CLINICAL APPLICATIONS OF SURFACE IMAGING SYSTEMS

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*****No disclosures*****

Learning Objective

1. Learn to incorporate QA for surface imaging into current QA procedures for IGRT.
2. Understand the advantages and limitations of surface imaging for clinical use in breast radiotherapy and cranial radiosurgery.
3. Learn about the potential use of surface imaging for real-time motion tracking.

Learning Objective

- Integrate surface imaging isocenter congruence testing into current IGRT QA
- Describe the commissioning process of surface imaging systems for whole breast radiotherapy

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Acceptance: Isocenter Coincidence

- "If individual errors are small by themselves, cumulative system accuracy for the procedure can be significant and needs to be characterized through an **end-to-end** test using phantoms with measurement detectors and imaging" (TG-101)

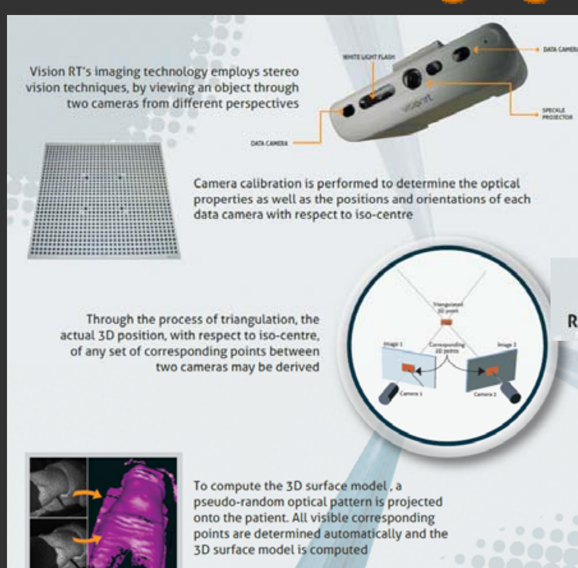
TG-142: Imaging & Treatment Isocenter Coincidence

Collision interlocks	Functional	Functional
Positioning/repositioning	≤2 mm	≤1 mm
Imaging and treatment coordinate coincidence (single gantry angle)	≤2 mm	≤1 mm
Cone-beam CT (kV and MV)		
Collision interlocks	Functional	Functional
Imaging and treatment coordinate coincidence	≤2 mm	≤1 mm
Positioning/repositioning	≤1 mm	≤1 mm
Monthly		
Planar MV imaging (EPID)		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling[b]	≤2 mm	≤2 mm
Spatial resolution	Baseline[c]	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Planar kV imaging[d]		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Cone-beam CT (kV and MV)		
Geometric distortion	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
HU constancy	Baseline	Baseline
Uniformity and noise	Baseline	Baseline

IGRT QA Goals

- To develop an end-to-end test to characterize isocenter coincidence:
  - Planning CT
  - MV
  - kV
  - CBCT
  - Surface imaging

3D Surface Imaging by VisionRT



3-camera installation
Non-HD cameras

alignrt®
Patient Setup and Surveillance

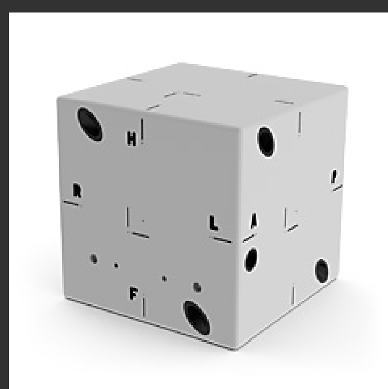
gatect®
Real Time Tracking For 4D CT Reconstruction

gatert®
Markerless Respiratory Gating

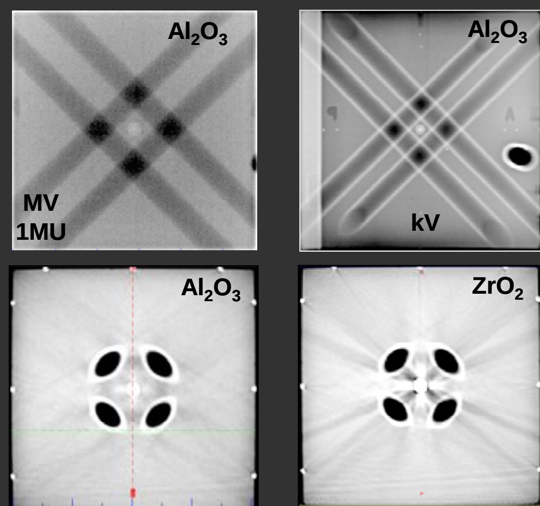
Multiple Imaging Modality Isocentricity (MiMi) Phantom from Standard Imaging

- Easy Alignment due to Unique Design:
  - "The MIMI Phantom incorporates five bone equivalent rods uniquely set so that four of them intersect at 90º angles when viewed in DRRs or a 2D projection image. The rods traverse the entire phantom making them visible in any image or slice allowing for easy 2D/2D and 3D/3D matching for fast verification of isocenter position."
- Test Integrated System Accuracy of:
  - 3D Cone Beam CT
  - MV/kV x-ray
  - Lasers and Couch Table Adjustments
  - Optical Guidance Systems

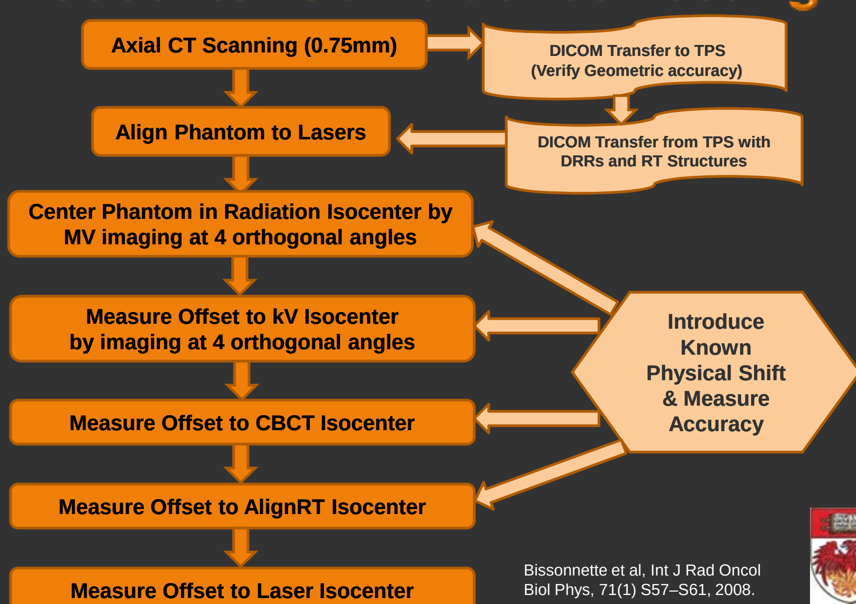
MiMi Phantom Makeover



MiMi Phantom Makeover

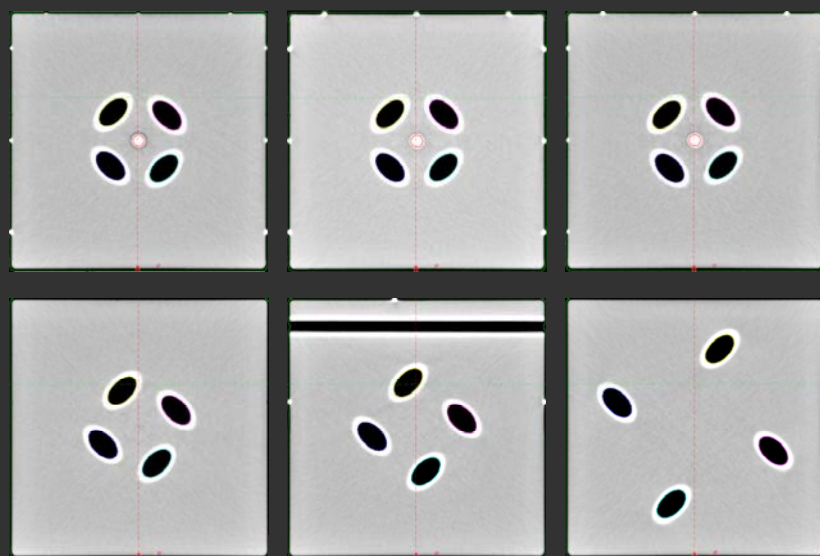


Isocenter Coincidence Testing

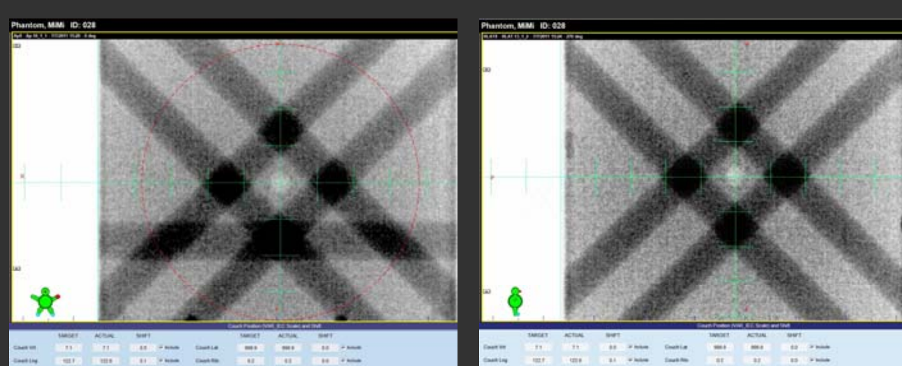


Bissonnette et al, Int J Rad Oncol Biol Phys, 71(1) S57–S61, 2008.

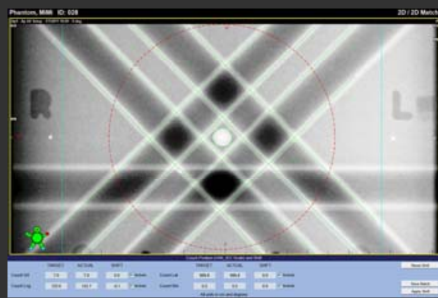
MiMi Phantom Axial CT Scans

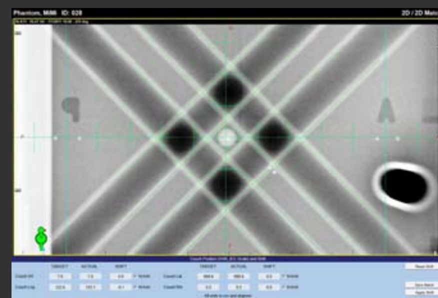


Center Phantom in MV Isocenter by Imaging at 4 Gantry Angles

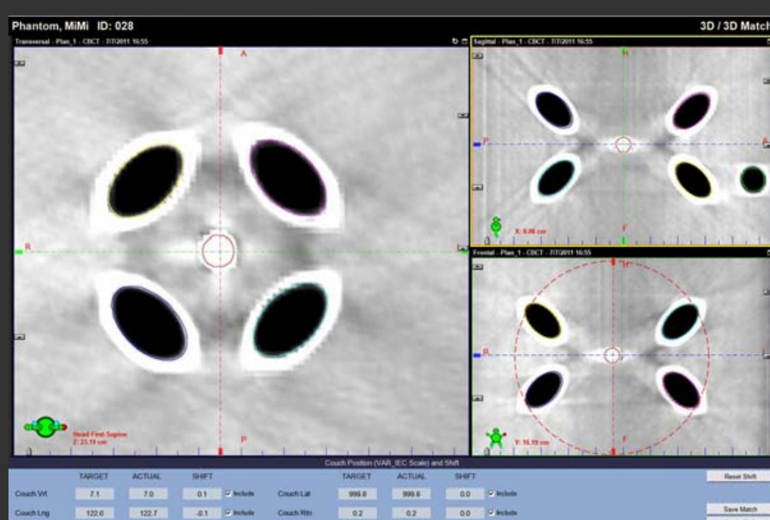


Measure Offset to kV Isocenter by 2D/2D Match at 4 Angles





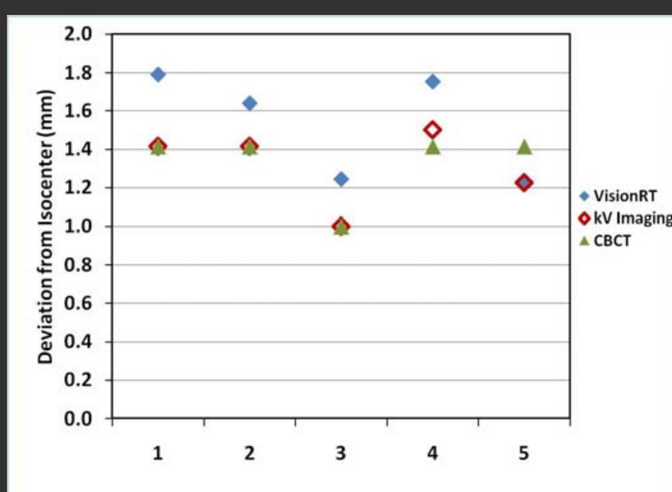
Measure Offset to CBCT Isocenter



Dependent upon CBCT Technique!

Measure Offset to Laser Isocenter

Root Mean Square Distances of IGRT Isocenter Offsets



IGRT isocenter aligned to SRS isocenter at our institution!

Learning Objective

- Integrate surface imaging isocenter congruence testing into current IGRT QA
- Describe the commissioning process of surface imaging systems for whole breast radiotherapy

Commissioning

- "Commissioning tests should be developed by the institution's physics team to explore in detail every aspect of the system with the goal of *developing a comprehensive baseline characterization of the performance of the system*." (TG-101)

APPENDIX D PERFORMANCE AND ACCURACY CLAIMS

Accuracy
3D surface data: Root Mean Square (RMS) error[4] of surface data < 1mm
Positioning accuracy: RMS target registration error[5] (TRE) <1mm
FSD measurement: RMS error[6] < 2mm
Contour extraction for 3D planning: RMS error of skin contour data < 1mm Dosimetric errors[7] for breast planning < 2%
Calibration Drift:
Typically[8] < 1mm per month

[4] As validated on rigid torso mannequin; Note: on importing DICOM RT data as reference surface, Vision RT accepts no responsibility for the accuracy of such data which may be affected by data resolution and breathing artefacts. Such errors could influence positioning accuracy.

[5] As validated on rigid torso mannequin. Note: on humans, RMS TRE's on torso region <2mm (additional errors caused by irregularity of different breathing cycles)

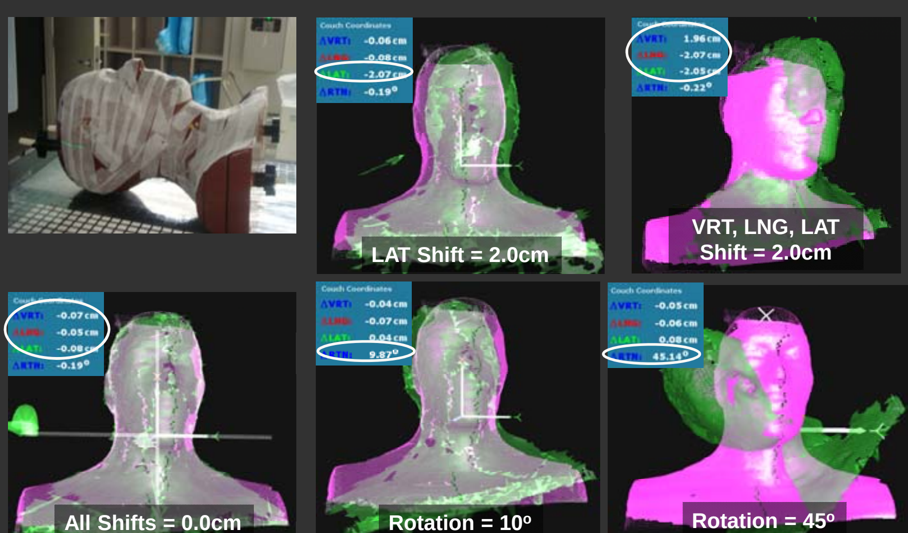
[6] As validated on rigid torso mannequin and human subjects. It is important to note that the FSD measurement methods used to validate AlignRT were precise to not more than 2mm. Thus it is possible that the accuracy of FSD measurement in AlignRT is better than quoted above.

[7] Dose errors to the breast either side of the lung (7mm from back edge)

[8] This assumes that the cameras have not been knocked and that the building structure to which they are attached has not changed materially.

"As validated on rigid torso mannequin. Note: on importing DICOM RT data as reference surface, VisionRT accepts no responsibility for the accuracy of such data which may be affected by data resolution and breathing artefacts. Such errors could influence positioning accuracy."

Commissioning: Translational & Rotational Accuracy



Commissioning: Whole-Breast RT

- While the patient's surface is a good surrogate for the target, the quality of 3D surface registration could be compromised by deformation
- We investigated the reliability of 3D surface matching using AlignRT compared to positioning using skin marks followed by MV portal imaging for whole-breast radiotherapy (WBRT)

Commissioning: WBRT

- *Absolute* or *Relative* positioning?
- Absolute:
  - Use same DICOM surface throughout treatment
  - Reduce systematic errors?
  - Reduce frequency of filming?
- Relative:
  - Capture new reference surfaces
  - Reduce intra-fraction errors?
  - Relies on use of "other" IGRT modality

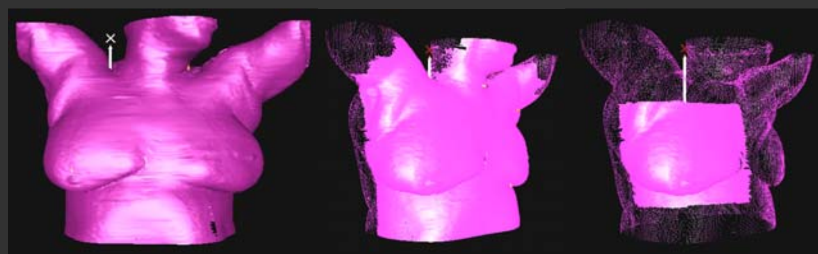
WBRT: Methods

- 11 patients:
  - Positioned supine with both arms above the head
  - Immobilized on alpha cradle and slant board
  - No respiratory gating
- Verification of breast positioning includes:
  - Setup to skin marks using lasers/tattoos *daily*
  - MV verification & alignment *weekly*
    - Orthogonal pair (AP & LAT)
    - Tangential portal images

WBRT: Methods

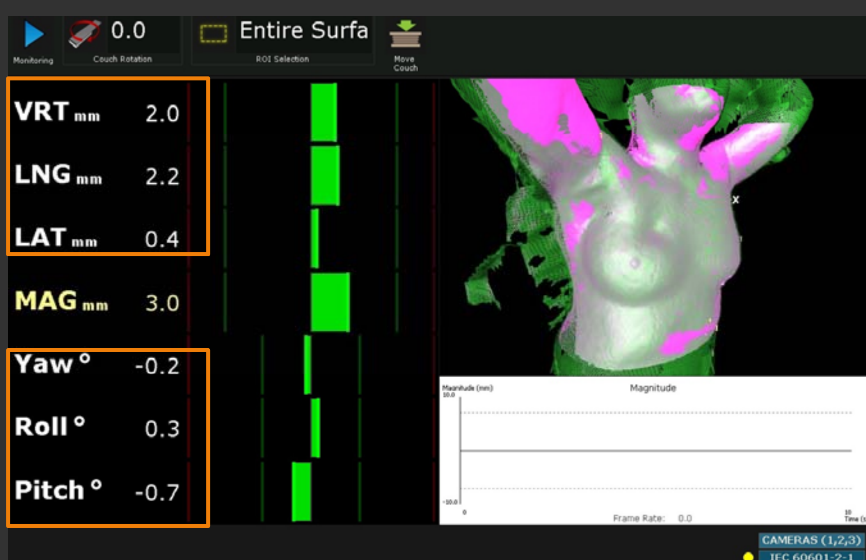
- 3D "reference" surface generated from planning CT scan (slice thickness = 3mm, pixel size = 1.07-1.37mm)
- AlignRT (v5.0) use to capture surfaces but *not* for patient alignment:
  - 28 Pre-shifts (after correction for rotations using MV)
  - 41 Post-shifts
  - 162 Daily (non-filmed fractions)
- Statistical analysis:
  - PTV margin using van Herk formulation
  - 95% limits-of-agreement (LOA) range

WBRT: Methods



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

WBRT: AlignRT Translations & Rotations



WBRT: Filmed Fractions Results

	Body mass index (kg/m2)
Median (range)	29 (23-36)
18.5-25 (normal)	3
> 25-30 (overweight)	4
> 30 (obese)	4

	PTV Margin (mm)		
	AP	CC	LR
MV Films	5.4	13.4	12.1
Entire surface Pre-Shifts	10.2	9.8	12.0
Breast surface Pre-Shifts	9.2	8.3	10.9

Results presented in Poster SU-E-J-56.

WBRT: Filmed Fractions Results

		LOA range (mm)		
		AP	CC	LR
Pre-shifts	Entire Surface	12.8	21.1	15.5
	Breast Surface	12.6	21.9	15.1
Post-shifts	Entire Surface	9.8	13.6	14.8
	Breast Surface	13.0	18.4	15.9

	Pearson's correlation coefficients		
	AP	CC	LR
Entire surface	0.49	0.14	0.66
Breast surface	0.47	-0.07	0.69

Results presented in Poster SU-E-J-56.

WBRT: Intra-patient & Inter-fraction variability of breast surface

Patient A | Patient B | Patient C

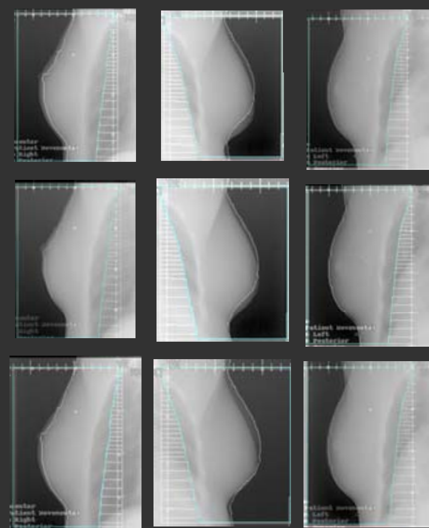
Intra-patient →

Inter-fraction ↓

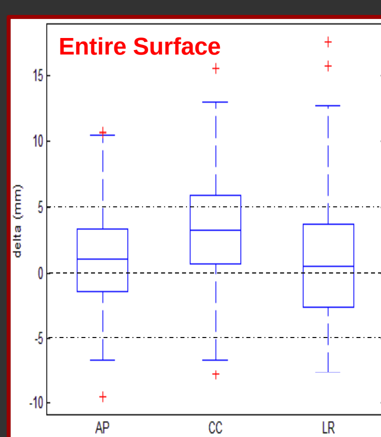
Fraction 1

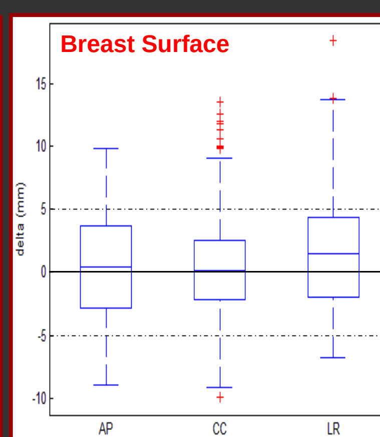
Fraction 2

Fraction 3



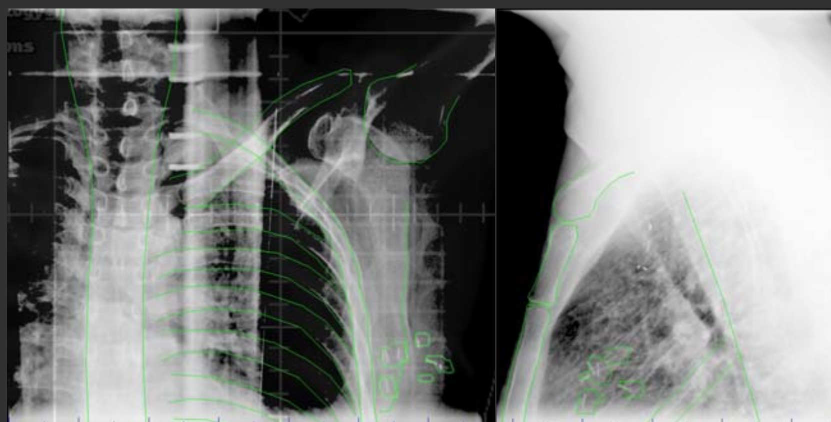
WBRT: 162 Daily Fractions Results



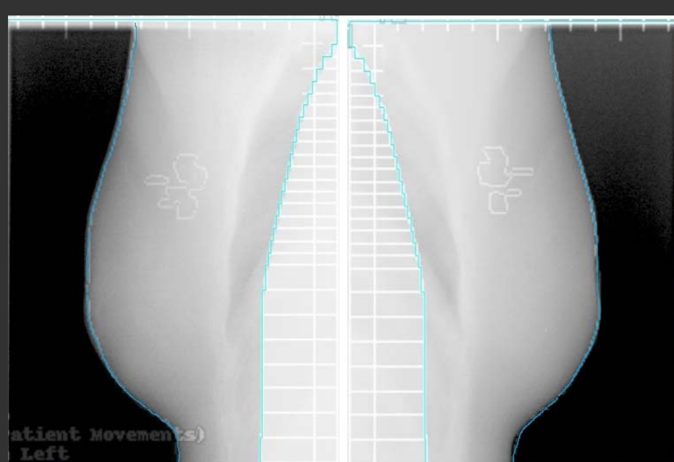


Box plots show the 25^{th}, median and 75^{th} percentile values. The bars indicate the smallest and largest non-outlier values. Red crosses designate outliers (values beyond 1.5*interquartile range from the 25^{th} and 75^{th} percentile values).

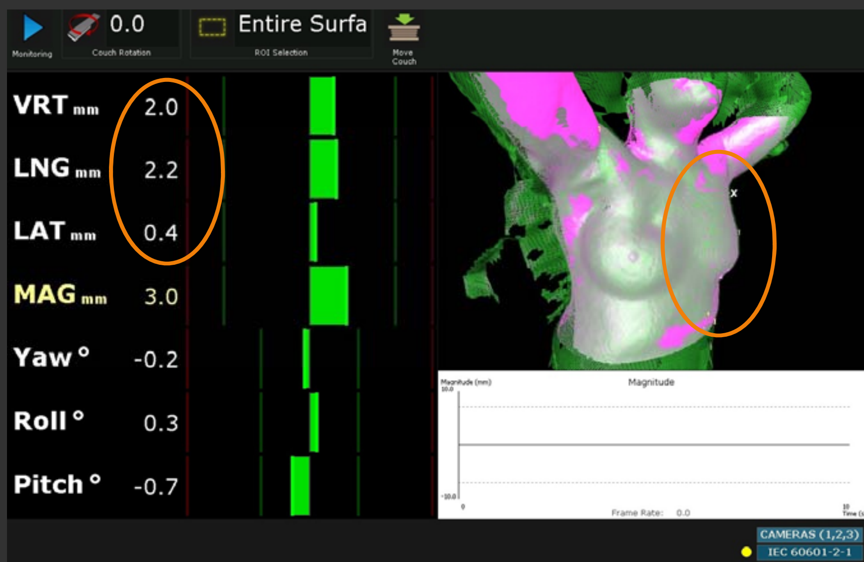
WBRT Example: First Day Orthogonal kV Films



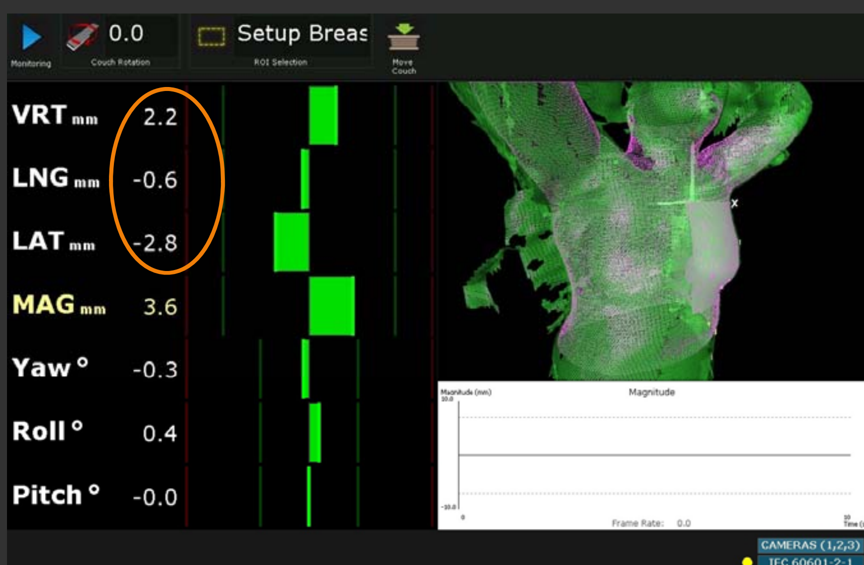
WBRT Example: First Day Tangent MV Films



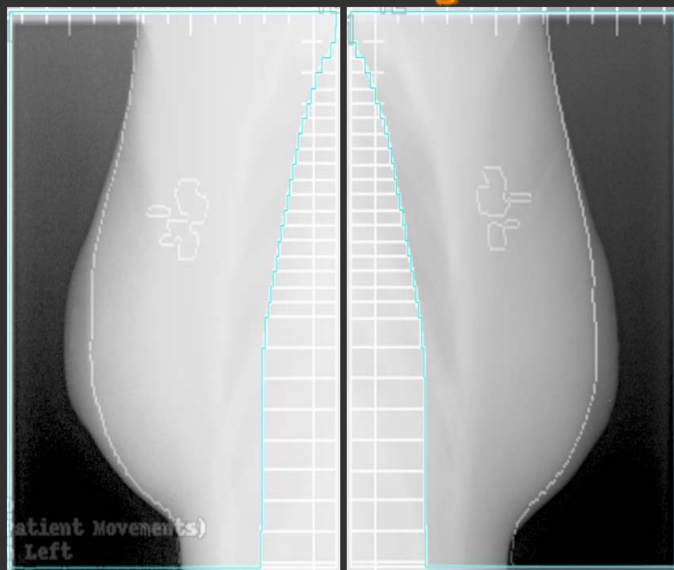
WBRT Ex: First Day Entire Surface



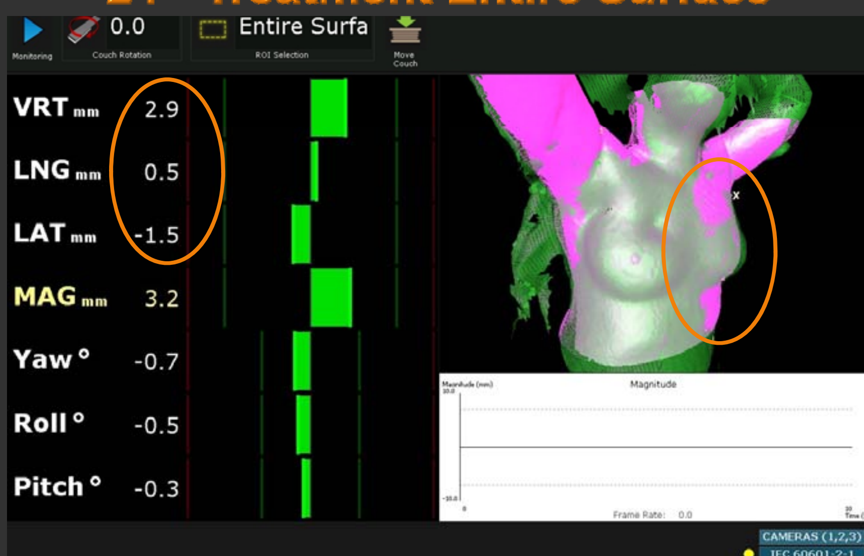
WBRT Ex: First Day Breast Surface



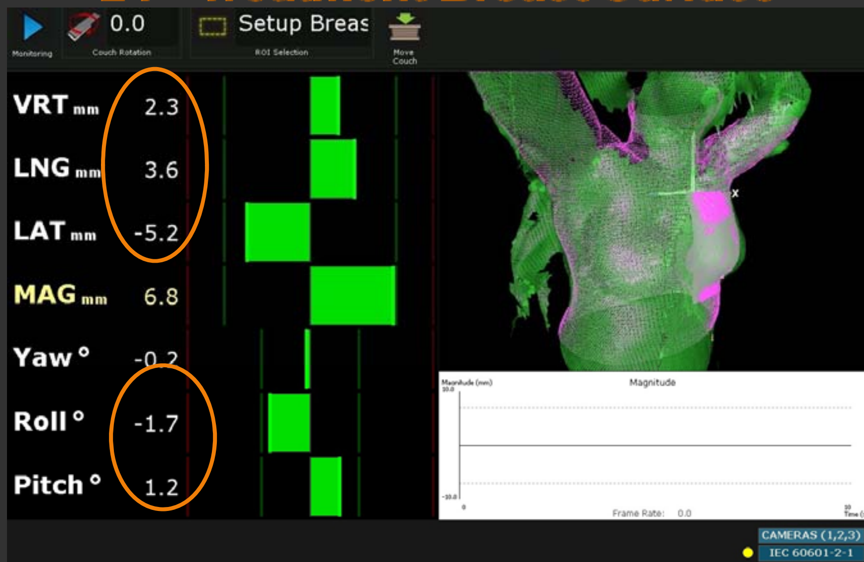
WBRT Ex: 24th Treatment Tangent Films



WBRT Ex: 24th Treatment Entire Surface



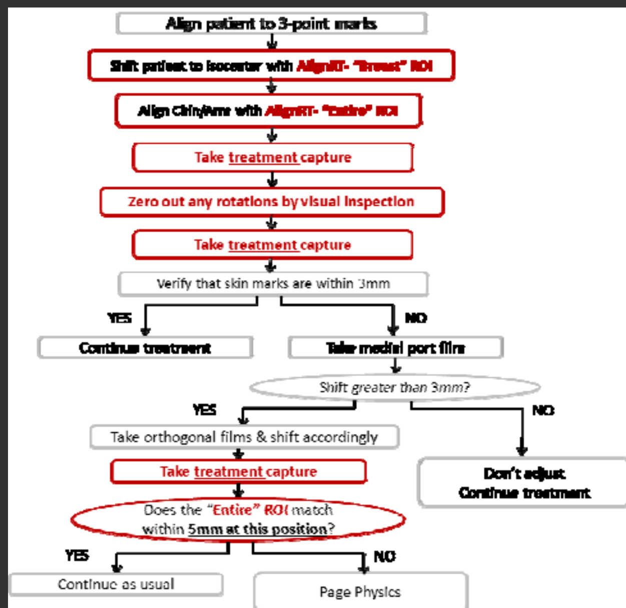
WBRT Ex: 24th Treatment Breast Surface



WBRT: Conclusions

- Positioning to bony anatomy does not necessarily provide accurate breast surface alignment due to breast deformation
- External anatomy can change throughout treatment due to factors such as:
  - Healing from surgery
  - Swelling from lymphatic drainage
  - Patient’s comfort level maintaining treatment position

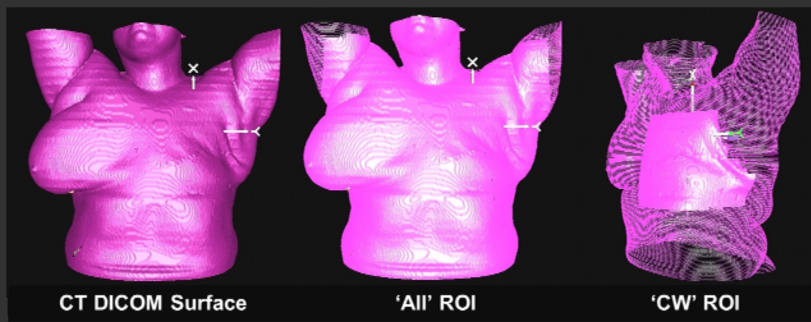
WBRT: Workflow



Commissioning: Chestwall SI vs. kV

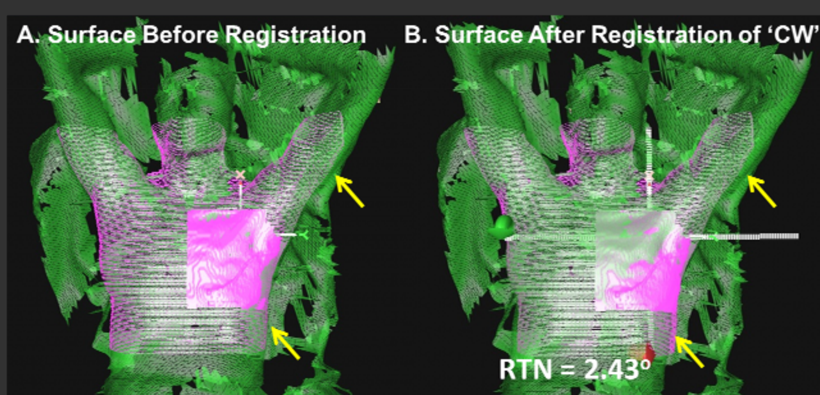
- Post-mastectomy chestwall targets expected to be less affected by deformation than breast
- We investigated the accuracy of 3D surface matching using AlignRT (v4.5/v5.0) compared to positioning with daily orthogonal kV imaging
- 130 surfaces from 10 patients:
  - Immobilized with upper/lower custom alphacradles
  - Treated *without* respiratory management
  - Treated with inverse-planned IMRT to cw + nodes
  - Setup with skin marks/daily kV imaging only

Surface Imaging



3D surface image and ROIs selected for registration.

Registration of 'CW' (v4.5)

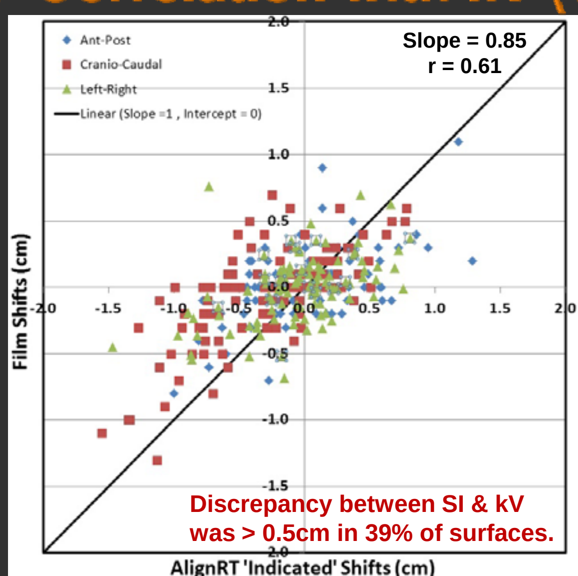


Registration of 'Entire' yielded rotation of 0.47°.

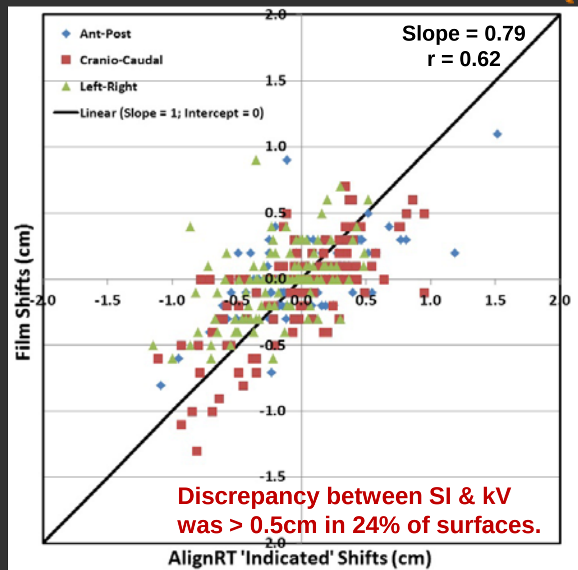
Identification of Unstable Registration

- Rotational (yaw) changes > 1º between consecutive surfaces:
  - 2.3% of 'Entire' surfaces
  - 3.8% of 'CW' surfaces
- Rotational (yaw/roll/pitch) changes > 1º between consecutive surfaces:
  - 5.6% of 'Entire' surfaces
  - 13.1% of 'CW' surfaces

'CW' Correlation with kV (v5.0)



'Entire' Correlation with kV (v5.0)

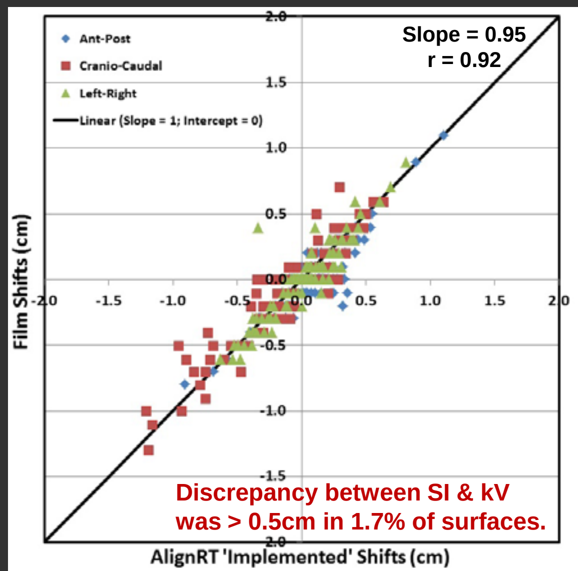


CW: Filmed Fractions Analysis

	PTV Margin (mm)		
	AP	CC	LR
kV Films	4.2	6.3	3.7
Entire surface Pre-Shifts	8.1	9.1	6.7
CW surface Pre-Shifts	8.6	12.2	9.3

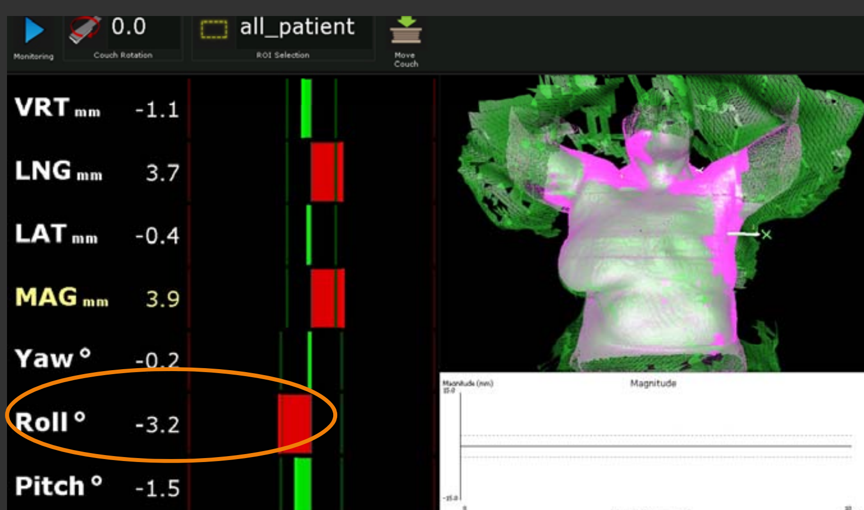
		LOA range (mm)		
		AP	CC	LR
Pre-shifts	Entire Surface	11.5	12.1	11.8
	CW Surface	12.7	15.8	17.2
Post-shifts	Entire Surface	11.8	11.0	10.9
	CW Surface	12.8	15.4	16.1

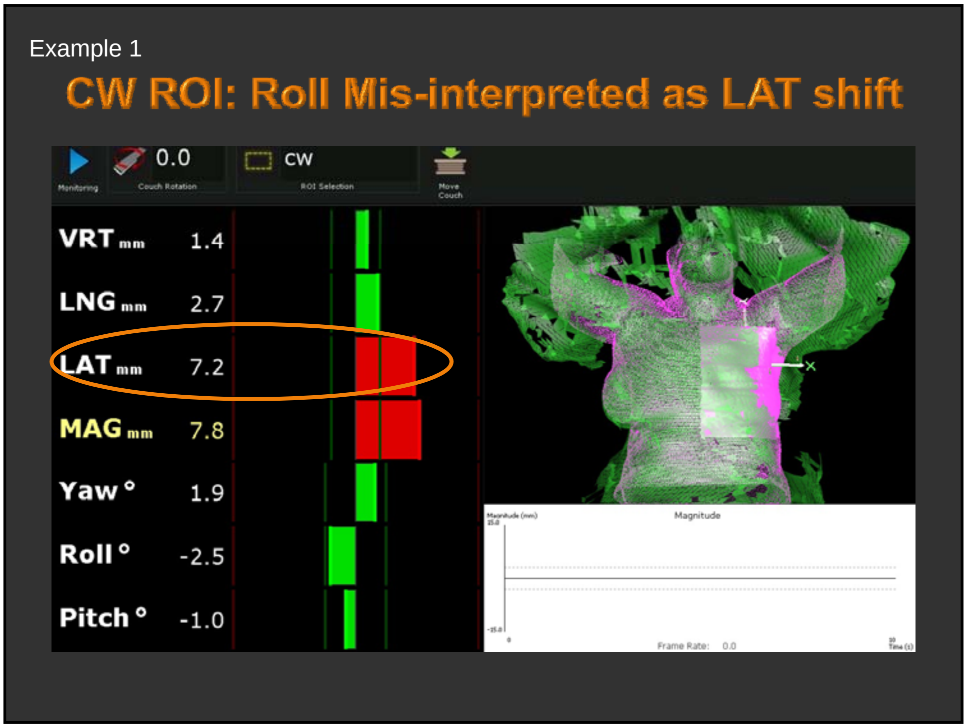
'Entire' Correlation with Table Shifts (v5.0)

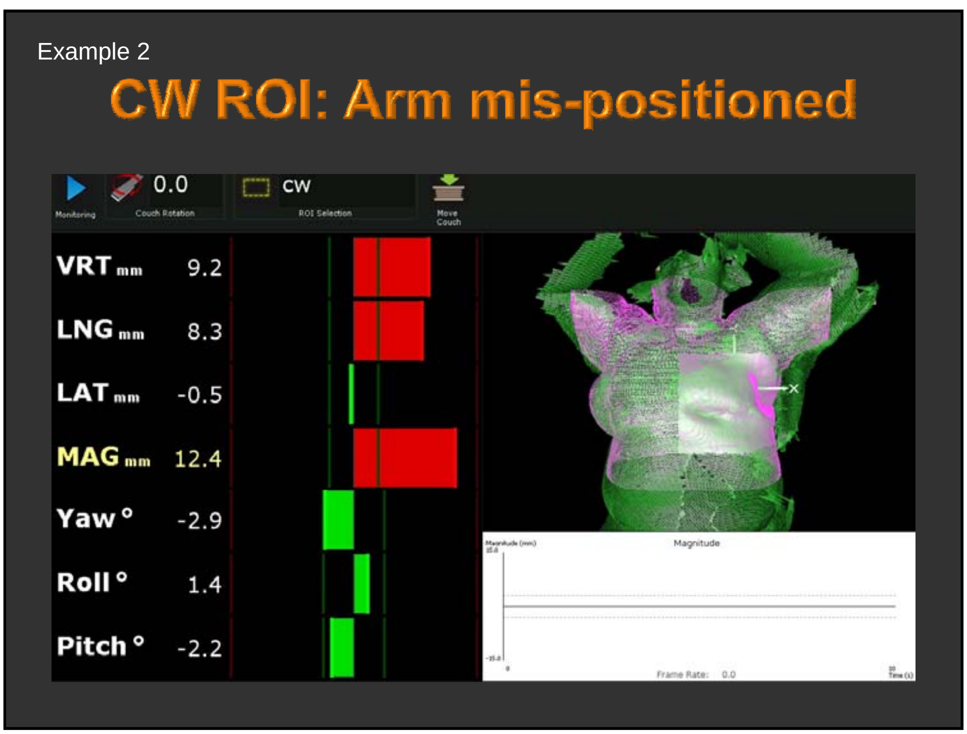


Example 1

Entire ROI: Roll Identified

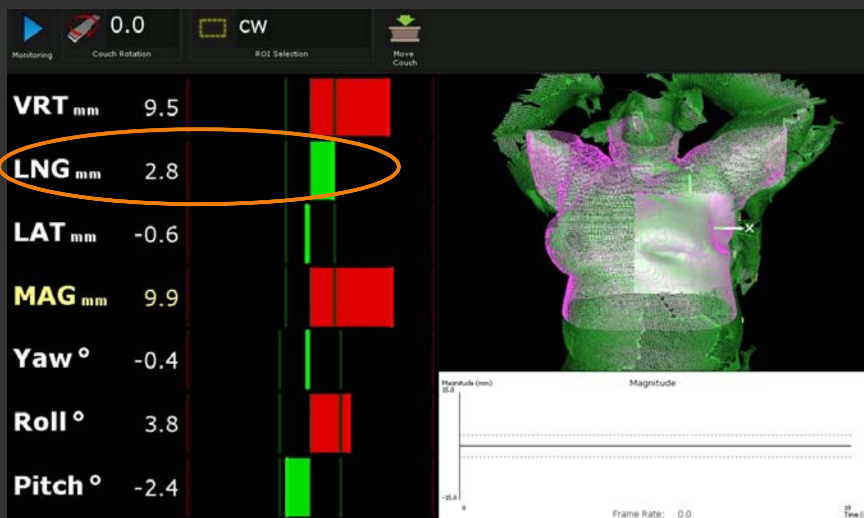



Example 1
CW ROI: Roll Mis-interpreted as LAT shift
0.0
CW
VRT mm 1.4
LNG mm 2.7
LAT mm 7.2
MAG mm 7.8
Yaw ° 1.9
Roll ° -2.5
Pitch ° -1.0
Magnitude


Example 2
CW ROI: Arm mis-positioned
0.0
CW
VRT mm 9.2
LNG mm 8.3
LAT mm -0.5
MAG mm 12.4
Yaw ° -2.9
Roll ° 1.4
Pitch ° -2.2
Magnitude

Example 2

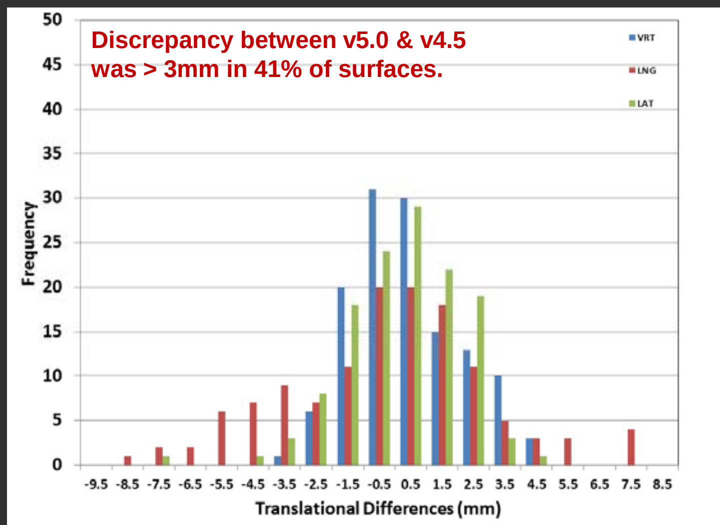
CW ROI: Arm movement



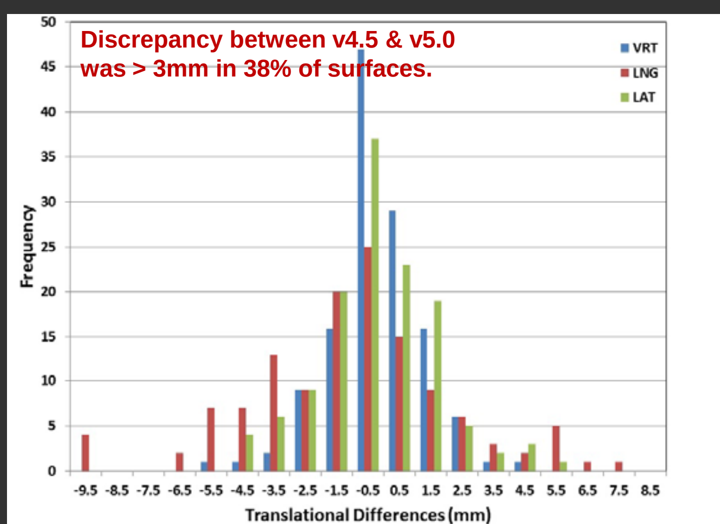
Chestwall RT: Conclusions

- Surface registration depends upon the ROI
- A smaller ROI ('cw') showed:
  - Larger LOA range compared to kV shifts
  - Less stability when calculating rotations
- Before clinical implementation:
  - Reconcile frequent mismatch (20-40%) between kV & AlignRT shifts > 0.5cm
  - Identify "unstable" registrations (4-13%)
  - Distinguish translations from deformations

Entire ROI: Variability between v5.0 & v4.5



CW ROI: Variability between v5.0 & v4.5



Variability between versions: v5.0-v4.5

	Pearson's correlation coefficients		
v5.0	**AP**	**CC**	**LR**
Entire surface	0.62	0.70	0.50
CW surface	0.58	0.66	0.38

	Pearson's correlation coefficients		
v4.5	**AP**	**CC**	**LR**
Entire surface	0.65	0.38	0.52
CW surface	0.65	0.66	0.44

Commissioning: Conclusions

- Surface imaging systems must undergo extensive acceptance testing & commissioning
- Isocenter congruence must be verified for all imaging modalities simultaneously
- Comprehensive testing of AlignRT revealed registration differences between v5.0 & v4.5
- Commissioning of AlignRT indicates that discrepancies are larger for:
  - Registration to CT reference surface
  - Registration of smaller ROIs

Surface Imaging for Breast Cancer

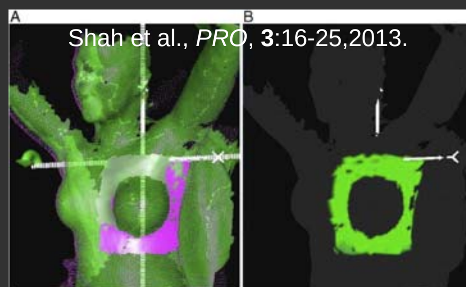
- Advantages of surface imaging:
  - 3D modality
  - Real-time monitoring
  - No radiation dose
  - Highlights surface changes (with absolute reference)
- Disadvantages of surface imaging:
  - Variations with ROI used for registration
  - Sensitive to deformation/difficult to interpret
  - Low correlation with MV films

X-ray Imaging for Breast Cancer

- Advantages of MV/kV:
  - Focuses only on bony anatomy
  - Better surrogate for nodal treatment?
- Disadvantages of MV/kV:
  - 2D modality
  - Limited field-of-view
  - Radiation dose
- Disadvantages of MV:
  - Low contrast
  - Subjectivity of alignment

Workflow Decisions

- Absolute vs. relative positioning
- Region-of-interest (ROI) for registration
- Elimination of skin marks
- Threshold for discrepancy between SI & films
- Identification of “unreliable” registrations
- Visual inspection of surfaces



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

Does SI offer benefits other than positioning accuracy?

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

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

IGRT with Surface Imaging

- "Variability in repositioning is dominated by the ability of therapists to make small, controlled changes in the position of the patient." (Milliken *et al.*, *Int J Rad Onc Biol Phys*, 38(4):855-866, 1997)
- Surface imaging does not preclude need for:
  - Good immobilization
  - Adequate PTV margins
  - Common sense!

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Emily Gerry

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Steven Chmura, M.D., Ph.D.
Yasmin Hasan, M.D.