AAPM2015
REINVIGORATING SCIENTIFIC EXCELLENCE
57th Annual Meeting & Exhibition • July 12–16 • Anaheim, CA

Real-time imaging and tracking techniques for intra-fractional motion management: MV tracking

Ross Berbeco, PhD
Associate Professor
Department of Radiation Oncology
Brigham and Women's Hospital
Dana-Farber Cancer Institute
Harvard Medical School

DANA-FARBER/BRIGHAM AND WOMEN'S CANCER CENTER

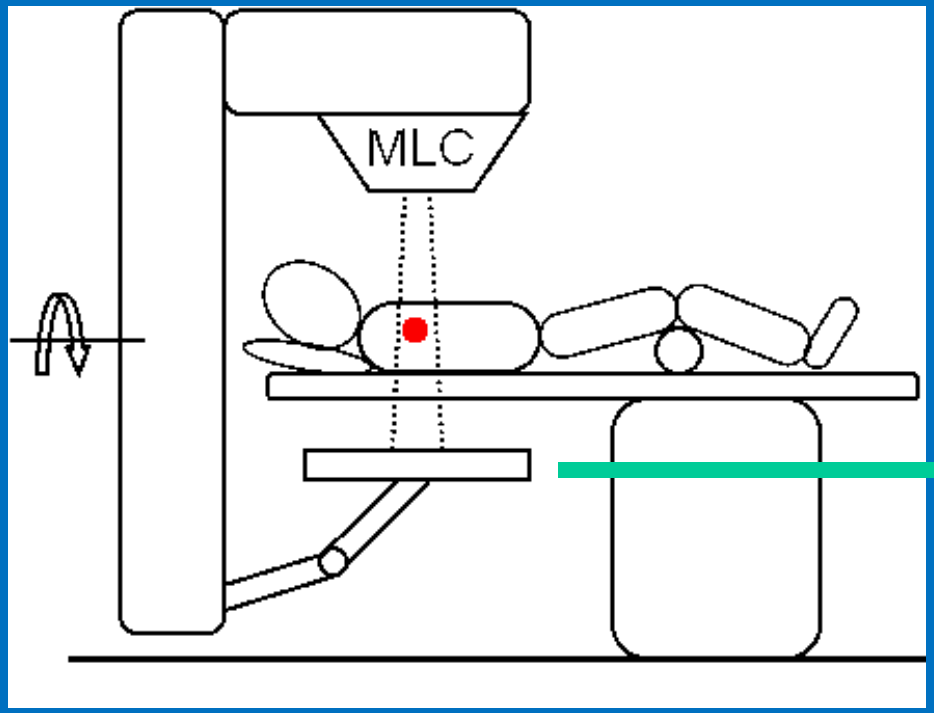
HARVARD MEDICAL SCHOOL

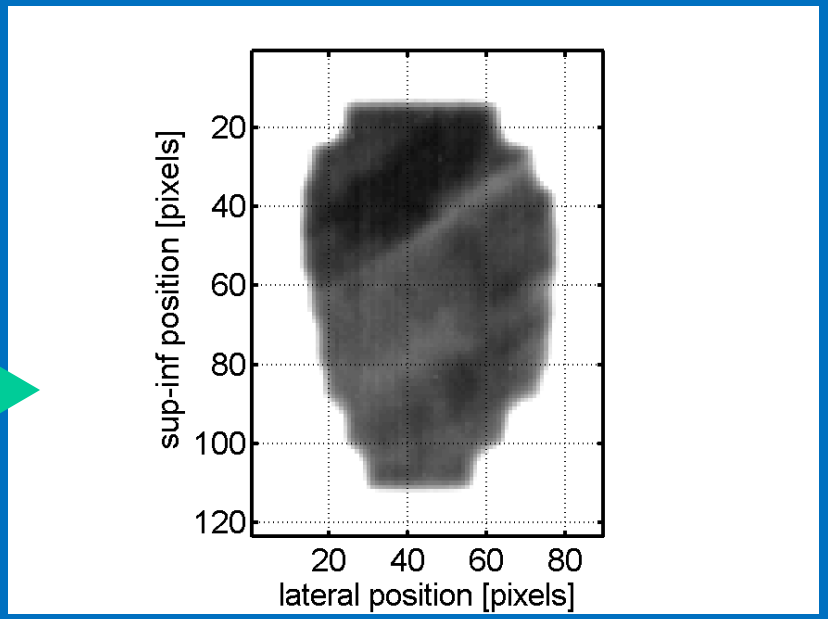
Disclosures

- Varian Medical Systems Research Grants
- Kaye Scholar Award
- JCRT Foundation Grant
- NIH/NCI R01CA188446, NIH/NCI R21CA156068

What is MV tracking?

A.K.A. "*cine* EPID" or "beam's-eye-view" (BEV)



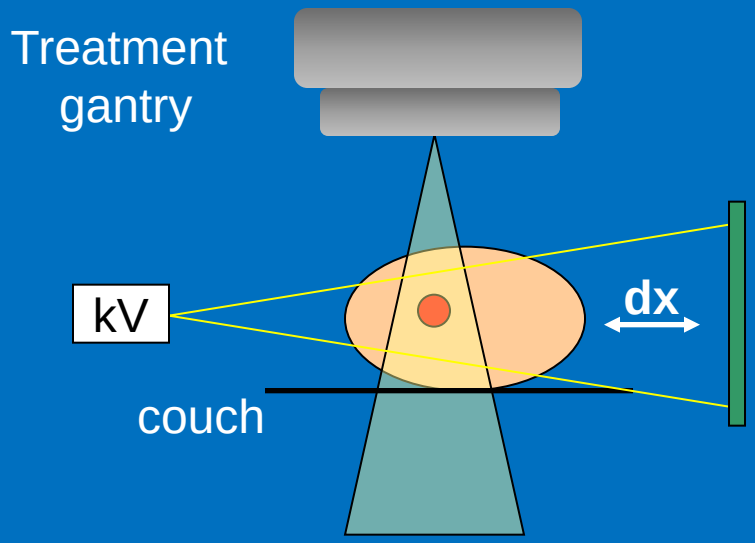


EPID = Electronic Portal Imaging Device

Berbeco et al., A technique for respiratory-gated radiotherapy treatment verification with an EPID in cine mode. Physics in Medicine and Biology. 2005; 50 (16): 3669-79.

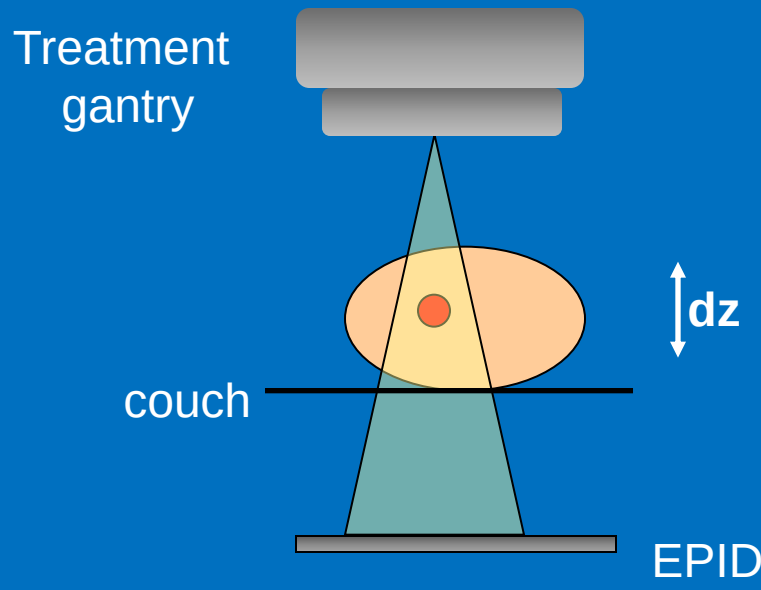
(Dis)advantages of MV imaging

kV imaging



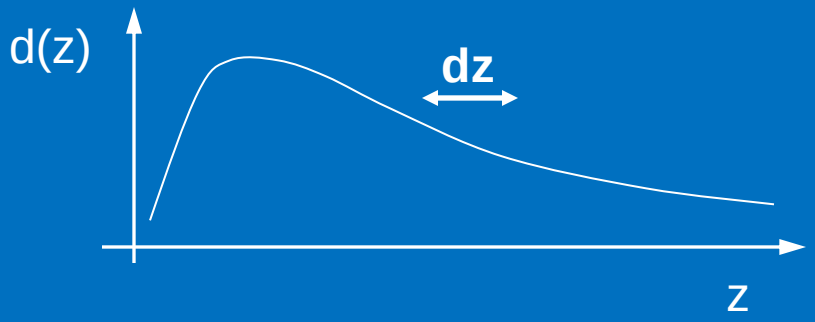
- Image quality decreased when MV on
- Additional dose to the patient
- Degenerate in a potentially important direction

MV imaging

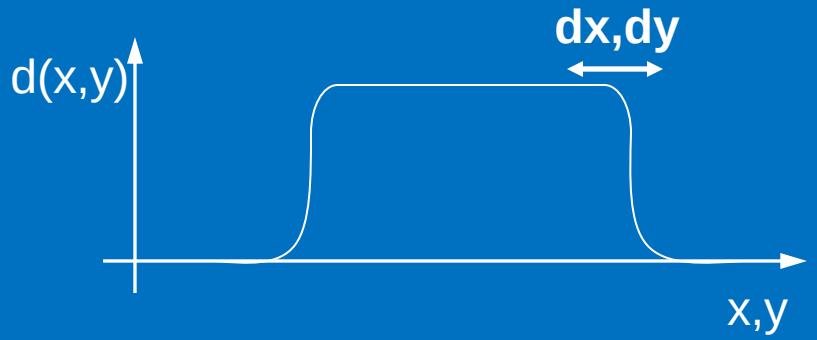


- What you see is what you treat
- No dose
- Less cost and effort
- Less contrast
- IMRT/VMAT

The 2D to 3D "problem"



Along the beam direction



Transverse to the beam direction

In-line error (rms) < 2 mm for non-coplanar lung/liver treatments with motion greater than 5 mm.

Suh et al., Geometric uncertainty of 2D projection imaging in monitoring 3D tumor motion. PMB 2007;52 (12): 3439-3454.

The 2D to 3D "problem"

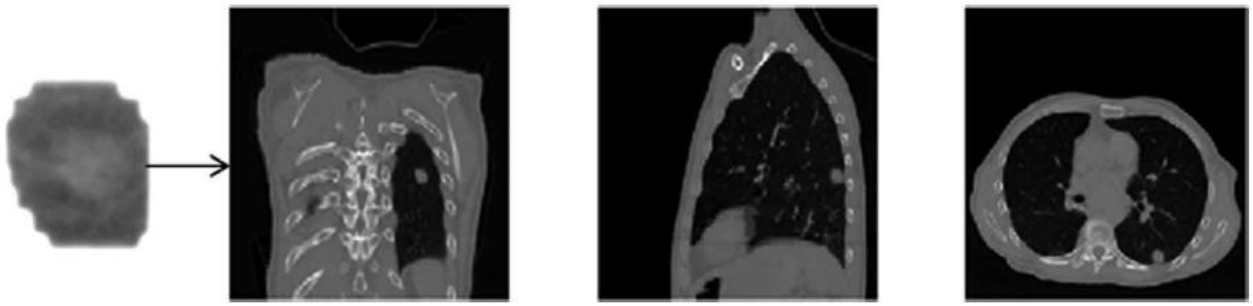


FIG. 6. Coronal (middle-left), sagittal (middle-right), and axial (right) slices from a volumetric fluoroscopic image estimated from a single EPID image (left).

Key result: sub-mm tracking accuracy

Mishra P et al., An initial study on the estimation of time-varying volumetric treatment images and 3D tumor localization from single MV cine EPID images. Medical Physics. 2014; 41 (8): 081713

MV Tracking...

2%	1. Is advantageous due to the use of laser beams
2%	2. Cannot be performed while the treatment beam is on
94%	3. Utilizes an electronic portal imaging device
1%	4. Delivers substantial extra radiation dose to patients
1%	5. Cannot be performed with a medical linear accelerator

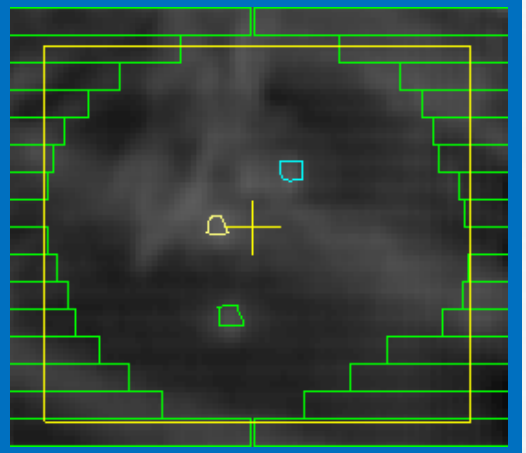
MV Tracking...

1. Is advantageous due to the use of laser beams
2. Cannot be performed while the treatment beam is on
3. Utilizes an electronic portal imaging device
4. Delivers substantial extra radiation dose to patients
5. Cannot be performed with a medical linear accelerator

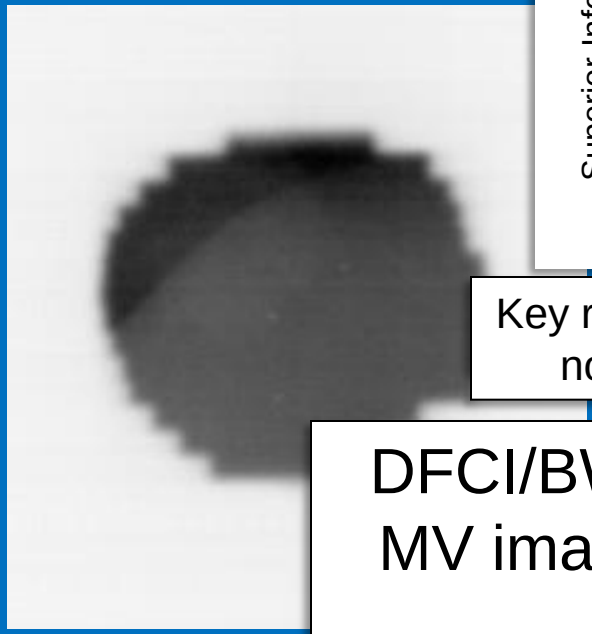
Ref: Berbeco et al., A technique for respiratory-gated radiotherapy treatment verification with an EPID in cine mode. Physics in Medicine and Biology. 2005; 50 (16): 3669-79.

Liver SBRT Verification

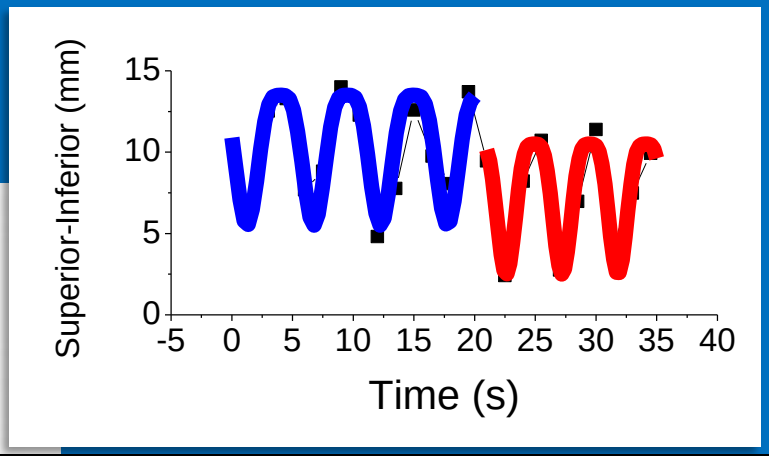
c. 2006
Varian as500 EPID
Frame rate = 0.7 Hz



DRR



EPID



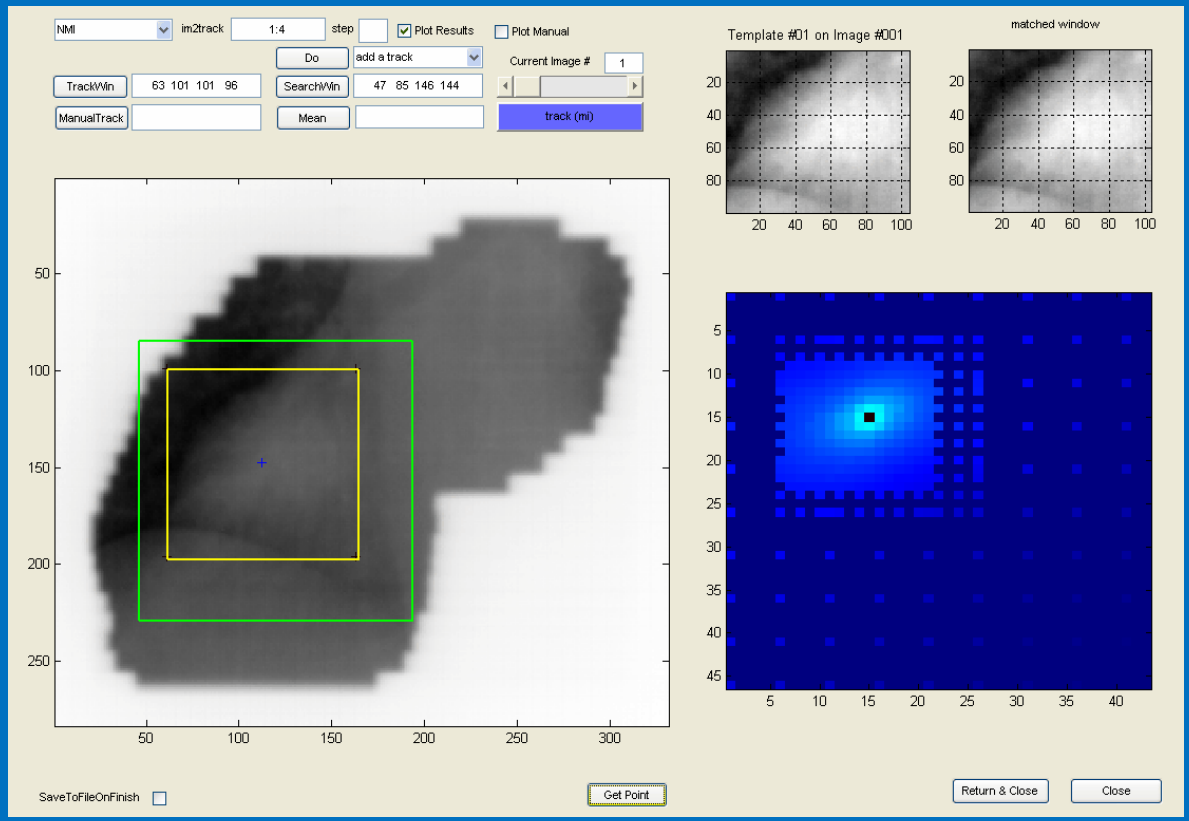
Key result: In-treatment monitoring captures non-periodic intra-fractional changes.

DFCI/BWH: Capture in-treatment MV images for all SBRT patients (>200)

Park SJ *et al*., Automatic marker detection and 3D position reconstruction using cine EPID for SBRT verification. MP 2009; 36(10) 4536-4546.
Berbeco RI, *et al*., Clinical feasibility of using an EPID in cine mode for image-guided verification of SBRT. IJROBP 2007; 69(1) 258-266.

Lung RT Verification

Single template matching

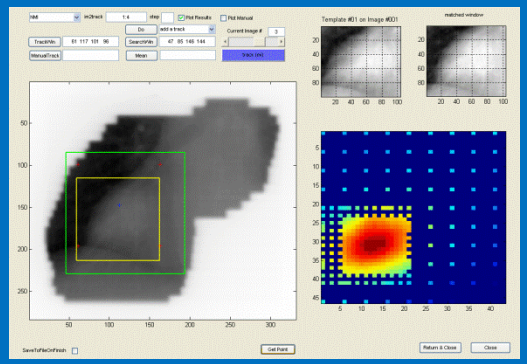


J. Rottmann

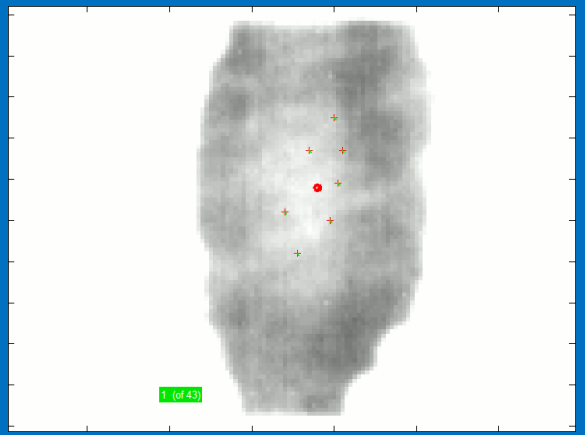
Lung RT Verification

PROBLEM: Single template matching is insufficient for many clinical applications

- Deformations and rotations
- Partial obscurations
  - Target too close to aperture
  - IMRT
  - VMAT



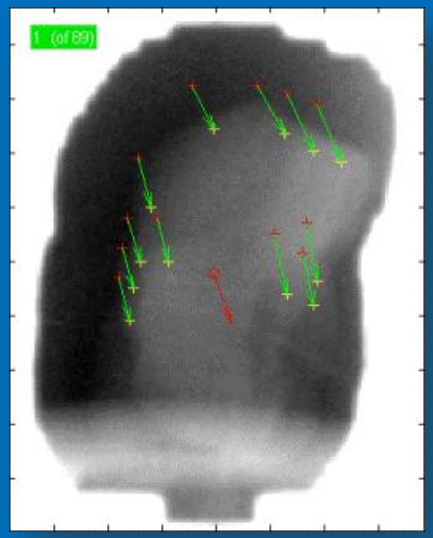
SOLUTION: Automatically identify and track multiple regions simultaneously



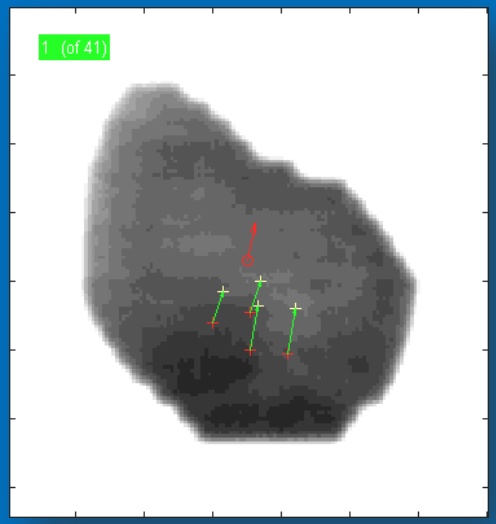
Rottmann *et al*., A multi-region algorithm for markerless beam's-eye-view lung tumor tracking. PMB. 2010; 55 :5585-5598.

Lung RT Verification

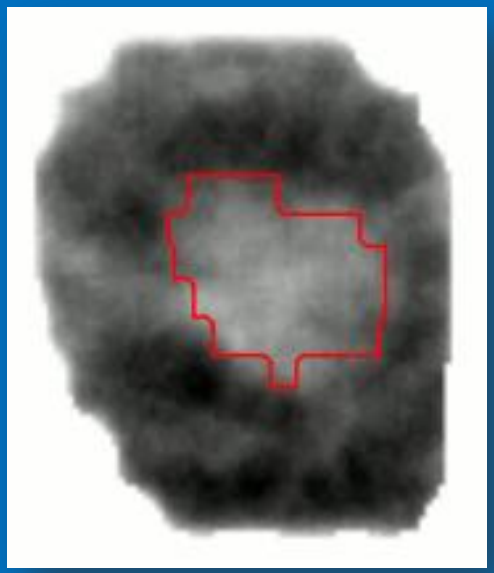
Multi-region (marker-less) tracking



$\Delta_{phantom} < 1$ mm



$\Delta_{patient} < 2$ mm



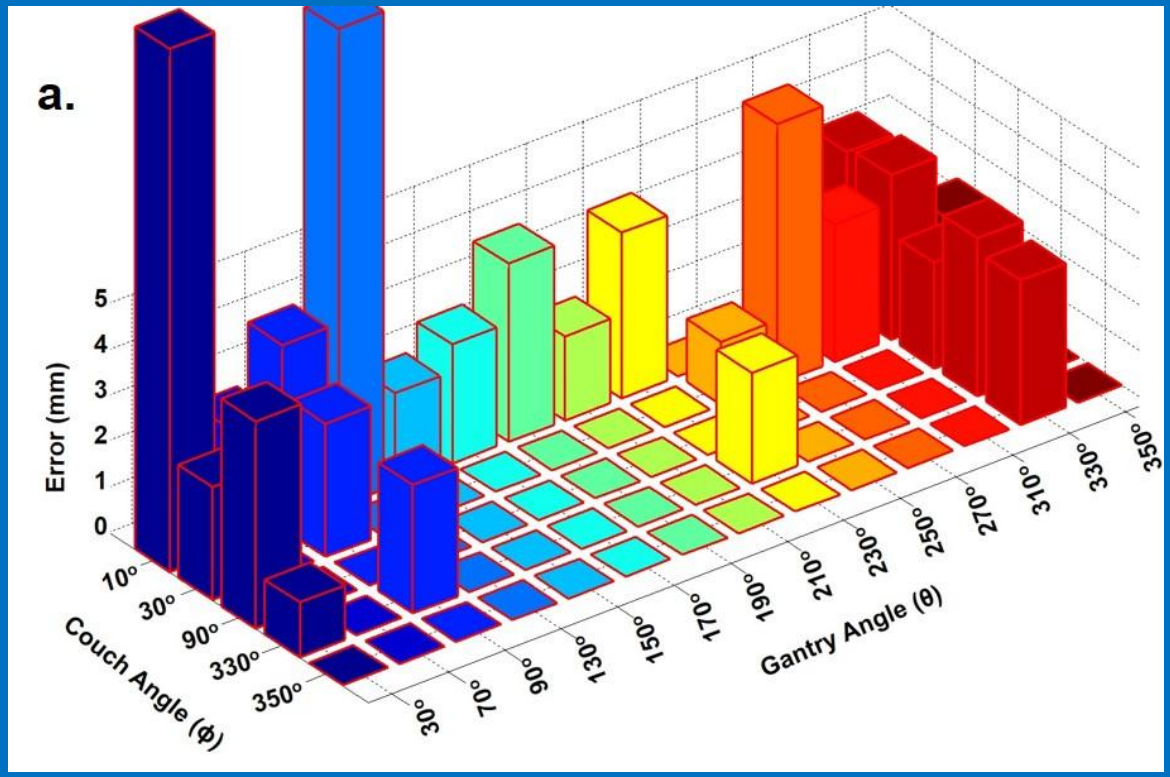
Physician-drawn GTV tracking

Rottmann J et al., Real-time soft tissue motion estimation for lung tumors during radiotherapy delivery. Medical Physics. 2013; 40 (9): 091713-1.

Bryant JH et al., Registration of clinical volumes to beam's-eye-view images for real-time tracking. Medical Physics. 2014; 41 (12): 121703-1.

Angular dependence of MV imaging

120+ BEV sequences of Lung SBRT

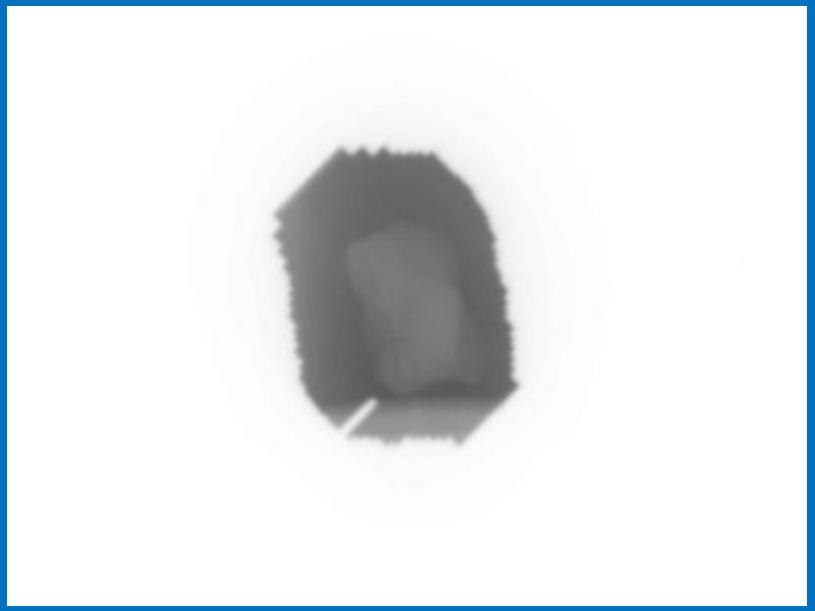


Yip *et al.*, *under review.*

Key results: Best angles for clinical MV tracking is patient-specific.
Lateral angles tend to be most challenging.

MV imaging during IMRT/VMAT

IMRT/VMAT will obscure parts of the target during part of the treatment delivery



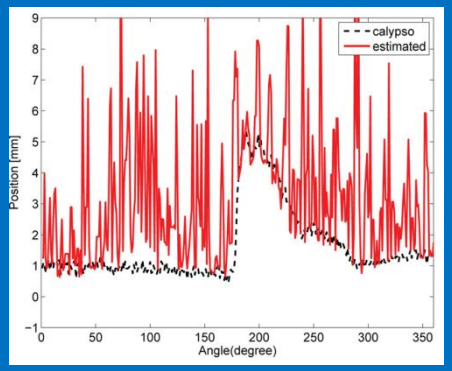
VMAT

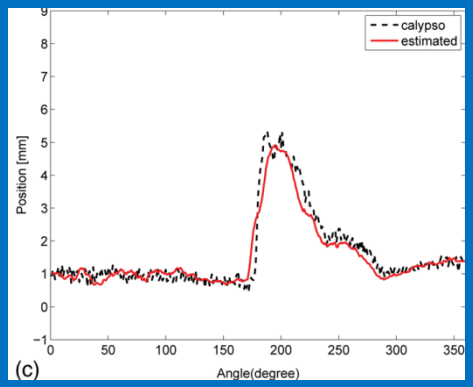
IMRT

MV imaging during IMRT/VMAT

Ex. Prostrate (clinical)

Prior knowledge can be used to estimate target location with limited projections

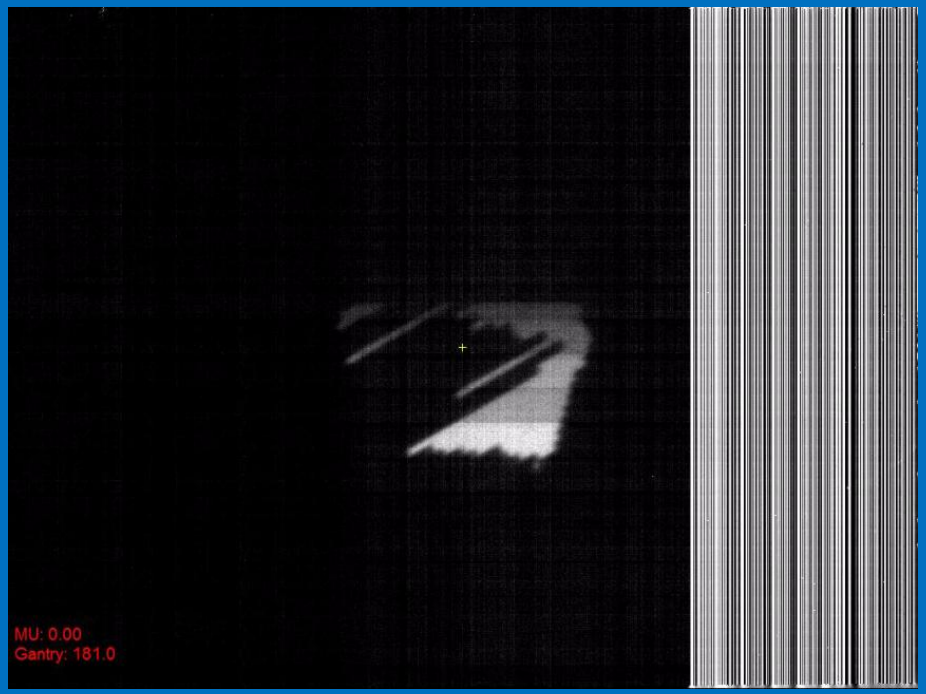




Yue Y *et al*., 3-D fiducial motion tracking using limited MV projections in arc-therapy. Med Phys. 2011; 38 (6): 3222-3231.

MV imaging during IMRT/VMAT

Automatic multiple fiducial tracking during VMAT delivery

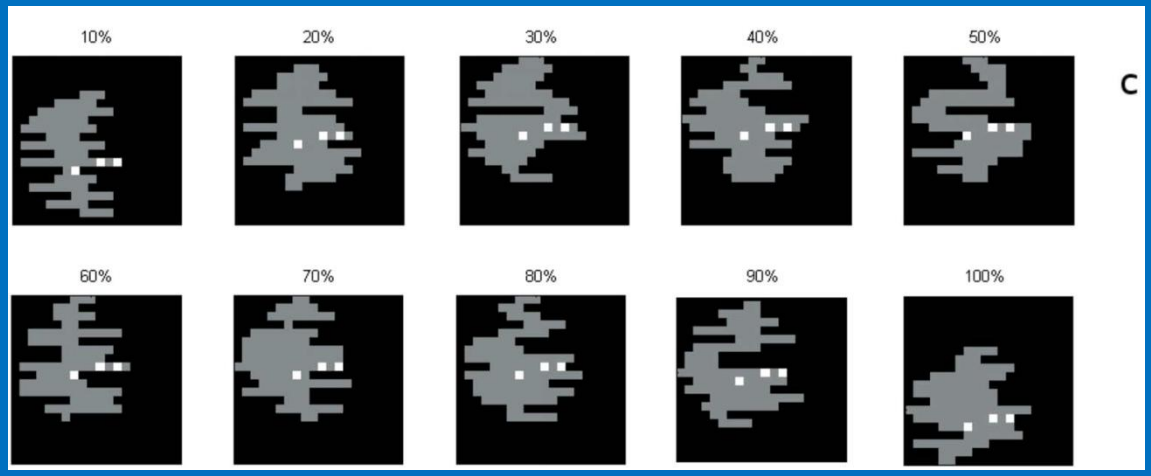


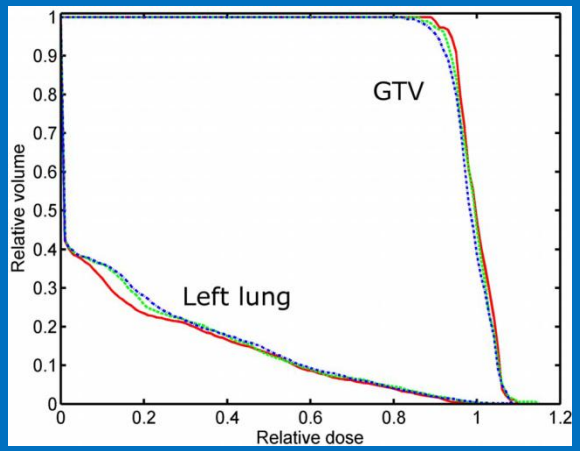
Courtesy of Lei Xing, Stanford U.

Azcona JD et al., Automatic prostate tracking and motion assessment in volumetric modulated arc therapy with an electronic portal imaging device.. IJROBP. 2013; 86 (4): 762-8

MV imaging during IMRT/VMAT

Fiducials can be explicitly included in the IMRT or VMAT optimization

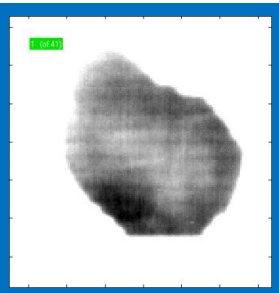


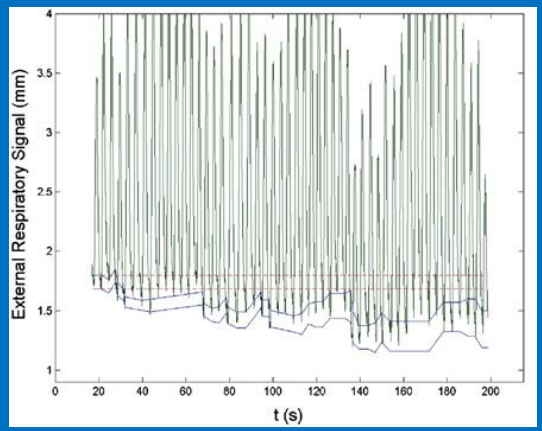


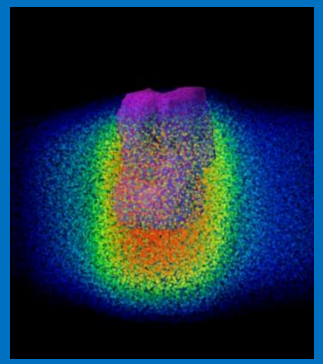
Ma Y et a., 4D inverse treatment planning with inclusion of implanted fiducials in IMRT segmented fields. Medical Physics. 2009; 36(6) 2215-2221.

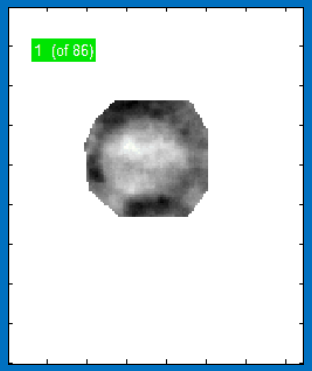
Applications of in-treatment imaging

- ✓Tx verification
- ✓Adaptive/dynamic gating
- ✓Delivered dose calculation
- ✓Adaptive radiation therapy
- ✓Beam tracking



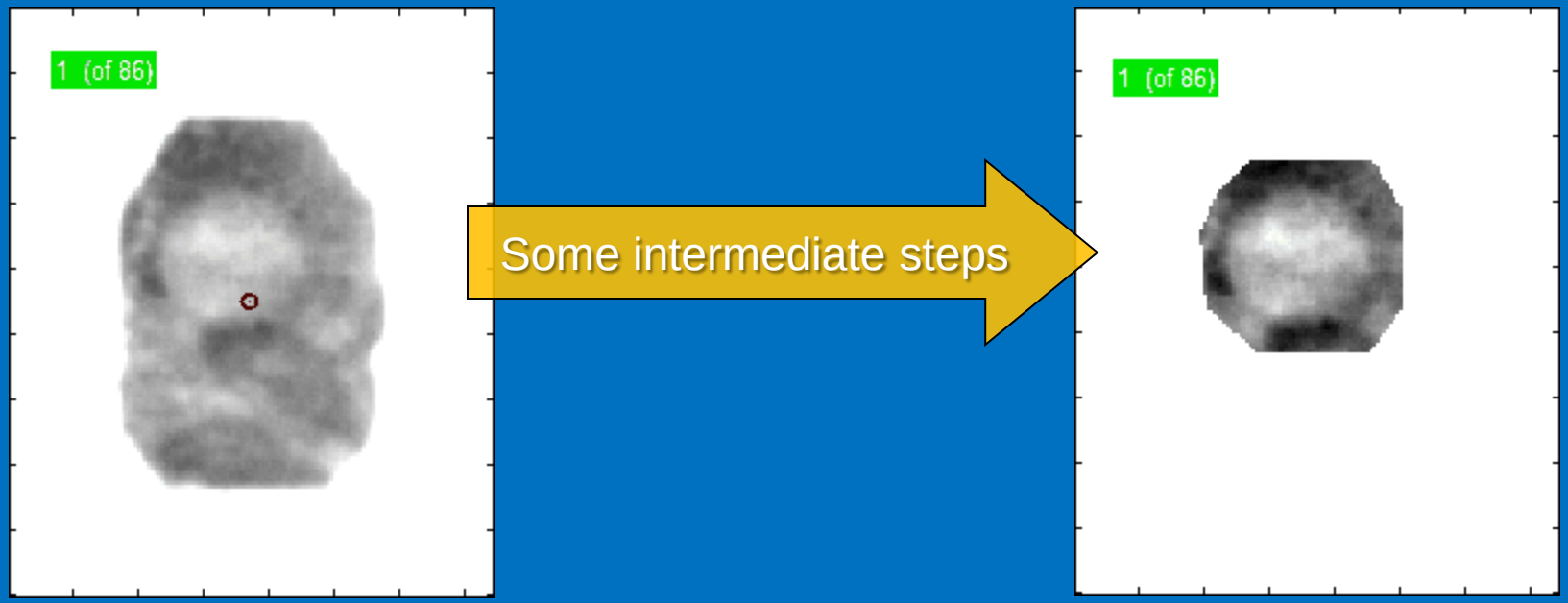






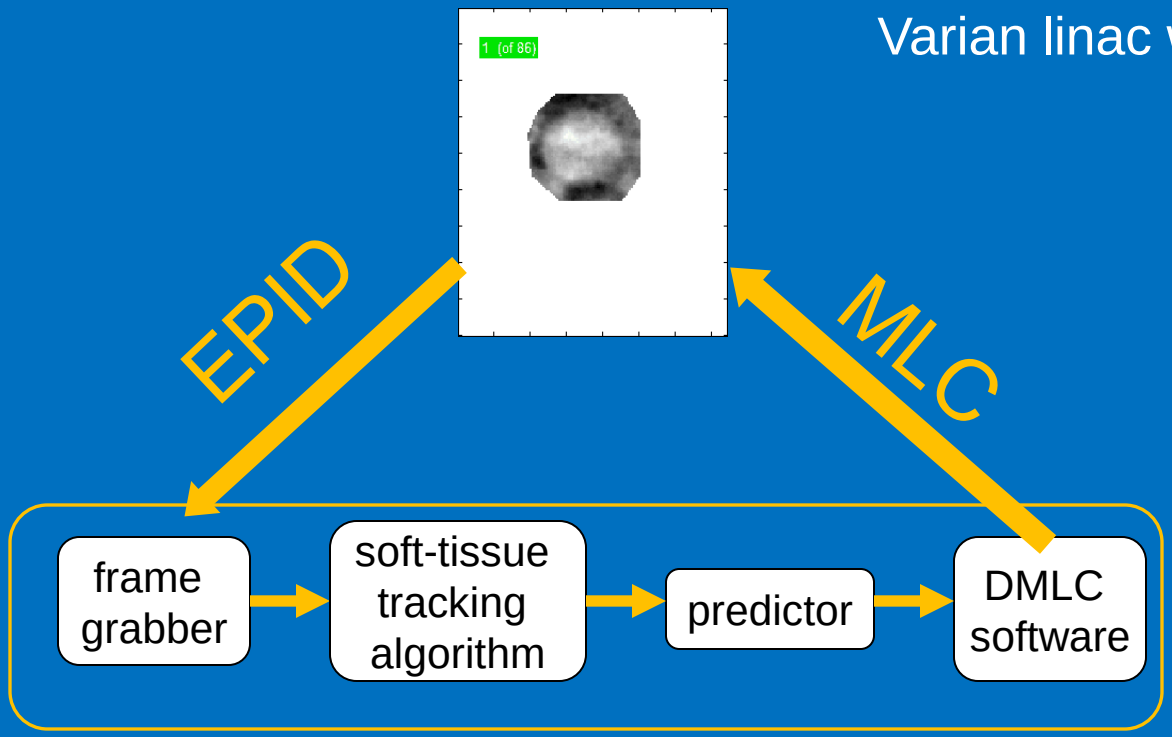
Applications – Tumor tracking

Real-time lung tumor tracking using MV tracking and DMLC



Applications – Tumor tracking

Real-time lung tumor tracking on a Varian linac with MV imaging and DMLC

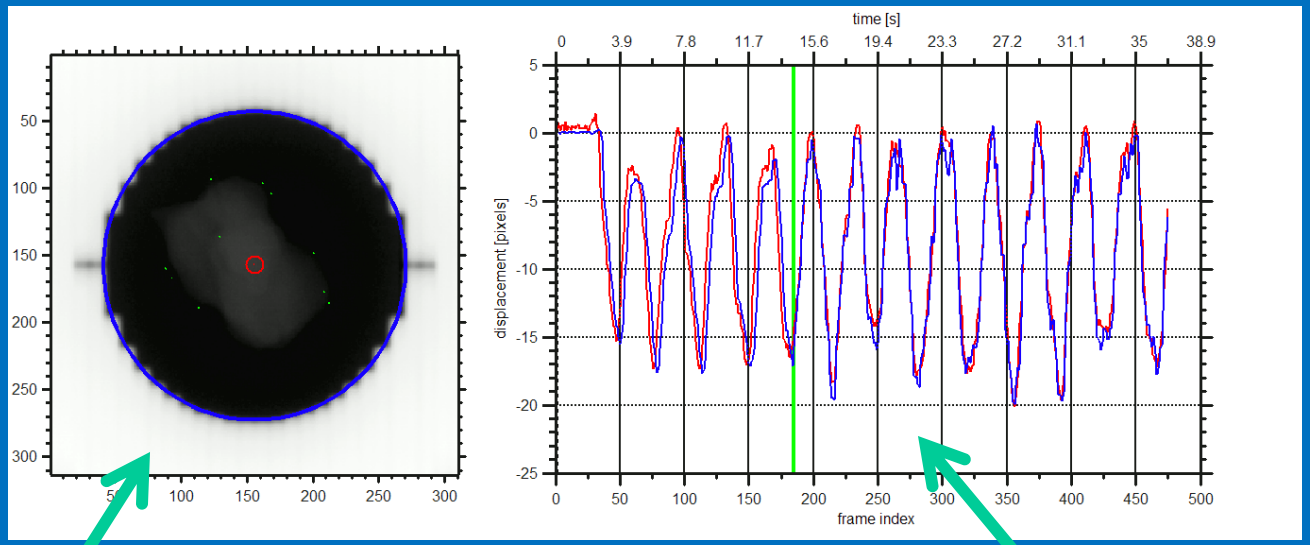


Real-Time Imaging Interface PC

Rottmann J et al., Markerless EPID image guided dynamic multi-leaf collimator tracking for lung tumors. 2013; 58: 4195-4204.

Applications – Tumor tracking

Real-time lung tumor tracking on a Varian linear accelerator using MV imaging and DMLC



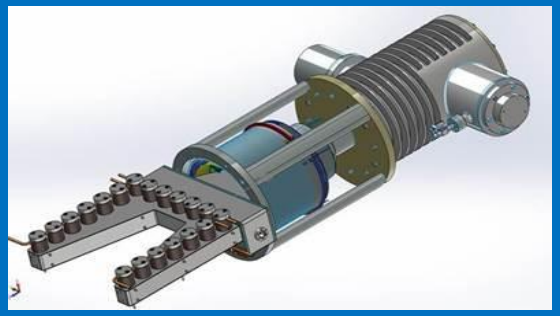
Real-time MV image

Aperture (blue) and target (red) traces

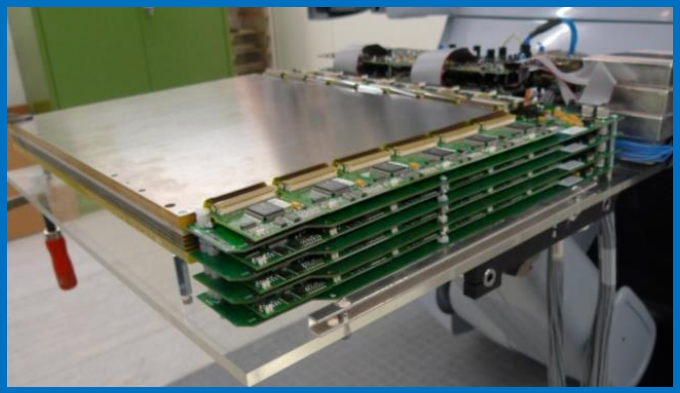
Rottmann J et al., Markerless EPID image guided dynamic multi-leaf collimator tracking for lung tumors. PMB. 2013; 58: 4195-4204.
Rottmann J et al., Using an external surrogate for predictor model training in real-time motion management of lung tumors. Medical Physics. 2014; 41 (12): 121706.

Future MV imaging

Source – more low energy photons



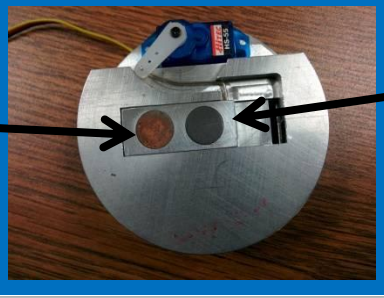
Detector – collect more photons



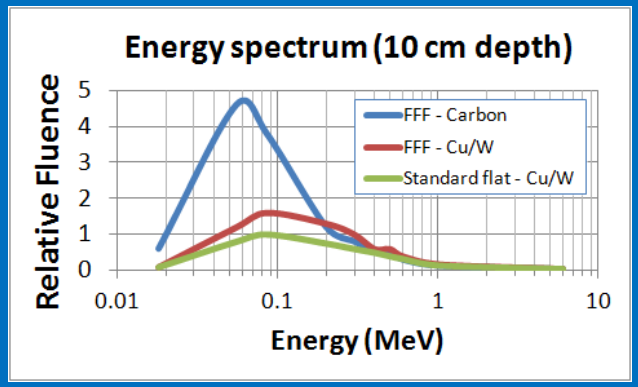
Future MV imaging

Switching target to include more low energy photons

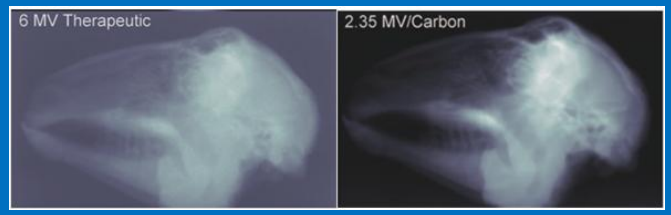
Copper/Tungsten



Carbon

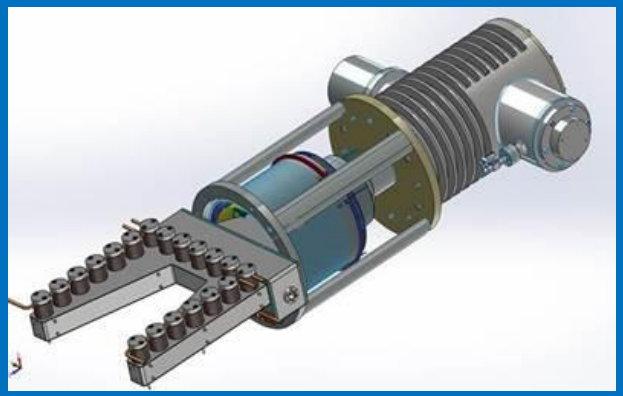


Yewondwossen M *et al*. Dalhousie University
Halifax, Nova Scotia

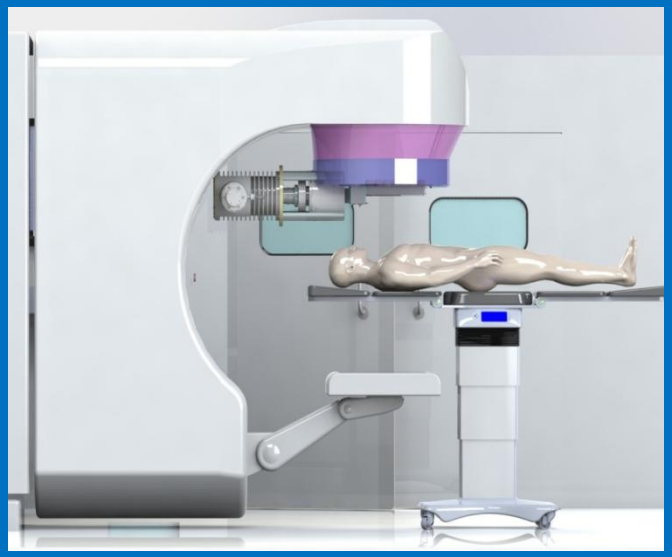


Future BEV imaging

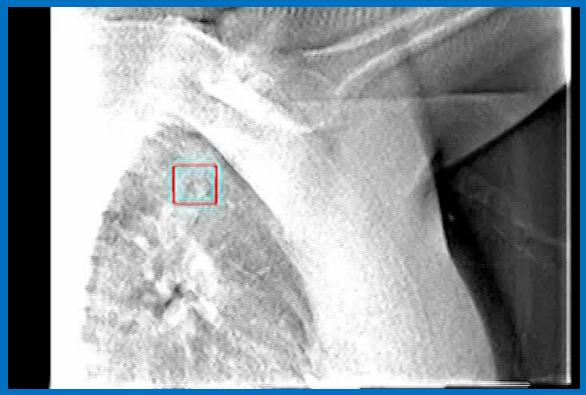
TumoTrak™



19 anode x-ray source fits on the linac head

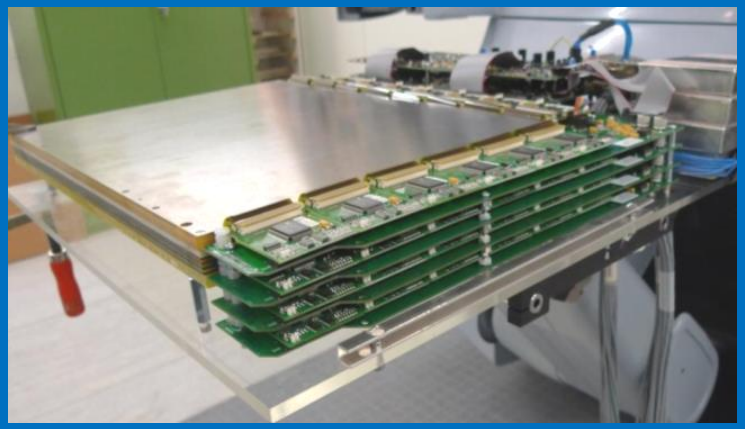


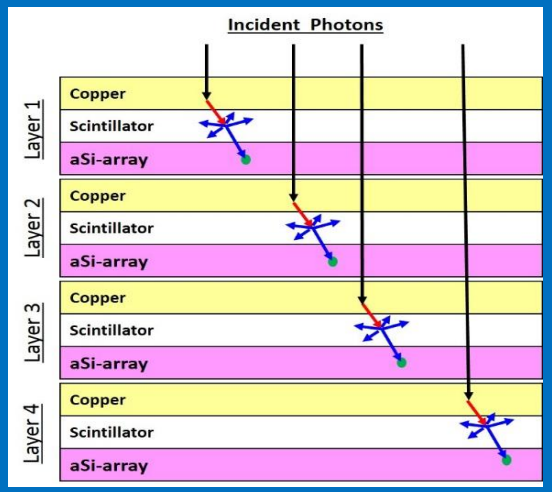
SU-E-J-56
Partain *et al*.
"Static Gantry Digital Tomosynthesis from the Beam's-Eye-View"

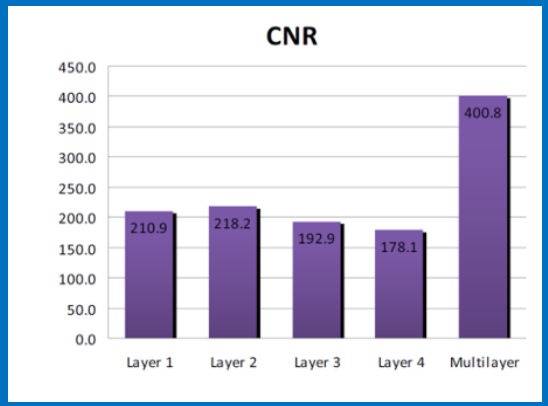


Future MV imaging

Higher DQE imager – multiple layers



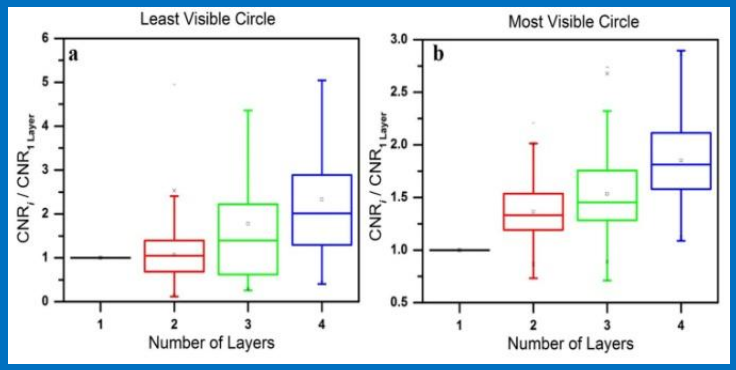




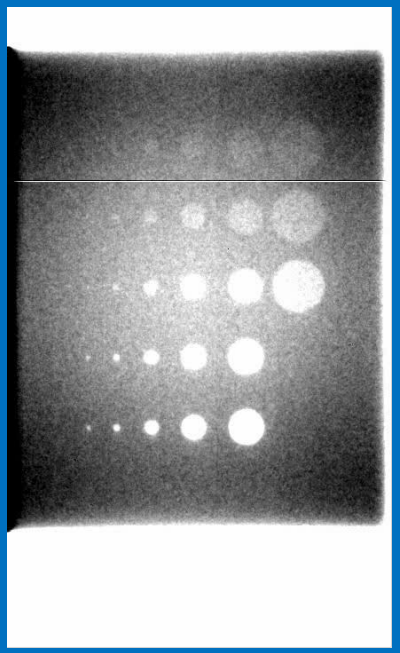
Jack Fowler Junior Investigator Competition Winner
Thursday 1:00pm (TH-EF-BRB-1)
"Novel EPID for Enhanced Contrast and Detective Quantum Efficiency "
Joerg Rottmann *et al*.

Future MV tracking

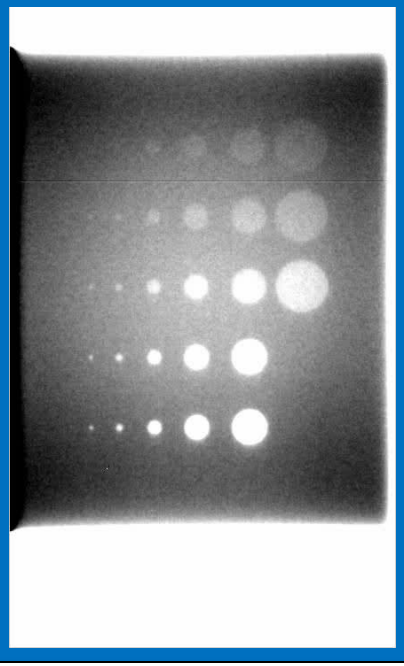
Thursday 1:20pm (TH-EF-BRB-2)
"Combination of Multiple EPID Imager Layers Improves Image Quality and Tracking Performance of Low Contrast Objects"
Stephen Yip *et al.*

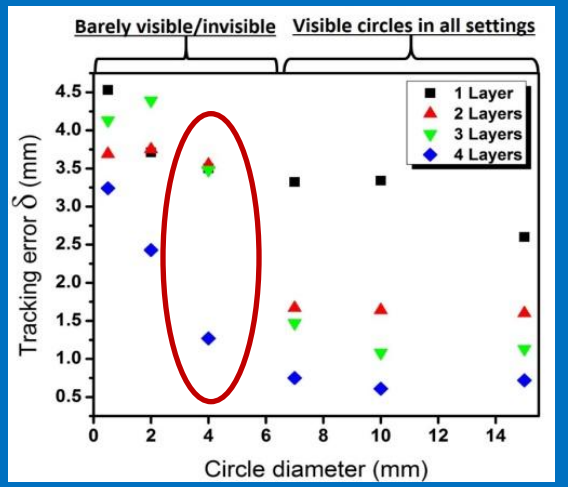


Single EPID layer



Four EPID layers





Key result: 4 layers enables reliable MV tracking of smaller, low-contrast objects than a single layer.

MV tracking...

90%

1. Has been demonstrated on a medical linear accelerator

4%

2. Is incompatible with other monitoring technologies, such as MRI and EM

1%

3. Cannot be used to visualize or track tumors for any patients under any conditions

1%

4. Cannot be integrated with a dynamic multileaf collimator

4%

5. Requires major infrastructure changes to implement

MV tracking...

1. Has been demonstrated on a medical linear accelerator
2. Is incompatible with other monitoring technologies, such as MRI and EM
3. Cannot be used to visualize or track tumors for any patients under any conditions
4. Cannot be integrated with a dynamic multileaf collimator
5. Requires major infrastructure changes to implement

Ref: Rottmann J et al., Markerless EPID image guided dynamic multi-leaf collimator tracking for lung tumors. 2013; 58: 4195-4204.

Summary

- MV imaging provides a cost effective, simple solution
- Moving targets can be tracked with MV imaging
- Future improvements to the detectors and/or the source will improve in-treatment MV image quality
- Remaining challenges include MV imaging during IMRT and VMAT

Acknowledgements

Dana-Farber Cancer Institute and Brigham and Women's Hospital

- Dan Ionascu, PhD
- Sang-June Park, PhD
- Desmond O'Farrell, MS
- Fred Hacker, PhD
- Joe Killoran, PhD
- Chris Zatwarnicki, MS
- Yong Yue, PhD
- Jonathan Bryant, PhD
- Laurence Court, PhD
- Chris Jensen, BS
- Pankaj Mishra, PhD
- Harvey Mamon, MD, PhD
- Aaron Allen, MD
- Aileen Chen, MD
- David Sher, MD
- David Kozono, MD, PhD
- Ray Mak, MD
- Paul Nguyen, MD
- Tania Lingos, MD
- DFCI and BWH therapists
- Joerg Rottmann, PhD
- Michalis Aristophanous, PhD
- John Lewis, PhD
- Stephen Yip, PhD
- Haijian Chen, PhD

Varian Medical Systems, Inc.

- Daniel Morf, MS
- George Zentai, PhD
- Josh Star-Lack, PhD
- Rony Fluegstaller, MS

TeleSecurity Sciences, Inc.

- Larry Partain, PhD

Stanford University

- Lei Xing, PhD

Dalhousie University (Halifax, NS)

- James Robar, PhD
- David Parsons, PhD
- Mammo Yewondwossen, PhD

References

- Aristophanous M *et al*., Image-guided adaptive gating of lung cancer radiotherapy: a computer simulation study. Phys Med Biol. 2010; 55: 4321-4333.
- Aristophanous M *et al*, EPID-guided 3D dose verification of lung SBRT. Medical Physics 2011; 38(1): 495-503.
- Azcona JD et al., Automatic prostate tracking and motion assessment in volumetric modulated arc therapy with an electronic portal imaging device. IJROBP. 2013; 86 (4): 762-8
- Berbeco RI *et al*., A technique for respiratory-gated radiotherapy treatment verification with an EPID in cine mode. Phys Med Bio. 2005; 50 (16): 3669.
- Berbeco RI, *et al*., Clinical feasibility of using an EPID in cine mode for image-guided verification of SBRT. IJROBP 2007; 69 (1) 258-266.
- Berbeco RI, *et al*., A novel method for estimating SBRT delivered dose with BEV images. Medical Physics 2008; 35 (7): 3225-3231.
- Bryant JH et al., Registration of clinical volumes to beam's-eye-view images for real-time tracking. Medical Physics. 2014; 41 (12): 121703-1.
- Court LE *et al*. Use of a realistic breathing lung phantom for evaluation of dose delivery errors. Medical Physics. 2010; 37(11): 5850-5857.
- Ma Y et a., 4D inverse treatment planning with inclusion of implanted fiducials in IMRT segmented fields. Medical Physics. 2009; 36(6) 2215-2221.
- Park SJ *et al*., Automatic marker detection and 3D position reconstruction using cine EPID for SBRT verification. Med Phys. 2009; 36(10) 4536-4546.
- Rottmann J *et al*., A multi-region algorithm for markerless beam's-eye-view lung tumor tracking. Phys Med Biol. 2010; 55: 5585-5598.
- Rottmann J et al., Markerless EPID image guided dynamic multi-leaf collimator tracking for lung tumors. Phys Med Biol. 2013; 58: 4195-4204.
- Rottmann J et al., Real-time soft tissue motion estimation for lung tumors during radiotherapy delivery. Medical Physics. 2013; 40 (9): 091713-1.
- Suh Y *et al*., Geometric uncertainty of 2D projection imaging in monitoring 3D tumor motion. Phys Med Biol. 2007;52 (12): 3439-3454.
- Yip S *et al*., The impact of cine EPID image acquisition frame rate on markerless soft-tissue tracking, Medical Physics. 2014; 41 (6): 061702-1.
- Yue Y *et al*., 3-D fiducial motion tracking using limited MV projections in arc-therapy. Med Phys. 2011; 38 (6): 3222-3231.