OVERCOMING the CHALLENGES of MOTION MANAGEMENT in Current LUNG SBRT Practice

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DISCLOSURE

Presenter has NO financial interest in any of the technology reported here.

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OUTLINE

- Tumor Motion in Lung SBRT
  - Characteristics of respiratory motion.
  - Specifics of tumor motion in the lung.
- Treatment with Motion Control
  - External breathing control.
  - Internal breathing control.
- Treatment with Tumor Tracking
  - Respiration gated treatment.
  - Tumor tracking and adaptive treatment.

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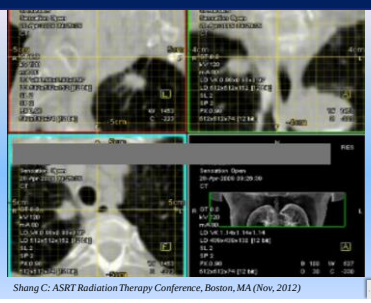
TUMOR MOTION – In SBRT

Optimal dosimetric requirements in lung SBRT are to ensure:

- **Adequate dose coverage to PTV (ITV +margins), and**
- **Dose sparing for the vital organs.**

The range of tumor motion in the thorax can reach up to 3.0 to 5.0 cm, often 1.5 to 2.5 cm with respiration, which posts an obvious challenge in lung SBRT*.

* *Buyyounouski MK, Balter P, Lewis B, et al; Int J Rad Onc Bio Phy 2010;78:3-10*

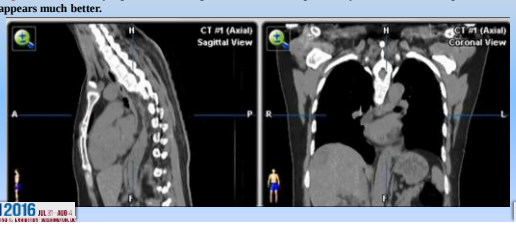


Shang C: ASRT Radiation Therapy Conference, Boston, MA (Nov, 2012)

TUMOR MOTION – with Respiration

Review **- Normal respiration consists of two processes: Inspiration and Expiration**

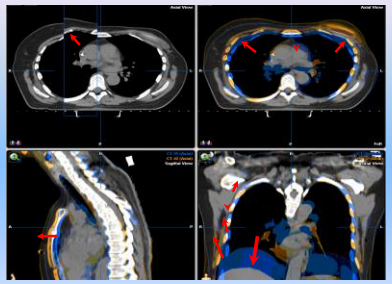
- **Inspiration is an actively engaged process where the diaphragm moves inferiorly and stretch laterally, while the chest wall expands anterior and laterally. Its amplitude likely varies during respiration cycles.**
- **Expiration is normally a passive, shorter process, where the repeatability of the anatomic displacement appears much better.**



TUMOR MOTION – with Respiration

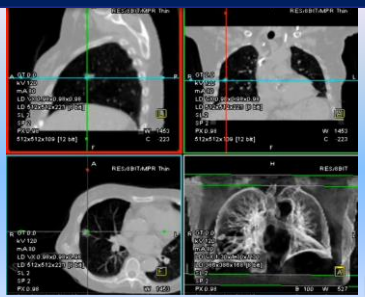
Arrows in the diagrams point the moving directions of the anatomy from exhale to inhale status.

Depending on the amplitude of motion, two types of respiration can be classified- diaphragmic & thoracic respirations.



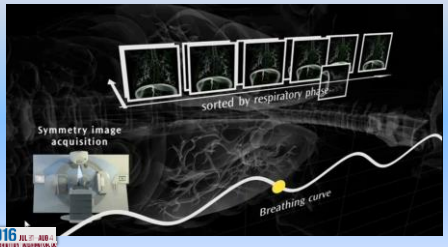
TUMOR MOTION – with Chest Wall

In this mid-aged patient, the lung tumor moves along with the motion of the chest wall and diaphragm. In this case, a surface point of the chest can be used as a surrogate to predict the locations of this lung tumor with a higher confidence.



TUMOR MOTION – 4D Imaging

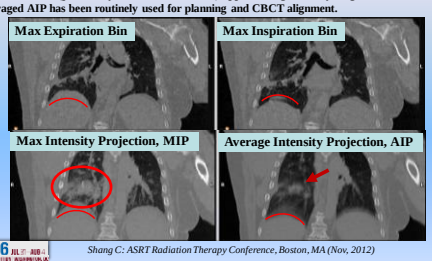
In respiration synchronized 4DCT scan, the faster **retrospective** 4DCT acquisition (as shown) is widely used in clinic, in contrast to the **prospective** scans. In addition, slow imaging modalities, such as PET, CBCT can also encompass the range of tumor motion.



Courtesy of Elekta and Varian

TUMOR MOTION – in 4D CT

The diaphragm positions in the selected 4DCT sets display differently (the red curves indicate its average position). The tumor (pointed by the arrow and circle) appears a significantly larger in MIP due to its motion. The time-averaged AIP has been routinely used for planning and CBCT alignment.



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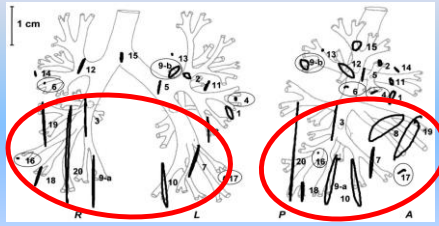
MOTION CONTROL in Lung SBRT

Larger motions are usually found in the peripherally and inferiorly located tumors in the lung, as indicated in a study with real time fluoroscopy of 20 patients with 21 lung tumors.



Seppenwoolde Y, Shirato H, Kitamura K, et al.; Int J Rad Onc Bio Phy 2002;53:822-834

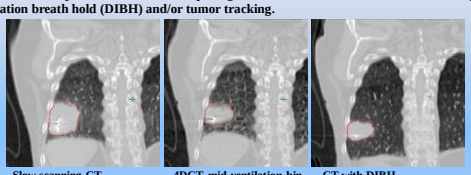
External Breathing CONTROL

In practice, abdominal and lower chest compression may effectively reduce the amplitude of tumor motion in the lung, especially when it is located in the lower lobes.

The compressions frequently used in clinic are to achieve a "forced sallow breathing".

MOTION CONTROL in Lung SBRT

In lung CT, the motion artifacts enlarge the apparent tumor volume. Treatment for lung tumor with less motion provides a better dose sparing for normal tissues – this can be realized by deep inhalation breath hold (DIBH) and/or tumor tracking.



Slow scanning CT
Showed maximal motion artifact. Volume = 64.9 cc.

4DCT, mid-ventilation bin
TV showed limited motion artifact.

CT with DIBH
TV showed sharp edges. Volume changed to 34.9 cc.

Adopted from: Persson GF, Nygaard DE, et al. Int J Rad Onc Bio Phy 2011; 80:1573-1580

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External Breathing CONTROL

Using Video and Laser based surface rendering systems for monitoring patient surface may improve the reproducibility of voluntary DIBH or respiration motion gated treatment.

Courtesy of C-Rad Inc.

Courtesy of VisionRT

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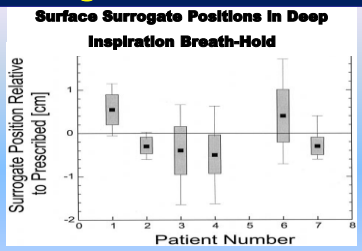
External Breathing CONTROL

However, the surface surrogate positions during DIBH may be less reproducible than we expected, as suggested by Mah, et al, in an investigation for 250 treatment setups of 6 patients.



Dennis Mah, Joseph Hanley, Kenneth et al., Int J Radiat Oncol Biol Phys 2000; 48:1175-1185, Memorial Sloan-Kettering Cancer

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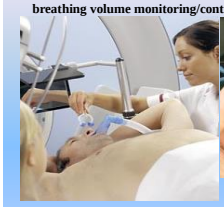
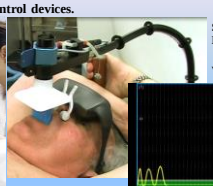
Internal Breathing CONTROL

The reproducibility of voluntary (or active) breath-hold can be improved when guided by breathing volume monitoring/control devices.



Active Breathing Coordinator
- Volume is mechanically controlled

Courtesy of Elekta: ABC system



Spirometric Motion Management System
- Air volume is controlled voluntarily

Courtesy of Qfix: SDX system

VY Wong, SY Tung, et al. Med. Phys. 2010. **37:** 4673

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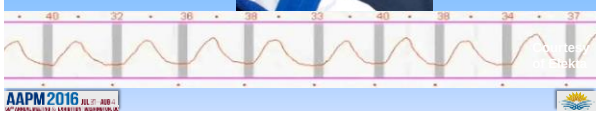
TRACKING with Surface Surrogate

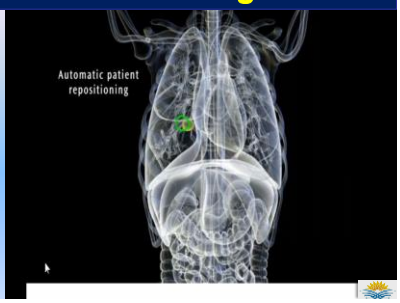
The most popular method is to use a body surface surrogate to predict tumor positions for the respiration gated treatment. Usually a non-invasive system such as IR, video, or laser is used to track such a surface surrogate.

In Varian's Real-time Position Management™ system (RPM), the infrared (IR) emitter and camera is tracking the surface position via IR reflectors. Other systems may use video and laser based surface rendering.



TRACKING with Surface Surrogate

When a reliable model can be built with the surrogate to correctly predict the tumor positions in the lung, a better normal tissue dose sparing can the be achieved without compromising tumor dose coverage (as shown).



Courtesy of Elekta

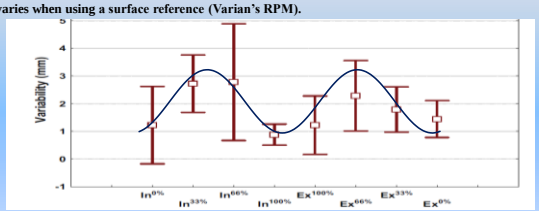
TRACKING with Surface Surrogate

Unfortunately, a lung tumor may move *asynchronously with body surface*, especially in the cases with limited chest wall motion due to aging and other pathological factors.

As demonstrated, this elderly patient presents a left upper lung cancer, in which tumor moves almost irrelevantly with the rib displacement. In such cases, it is prudent that the treatment shall include a full range of the tumor motion with a free breathing.

TRACKING with Surface Surrogate

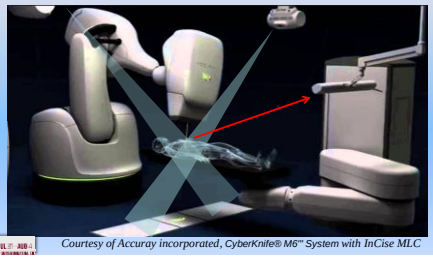
The uncertainty of the surface surrogate based tumor motion prediction was well demonstrated in this 4DCT investigation, in which 4 repeated helical 4DCTs were acquired every 10 min on 10 patients with 14 pulmonary metastases. The residual tumor position at a given respiration bin varies when using a surface reference (Varian's RPM).



Guckenberger M, et al.; Int J Rad Onc Bio Phy 2007;67:1352-1359

TRACKING with Surrogate Model

In clinic, the surrogate-motion correlation can be verified and adjusted with radiographic images. Such a model can then guide radiation delivery with a higher confidence.



One of such examples is CyberKnife® System.

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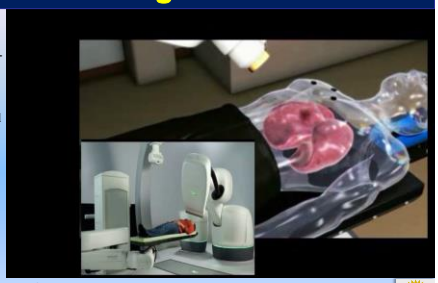
Courtesy of Accuray incorporated, CyberKnife® M6™ System with InCise MLC

TRACKING with Surrogate Model

In this example, throughout the treatment, a surrogate-motion correlation model is periodically verified and updated with paired orthogonal radiographic images.



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Courtesy of Accuray incorporated, CyberKnife® M6™ System with InCise MLC

TRACKING with Surrogate Model

As shown, the synchronization of the surface surrogate – tumor position (represented by 3 fiducials) is checked periodically throughout the treatment.

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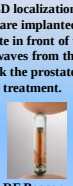
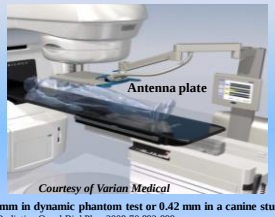
TRACKING with Tumor Implants

Alternatively, the implanted radiofrequency (RF) generating beacons (Varian Medical) can also be used to track tumors.

As used in the Calypso ® 4D localization system, 3 to 4 RF beacons are implanted to the prostate, a antenna plate in front of the patient can capture radio waves from the beacons and real-time track the prostate or tumor positions during the treatment.



RF Beacon



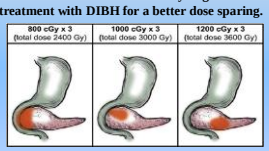
Courtesy of Varian Medical

A study indicated its localization accuracy of 0.33 mm in dynamic phantom test or 0.42 mm in a canine study.
Satanam L, Malinowski K, Hubenshmidt J, et al. Int J Radiation Oncol Biol Phys 2008;70:892-899

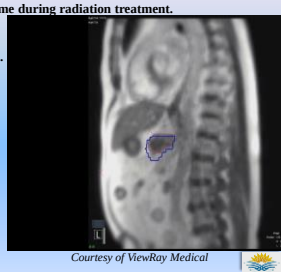
TRACKING with Real-time Imaging

An accurate tumor tracking has also been achieved using non-ionizing radiations, such as ultrasound and, more promisingly, MRI in real-time during radiation treatment.

In the example, the radiation dose in pancreatic SBRT is often limited due to its surrounding radiosensitive organs and motion with respiration. MRI has demonstrated its ability to guide treatment with DIBH for a better dose sparing.



Mahadevan A, Jain S, Goldstein M, et al, IJROBP 2010; 78:735–742



Courtesy of ViewRay Medical

SUMMARY

- **Understanding the physio-pathological basics of patient's respiration and lung tumor motion is essential to construct an effective motion control strategy in lung SBRT program.**
- **Common tools to assess tumor motion include 4DCT, images at different respiratory phases, slow imaging modalities (PET, CBCT).**
- **The tumor position prediction model using a body surface surrogate shall be verified and adjusted throughout the treatment. Otherwise, it is prudent to apply comfortable margins and treat the full motion range in lung SBRT.**
- **Intra-fractional real-time tumor tracking using advanced imaging techniques has promised a new paradise in radiation therapy.**

Thank You!

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