

PRODVANCE

Motion Management in Liver SABR

Kausik Bhattacharya



INSTITUTE OF
ONCOLOGY

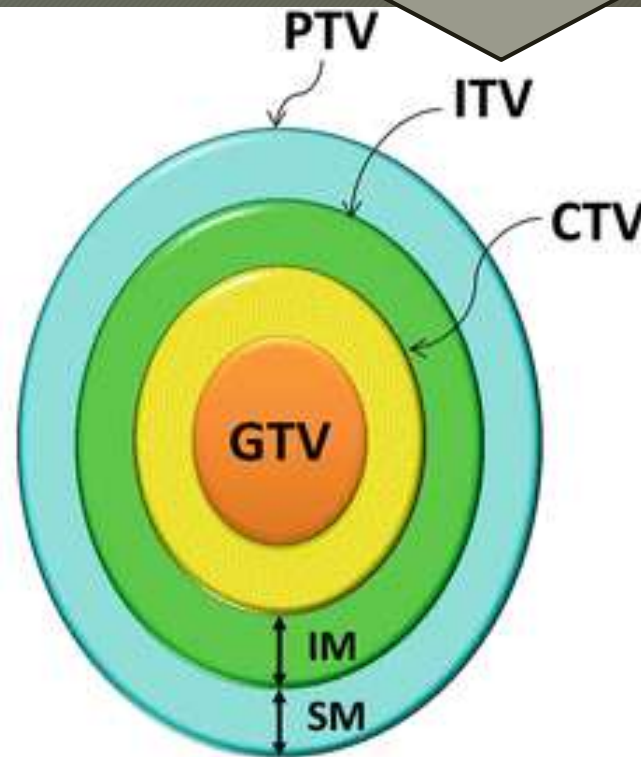
How to reduce ITV

GTV: gross tumor volume, defined as visible tumor volume in images

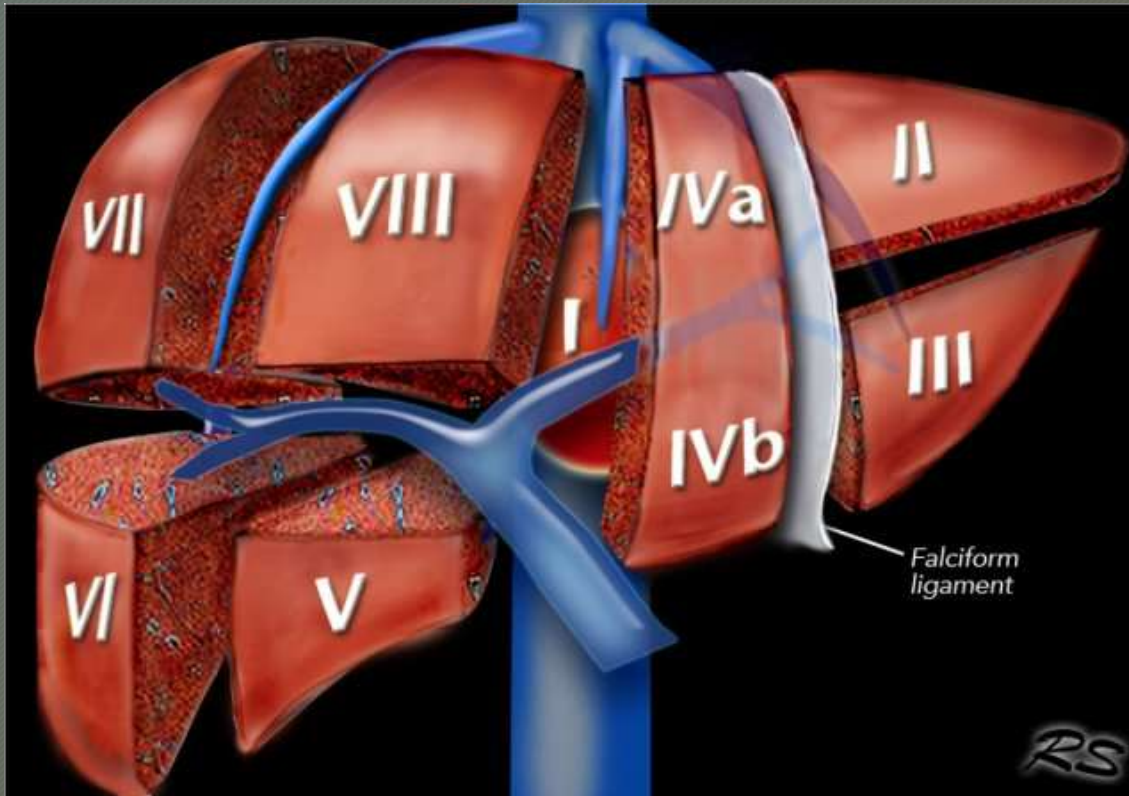
CTV: clinical target volume, defined as GTV + subclinical/invisible invasion

ITV: internal target volume, defined as CTV + IM (internal margin for organ motion)

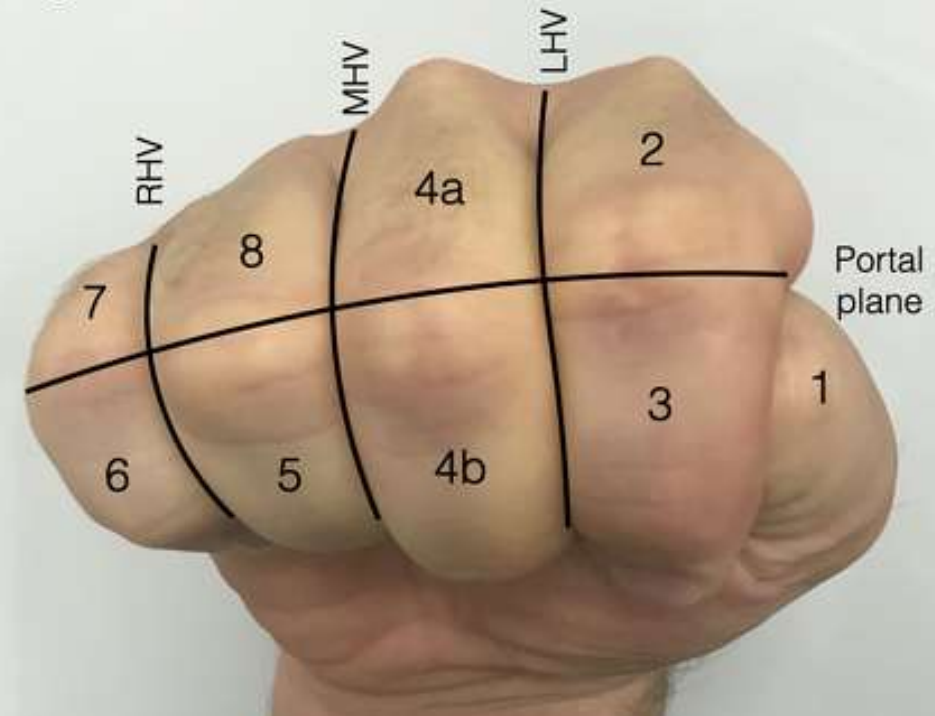
PTV: planning target volume, defined as ITV + SM (setup margin for setup error)



Segments of liver



Right hand

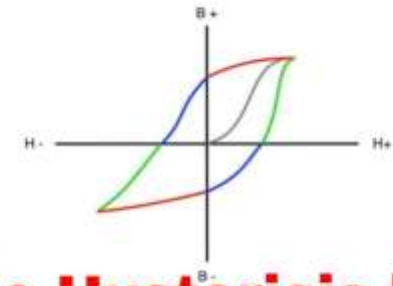


Liver moves with Respiration

Navigator



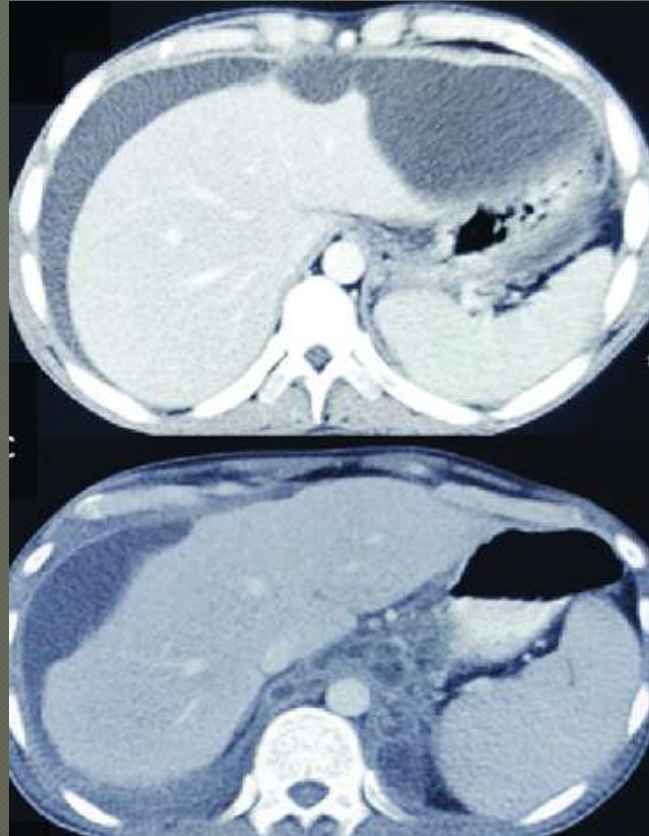
- Asymmetric
- Non reproducible
- Individual variation
- Deformation
- Hysteresis



The Hysteresis loop

MOVEMENT OF LIVER

- Measured by
 - Fluoroscopy
 - 4D CT
 - Cine MRI



- Influenced by
 - Ascites
 - Stomach filling
 - Abdominal gas

MOVEMENT OF LIVER



Acta Radiologica Diagnostica 25 (1984) Part 2

FROM THE DEPARTMENT OF DIAGNOSTIC RADIOLOGY, UNIVERSITY OF OULU, SF-90220 OULU, FINLAND.

CRANIO-CAUDAL MOVEMENTS OF THE LIVER, PANCREAS AND KIDNEYS IN RESPIRATION

I. SURAMO, M. PAIVANSALO and V. MYLLYLÄ

Computer Aided Surgery 7:291-299 (2002)

Review Article

Assessment of Hepatic Motion Secondary to Respiration for Computer Assisted Interventions

Mark A. Clifford, M.S., Filip Banovac, M.D., Elliot Levy, M.D., and Kevin Cleary, Ph.D.
Imaging Science and Information Systems (ISIS) Center, Department of Radiology, Georgetown University Medical Center (M.A.C., F.B., E.L., K.C.), and Department of Radiology, Georgetown University Hospital/MedStar Health (F.B., E.L.), Washington, DC

Table 1

*Movement of organs in respiration examined by ultrasound.
Mean and range*

Organ	Excursion	
	Maximum respiration (cm)	Normal respiration (cm)
Liver	5.5 (3-8)	2.5 (1-4)
Pancreas	4.3 (2-8)	2.0 (1-3)
Right kidney	4.0 (2-7)	1.9 (1-4)
Left kidney	4.1 (2-7)	1.9 (1-4)

294 Clifford et al.: Assessing Hepatic Motion for CAS Interventions

Table 1. Hepatic Motion Secondary to Respiration in Nine Human Studies

Study/date	Number of subjects	Cranio-caudal (mm)		Anterior-posterior (mm)	Lateral (mm)	Modality
		Quiet inspiration	Deep inspiration			
Weiss (1972) ³²						
(using scintigraphy)	12	11 ± 3	12-75			Scintigraphy
(using fluoroscopy)	25	13 ± 5				Fluoroscopy
Harauz (1979) ³³	51	14				Scintigraphy
Suramo (1984) ³⁴	50	25	55			US
Korin (1992) ³⁵	15	13	39	2.5		MRI
Davies (1994) ²⁷	9	10 ± 8	37 ± 8			US
Herline (1999) ¹³	2	10.8 ± 2.5				Optical tracking
Shimizu (1999) ³⁷	1	21		8	9	MRI
Shimizu (2000) ³⁶	6	10.6 ± 7.0		4.6 ± 1.6	5.2 ± 1.8	MRI
Rohlfing (2001) ³⁸	4	12-26		1-12	1-3	MRI

MOVEMENT OF LIVER

Tsai et al. *Radiation Oncology* (2018) 13:59
<https://doi.org/10.1186/s13014-018-1007-0>

Radiation Oncology

RESEARCH

Open Access



Quantitative analysis of respiration-induced motion of each liver segment with helical computed tomography and 4-dimensional computed tomography

Yu-Lun Tsai¹, Ching-Jung Wu^{1,2,3}, Suzun Shaw¹, Pei-Chieh Yu¹, Hsin-Hua Nien¹ and Louis Tak Lui^{1*}

Table 2 Amplitudes of respiration-induced liver motion of each liver segment during expiration period in free breathing

Segment	Average amplitude \pm SD (mm)		
	LR	AP	SI
S1	-2.0 ± 2.6	1.0 ± 1.3	5.5 ± 2.6
S2	0.3 ± 2.2	1.2 ± 3.5	6.3 ± 4.2
S3	-0.3 ± 1.9	2.4 ± 1.4	5.8 ± 2.8
S4a	-1.4 ± 3.3	1.5 ± 2.4	3.0 ± 2.6
S4b	-1.2 ± 1.6	2.0 ± 1.9	5.3 ± 3.4
S5	-0.2 ± 2.1	3.2 ± 2.0	5.5 ± 2.4
S6	-0.1 ± 4.6	2.2 ± 2.3	6.5 ± 3.5
S7	-1.4 ± 3.8	3.5 ± 2.5	8.6 ± 3.4
S8	1.0 ± 2.6	3.3 ± 2.3	5.0 ± 3.3
mean	-0.6 ± 3.0	2.3 ± 2.4	5.7 ± 3.4

Positive values denote excursion in the left, posterior, or superior directions;
 Negative values, right, anterior, or inferior

Abbreviations: LR left-right, AP anterior-posterior, SI superior-inferior, SD standard deviation

Why manage motion

- Right Target
- Right Dose

Gargett et al. *Radiation Oncology* (2019) 14:93
<https://doi.org/10.1186/s13014-019-1300-6>

Radiation Oncology

RESEARCH

Open Access

Clinical impact of removing respiratory motion during liver SABR

M. Gargett^{1*}, C. Haddad¹, A. Kneebone¹, J. T. Booth^{1,2} and N. Hardcastle^{2,3}

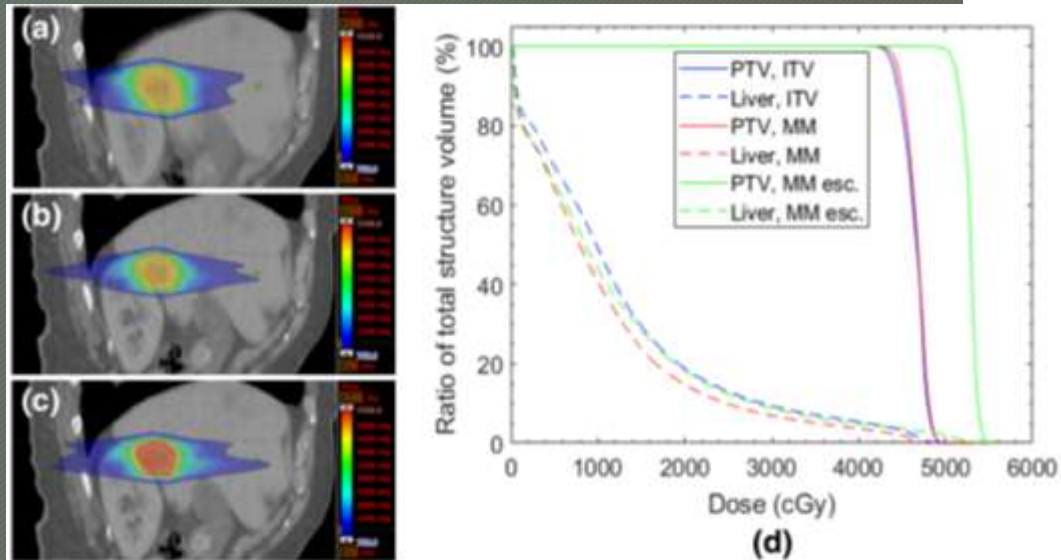
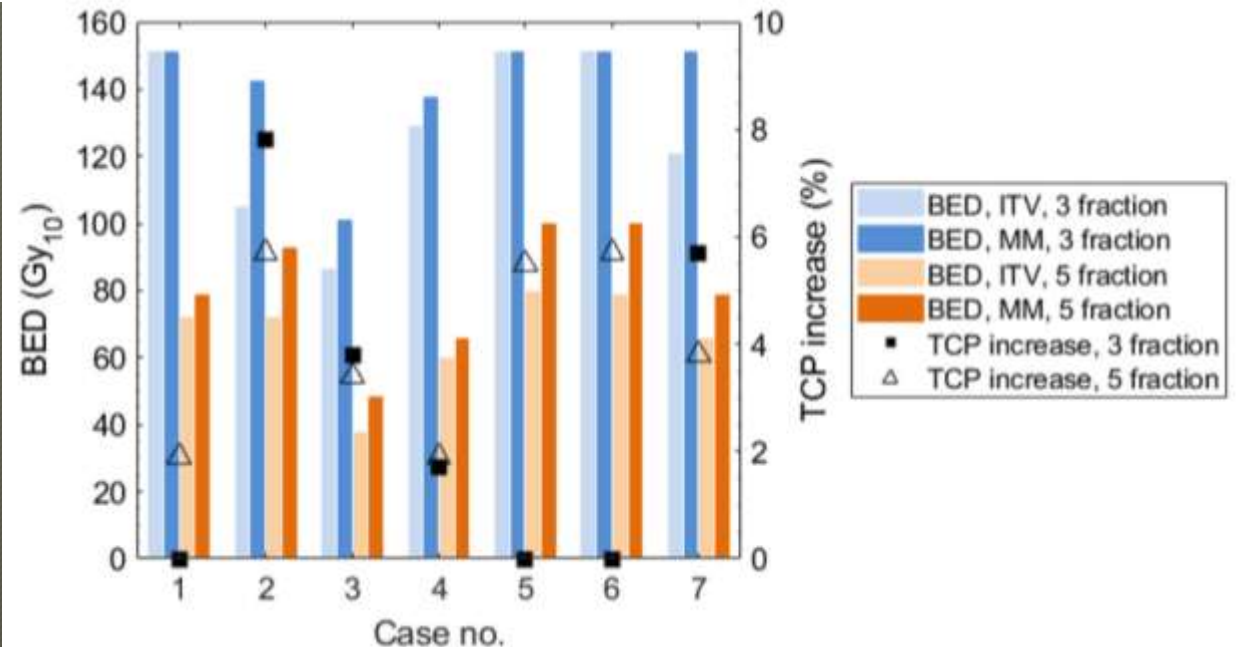
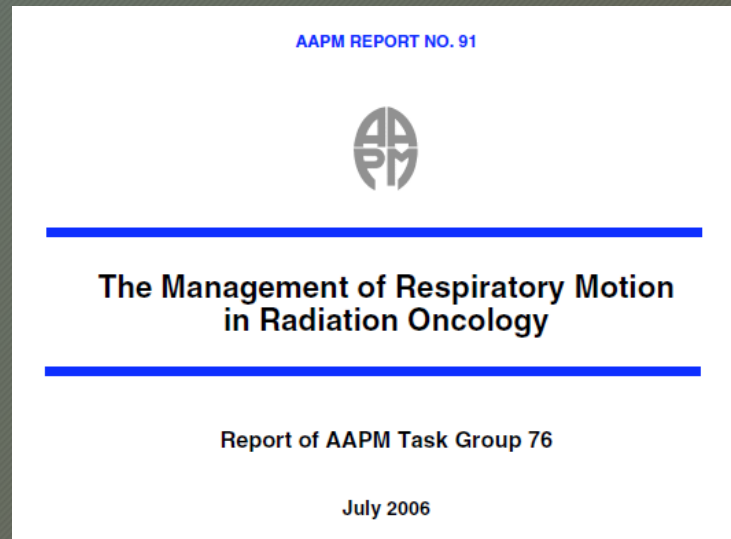


Fig. 6 Part (a) shows the dose distribution to a lesion planned using the ITV method. Part (b) shows the re-plan using the motion managed PTV, at the same prescription level as in (a). Part (c) shows the escalation of dose, from 42.5 Gy to 50 Gy (78.6 Gy₁₀ to 100 Gy₁₀), whilst adhering to OAR dose tolerances. Part (d) is a DVH demonstrating PTV coverage (solid lines) for the three cases shown in (a) – (c), as well as liver dose (broken lines). ITV – ITV-based, MM – motion managed, MM esc – dose escalated motion management



Strategies to Manage Motion

- 1. Reduce Motion
- 2. Follow the Motion



AAPM TG 76



AAPM REPORT NO. 91



The Management of Respiratory Motion in Radiation Oncology

Report of AAPM Task Group 76

July 2006

- DIBH (DEBH)
- Active Breath Control
- Self breath-hold
- Shallow Breathing
- Abdominal Compression
- Tumour Tracking
 - Fiducial
 - IR Surrogate
 - RF device

UK SABR Guidelines



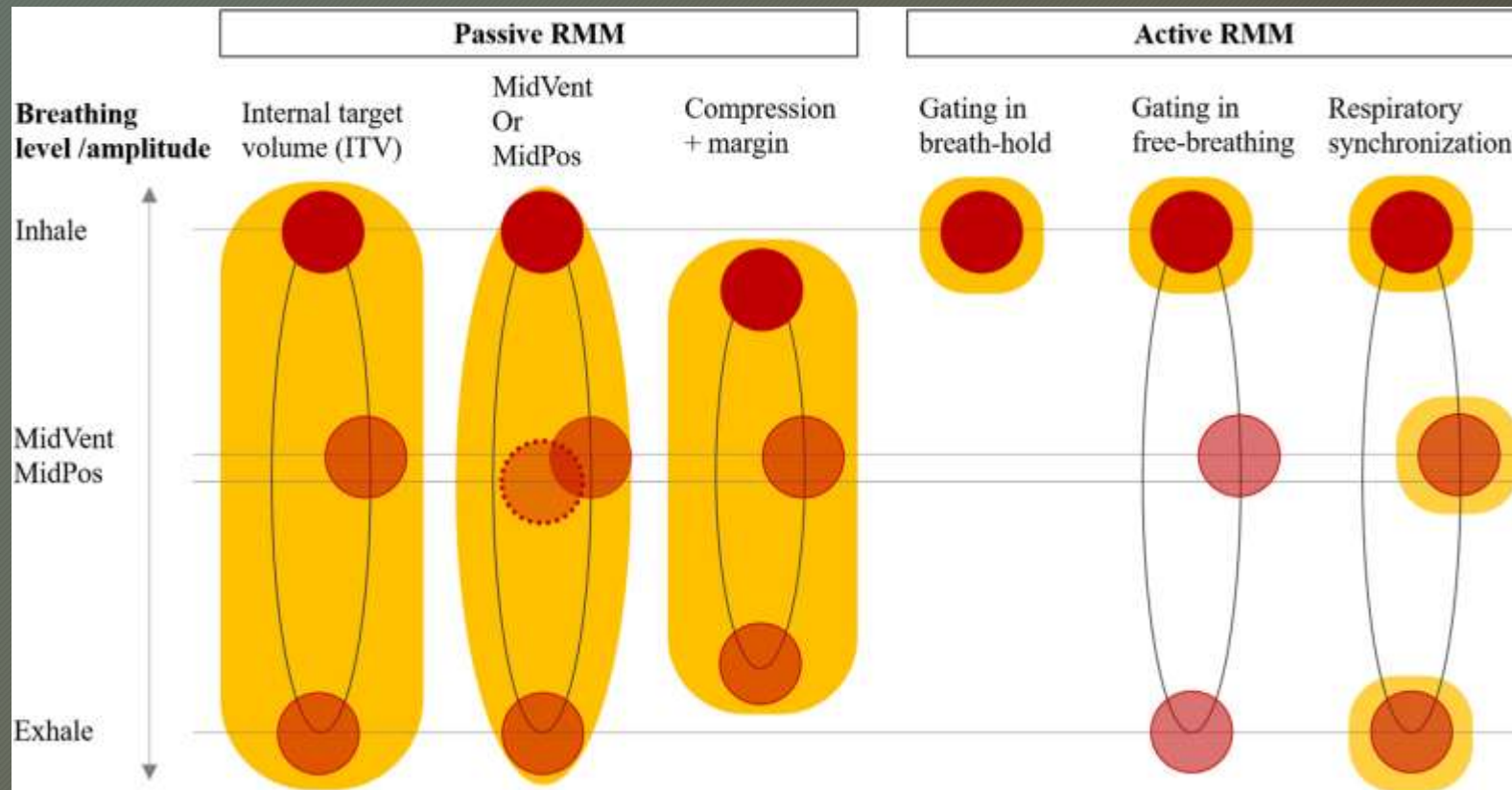
**Stereotactic Ablative Body
Radiation Therapy (SABR):**

A Resource

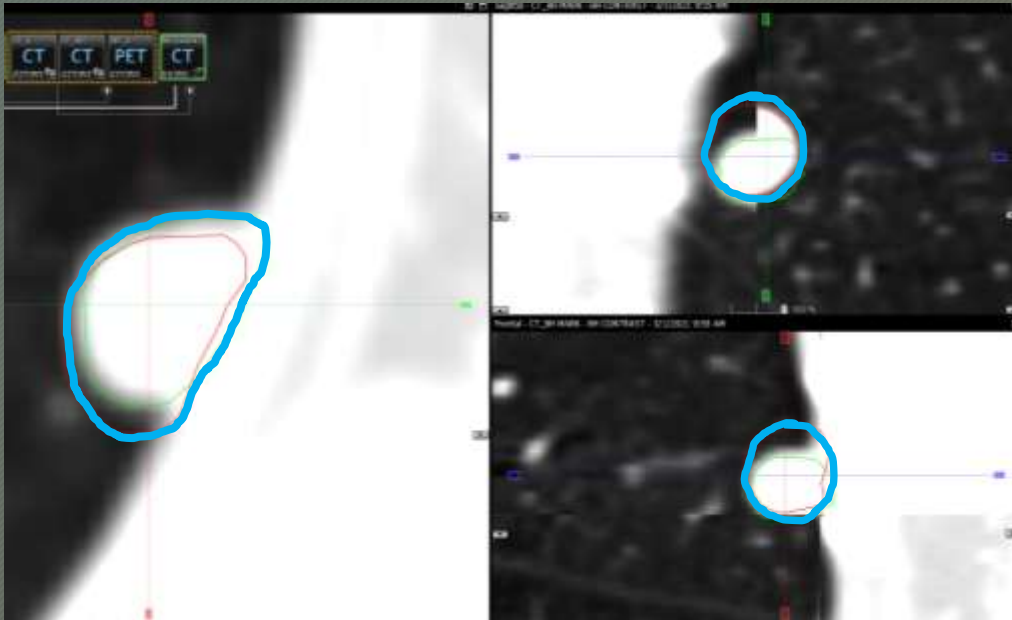


- Reducing
 - Compression
 - ABC
 - Voluntary/ Coached Breath-holding
- Mitigating
 - Passive Gating
 - Fiducial tracking
 - Unrestrained Respiration
 - ITV
 - 4DCT

Passive vs Active



ITV Approach



- Inspiration phase CT
- Expiration phase CT
- Free breathing
- Fuse image sets
- Combine all phases
- *Poor man's* 4DCT
- Best for Lungs
- Time for scan is a concern in Liver

Typcal ITV

Tsai et al. *Radiation Oncology* (2018) 13:59
https://doi.org/10.1186/s13014-018-1007-0

Radiation Oncology

RESEARCH

Open Access

Quantitative analysis of respiration-induced motion of each liver segment with helical computed tomography and 4-dimensional computed tomography

Yu-Lun Tsai¹, Ching-Jung Wu^{1,2,3}, Suzun Shaw¹, Pei-Chieh Yu¹, Hsin-Hua Nien¹ and Louis Tak Lui^{1*}

Table 2 Amplitudes of respiration-induced liver motion of each liver segment during expiration period in free breathing

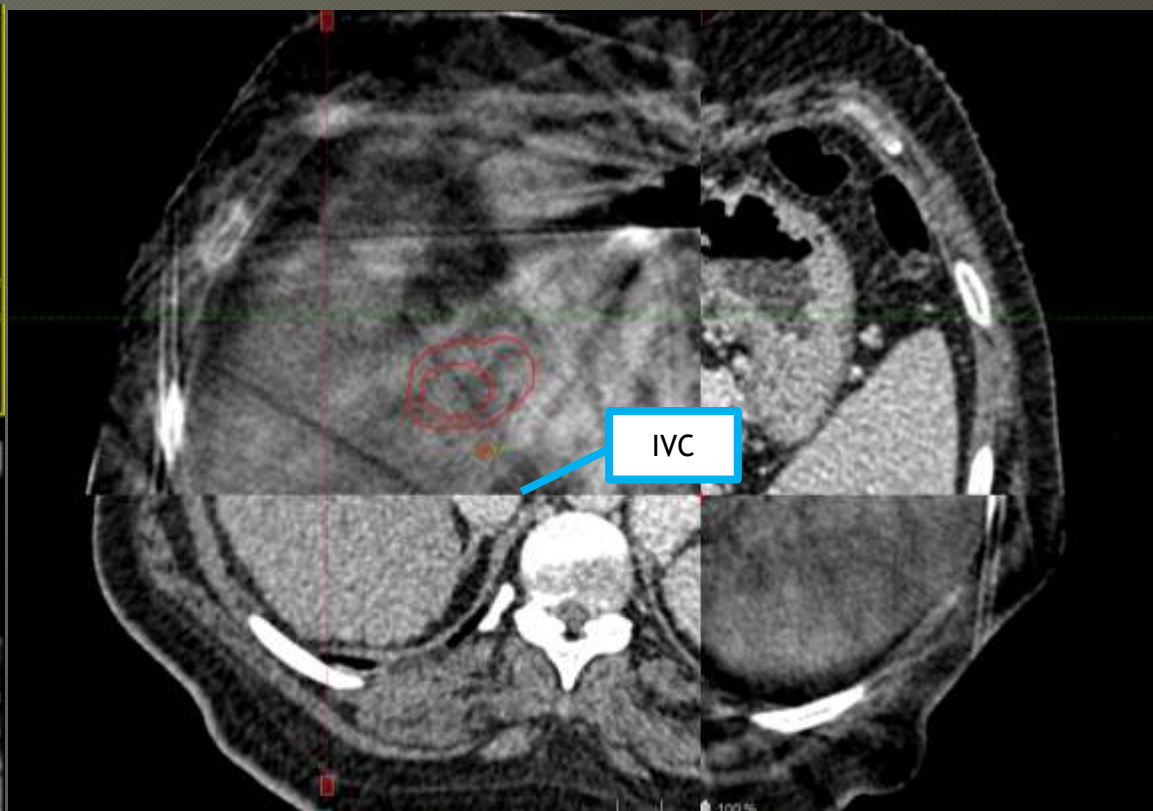
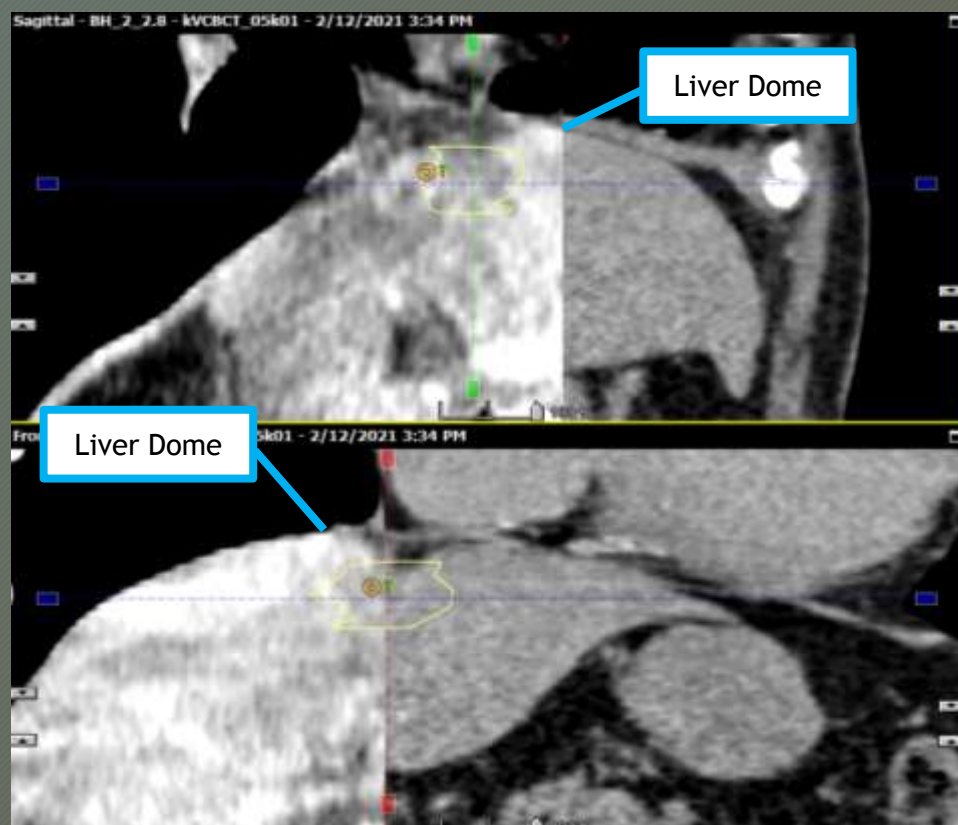
Segment	Average amplitude \pm SD (mm)		
	LR	AP	SI
S1	-2.0 ± 2.6	1.0 ± 1.3	5.5 ± 2.6
S2	0.3 ± 2.2	1.2 ± 3.5	6.3 ± 4.2
S3	-0.3 ± 1.9	2.4 ± 1.4	5.8 ± 2.8
S4a	-1.4 ± 3.3	1.5 ± 2.4	3.0 ± 2.6
S4b	-1.2 ± 1.6	2.0 ± 1.9	5.3 ± 3.4
S5	-0.2 ± 2.1	3.2 ± 2.0	5.5 ± 2.4
S6	-0.1 ± 4.6	2.2 ± 2.3	6.5 ± 3.5
S7	-1.4 ± 3.8	3.5 ± 2.5	8.6 ± 3.4
S8	1.0 ± 2.6	3.3 ± 2.3	5.0 ± 3.3
mean	-0.6 ± 3.0	2.3 ± 2.4	5.7 ± 3.4

Positive values denote excursion in the left, posterior, or superior directions; Negative values, right, anterior, or inferior

Abbreviations: LR left-right, AP anterior-posterior, SI superior-inferior, SD standard deviation

Segment	ITV margin (mm) (to cover more than 95% of each tumor)		
	LR	AP	SI
S1	- 2.2 and 2.3	- 0.4 and 2.3	-4.4 and 4.7
S2	- 2.3 and 0.5	-2.4 and 1.6	- 4.7 and 5.9
S3	- 2.2 and 1.1	-3.3 and 2.1	- 4.6 and 4.1
S4a	-1.8 and 1.8	-2.4 and 1.3	- 2.4 and 4.0
S4b	- 2.6 and 0.3	-2.8 and 1.4	- 4.1 and 4.5
S5	-3.0 and 0.0	-2.4 and 2.9	- 3.0 and 4.7
S6	- 1.9 and 2.3	-2.3 and 2.1	-4.6 and 5.1
S7	- 2.4 and 2.3	-3.1 and 2.8	-5.7 and 7.3
S8	-3.4 and 0.0	-2.8 and 3.0	- 3.5 and 4.7
mean	- 2.5 and 1.2	-2.5 and 2.2	- 4.2 and 5.0

Surrogate Structure Matching

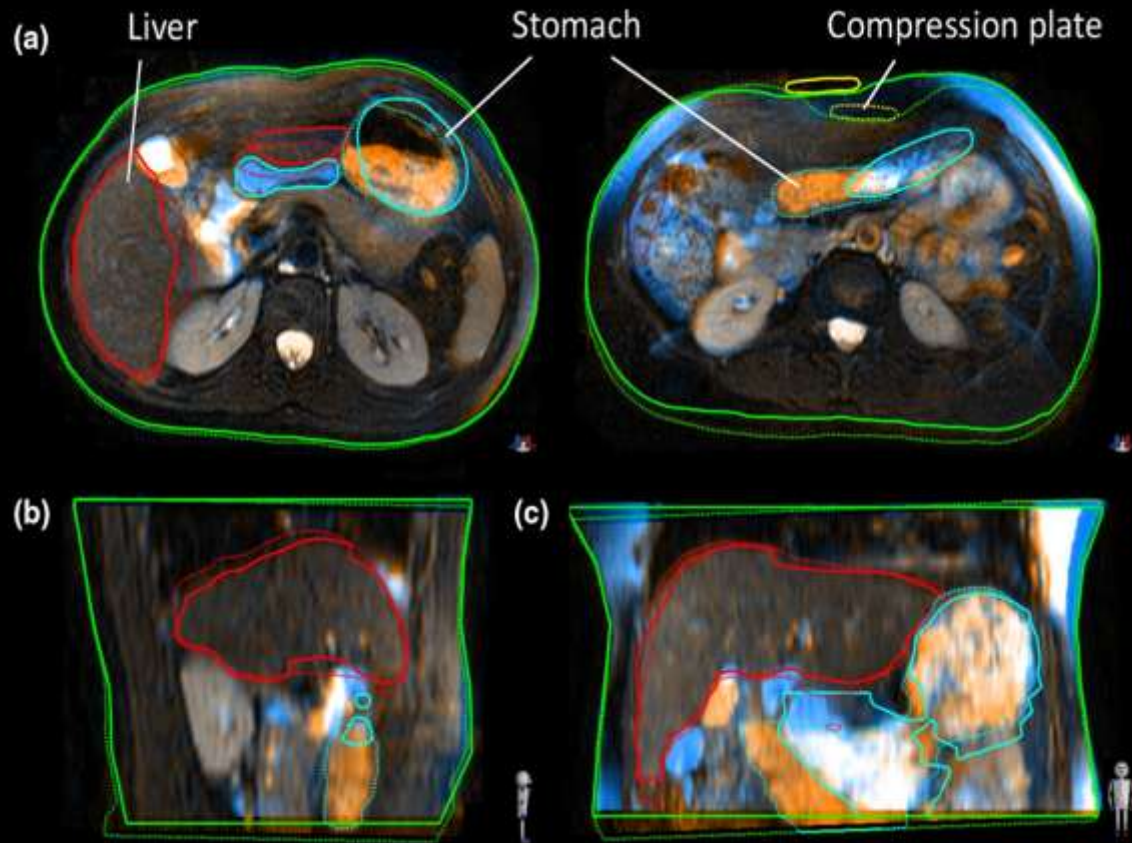


Abdominal Compression



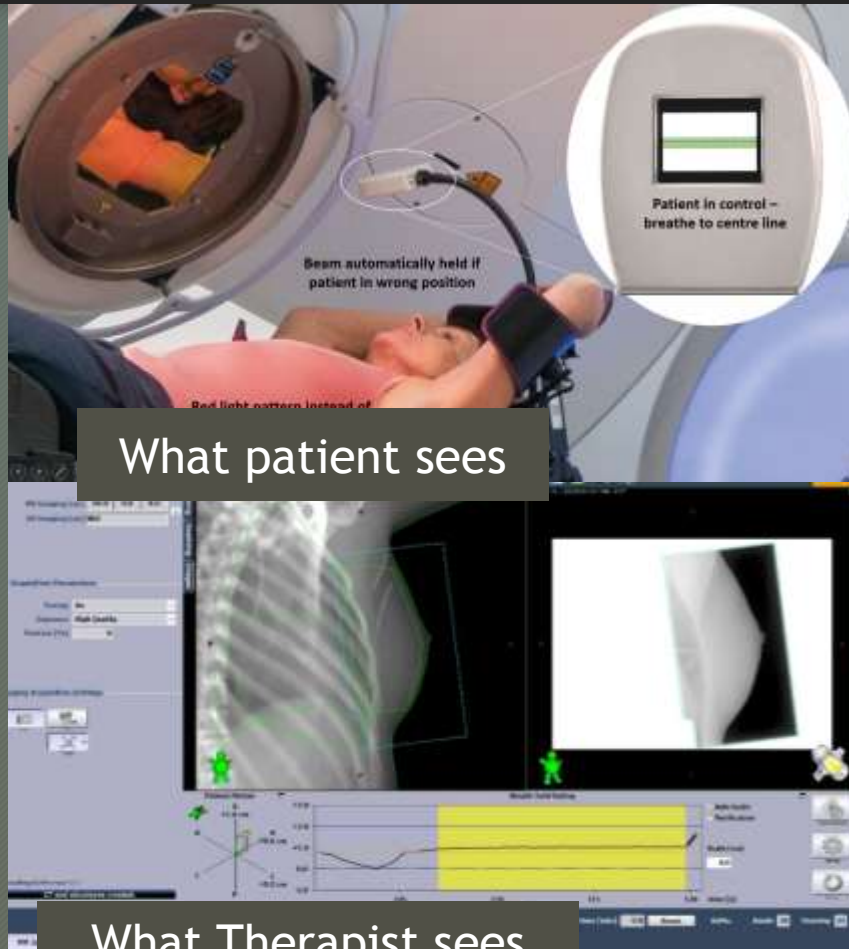
- Forced shallow respiration
- Reduces diaphragmatic motion significantly
- Mechanical
- Pneumatic
- Can be used with conjunction with 4DCT/gating

Abdominal Compression



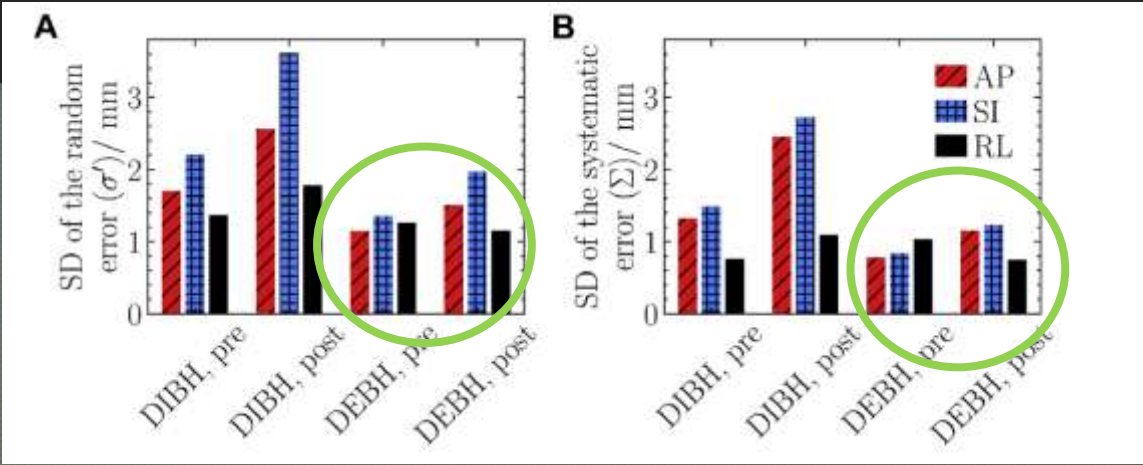
- Discomfort
 - Obese
 - Ascites
- Reproducibility issues
- Significant deformity of internal organs

DIBH/DEBH



- Patient is coached to hold breath in comfortable position
- 20-30 seconds
- IR marker and IR camera
- Respiratory graph is generated
- Planning CT → Planning
- In treatment room same position is reproduced
- Beam is on only when graph is in the threshold

DIBH VS DEBH



Advances in Radiation Oncology (2021) 6, 1006-10

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in radiation oncology

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Scientific Article

Influence of intra- and interfraction motion on planning target volume margin in liver stereotactic body radiation therapy using breath hold

Patricia A.K. Oliver, PhD,^{a,*} Mammo Yewondwossen, PhD,^{a,b,c} Clare Summers, RTT,^b Conor Shaw, PhD,^a Slawa Cwajna, MD,^b and Alasdair Syme, PhD^{a,b,c,*}

^aDepartment of Medical Physics, Nova Scotia Health Authority, Halifax, Canada; ^bDepartment of Radiation Oncology, Dalhousie University, Halifax, Canada; and ^cDepartment of Physics and Atmospheric Science, Dalhousie University, Halifax, Canada

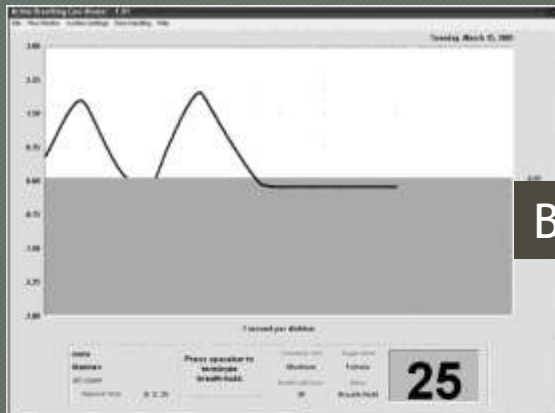
Table 2 Standard deviations of random and systematic errors, values of the mean of means, and PTV margin estimates for DIBH and DEBH with pre- and posttreatment images analyzed together

	DIBH			DEBH			
	AP	SI	RL	AP	SI	RL	
Random	2.2	3.1	1.6	1.3	1.6	1.2	mm
Systematic	1.7	1.8	0.8	0.9	1.0	0.8	mm
Mean of means	0.3	0.0	0.0	0.1	-0.5	0.0	mm
PTV margin	5.7	6.3	3.0	3.1	3.4	2.8	mm

Abbreviations: AP = anterior–posterior; DEBH = deep expiration breath hold; DIBH = deep inspiration breath hold; PTV = planning target volume; RL = right–left; SI = superior–inferior.



Active Breathing Coordinator



Biofeedback screen

Digital spirometer



- Simple
- Reproducible
- Cheap
- Beam On/OFF
- Very small ITV
- ‘quasi’ invasive
- Patient cooperation

Active Breathing Coordinator



Int. J. Radiation Oncology Biol. Phys., Vol. 64, No. 3, pp. 751–759, 2006
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0360-3016/06/\$ – see front matter

doi:10.1016/j.ijrobp.2005.05.066

CLINICAL INVESTIGATION

Liver

REPRODUCIBILITY OF LIVER POSITION USING ACTIVE BREATHING COORDINATOR FOR LIVER CANCER RADIOTHERAPY

CYNTHIA ECCLES, M.R.T.(T)., KRISTY K. BROCK, PH.D., JEAN-PIERRE BISSENETTE, PH.D.,
MARIA HAWKINS, M.D., AND LAURA A. DAWSON, M.D.

Received: 30 May 2017 | Revised: 22 August 2017 | Accepted: 21 September 2017

DOI: 10.1002/acm2.12220

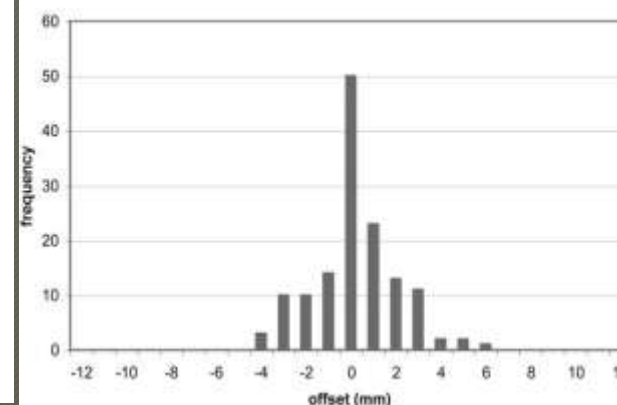
RADIATION ONCOLOGY PHYSICS

WILEY

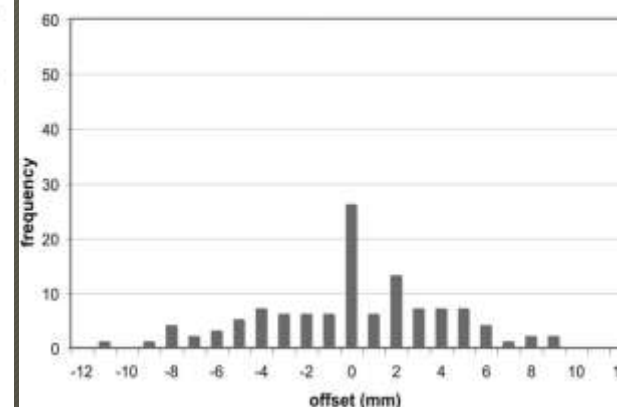
Intra- and inter-fractional liver and lung tumor motions treated with SBRT under active breathing control

Lan Lu | Claudiu Diaconu | Toufik Djemil | Gregory MM Videtic |
May Abdel-Wahab | Naichang Yu | John Greskovich Jr. | Kevin L Stephans | Ping Xia

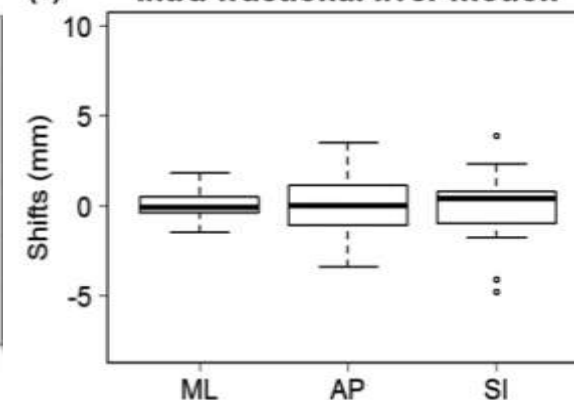
3A Intra-fraction CC reproducibility



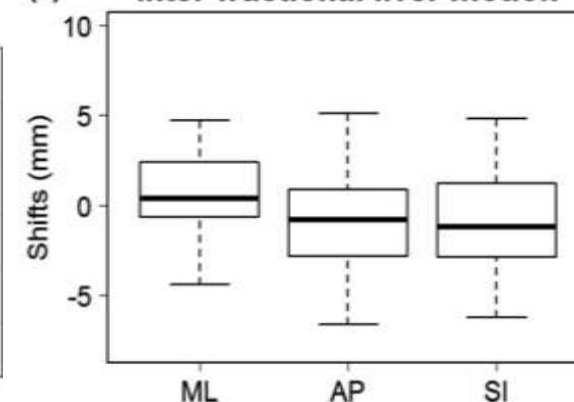
3B Inter-fraction CC reproducibility



(a) Intra-fractional liver motion



(c) Inter-fractional liver motion

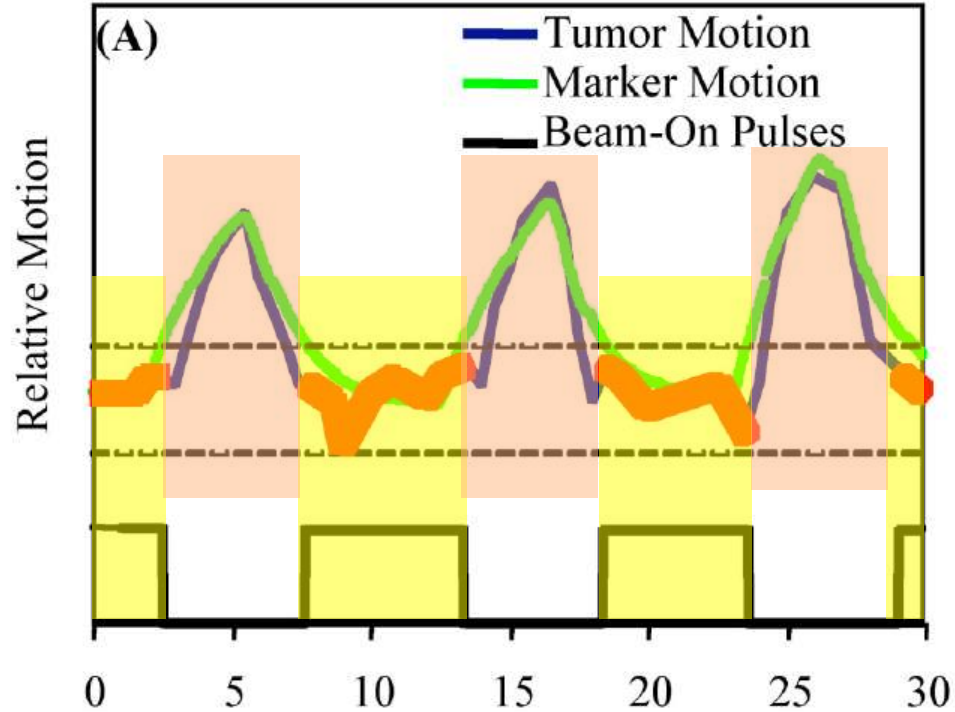


Respiratory Gating (RPM)



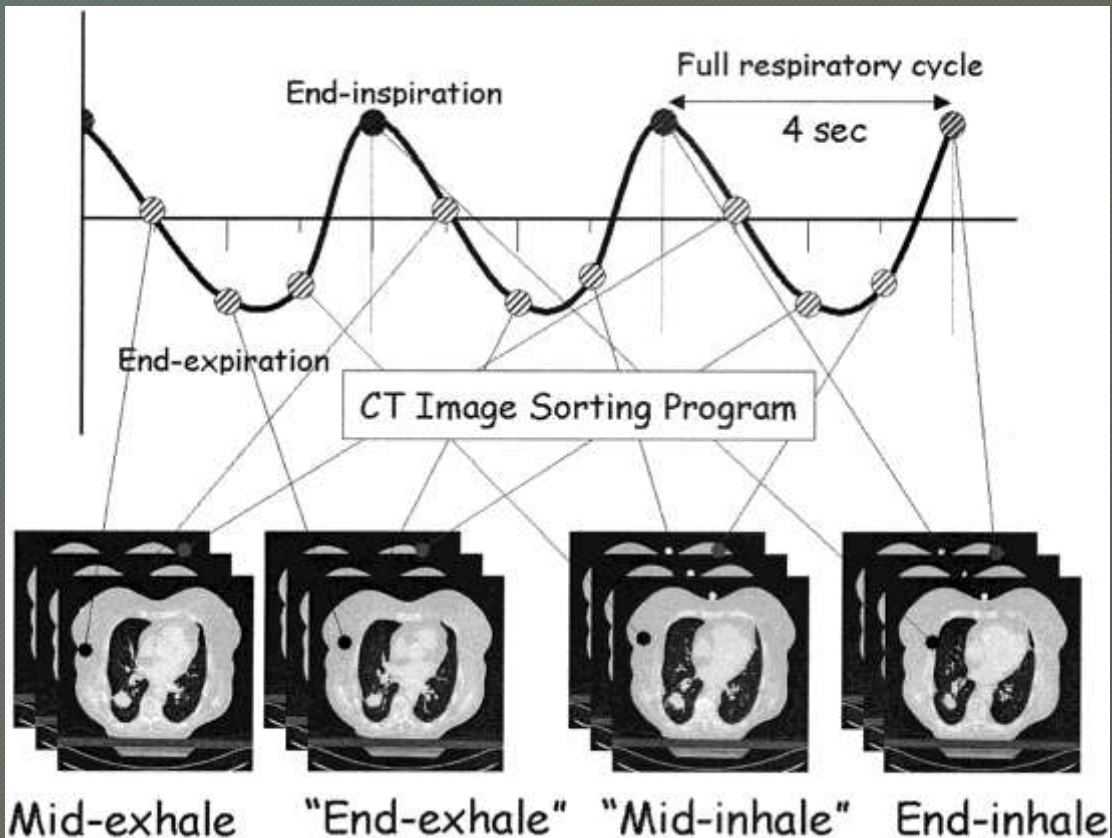
- Infrared surrogate
- Implanted Fiducial (BrainLab)
- Implanted RFID/EM (Calypso)
- Generates a respiratory graph

Respiratory Gating (RPM)

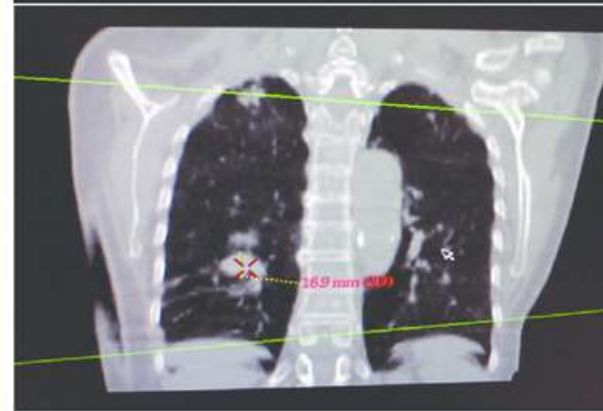


- Define Threshold
- ITV correlates to threshold
- Track the motion on machine
- Beam is automatically switched on/off
- Comfortable
- Small ITV (with Abdominal Compression)

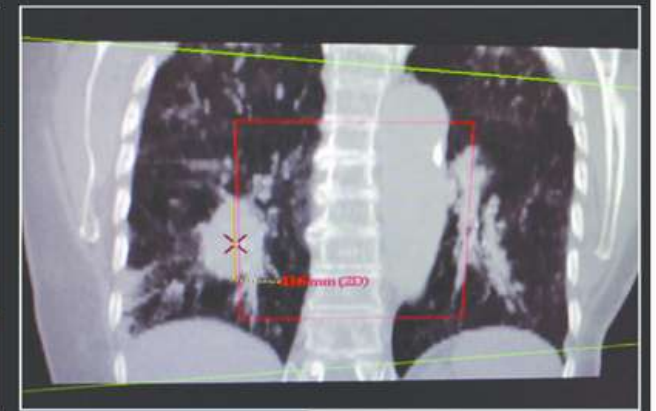
4D CT Acquisition



Gross Tumor Volume (GTV) defined by Conventional CT (Free Breathing)



Internal Target Volume (ITV) defined by 4 dimensional CT (10 Phases Combined)



4D CT in Liver- challenges

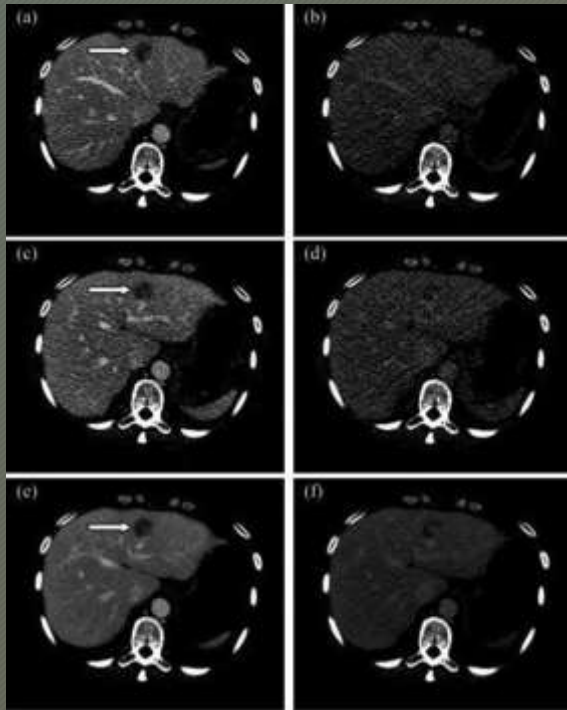
- Lesions are best seen in late arterial/ early venous phase
- 4DCT takes a long time to acquire
- Image quality (MnIP / AvG) is not good for marking the target

Dual 4DCT

4DCT Simulation With Synchronized Contrast Injection in Liver SBRT Patients

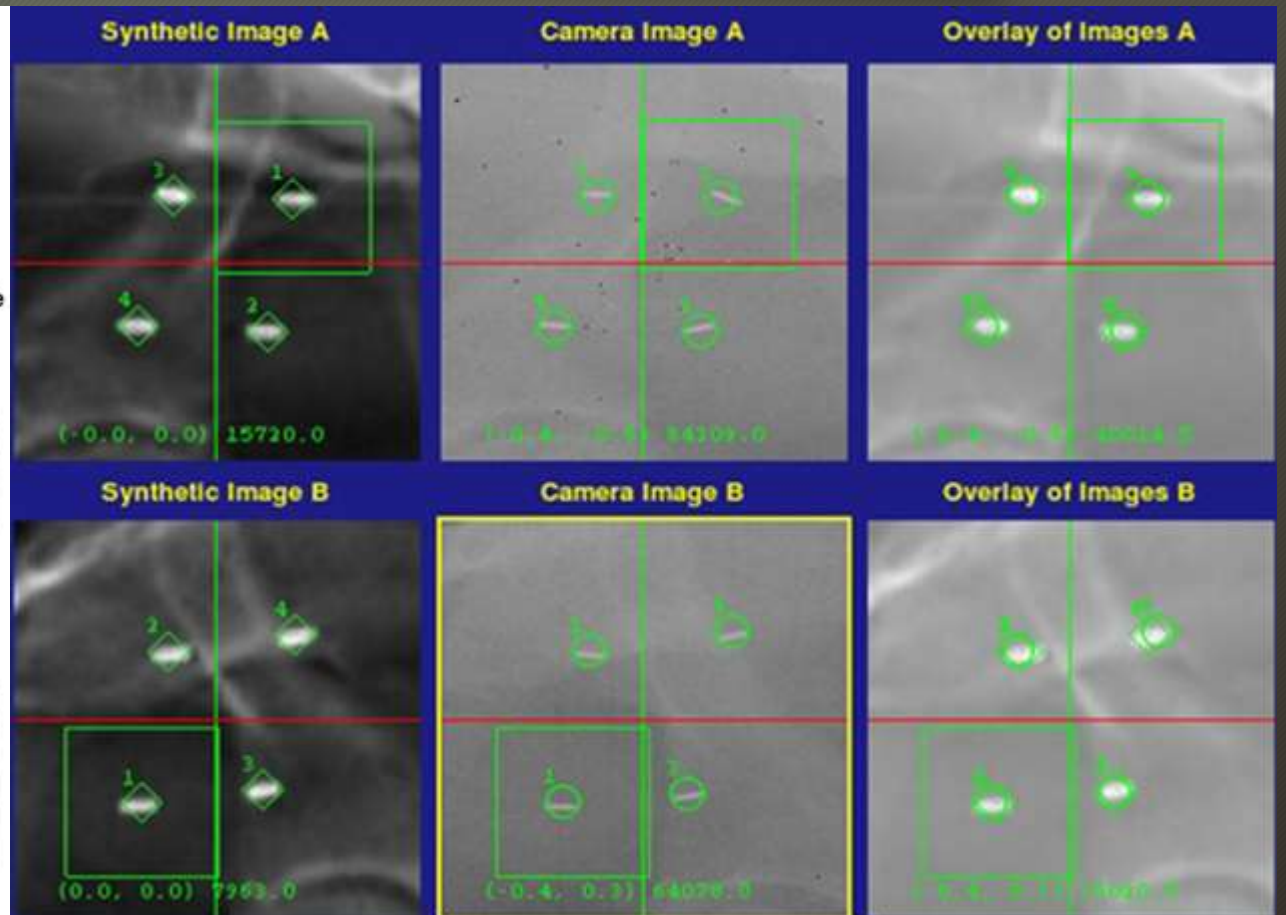
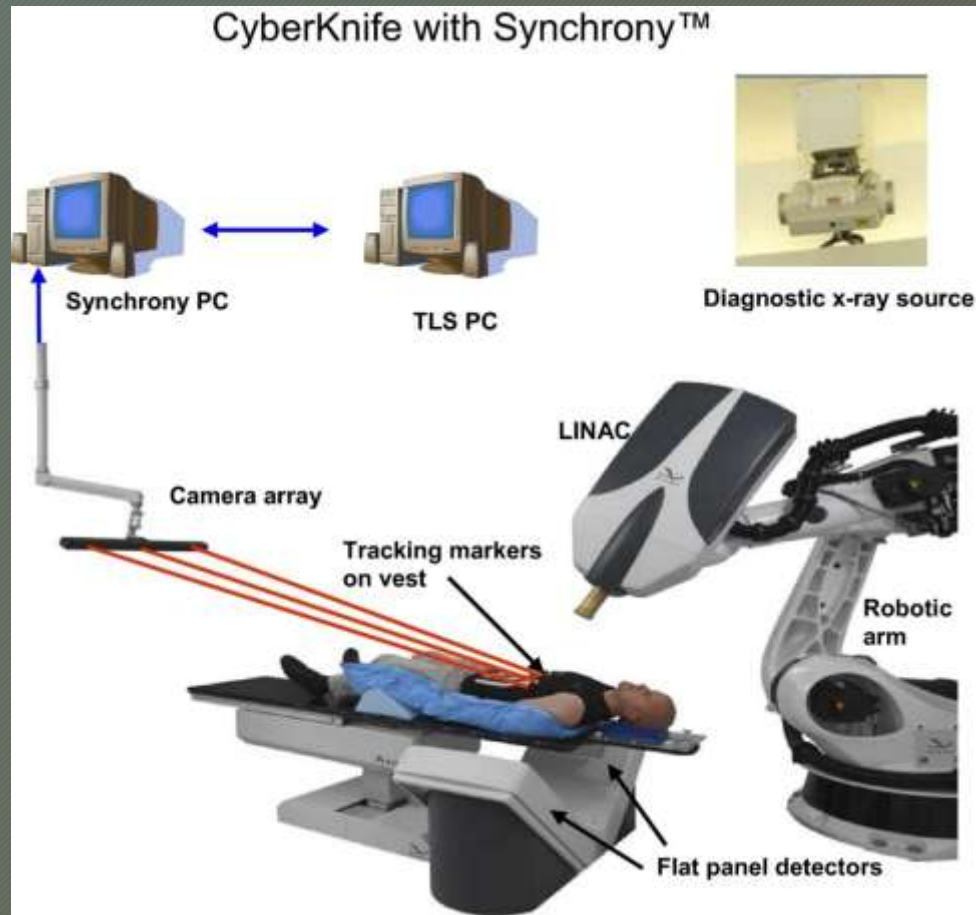
Joelle Helou, MD^{1,2}, Aliaksandr Karotki, PhD³,
Laurent Milot, MD⁴, William Chu, MD^{1,2},
Darby Erier, BSc, MHSc¹, and Hans T. Chung, MD^{1,2}

Technology in Cancer Research &
Treatment
2016, Vol. 15(1) 55-59
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DOI: 10.1177/1533034615572341
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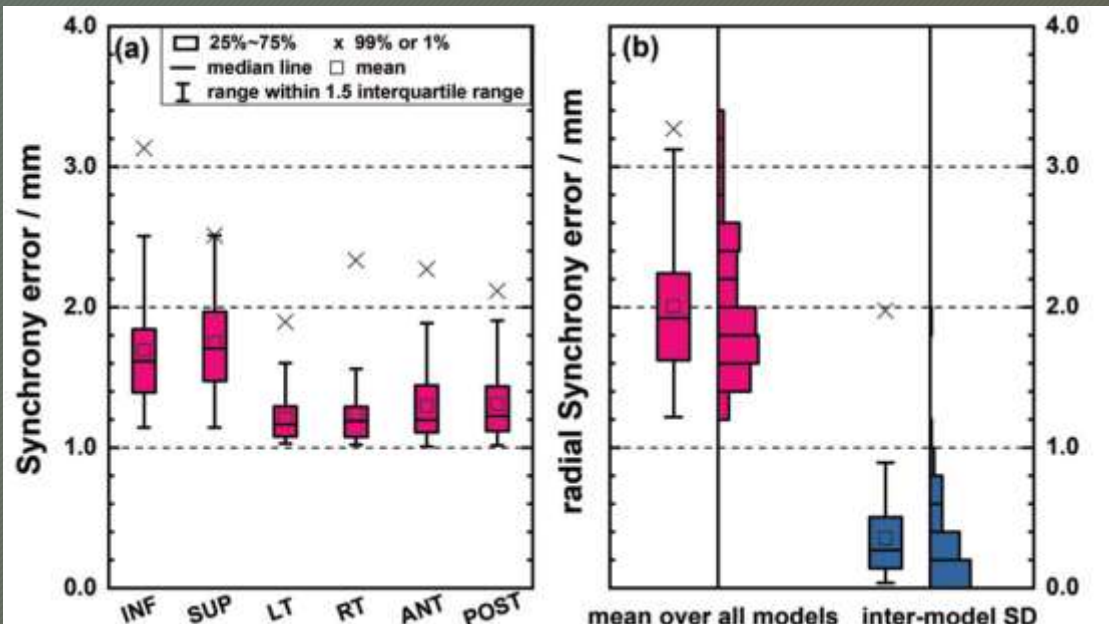
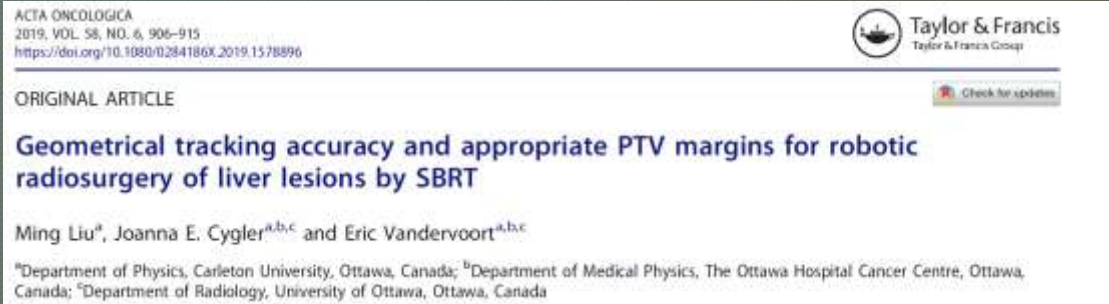


- 2 sets of 4DCT
- Short CT- only area OF INTEREST
- Long CBCT - all OARs
- Mark in Short 4DCT
- Fuse with Long 4DCT
- Plan on Long 4DCT

Cyberkife: Synchrony & Fiducial

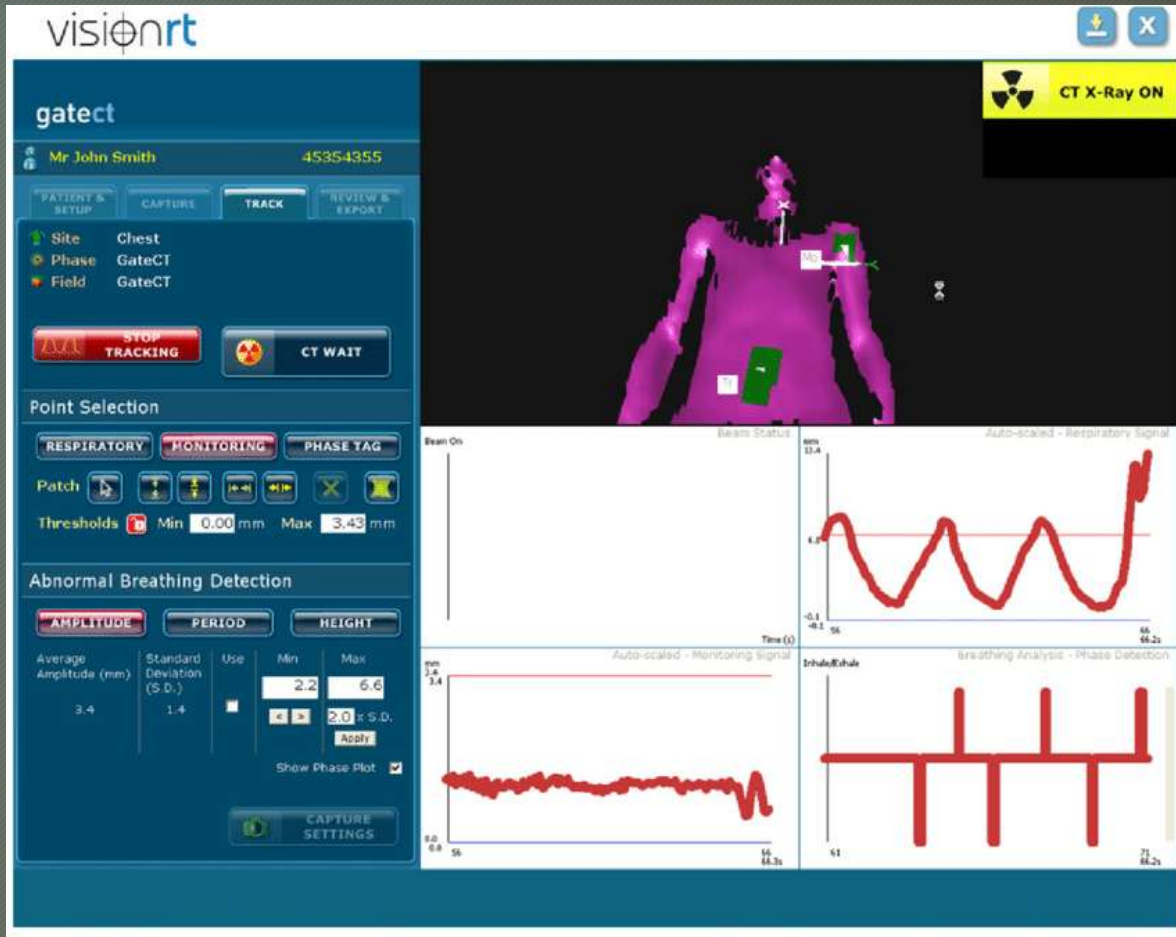


Fiducial Tracking (Synchrony - Cyberknife)



- Translational error 2-3 mm
- Rotational error not correctable in most cases
- 4 - 5 mm margin would suffice in 95% cases

Surface Guidance



- Uses body surface as surrogate for motion
- Produces respiratory graphs
- Can be used for
 - DIBH/DEBH
 - Gating
- Integrated with
 - IGRT Couch movement
 - Beam On/Off

Comparison of Different Techniques







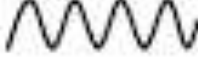



- Abdominal Compression
- Voluntary Breath-hold
- Shallow Breathing

• DEBH, DIBH

• RPM Gating

- Tumor Tracking
- Fiducial Tracking

- 4DCT
- ITV Approach

Method of RMC	Respiratory status	Tuning of beam-on	Time-efficiency	Internal margin
Suppress			good	large
Breath-hold			bad	small
Gating			bad	medium
Tracking			good	small
Free Breathing			good	large

your eyes cannot see what your mind doesn't know
one size does not fit all
horses for courses



Thank You

