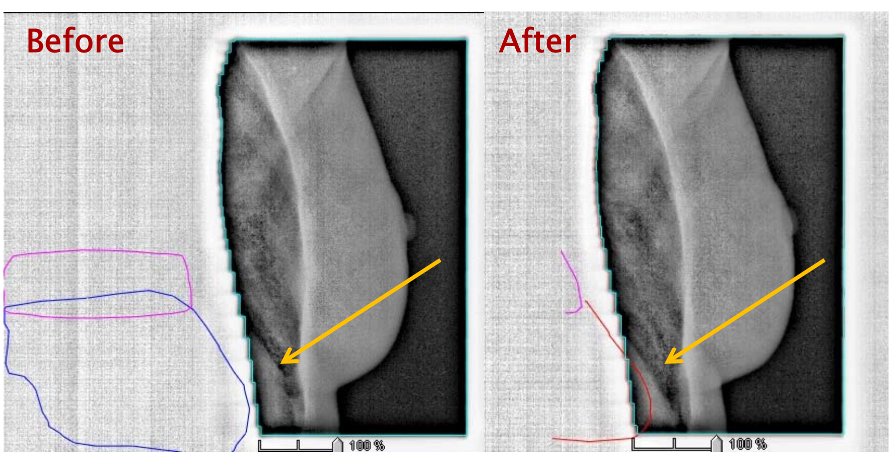


Project Plan onto New CT Scan Following Changes in Breathing Pattern



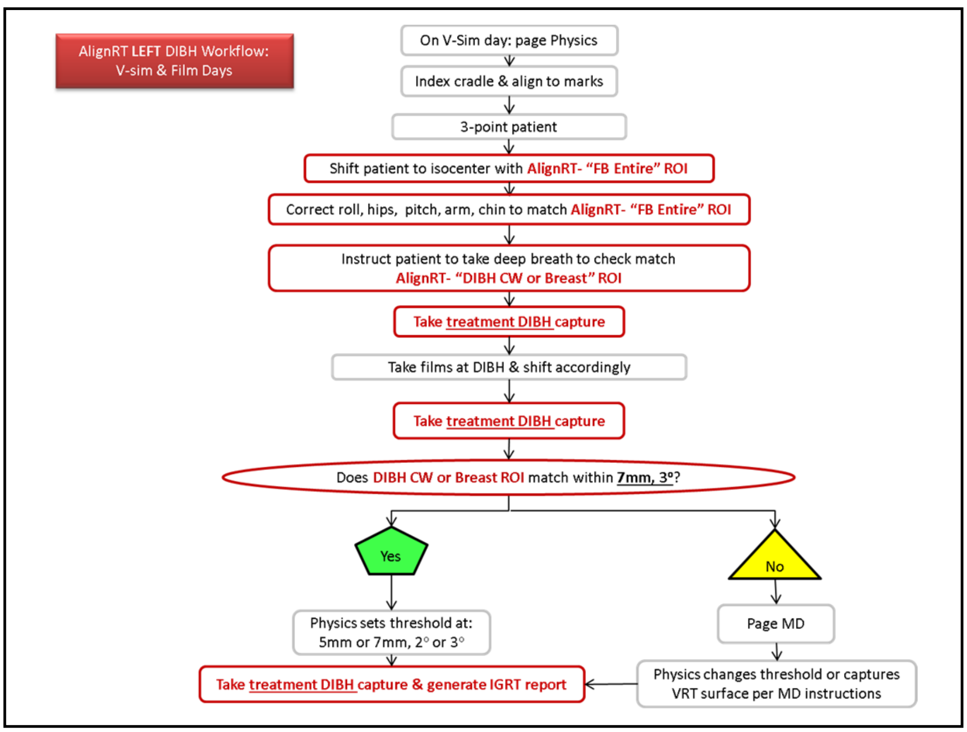
Mean Heart Dose	0.5 Gy	1.4 Gy	2.7 Gy
Lung V20Gy	15%	17.7%	23%

MV Ports Pre & Post Re-simulation



Surface Imaging with AlignRT

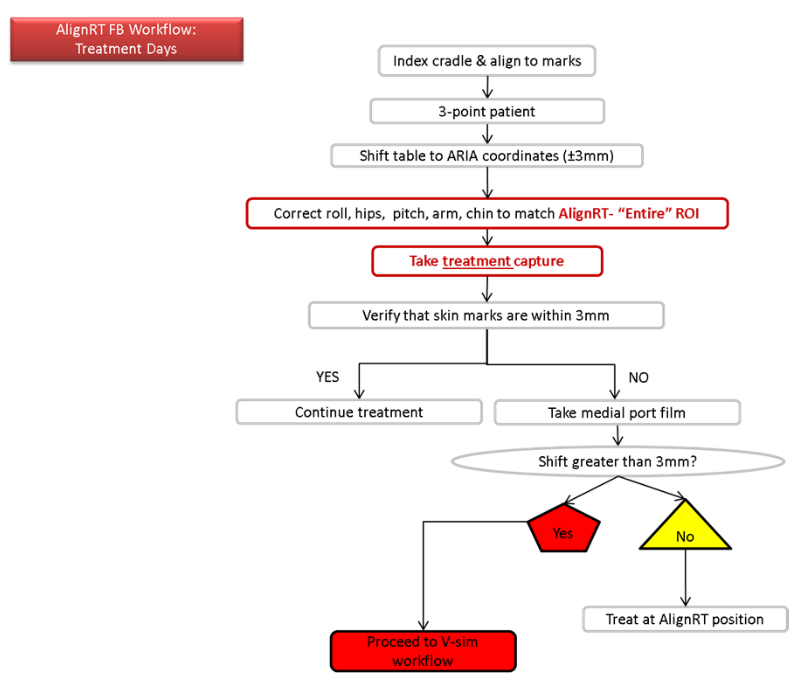
Workflows



Benefits of SI other than DIBH?

- Improve intra-fraction positioning
  - Real-time monitoring throughout treatment
- Improve patient safety
  - Particularly for multiple isocenter treatments
- Reduce filming frequency
  - Requires absolute positioning?
- Improve throughput?

n=50	Before AlignRT	AfterAlignRT
% of Patients with shifts < 1cm	64%	92%
% of Patients with shifts < 1cm; total time < 30mins	44%	72%



FUTURE DIRECTIONS

IMRT, VMAT, Protons

Inverse-Planned IMRT

- Optimizes radiation intensity levels in many non-opposing beam angles (e.g., 9 beams)
- Advantages:
  - Create concave dose volumes
  - Control placement of steep dose gradients
- Disadvantages:
  - Low dose spillage to heart, contralateral lung
  - Longer treatment time

IS MULTIBEAM IMRT BETTER THAN STANDARD TREATMENT FOR PATIENTS WITH LEFT-SIDED BREAST CANCER?

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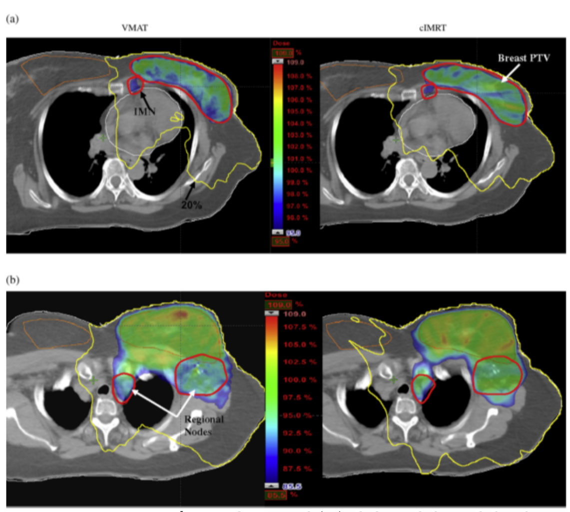
- **Conclusions**: "IMRT significantly improved conformity and homogeneity for plans when the breast + IMNs were in the CTV. Heart and lung volume receiving high doses were decreased, but more healthy tissue received low doses."
- **Discussion**: "Current practice is to use conformal IMRT if the plan results in an absolute reduction in heart V30 of 10% or greater compared to MWT or DIM technique."

Beckham *et al*, *IJROBP*, 69(3):918-924, 2007.

VMAT Mimics IMRT with ↓ Delivery Time



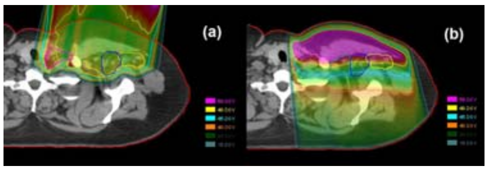
VMAT + DIBH?

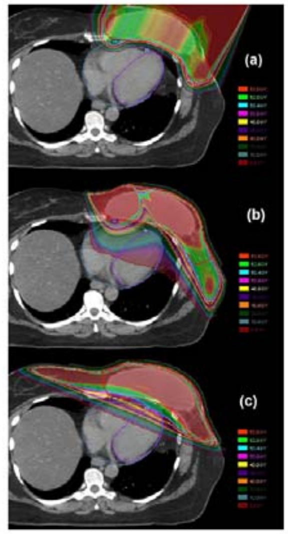
Popescu *et al*, *IJROBP*, 76(1):287-295, 2010.

Ongoing Research: Protons

protons + DIBH?

- Prospective clinical trial
  - 12 patients
  - Acceptable skin toxicity
  - Heart Mean = 0.1 – 1.2Gy
  - Lung Mean = 2.4 – 10.1Gy
  - Lung V20 = 4.4 – 22.1%





MacDonald *et al*, *IJROBP*, 86(3):484-490, 2013.

Collision prediction software for radiotherapy treatments

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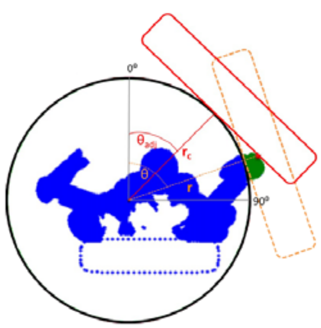

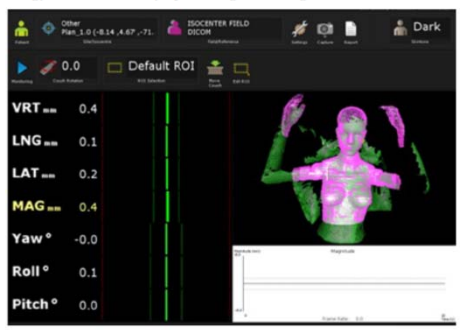

Padilla *et al*, *Med Phys*, 42(11):6448, 2015.

SI for Breast RT: Take-Home Points

- Advantages:
  - No radiation dose
  - 3D & real-time monitoring
  - Cardiac sparing using DIBH
  - Highlights surface changes (absolute positioning)
- Disadvantages:
  - Variations with ROI used for registration
  - Variability in surface (swelling, skin darkening) can lead to registration errors
  - Discrepancy with kV/MV films
  - Steep learning curve

Acknowledgements

- Colleagues:
  - Steven Chmura, M.D., Ph.D.
  - Yasmin Hasan, M.D.
  - Hyejoo Kang, Ph.D.
  - Martha Malin, Ph.D.
  - Maxine Washington, RTT