Real-time and offline treatment delivery error detection via aSi EPID transmission dosimetry

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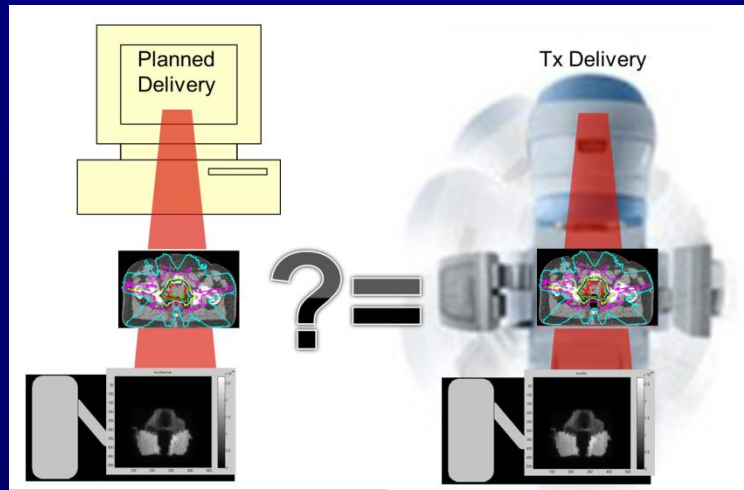
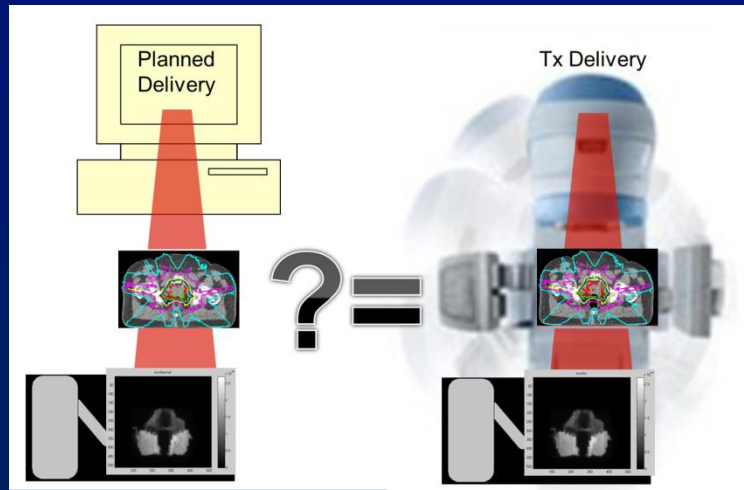
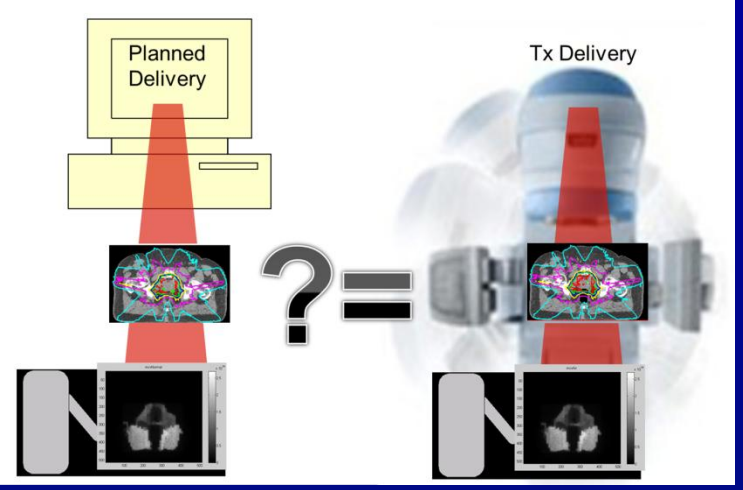


Disclosures

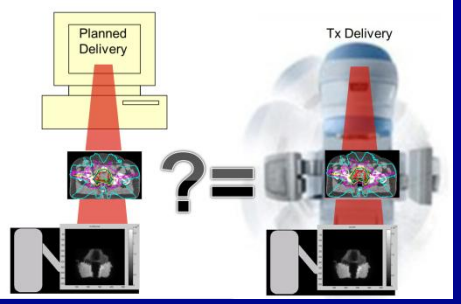
- This work has been supported in part by
  - 2013 ROI Grant from ASTRO "Safety and Quality: IMRT treatment delivery accuracy“, Peter Greer PI
  - Varian Medical Systems (6/2015)





Objectives

- Understand
  - real-time EPID-based transmission dosimetry
  - goals of real-time delivery monitoring

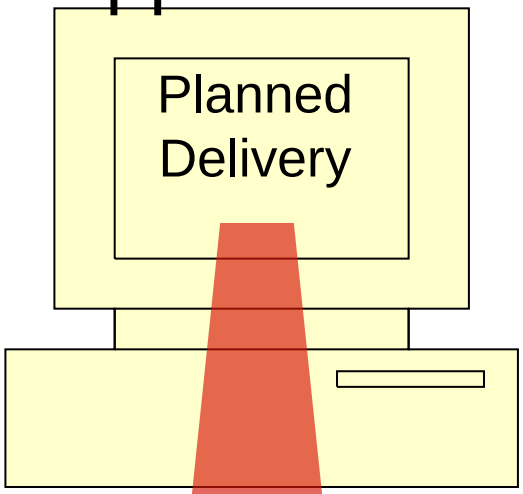


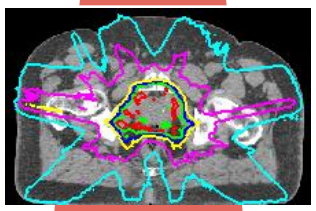
Background

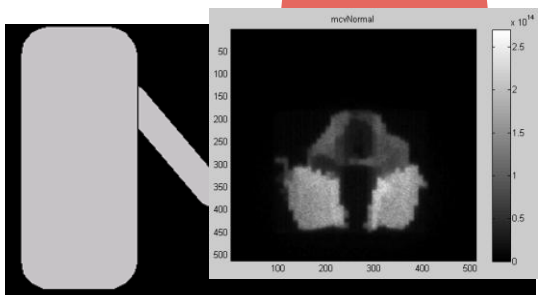
- QA methods lag modern delivery capabilities
- Significant error pathways persist even when pre-treatment QA is performed
  - R&V parameters *could* be altered inter-fractionally
    - unintentional modification while viewing, database corruption, …
  - Equipment *could* malfunction
    - position encoder disconnect from leaf, …
  - Current pre-treatment QA is insensitive to delivery errors
    - %γ<1 (3%,3mm) reliably detects 10% fluence errors in 20x20 mm^2 area
  - During treatment motion & intra- & inter-fractional patient changes can occur
- Practical QA needed for real-time adaptive RT

Treatment QA Goal

Approved Plan = Achieved in Patient







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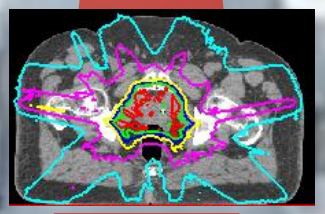
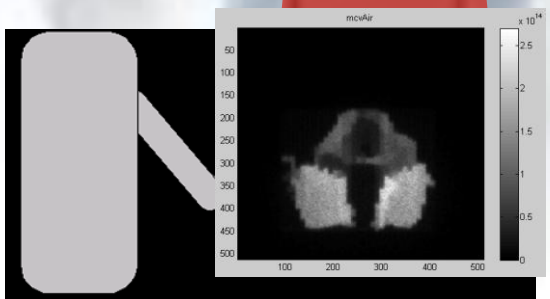
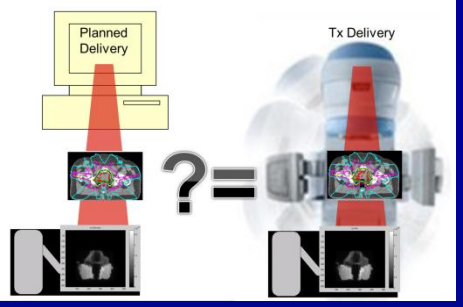
Tx Delivery

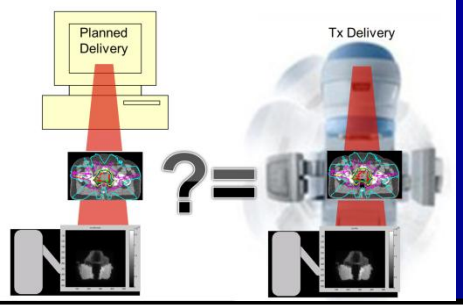






during treatment uses

- dose back-projection-based estimators
  - point-dose
  - iso-center-plane dose
  - 3D-dose (PTV dose in accelerator coordinate system)
- tissue-localization (±fiducials)
- patient changes (Δ attenuation / tumor shrinkage)
- MLC leaf position variations



Findings

Catching errors with *in vivo* EPID dosimetry

A. Mans,[a] M. Wendling,[b] L. N. McDermott,[c] J.-J. Sonke, R. Tielenburg, R. Vijlbrief, B. Mijnheer, M. van Herk, and J. C. Stroom

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2638 Med. Phys. 37 (6), June 2010 0094-2405/2010/37(6)/2638/7/$30.00

- Gross error rates ~0.3%
- Most detected errors were not / would NOT have been picked up by pre-treatment QA

To date, EPID-base exit-fluence has NOT been used to

27% 1. Monitor fiducial locations

20% 2. Detect miss-positioned MLC leaves

10% 3. Detect tumor spread

17% 4. Re-compute PTV dose

27% 5. Detect tumor response

To date, EPID-base exit-fluence has NOT been used to

1. Monitor fiducial locations:
   Lin, W.-Y., *et al.* (2013). Real-time automatic fiducial marker tracking in low contrast cine-MV images. *Medical Physics*, *40*(1), 011715.
2. Detect miss-positioned MLC leaves:
   Fuangrod, T., *et al.* (2014). An independent system for real-time dynamic multileaf collimation trajectory verification using EPID. *Physics in Medicine and Biology*, *59*(1), 61–81.
3. Detect tumor spread:
   This, to my knowledge, has not been reported in published works.
4. Re-compute PTV dose:
   Mans, A, *et al.* (2010). Catching errors with in vivo EPID dosimetry. *Medical Physics*, *37*(6), 2638–2644.
5. Tumor shrinkage:
   McDermott, L. *et al.* (2006). Anatomy changes in radiotherapy detected using portal imaging. *Radiotherapy and Oncology*, *79*(2), 211–217. http://doi.org/10.1016/j.radonc.2006.04.003

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An example real-time QA program

ASTRO Radiation Oncology Institute Grant

- International consortium

Center
Calvary Mater Newcastle (CMN) – Lead Site
Northern Sydney Cancer Centre (NSCC)
University of Virginia (UVA)
Cancer Care Manitoba (CCM)
Central Coast Cancer Center (CCCC)
Memorial Sloan Kettering Cancer Center (MSKCC)

- verification *as the radiation is delivered to the patient for every fraction*
- EPID-based detection

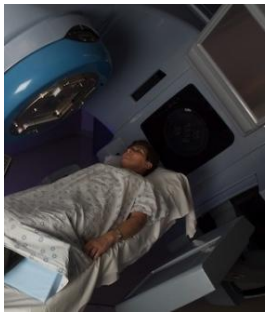
Real-time verification

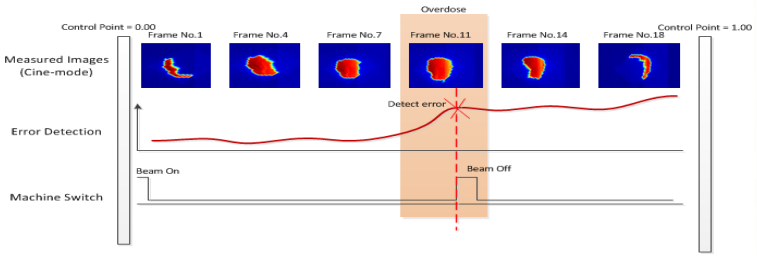
Center	Linac	Energy	MLC	EPID
Calvary Mater Newcastle (CMN) – Lead Site	C-Series (4)	6X	Millenium	aS1000
	TB2.0	6X, 10X	HDMLC	aS1200
		6XFFF, 10XFFF	HDMLC	aS1200
Northern Sydney Cancer Centre (NSCC)	C-Series	6X	Millenium	aS1000
	TB2.0	6X	HDMLC	aS1000
University of Virginia (UVA)	TB1.5	6X, 10X, 15X	Millenium	aS1000
		6XFFF, 10XFFF	Millenium	aS1000
	C-Series	6X, 15X	Millenium	aS1000
Cancer Care of Virginia (CCM)	C-Series	6X	Millenium	aS1000
Central Coast Cancer Center (CCCC)	C-Series (2)	6X	Millenium	aS1000
Memorial Sloan Kettering Cancer Center (MSKCC)	TB2.0	6X, 10X	Millenium	aS1000
	TB2.0	6X	Millenium	aS1200

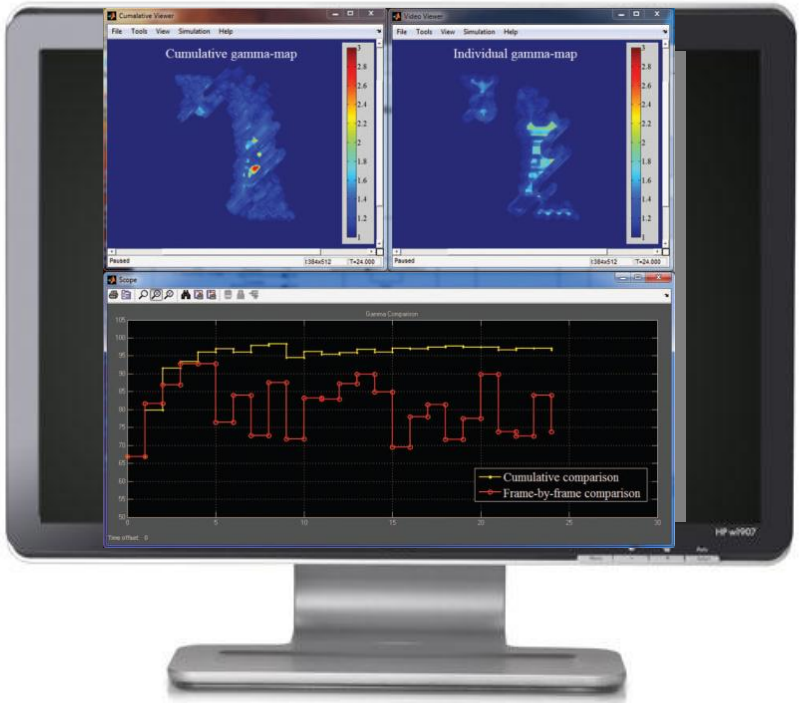
- diverse equipment
- goals:
  - Implementation
  - Quantify gross error rate

Description of research project

- Predict using a model the “cine” EPID images that should be measured during the patient’s radiation delivery
- Acquire EPID cine images during the delivery (frame-rate ~ 7 Hz) **Detection within 0.14 sec**
- Compare the measured to the predicted in real-time

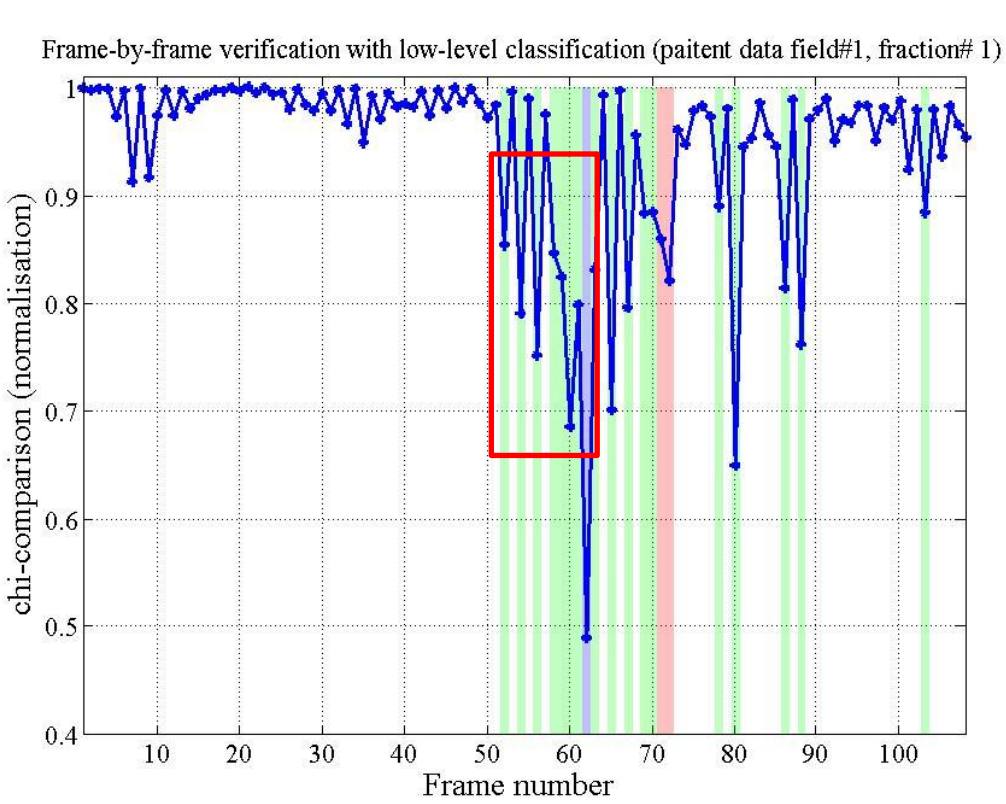




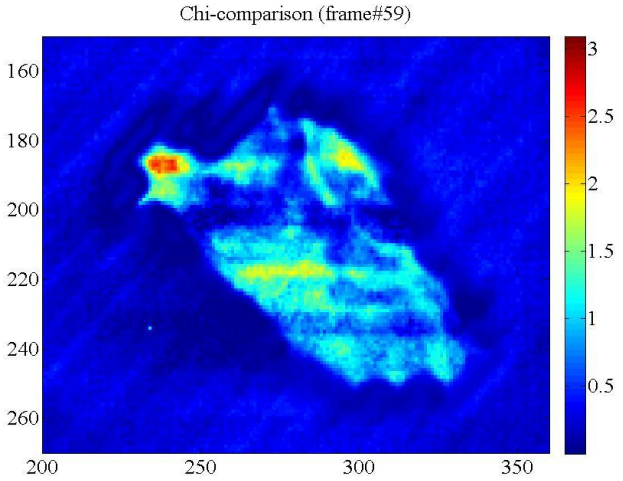


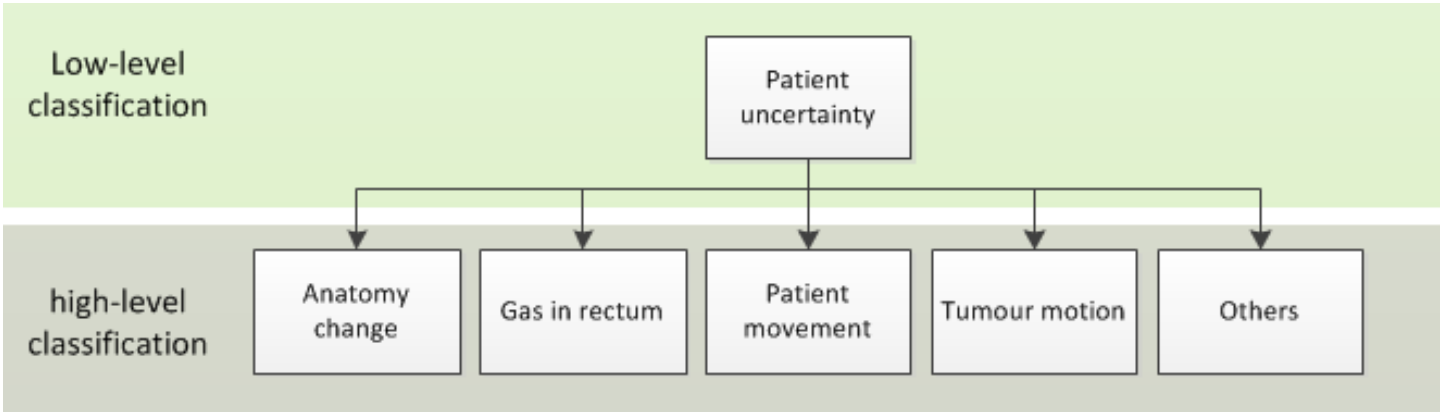
Courtesy of Peter Greer

- Development of optimal error detection tools – patient uncertainties



Patient uncertainty





Courtesy of Peter Greer

watchDOG

Planning System

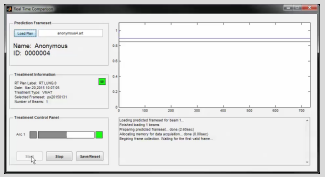
DICOM

Image Predictor
(McCurdy)

Record and Verify

watchDOG

WatchDog Computer



Frame Grabber

Portal Vision

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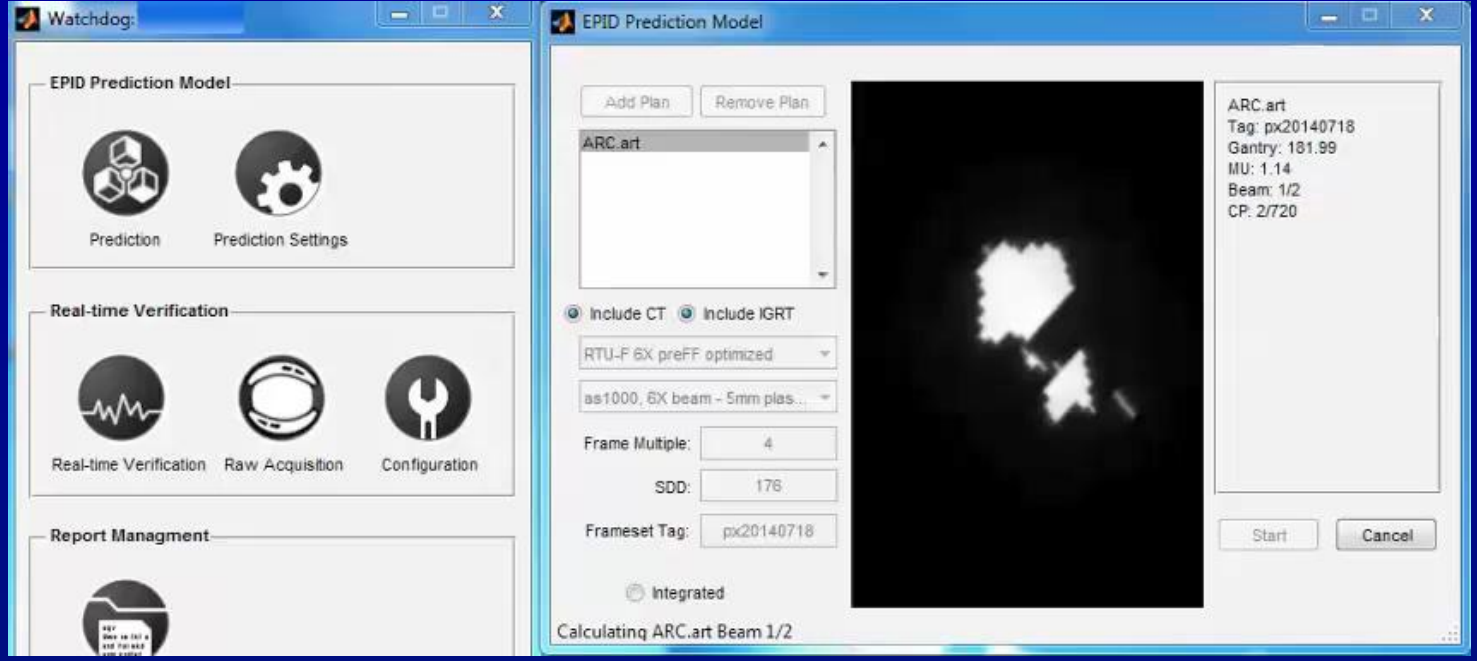
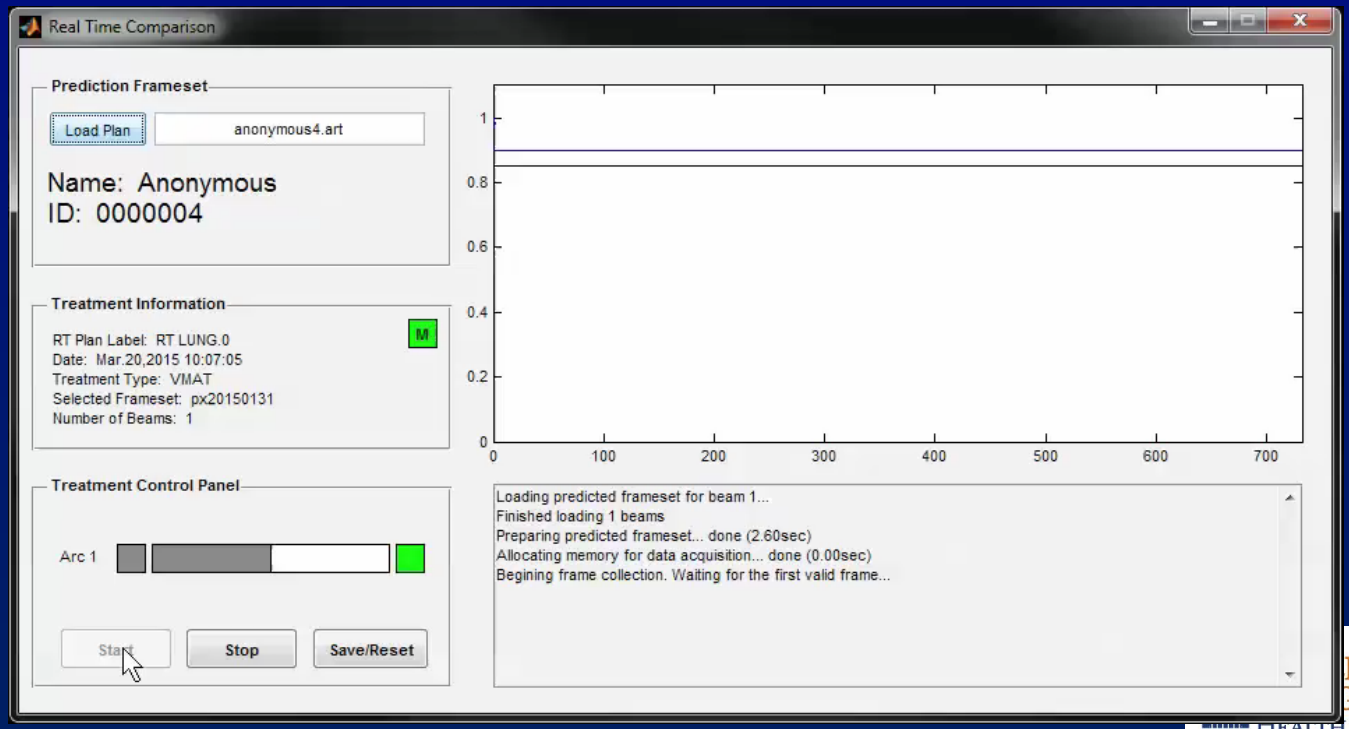
Prediction

Delivery





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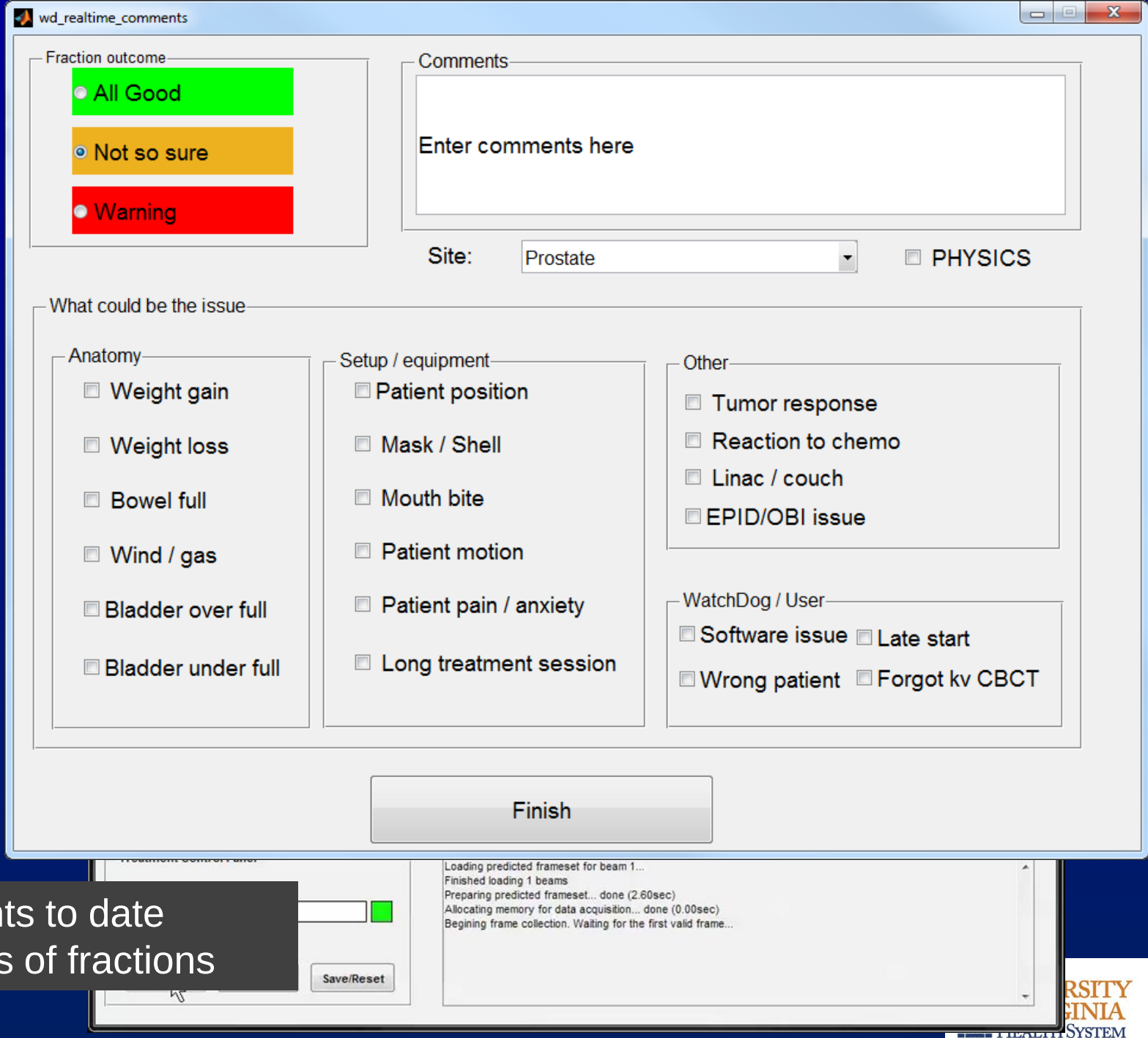


watchDOG

>250 patients to date
Thousands of fractions

Current WD application

- *during-treatment-delivery*
  - Gross-error detection (>10% from Rx)
    - Active exit-fluence monitor
    - Active MLC-position monitoring

- post-treatment -delivery
  - Non-gross error detection (>5%, <10%)

EPID-base exit-fluence dosimetry can detect gross delivery errors as fast as

17% 1. Between patient fractions

23% 2. Between beams of a fraction

17% 3. Within 10 seconds

17% 4. Within 1 second

27% 5. Within < 0.2 seconds

EPID-base exit-fluence dosimetry can detect gross delivery errors as fast as

5. Within <0.2 seconds

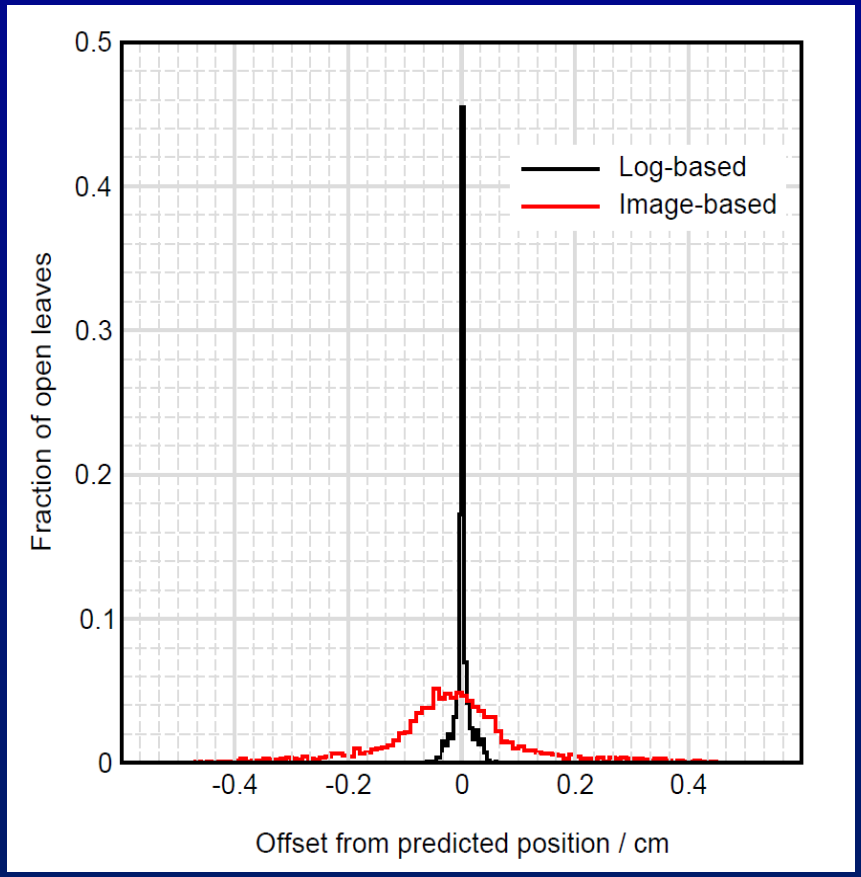
The EPID-based real-time delivery verification system successfully detected simulated gross errors introduced into patient plan deliveries in near real-time (within 0.1 s).

Fuangrod, T., *et al.* (2013). A system for EPID-based real-time treatment delivery verification during dynamic IMRT treatment. *Medical Physics*, *40*(9), 091907.

Real-time gross error detection is currently possible.

UVA post-delivery tools

- Offline leaf position analysis
  - Image-based edge detection
  - Log-based
- Image-based larger deviation due to leaf motion during image acquisition



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Offline Treatment Delivery QA

Patient Identifier:		[redacted]	
Tx Start Date:			
Tx End Date:			
Fx Delivered:		10	
Fx Analyzed:		9	
Missing Fractions from Analysis (if any):		Fx 3 ([redacted]/14)	
Number of Fields:		2	
Tx Type:		Rapid Arc	
Comments:		EPID images utilize gantry angles from machine logs, synchronized by EPID and machine time-stamps.	
QA performed by:	Kunal Kathuria	QA completion date:	[redacted]/14

EPID image-based leaf position analysis.
Software Versions: 1.1 (Analysis),
103 (Prediction), 102 (Acquisition)

Tx Day/Fraction	Field	$\bar{\Delta}$ (cm)	σ_Δ (cm)	F_{OK} (%)	Pass/Fail
AirScan	1	-0.036	0.1549	92.75	Pass
	2	0.036	0.1412	93.58	Pass
1	1	-0.036	0.1361	95.89	Pass
	2	0.035	0.2325	85.90	Pass
2	1	-0.036	0.1881	88.63	Pass
	2	0.038	0.2393	85.33	Pass
3	n/a	n/a	n/a	n/a	n/a
4	1	-0.035	0.1385	95.72	Pass
	2	0.037	0.2371	85.46	Pass
5	1	-0.036	0.1932	87.74	Pass
	2	0.039	0.2194	87.00	Pass
6	1	-0.038	0.1452	94.18	Pass
	2	0.038	0.1871	90.48	Pass
7	1	-0.034	0.1779	91.65	Pass
	2	0.039	0.1782	91.16	Pass
8	1	-0.036	0.1933	91.39	Pass
	2	0.037	0.2449	85.18	Pass
9	1	-0.039	0.1245	97.10	Pass
	2	0.036	0.3387	80.17	Pass
10	1	-0.034	0.1994	87.94	Pass
	2	0.039	0.1769	91.17	Pass

$\bar{\Delta}$ = Average deviation between predicted and measured leaf positions
σ_Δ = Standard deviation
F_{OK} = Fraction of active leaves with deviation < 3 mm
Passing Criteria: >70% (image-based leaf detection algorithm)

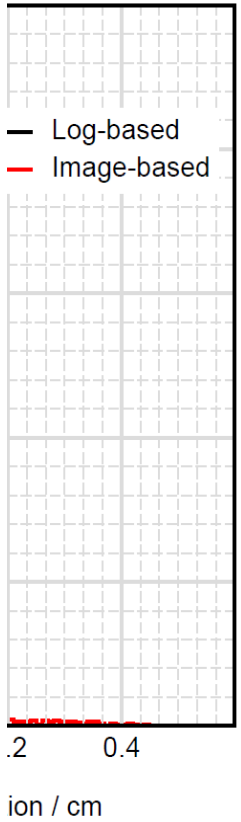
Dynalog-based leaf position analysis
Software Version: 1.1 (Analysis)

Tx Day/Fraction	Field	$\bar{\Delta}$ (cm)	σ_Δ (cm)	F_{OK} (%)	Pass/Fail
AirScan	1	-0.0001	0.0115	100	Pass
	2	0.0002	0.0098	100	Pass
1	1	-0.0001	0.0109	100	Pass
	2	-0.0002	0.0093	100	Pass
2	1	0.0001	0.0109	100	Pass
	2	-0.0002	0.0093	100	Pass
3	n/a	n/a	n/a	n/a	n/a
4	1	0.0003	0.0109	100	Pass
	2	0.0002	0.0093	100	Pass
5	1	0.0002	0.0109	100	Pass
	2	0.0002	0.0093	100	Pass
6	1	-0.0001	0.0109	100	Pass
	2	0.0002	0.0093	100	Pass
7	1	0.0002	0.0109	100	Pass
	2	0.0000	0.0093	100	Pass
8	1	0.0002	0.0109	100	Pass
	2	0.0002	0.0093	100	Pass
9	1	-0.0001	0.0109	100	Pass
	2	-0.0002	0.0093	100	Pass
10	1	0.0002	0.0109	100	Pass
	2	0.0001	0.0093	100	Pass

$\bar{\Delta}$ = Average deviation between planned and logged leaf positions
σ_Δ = Standard deviation
F_{OK} = Fraction of active leaves with deviation < 3 mm
Passing Criteria: >98% (control system should ensure)

Overall QA Verdict: **Pass**

Comments: Patient 1 data (1st Watchdog Patient) successfully analyzed by Watchdog offline QA. No real-time analysis was performed during treatment delivery.



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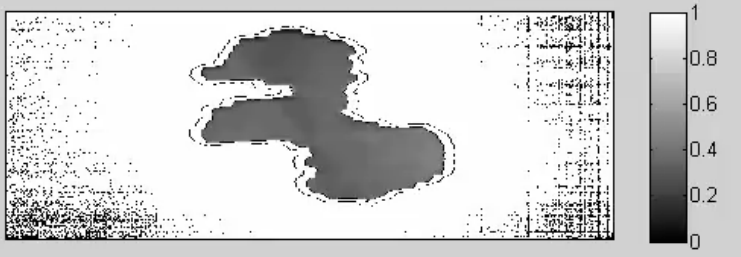
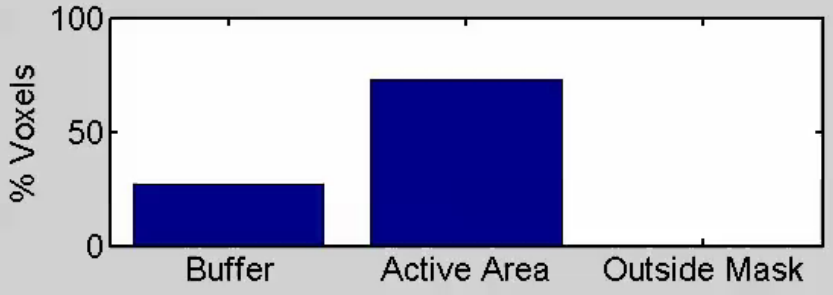
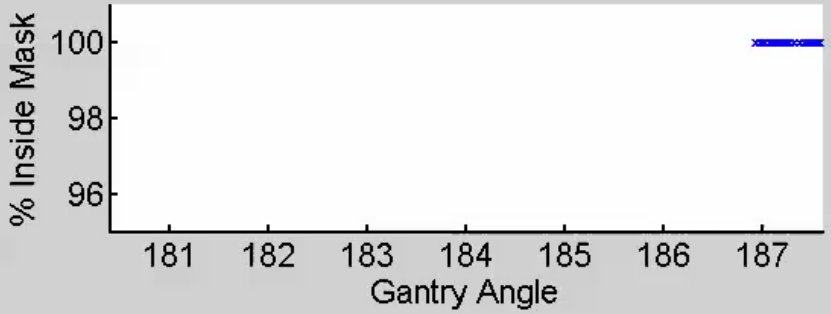
UVA during-treatment tools

- Beam monitoring

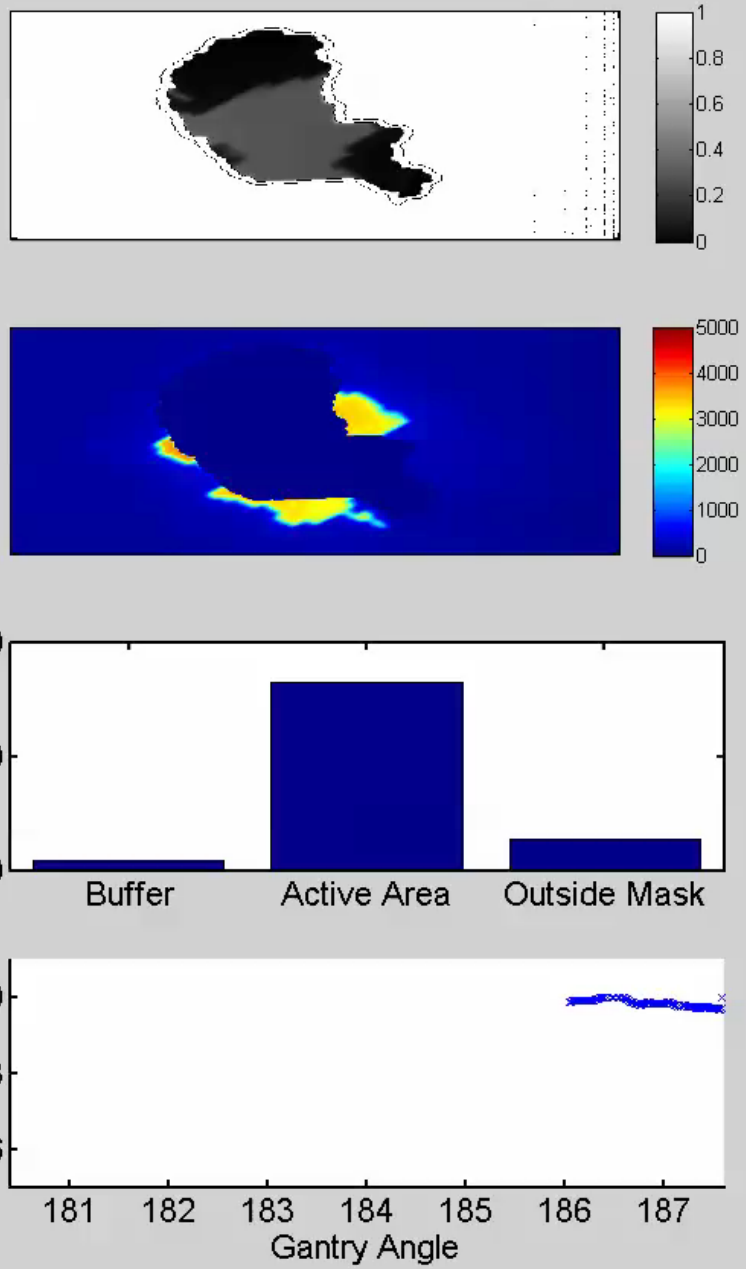






UVA during-treatment tools

- Beam monitoring
  - Intentional error via Tx beam miss-match



Summary

- Described a delivery-system independent real-time QA system
- Demonstrated functionality for gross error detection
- May be possible to detect patient/attenuator changes (in real time)
- Will
  - enable on-line adaptive RT
  - permit quantification of inter-fractional error rates