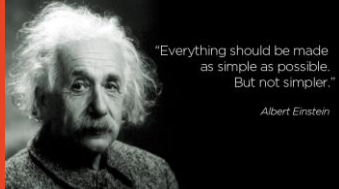


Make margins simple: Use real-time tumor tracking

Paul Keall and
many contributors



Disclosures

- **Patents**
- **Licenses:** Nano-X, Respiratory Innovations, Standard Imaging, Varian
- **Commercial grants:** IBA, Philips, Varian
- **Commercial ownership:** Cancer Research Innovations, Respiratory Innovations, Nano-X



<http://sydney.edu.au/medicine/radiation-physics/about-us/disclosures.php>

Outline

- What is tumor tracking?
- Why do tumor tracking?
- What is the clinical status of tumor tracking?
- What are the limitations of tumor tracking?
- What margins should I use for tumor tracking?
- Summary

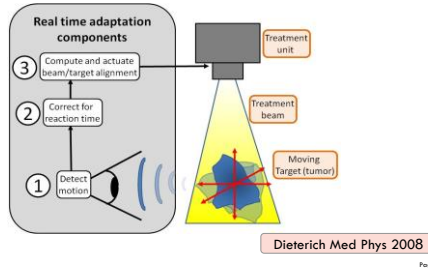


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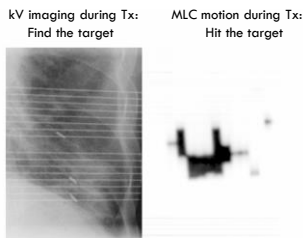
Tumor tracking components



The University of Sydney

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Tumor tracking components

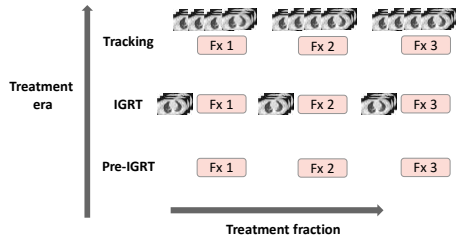


The University of Sydney

Courtesy Vincent Cailliet

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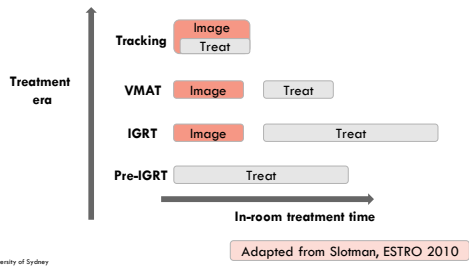
Tracking is IGRT performed more frequently



The University of Sydney

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Tracking can reduce treatment times



The University of Sydney

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Outline

- Why do tumor tracking?
- **Why do tumor tracking?**
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Anatomical changes with time

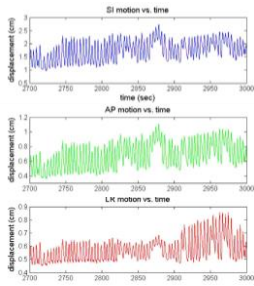


- Twitching
- Swallowing
- Breathing
- Heart beating
- Converting coffee to brain function and bladder filling
- Processing last night's festivities



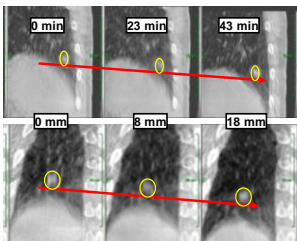
Why?

Variable frequency, baseline, range of motion, shape...



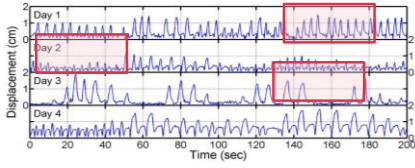
Dieterich et al. Med Phys 2008

CBCT-measured 18 mm intrafraction displacement during single fx 25 Gy NSCLC



Courtesy Hristov, Loo

Lung tumor motion

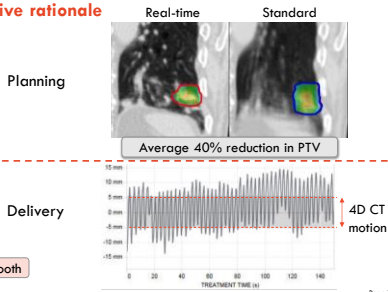


- Lung tumor motion varies between patients, between treatments and within each treatment

Shah IJROBP 2013



Real-time adaptive rationale

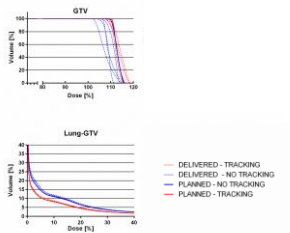


Courtesy Jeremy Booth



Tracking benefit for lung SABR

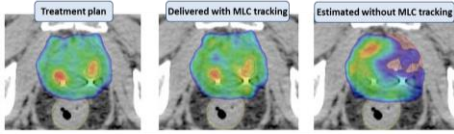
- Target dose increase
- Normal tissue dose decrease



Courtesy Jeremy Booth



Dose with and without tracking



Red = PTV

Colvill IJROBP 2015

Outline

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Real-time adaptation systems

Robotic linac
 CyberKnife
 Synchrony
 Clinical 2004



Gimbaled linac
 Vero/
 Mitsubishi
 Clinical 2011



MLC
 Clinical 2013
 Widely available
 Smallest, lightest
 6 DoF
 Deformation



Robotic couch
 Clinical 20??
 Widely available



Outline

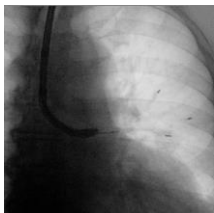
- Why do tumor tracking?
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Limitations

- Guidance independent issues – target delineation, dose calculation, ...
- Guidance dependent issues - surrogates, internal/external correlation, prediction, ...

Method – Endobronchial Implant



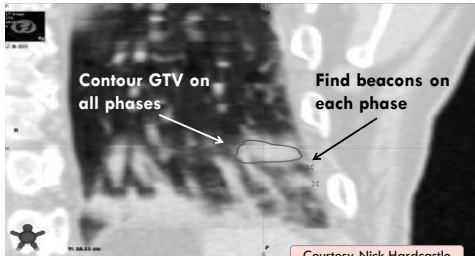
Implant snapshot



MIP of release

Courtesy Nick Hardcastle

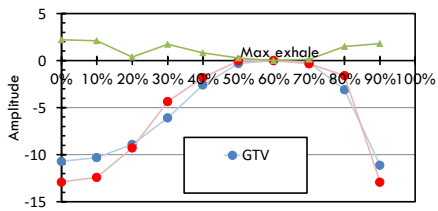
Surrogacy measurement – 4DCT



The University of Sydney

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Surrogacy measurement – 4DCT

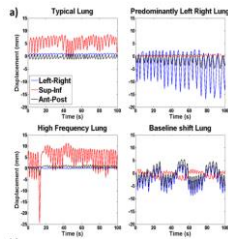


Courtesy Nick Hardcastle

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Motion is the largest error in the treatment delivery chain



Colvill Rad Onc 2016

The University of Sydney

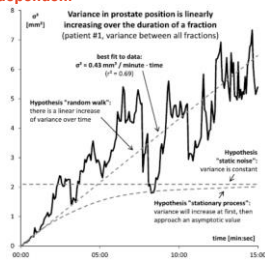
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Assumptions for margins without tracking

- Margins are time independent
- The underlying motion follows a normal distribution
- The beam penumbra is uniform for all patients and within patients
- ...

Margins without tracking are time dependent

- Intrafraction motion of the prostate is neither static nor stationary
- Fixed margins (which over-compensate at the beginning and under-compensate at the end of a fraction) cannot optimally account for intra-fraction motion
- Tracking should be the approach to counter intrafraction motion



Ballhausen PMB 2015 Page 31

Margins with tracking

- Simply add 5 mm to account for other errors

NRG ONCOLOGY
 RTOG 0938
 A RANDOMIZED PHASE II TRIAL OF HYPOFRACTIONATED RADIOTHERAPY FOR FAVORABLE RISK PROSTATE CANCER

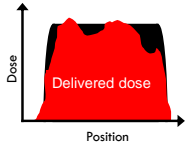
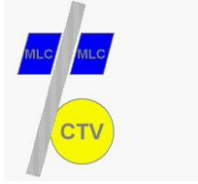
RTOG 0938 and others

Results of a Phase I Dose-Escalation Study Using Single-Fraction Stereotactic Radiotherapy for Lung Tumors

Derek The Li, MD*, Billy W. Lee, MD, PhD*, Anthony Ho, PhD*, Christian Cozzit, PhD*, Albert C. Koong, MD*, Heather Blalock, MD, Stephen F. Kee, MD, Dana Constantinou, MD, Richard J. White, MD, and Justice Deming, MD

Le JTO 2006

IMRT Delivery: Interplay between anatomy and MLC leaf motion leads to motion artifacts



- Cannot be corrected for by margins
- Literature states 0 – 400% dose impact

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Summary

- Margins are simpler with real-time tracking
- Margins are smaller with real-time tracking
- = safer radiotherapy
- = better outcomes
