Video and Surface Positioning

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I for one welcome our AI SUV overlords

Contributors

- Scott Hadley — University of Michigan
- Scott Johnson — Varian Medical Systems
- Shidong Li — Henry Ford Hospital
- Marco Riboldi — TMB Lab @ Politecnico di Milano
- Christoph Bert — GSI & MGH

Goal of Patient Positioning

- Reproduce patient position as seen in CT simulation
  - Aligning Skin Marks with Laser
  - Matching Boney Anatomy with MV
  - Target Positioning with US, markers, MV, kV, CBCT

Goal of Patient Positioning

- Frequency of Position Verification
  - First Day and weekly
  - Adaptive protocol, image for several days, move to average then weekly
  - Daily positioning or target localization

Advantages of Video & Surface

- No ionizing radiation
  - Daily use with no extra radiation
  - Operators can be at couch side for positioning
- Video cameras see what we see
- Can be "no touch" and "no marks"

Advantages of Video & Surface

- Quantitative 3D couch positioning, 6 parameter rigid transformation
- Intrafraction patient monitoring
- 4D acquisition
- Non-rigid positioning possible

Disadvantages of Video & Surface

- Positioning based on skin surface only
  - Skin surface as a surrogate for target anatomy
- Can be obstructed by clothes, mask, other objects

History of Video Techniques

- **1972** Kelsey, C.A., R.G. Lane, and W.G. Connor, Measurement of patient movement during radiation therapy. Radiology. 103(3): p. 697-8.
- **1975** Connor, W.G., et al., Patient repositioning and motion detection using a video cancellation system. Int J Radiat Oncol Biol Phys. 1(1-2): p. 147-53
- **1977** Renner, W.D., et al., The use of photogrammetry in tissue compensator design. Part II: experimental verification of compensator design. Radiology,
- **1982** Andrew, J.W. and J.E. Aldrich, A microcomputer-based system for radiotherapy beam compensator design and patient contour plotting. Med Phys. 9(2): p. 279-83

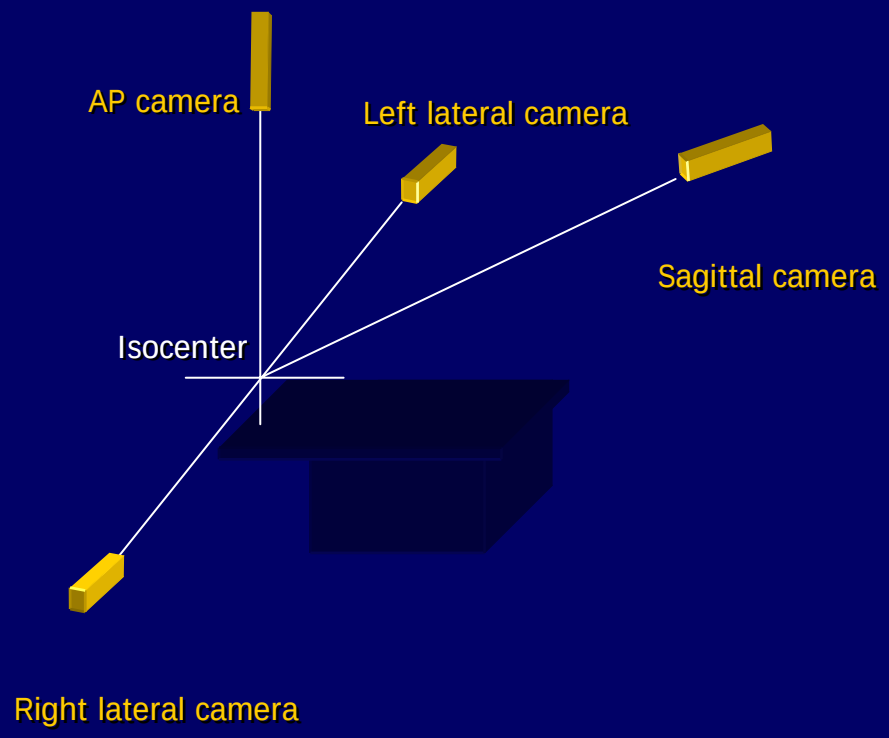
Three Technologies Come Together

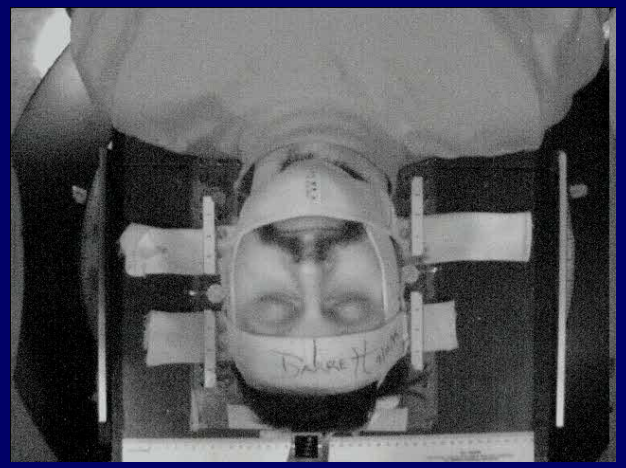
- Photogrammetric Calibration
- 3D Image Registration
- Cheap and good Digital Image Acquisition and Fast Computers

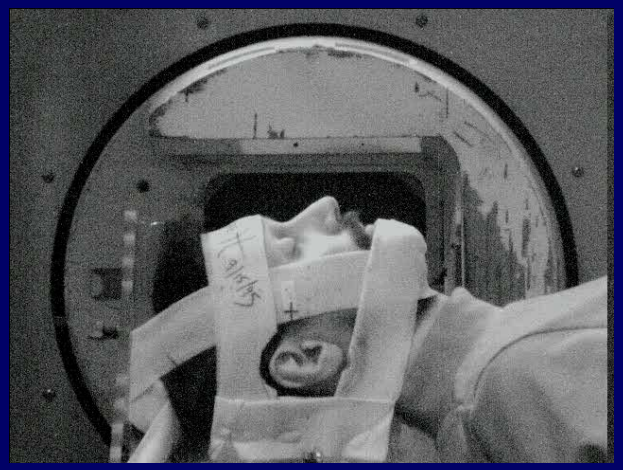
Image Guided Surgery

Grimson, W.E.L., et al., An automatic registration method for frameless stereotaxy, image guided surgery, and enhanced reality visualization. IEEE Transactions on Medical Imaging, 1996. 15(2): p. 129-140

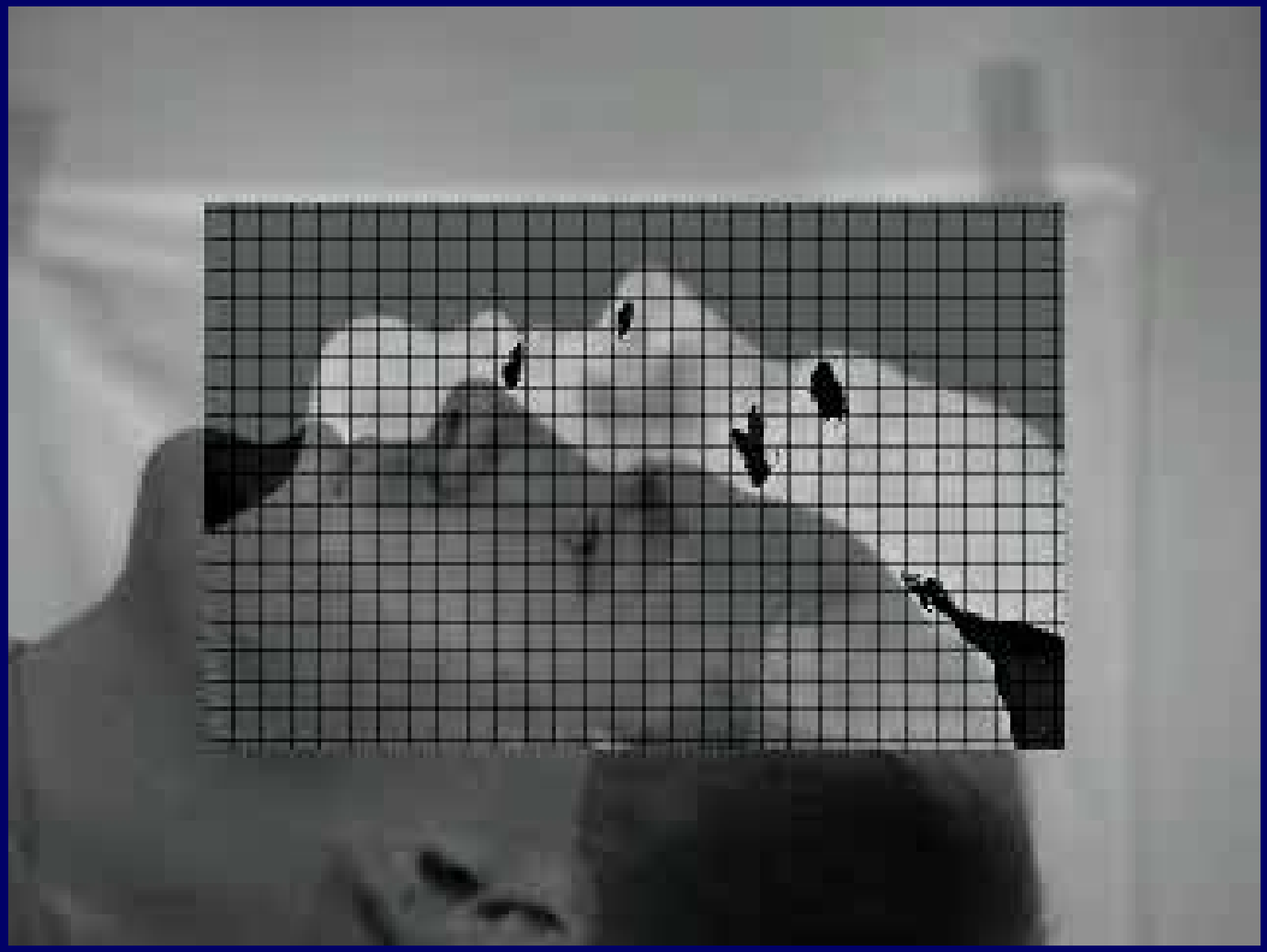
In Room (Spy) Cameras







Live Video Subtraction

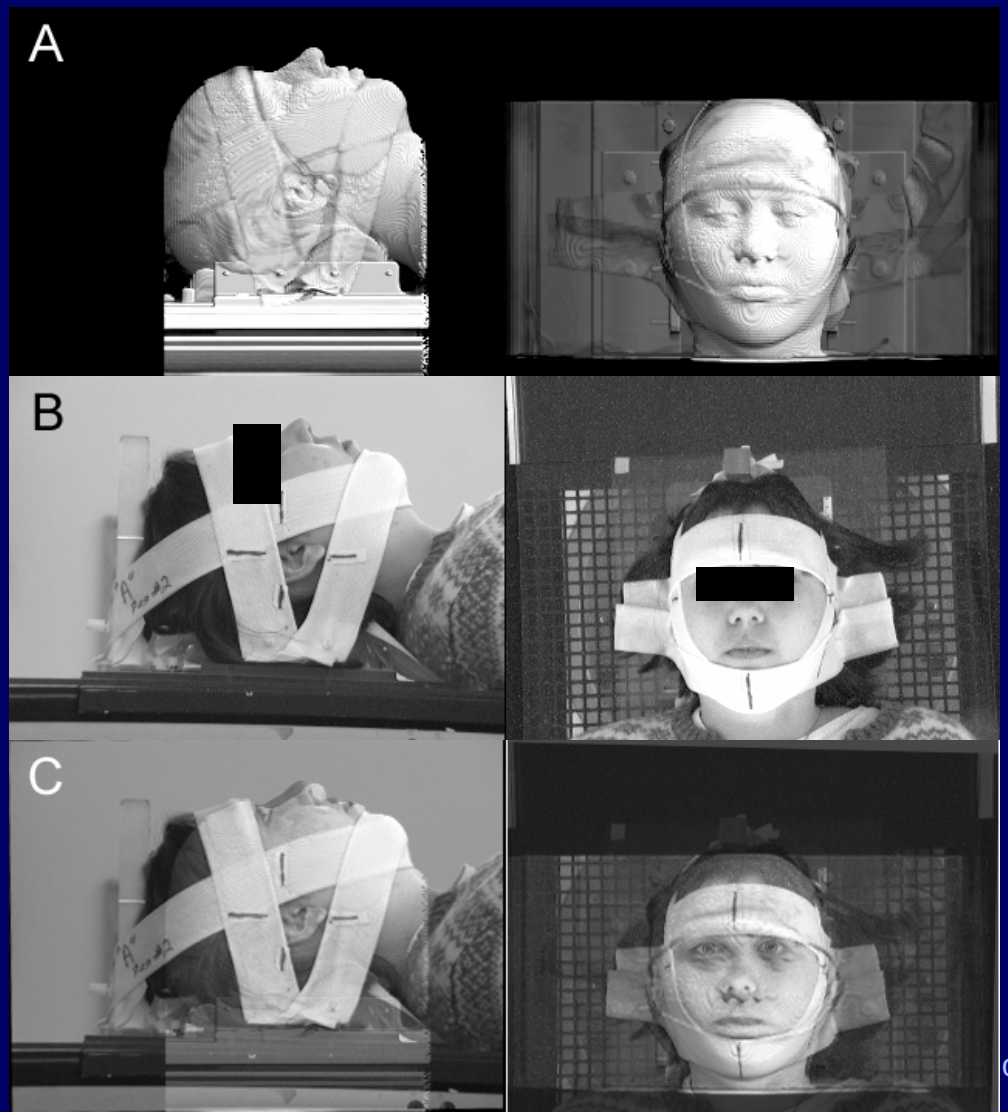


Volume Rendered Ref' Images

Volume Rendered Reference image from CT

Live Video of Patient on Table

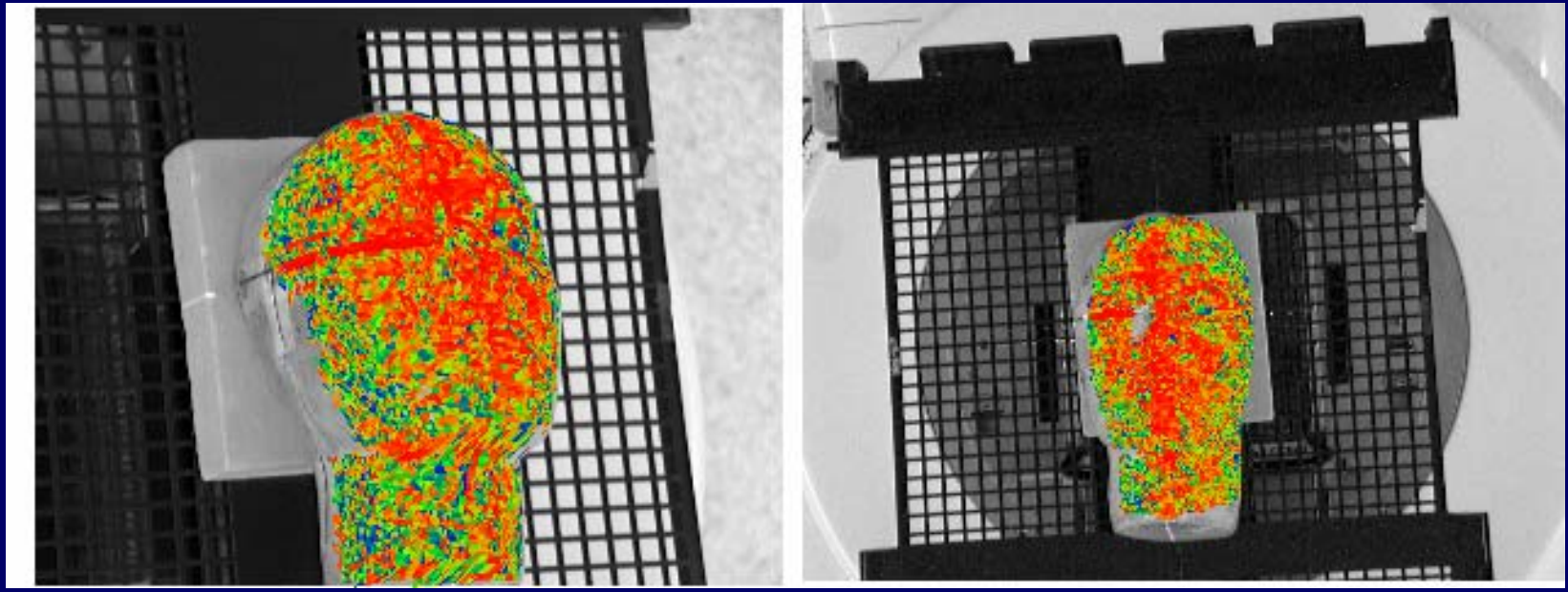
Video Subtraction for positioning



Patient Surface from CT Scans

Camera 1 | Camera 1 & 2 | Camera 2

3D Surface to 2D Image Matching



Latest Technology

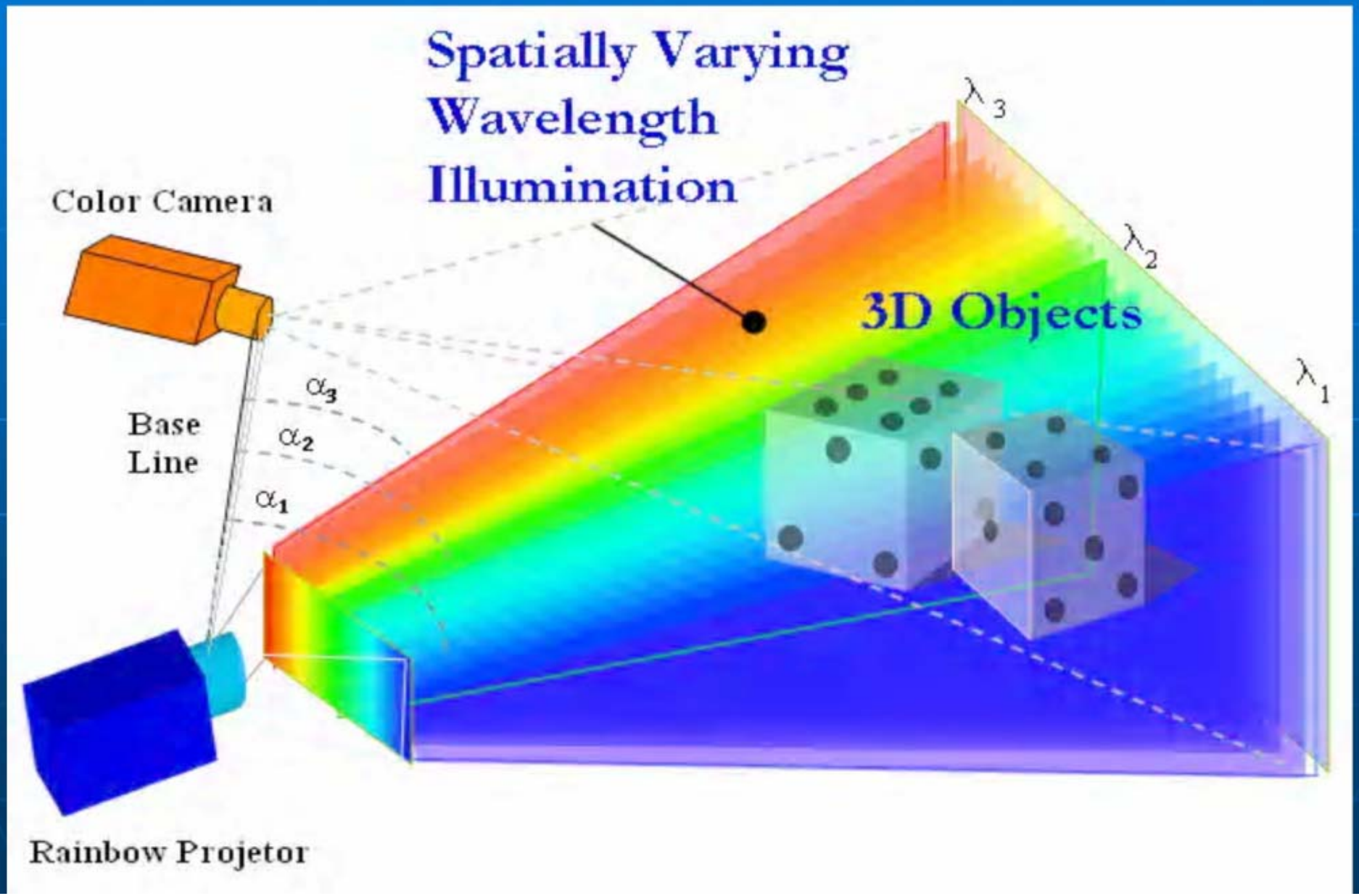
- 3D Surface Scanners
  - Video + Laser, interfermometry, light pattern
  - Large FOV
  - Multiple Frames per second
- Surface Registration software
  - 6 parameter rigid transformation
  - Direct measurement of positioning error

Integrated-Image-Guided Radiotherapy

Shidong Li, Ph.D.

Henry Ford Hospital, Detroit, MI

A Rainbow Camera For Rapid Imaging



Difference between CT surface and video surface

Proposed surface-based refixation is acceptable with error of $\sigma < 1$ mm patients wearing facemask.

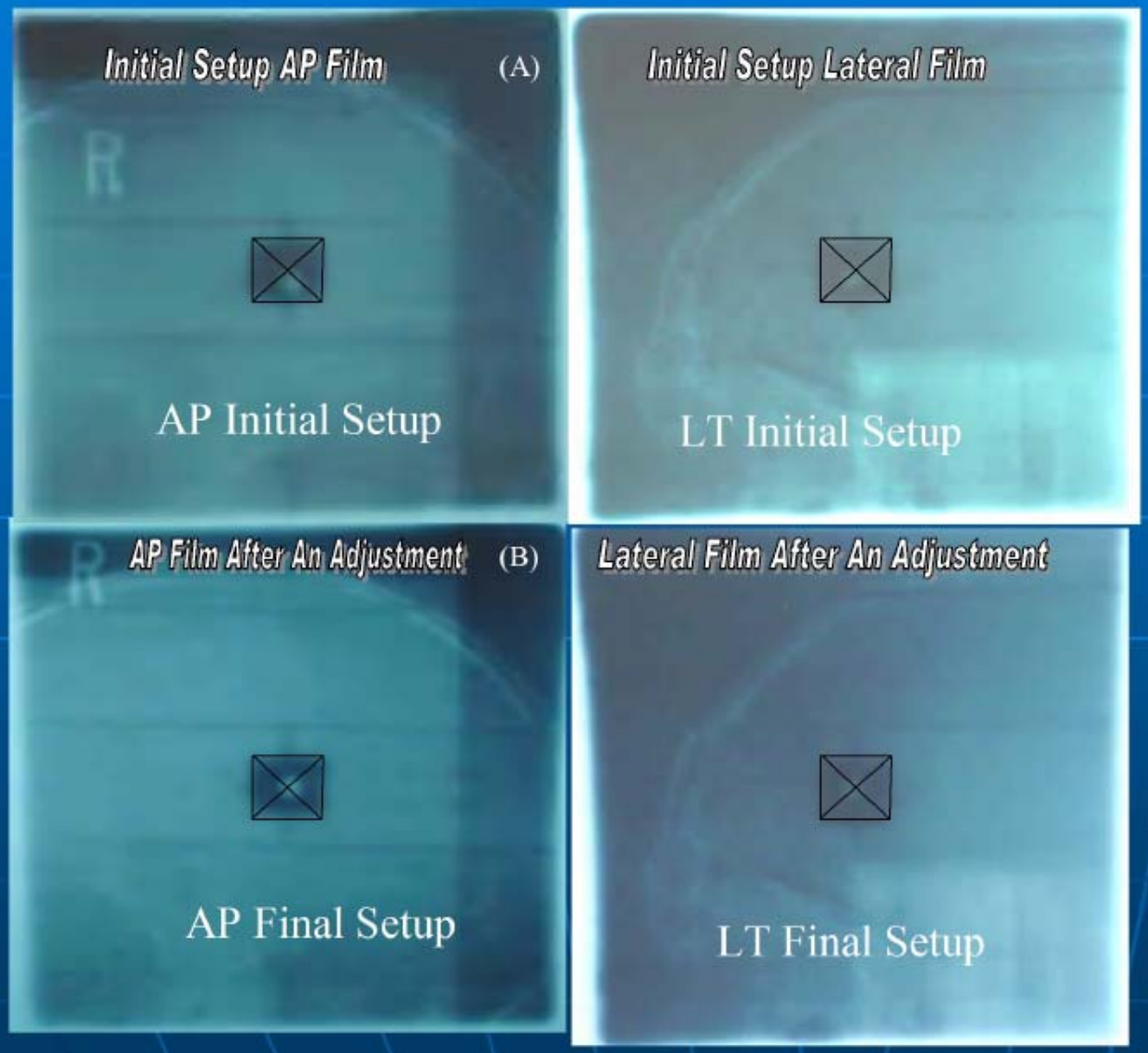
Shifts:

LAT	LNG	VRT
0.19	0.83	-0.76

Rotations

0.13^{o}	-0.61^{o}	0.34^{o}

Radiography Verification



Tungsten ball images from the CAX of 12x12 mm^2 (actual 13 x 11 mm^2) beam measure the setup errors of the planned isocenter

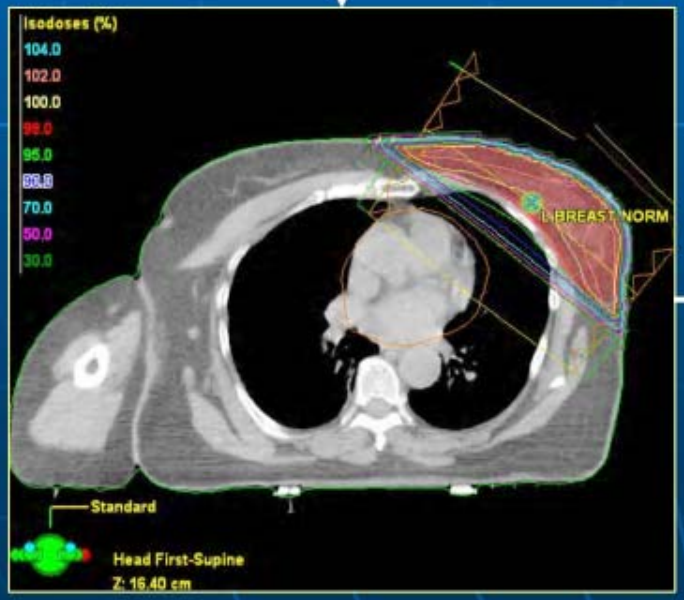
(-1, 4, 1) for initial setup agreed with (-0.6, -3.3, 1.4) from the surface registration

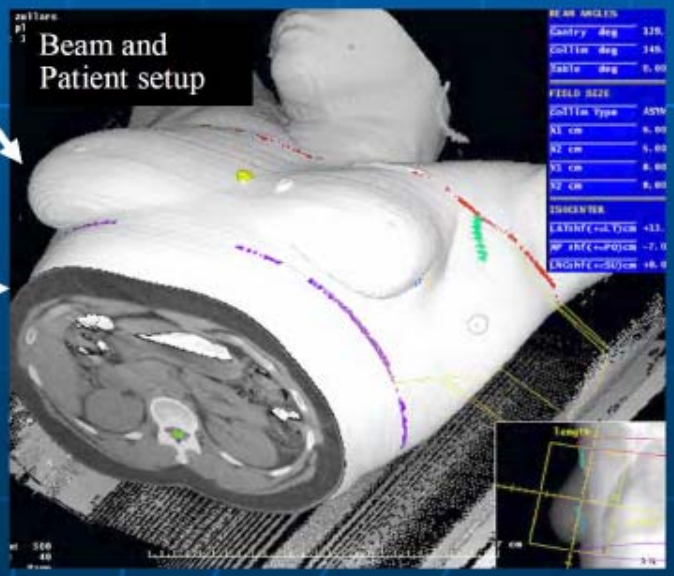
(-1, 0, 0) for final setup agreed with (-1.3, -0.5, 0.3) from the surface registration.

Typical position errors at one day treatment for a FSRT Patient with left acoustic neuroma at instances of initial setup (Initial), final setup position before rotating the table (Final), the position during the arc #1 irradiation with table angle of 90 degrees (T = 90), the position during the arc #2 irradiation with table angle of 5 degrees (T = 5), the position during the arc #3 irradiation with table angle of 355 degrees (T = 355), and the position during the arc #4 irradiation with table angle of 310 degrees (T = 310).

Instances	X (mm)	Y (mm)	Z (mm)	γ (degree)	β (degree)	α (degree)	RMS (mm)
Initial	0.633	2.081	-0.562	0.790	-0.130	0.551	1.492
Final	0.437	-0.081	-0.652	1.066	-0.130	0.751	1.092
T = 90	0.790	0.165	-0.196	-0.062	0.297	0.168	0.930
T = 5	-0.371	-0.739	-0.062	-0.702	0.034	0.113	1.242
T=355	0.268	0.539	-0.276	0.652	-0.189	0.257	1.156
T=310	-0.236	0.767	0.021	0.265	-0.114	-0.021	1.017

An Integrated Real-time Image-guided adaptive RT of Breast Cancer





3D surface imaging for PBI setup

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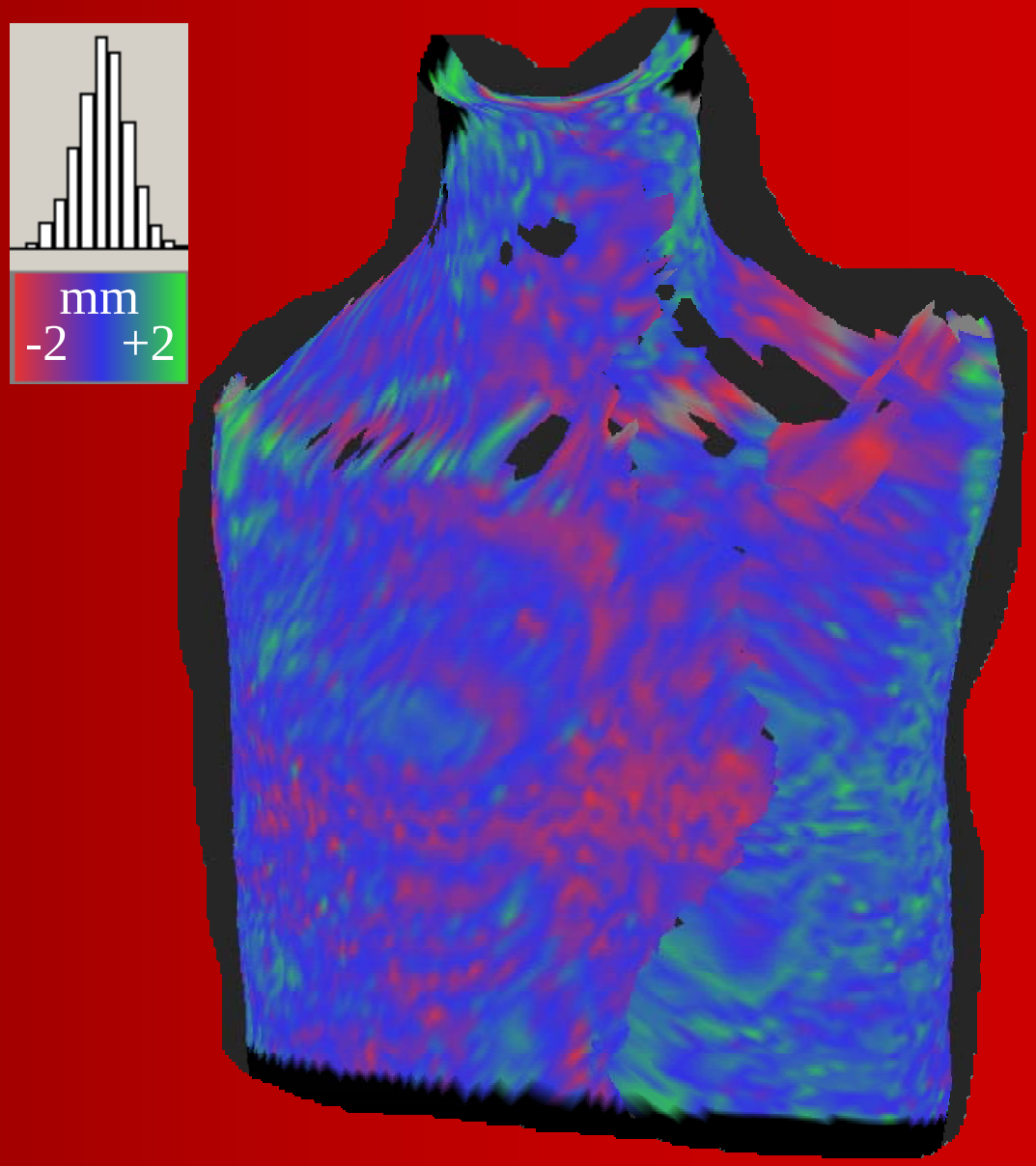
[2]Massachusetts General Hospital, Boston, Ma
[3]Harvard Medical School, Cambridge, Ma

Shape conservation CT-stereovision

- "Patient" contour TPS
  - Binary cube fill → marching cubes → decimation
- Any surface image
- Surface registration → distance projection → 0.65mm RMS

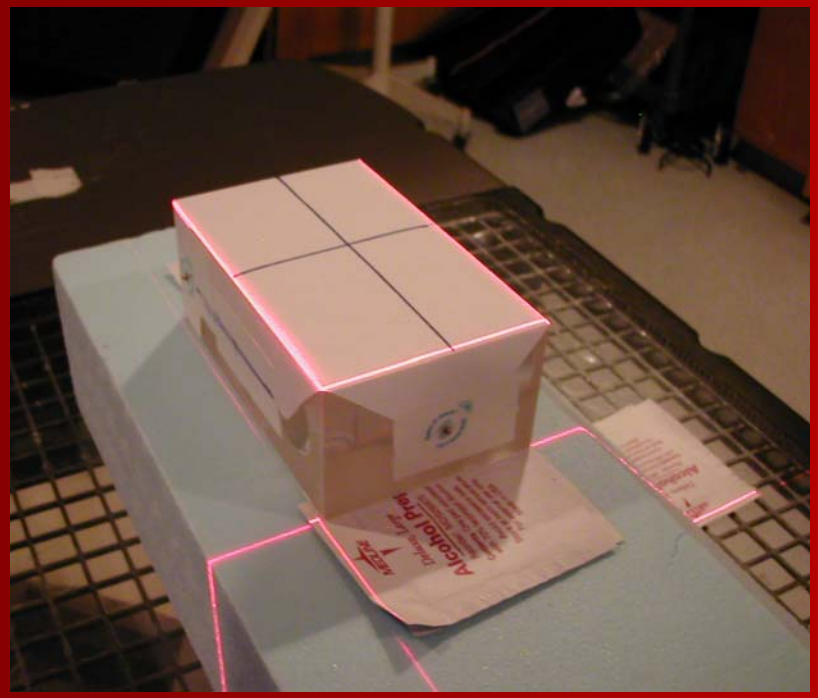


Surface imaging at MGH

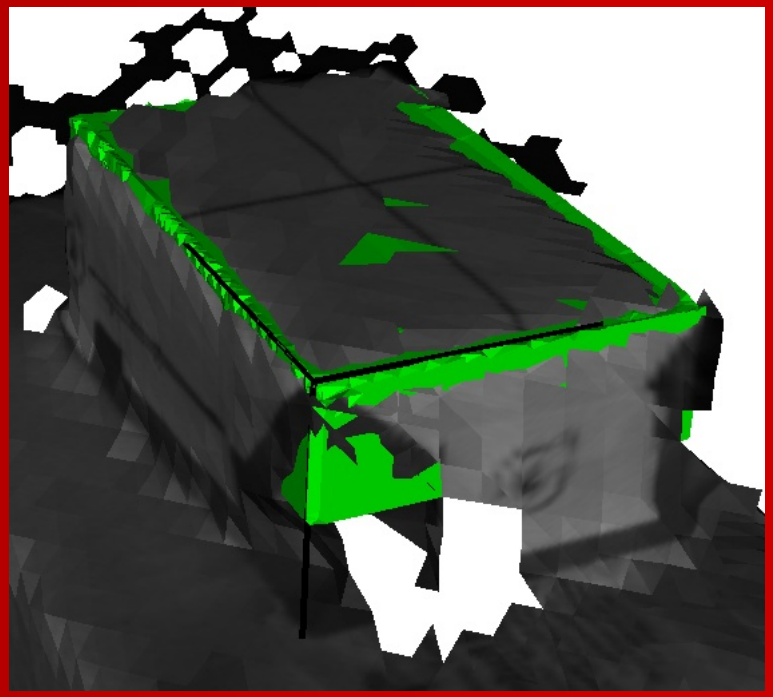
Comparison to CT surface

- Purpose: Check if CT, linac, and 3D camera coordinate systems match
- Methods:
  - CT scan phantom, extract surface, DRRs
  - a) line up according to 3D surface ⇒ b) compare portfilm with DRR (lat.+a.p.)
  - b) ⇒ a)

Surface data + Setup

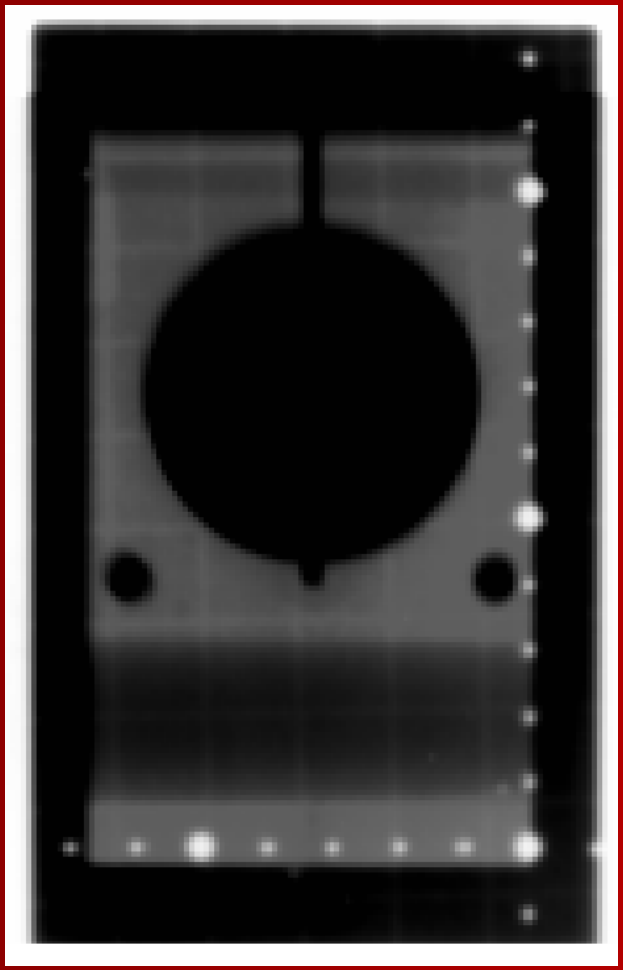


Markerblock

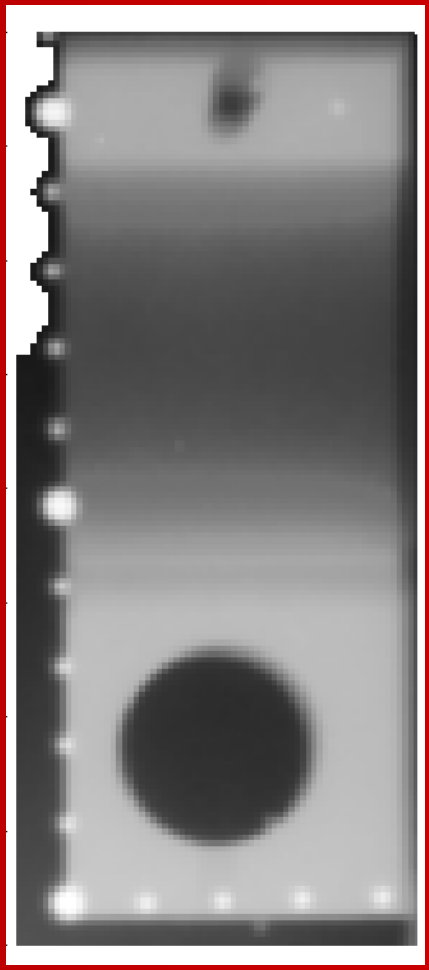


3D surfaces and origin

Film samples

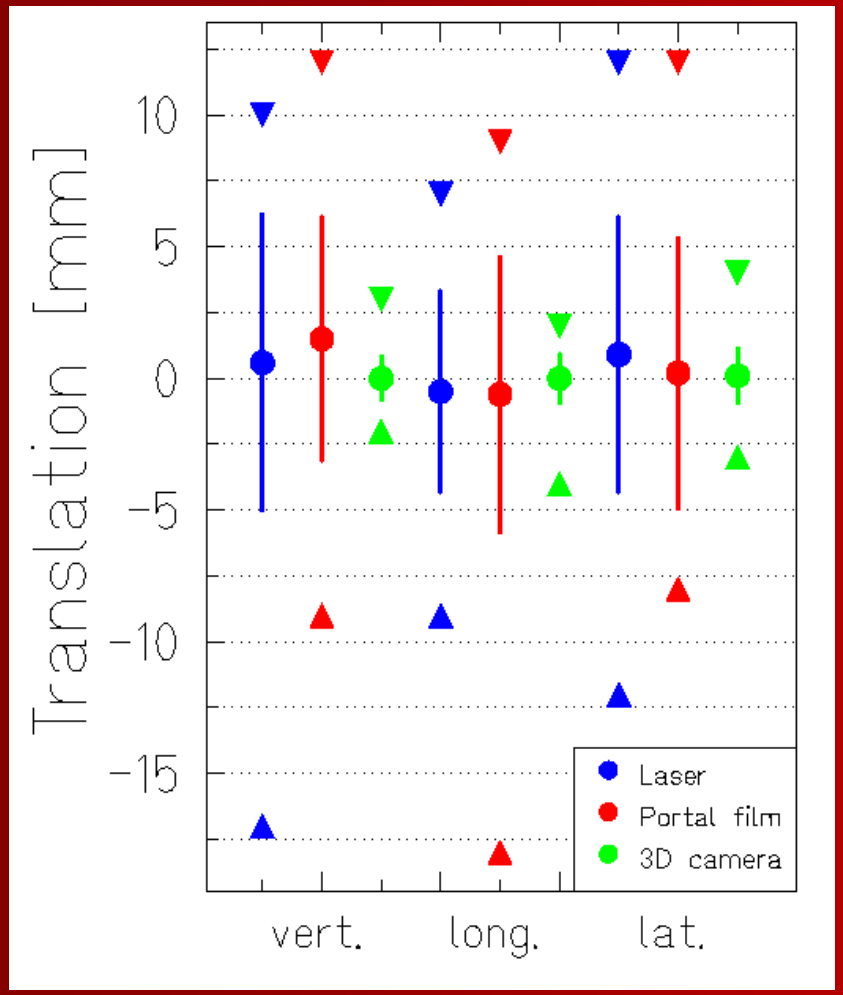


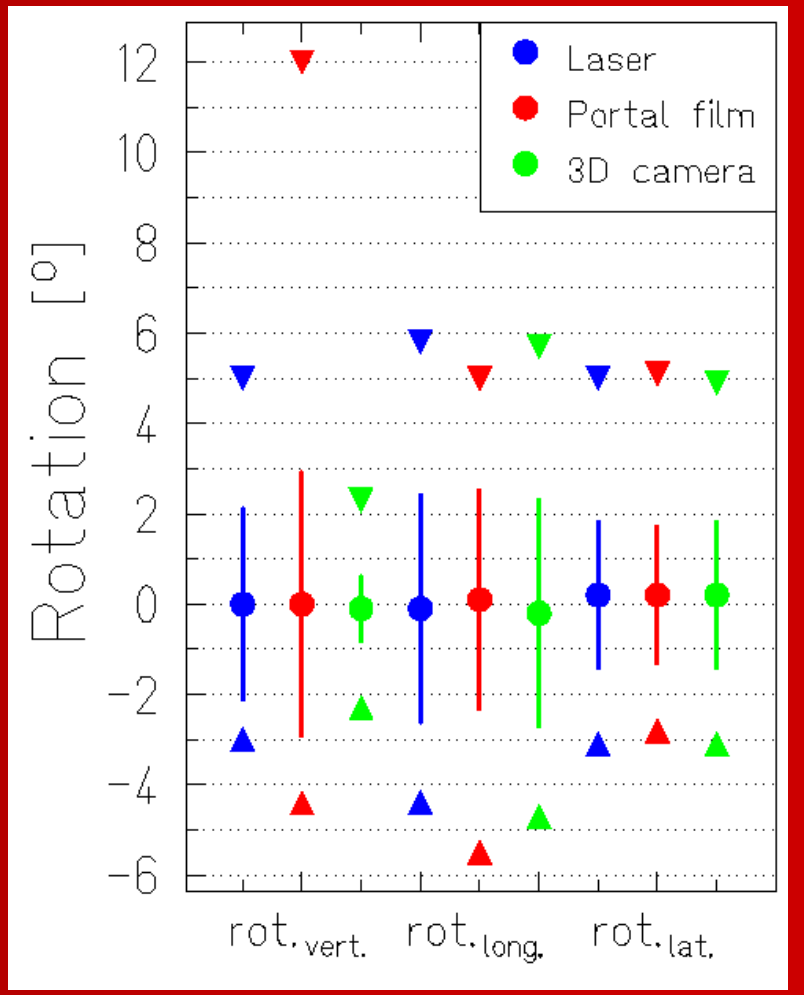
a.p.



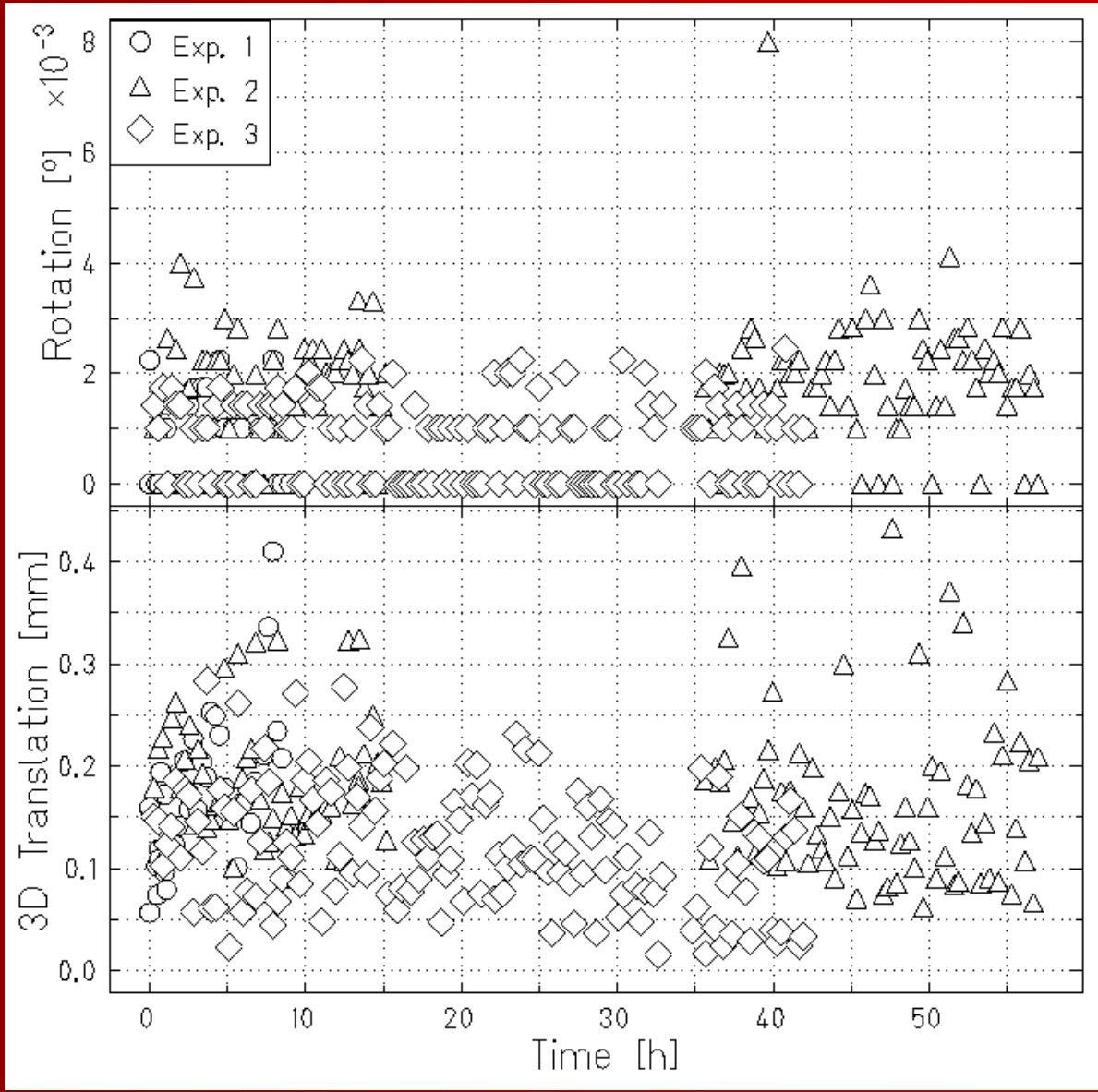
lateral

Combined results - alignment





Stability test - results



Surface imaging at MGH

PBI Setup by 3D video

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David Gierga [2,3], Julie Turcotte [2],
George T.Y. Chen[2,3]

[1] TBMLab - Department of Bioengineering
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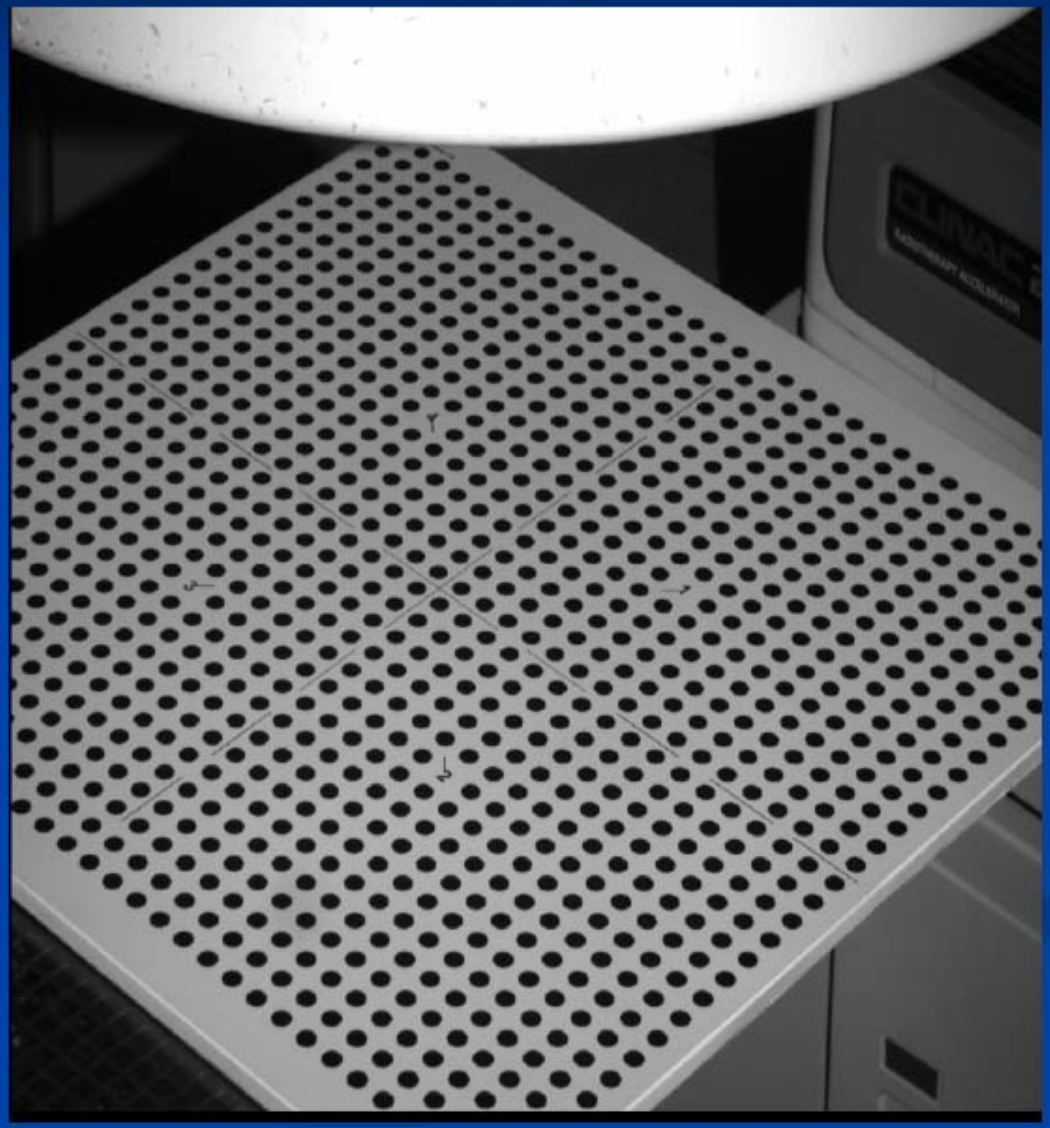
[2]Massachusetts General Hospital
[3]Harvard Medical School

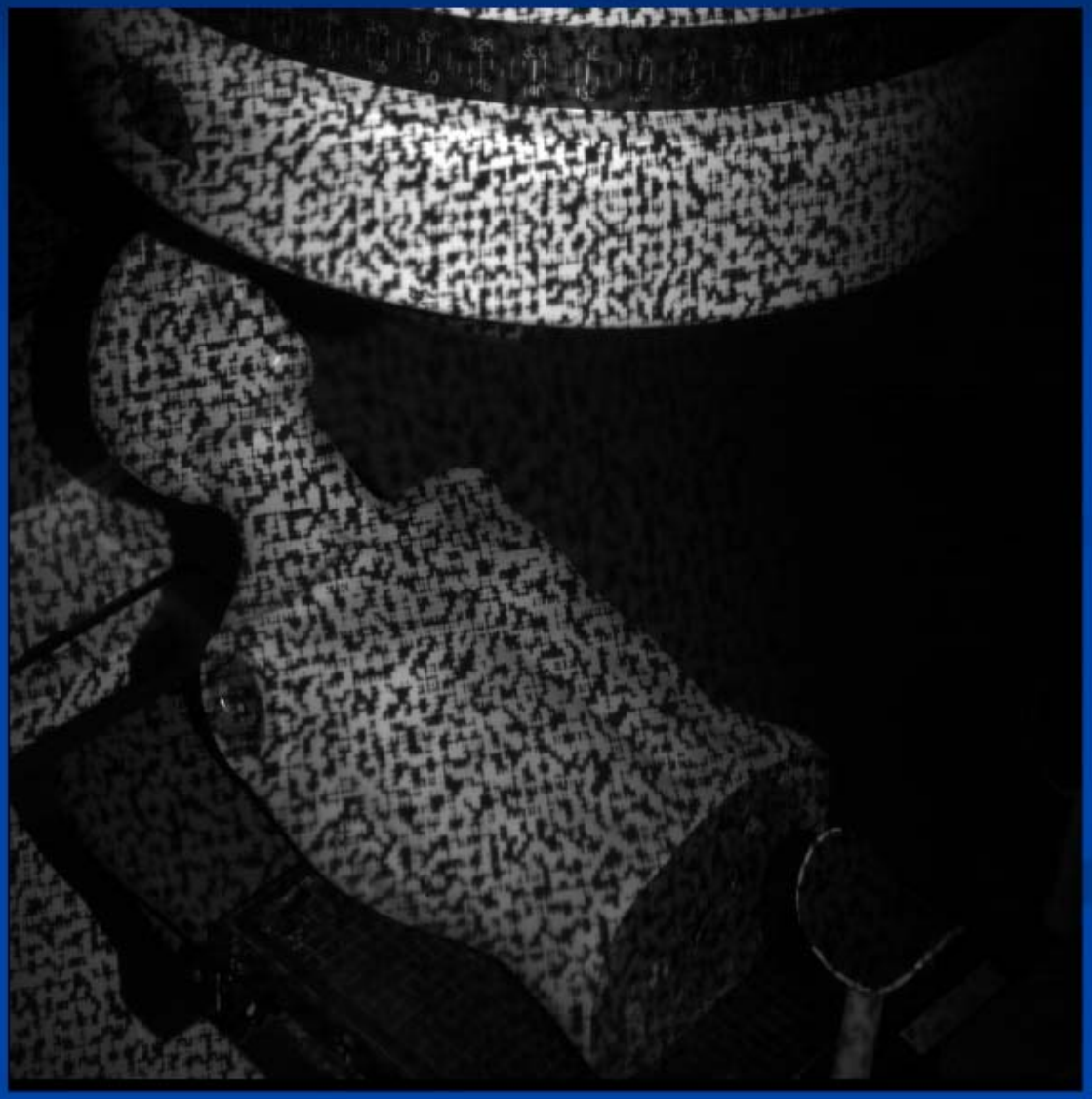
Calibration Process

- Align plate to lasers
- Capture, digitize specific points on plate
- Software calibrates cameras; common coordinate system with linac isocenter

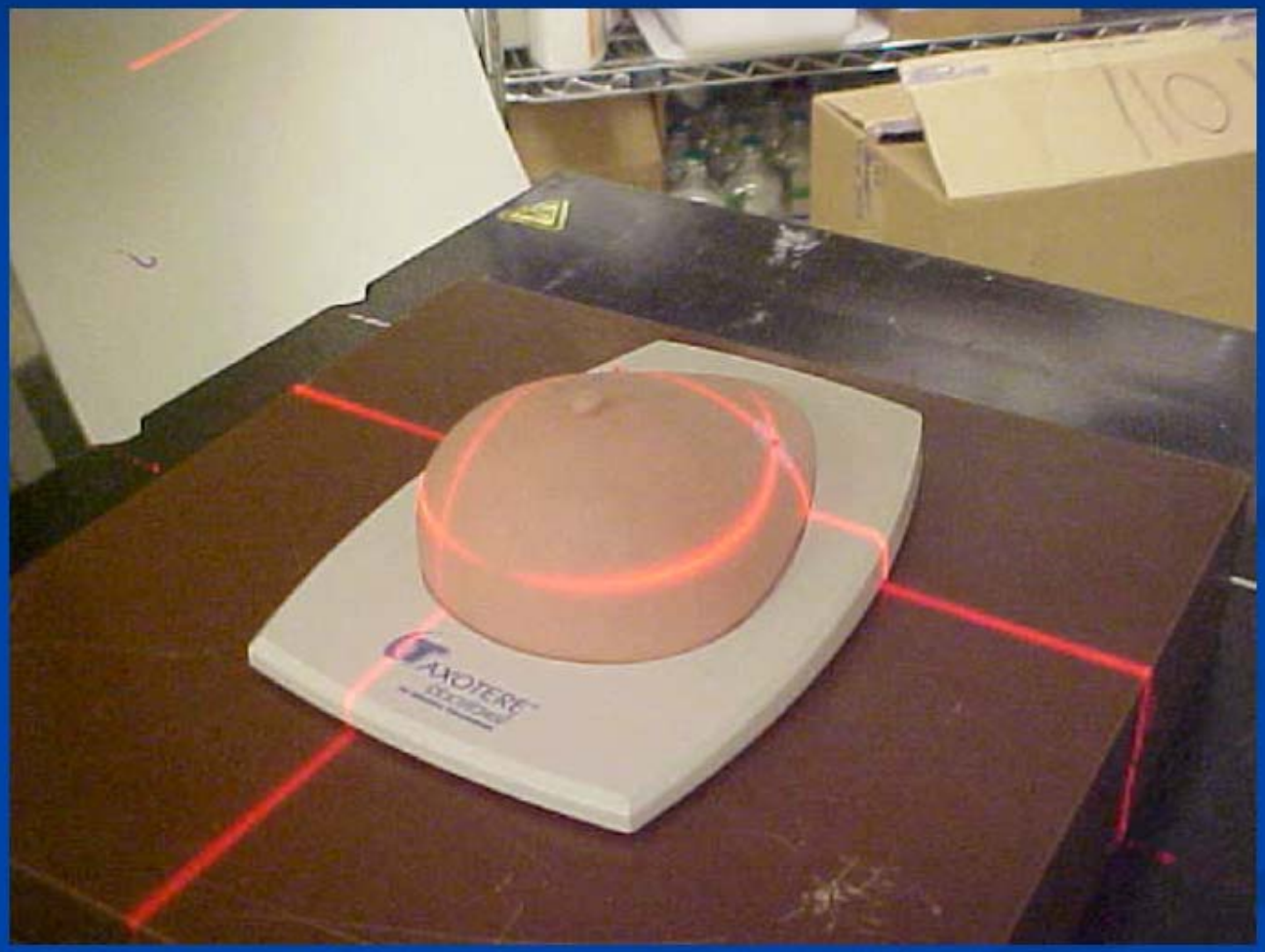


Speckle Flash Image

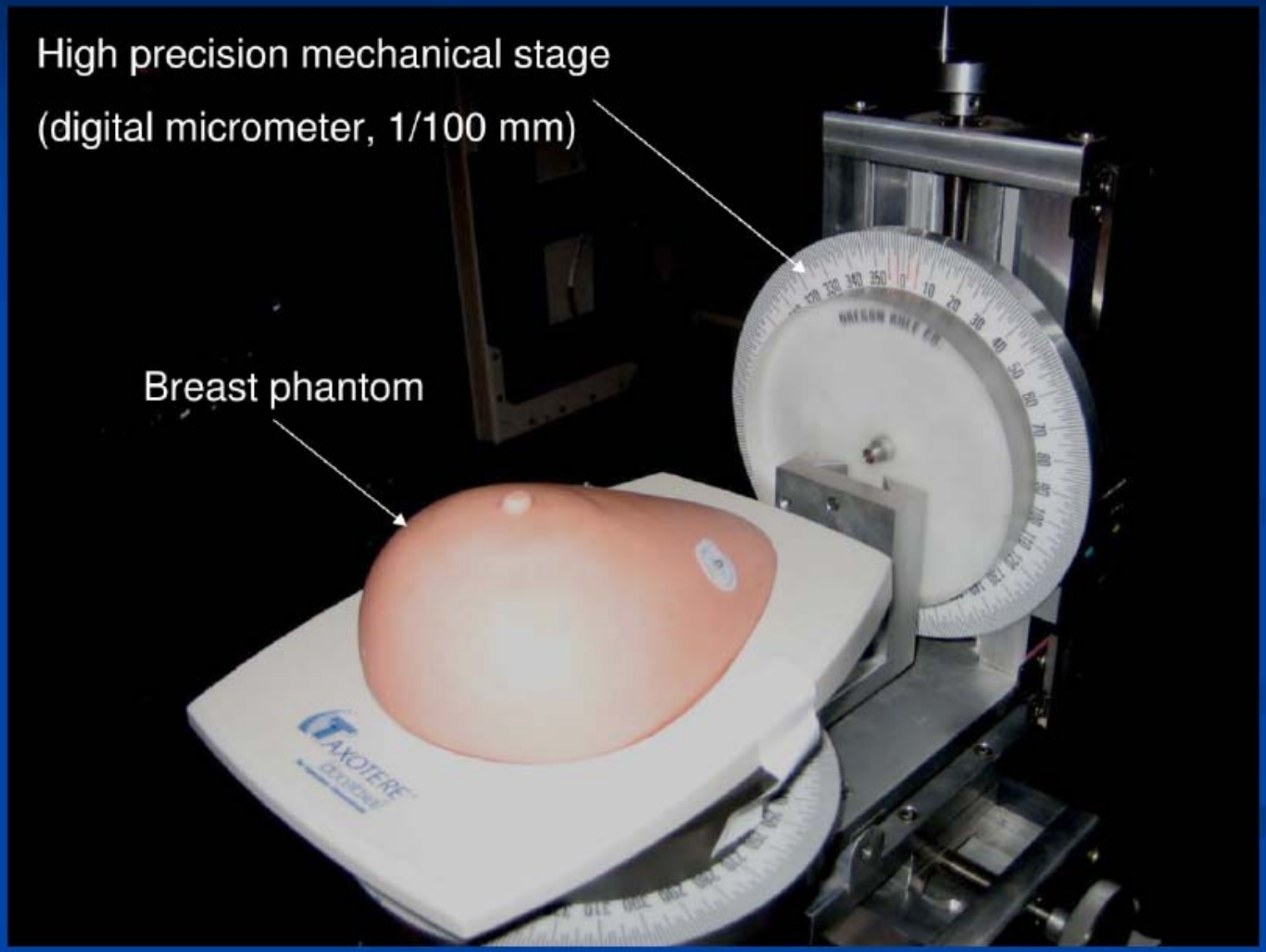
- Two camera pods
- Flash mode
  - Speckle pattern
  - 6 images captured
- Surface coords in 3D
- Surface matching to maximize congruence between reference and Rx surfaces



Phantom on CT Scanner



Breast phantom set-up



Phantom results

- 18 readings / data points
- range of shifts: [-2, +2] mm in each direction (VRT, LNG, LAT)
- compared VisionRT-suggested shifts vs. digital micrometers (ground truth)

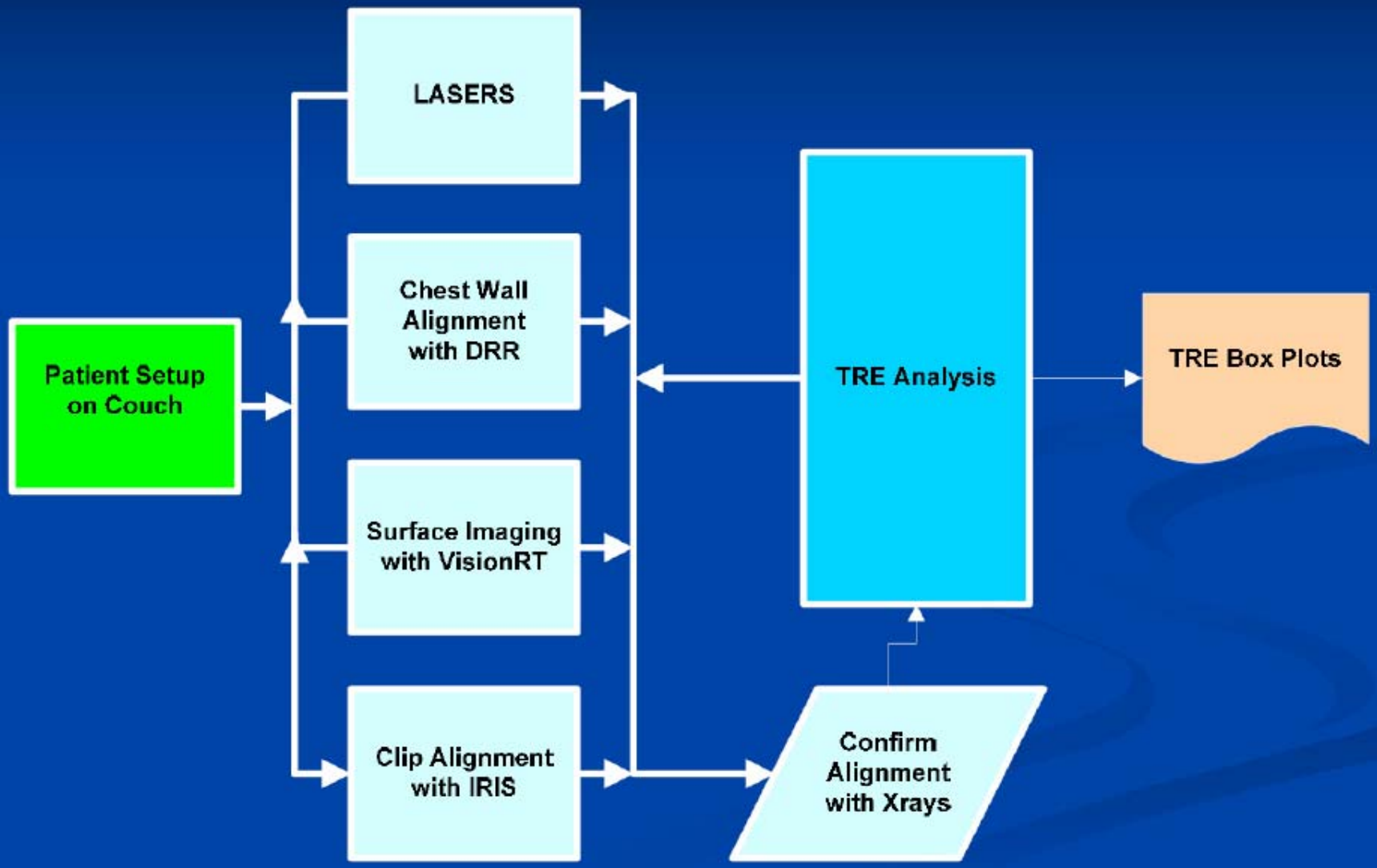
	Translation differences [mm]			
	VRT	LNG	LAT	3-D
MEAN	0.011	0.011	0.011	0.1
1SD	0.144	0.144	0.144	0.227

Accuracy of 3D Video System on breast phantom, in detecting translational moves is better than **0.5 mm (2SD)**.

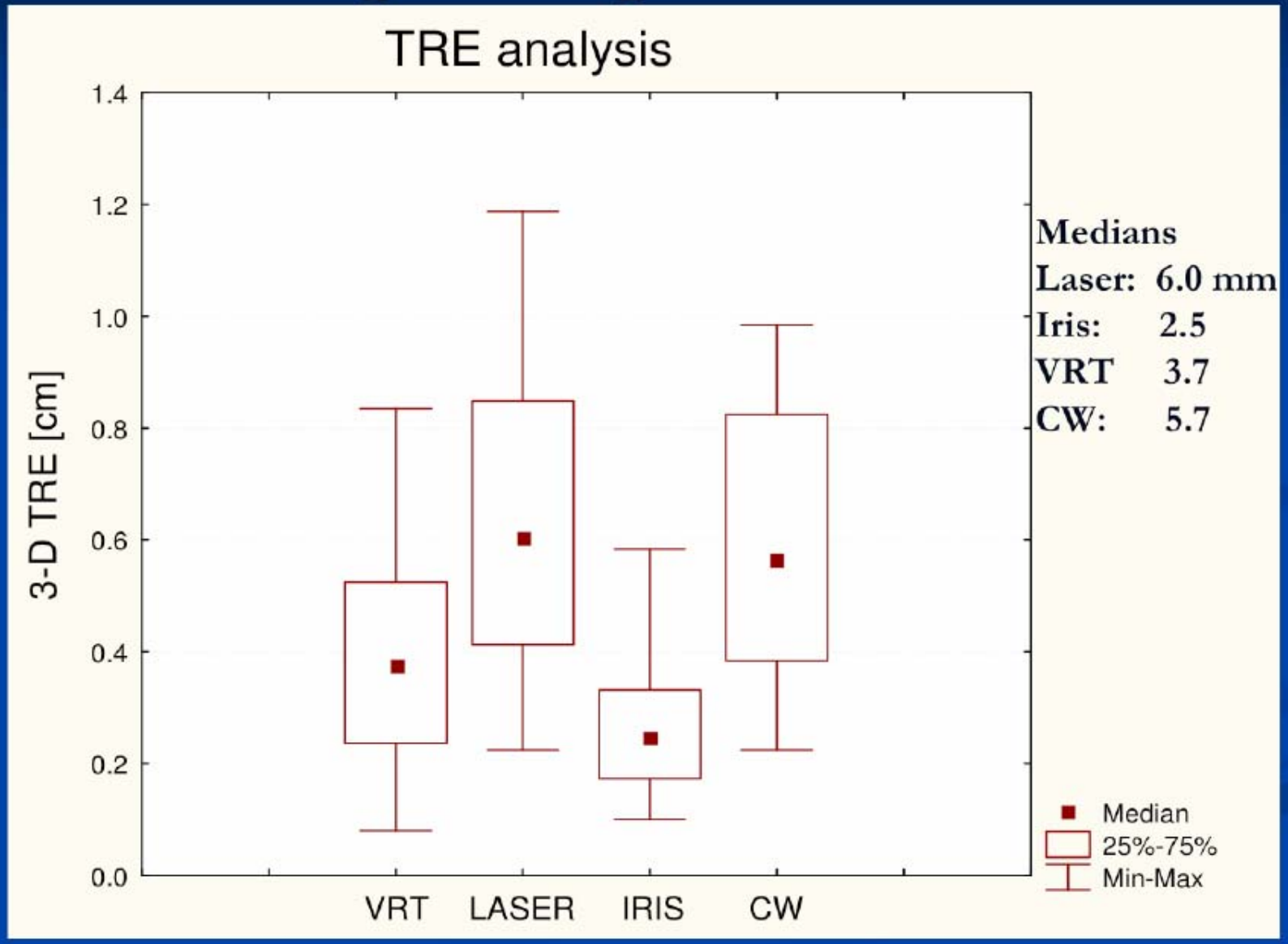
TRE Patient Studies

- Analyze multiple methods of PBI setup (Laser, Chest Wall, Iris, VisionRT)
- Metric: residual displacements on target localization after alignment (Target Registration Error)
- Data analysis performed on a statistical basis (non parametric Friedman ANOVA, Wilcoxon tests, Kruskal-Wallis ANOVA)

Breast Alignment Analysis



Box plot representation



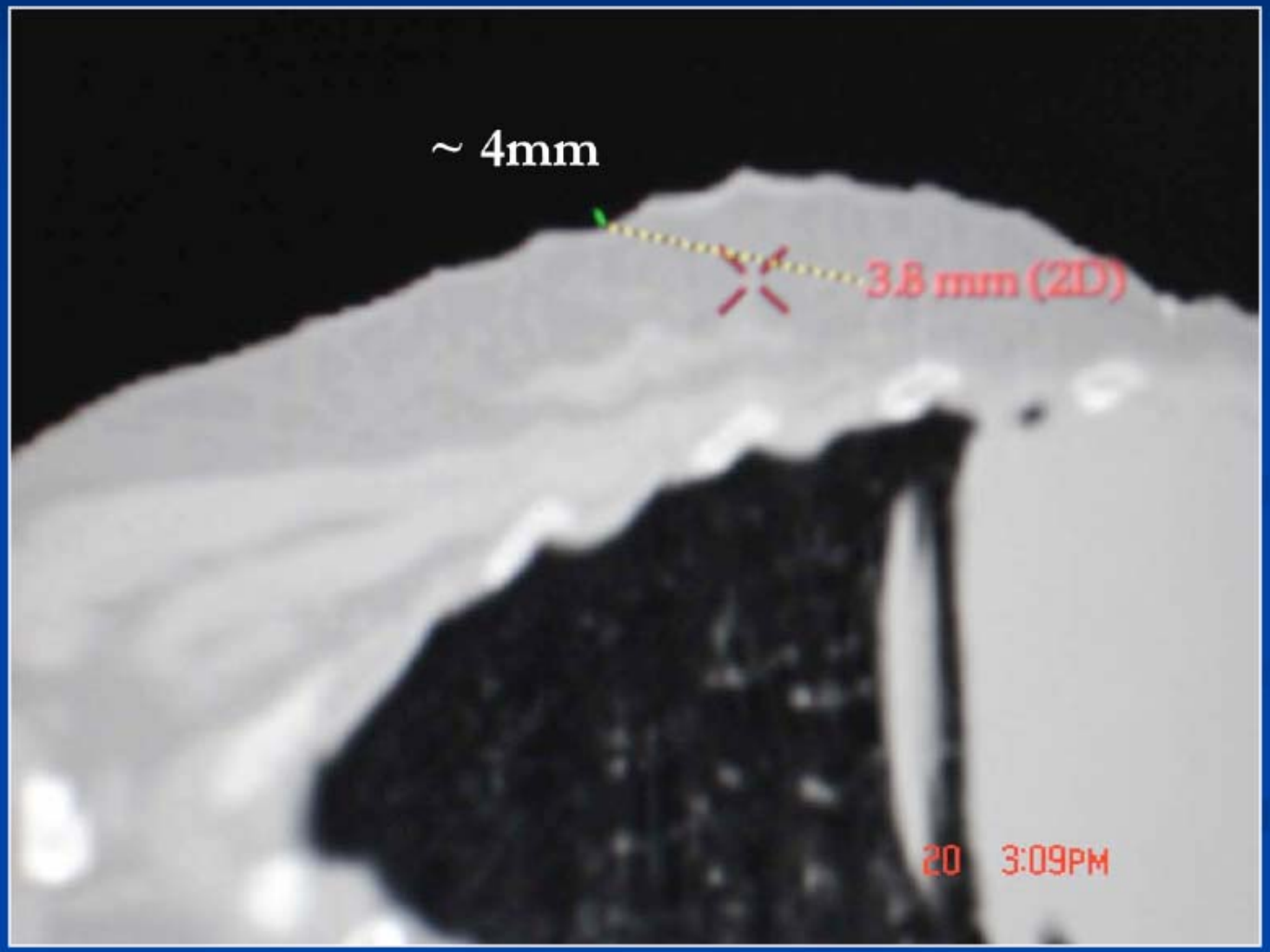
Statistical Analysis Results

- VisionRT TRE significantly lower than LASER (2-3 mm)
- No significant difference could be detected among VisionRT, CW and IRIS (5 patients)
- At least 20 patients are needed to detect a 2 mm difference with 80% power
- High inter-patient variability in VisionRT TRE (Kruskal-Wallis ANOVA, $p<0.025$)

Phantom vs. patients

- Accuracy of 3D Video System on breast phantom is better than **0.5 mm**.
- The VisionRT TRE measured on patients is ~ **3-4 mm**, with high inter-patient variability
- Breast deformation and patient breathing may negatively affect the results
- Can we quantify the effects of deformation and breathing?

Patient 5 – CT ripples



Conclusions

If You're Considering Video/Surface

- What role is it going to play
  - Laser replacement?
  - Daily Targeting of underlying target?
  - Monitor patient during treatment?
  - Tracking and Gating?

Conclusions

If You're Considering Video/Surface

- What Body Site
  - Head / Intracranial works well.
  - PBI near surface works well.
  - PBI near chest wall X-ray chest wall.
  - Prostate not so well but may be an aid to the therapists.

Conclusions

If You're Considering Video/Surface

- Questions to Ask When Purchasing
  - How many systems are needed?
  - What reference surface can be used?
  - Does it work with your planning system?
  - How does it calibrate and know isocenter?
  - What type of R&V system is included?

Conclusions

If You're Considering Video/Surface

- Installation, Commissioning and QA
  - Manufacture's CAP
  - Commissioning
    - Known phantom and site specific
  - QA
    - Daily isocenter check
    - Longer term stability