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Position Monitoring – State of the Art

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Laura Cerviño
Attending, Radiotherapy Physics Chief
Department of Medical Physics
cervinol@mskcc.org

Outline

- Intrafraction tumor motion
- Indirect motion monitoring
  - External surrogate
  - Internal surrogate (markers)
- Direct motion monitoring
- Summary

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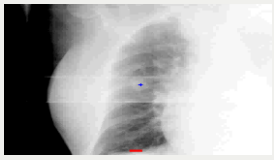
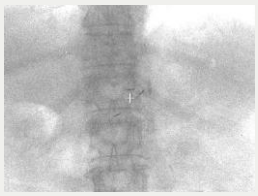
Challenge: tumors move





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Respiratory tumor motion

Site	Study	n	Normal breathing (mm)	Deep breathing (mm)
Lung	Palthow et al. Upper/middle/ lower	20	4.3±2.4 / 7.2±1.8 / 9.5±4.9	4±2 / 17±12 / 24±17
Liver	Suramo et al.	50	25 (10-40)	55 (30-80)
Pancreas	Suramo et al.	50	20 (10-30)	43 (20-80)
Kidney	Suramo et al.	100	19 (10-40)	41 (20-70)
Diaphragm	Davies et al.	9	12±7 (7-28)	43±10 (25-57)

Seppenwoolde et al. IJROBP 2002

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Other intrafraction motion

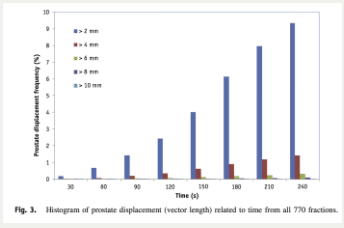
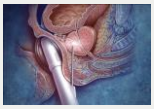


Fig. 3. Histogram of prostate displacement (vector length) related to time from all 770 fractions.

Sihono et al. IJROBP, 2018

livescience.com



webmd.com

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Challenge for RT simulation and treatment

- We need to know where the tumor is for imaging, planning, and treatment
- TG-76 recommends to use motion management techniques for motion > 5mm
- We need to monitor motion
  - Indirect monitoring
    - External or internal surrogates – assume perfect surrogate/tumor motion correlation
  - Direct tumor motion monitoring

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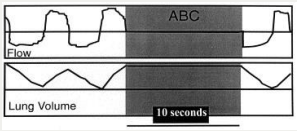
ABC system

Active Breathing Coordinator
Spirometry



Wong *et al.*, IJROBMP, 1999

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Anzai belt

Respiratory motion
External surrogate signal

Heinz et al., JACMP 2015

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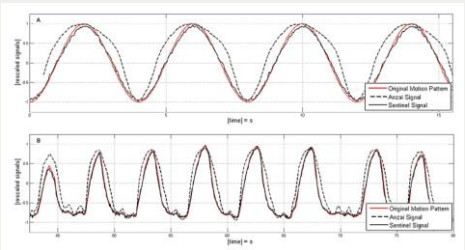

Heinz et al., JACMP 2015

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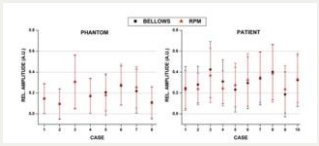
Philips Bellows pneumatic system



Glide-Hurst *et al.* JACMP 2013

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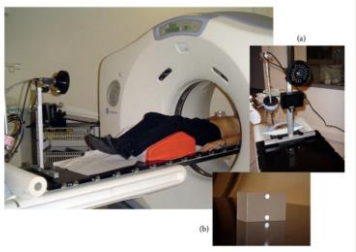
Varian RPM ™



- Real-time position management
- Respiratory motion
- External surrogate signal

P Giraud, A Houle - ISRN Pulmonology, 2013

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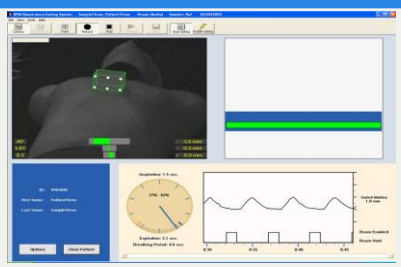

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Surface image-guided RT (SIGRT)

Identify
Varian (fka HumediQ)

AlignRT/GateRT
VisionRT

Catalyst
C-rad -

- Non-invasive and non-ionizing imaging modality
- Compares the acquired image with a reference image
- External surrogate

C-rad's Sentinel – laser based

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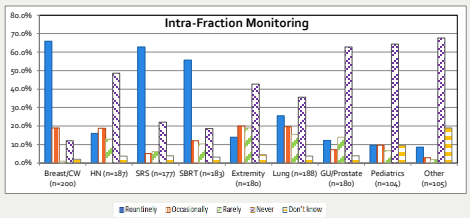
Current use of SGIRT in the United States



PO-GePV-P-82: A Survey of Surface Imaging Use in Radiation Oncology in the United States. Padilla, Havnen-Smith, Cervino, al-Hallaq.

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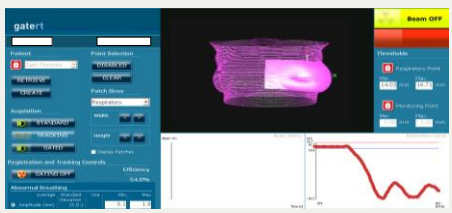

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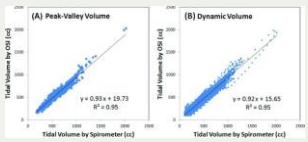
Surface Imaging



Li G, et al. Characterization of optical-surface-imaging-based spirometry for respiratory surrogating in radiotherapy. Med Phys 2016;43 (3):1348-1360.

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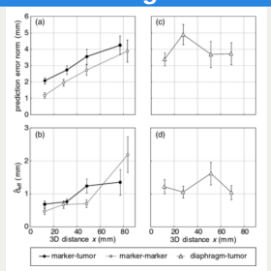
Internal fiducial tracking

- Use of IGRT
- Treatment precision depends on marker–tumour distance

Seppenwoolde *et al.* PMB 2011 (liver SBRT study)



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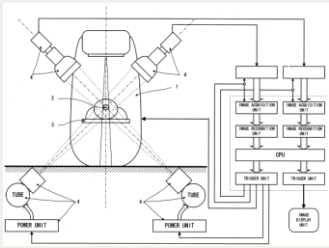
Hokkaido system



Shirato *at al.*, IJROBP, 2000

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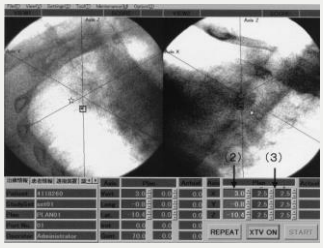

- Fluoroscopy
  - Ionizing radiation
  - 30 fps
- Marker-based
  - 2mm gold marker

Shirato *at al.*, IJROBP, 2000

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Voltage	Pulse width	Location	Dose rate (10^{-3} Gy/min)
70 kV	2 ms	Entrance	1.76
70 kV	2 ms	Isocenter	0.64
70 kV	2 ms	Exit	0.104
120 kV	4 ms	Entrance	10.8
120 kV	4 ms	Isocenter	5.6
120 kV	4 ms	Exit	0.8

Shirato *at al.*, IJROBP, 2000

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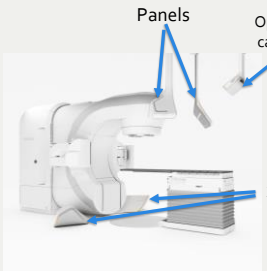
Brainlab ExacTrac / Novalis



- Internal / external
- External (IR) for continuous monitoring (respiratory)

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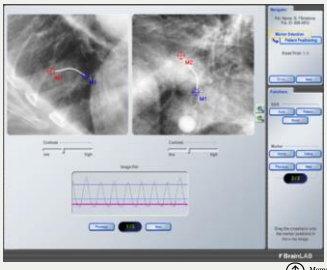

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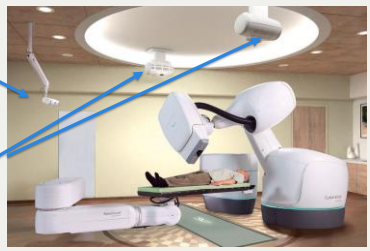
Synchrony™ Respiratory Tracking System



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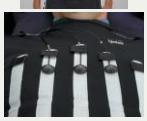

- Synchrony™ vest & camera – external surrogate
- Synchronization with internal surrogate by means of x-ray
  - Periodically updates the internal (fiducial) /external correlation model

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Calypso

- Implanted electromagnetic transponders
- Flat panel array – contains the source coils that emit EM
- 300-500 kHz

Belanger *et al.*, JACMP 2016

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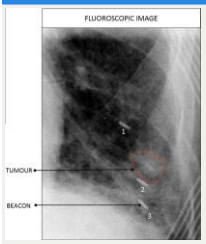
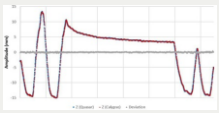


Booth *et al.*, Radiotherapy and Oncology, 2016

- Prostate
- Lung



Belanger *et al.*, JACMP 2016

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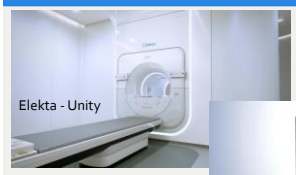
MRI/linac



Higher contrast than

- Fluoroscopy
- CBCT
- 4DCBCT

ViewRay - MRIdian

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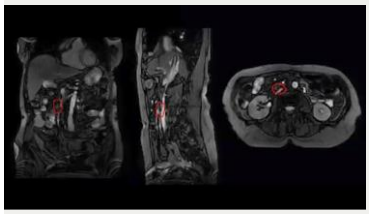
MRI/linac – Direct monitoring



Elekta.com

ViewRay.com

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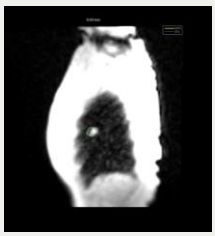
MRI/linac



Courtesy of David Thomas, John Lewis

	Free Breathing		Extended exhale		Irregular breathing		Forced breathing	
	$\bar{e}$ (mm)	e_{95} (mm)	$\bar{e}$ (mm)	e_{95} (mm)	$\bar{e}$ (mm)	e_{95} (mm)	$\bar{e}$ (mm)	e_{95} (mm)
ANN	**0.6**	**1.3**	**1.7**	**4.6**	**2.4**	**6.4**	**1.4**	**4.4**
Template Matching	**0.4**	**0.9**	**0.9**	**1.3**	**0.5**	**0.9**	**0.6**	**1.1**

MRI-guided tumor tracking in lung cancer radiotherapy, LI Cervino, J Du, SB Jiang, PMB 2011

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Summary

- There is a large variety of motion monitoring technologies being used in the clinic
- External and internal surrogate monitoring assumes perfect correlation between surrogate and tumor motion
  - Anzai, Calypso, RPM, ExacTrac, Hokkaido, Cyberknife, surface imaging
- Direct monitoring with MRI does not add extra radiation and provides better contrast than other modalities

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