Transitioning from 3D IMRT to 4D IMRT and Roles of Image-Guidance

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Disclosure

- I received research grants from Siemens Medical Solutions, Phillips, and BrainLab.

Learning Objectives

- Understand various currently available IGRT and 4DCT technologies
- Understand how these technologies can be used to improve dose delivery precision and accuracy, in particular with dynamically changing tumor volumes.
- Understand the challenges and strategies in clinical implementation of 4D-IMRT in three specific cancer sites - head and neck, and prostate, and lung.

IGRT Is Necessary for IMRT

- Highly conformal dose distributions produced from IMRT require precise delivery methods ï IGRT.
- IGRT permits us to reduce the PTV margins while better protecting normal tissue.
- IGRT allows us to precisely correlate patientôs anatomy of the day with the planned dose distributions.

KV/MV-Cone Beam CT

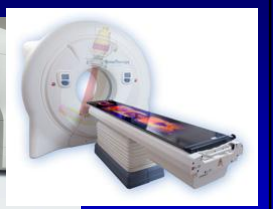
Elekta KV

Varian KV

Siemens MV

Daily CT Prior to Treatment

Siemens CTvision



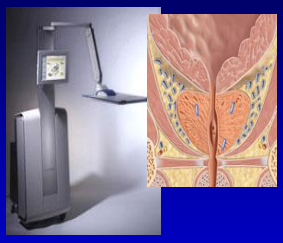
Tomotherapy Units

Organ Motion Tracking Systems

KV X-ray Tracking

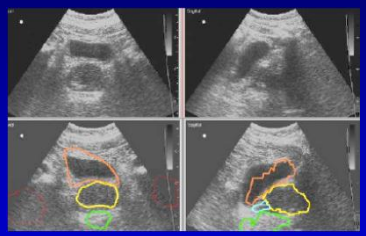
Organ Motion Tracking Systems

Optical Tracking



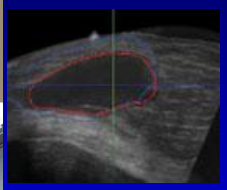
Electromagnetic Transponders

Ultrasound System- to Locate Prostate



NOMOS BAT System

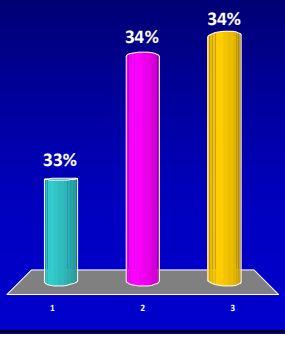
Ultrasound System to Localize Tumor Bed in Breast



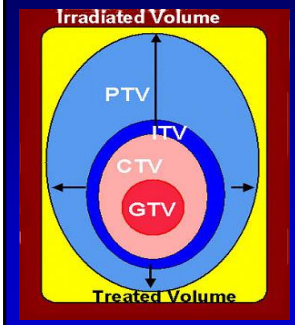
Resonant Medical Clarity system

How frequently does your clinic perform IGRT ?

1. The first fraction;
2. Every week;
3. Every fraction.



How Big are PTV Margins



- PTV is the greatest contribution to all margin expansions
- Large PTV margins will increase normal tissue toxicity
- The goal of IGRT is to reduce PTV margins to zero.

Gathering Evidence

- 67 patients, who received partial brain irradiation under daily IGRT.
- 2008 daily images were analyzed.
- According to Van Herk formulae, setup margins were calculated.

Setup Margins for Partial Brain Treatment

	Lateral (mm)	Vertical (mm)	Longitudinal (mm)
Setup Margin Without Daily IGRT	4.0	4.7	5.0
Setup Margin With Daily IGRT	0.8*	0.7*	0.6*

Van Herk Formulae: $M = 2.5(\Sigma) + 0.7(\sigma)$
* Assume precise implementation

Gathering Evidence

- 51 female patients, who received pelvis irradiation for endometrial cancer under daily IGRT.
- 1259 daily images were analyzed.
- According to Van Herk formulae, setup margins were calculated.

Setup Error for Pelvis Treatment

	Lateral (mm)	Vertical (mm)	Longitudinal (mm)
Setup Margin Without Daily IGRT	11.6	9.0	18.2
Setup Margin With Daily IGRT	1.9*	1.7*	1.9*

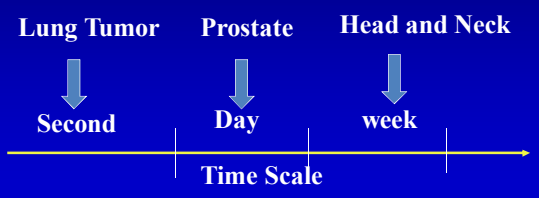
Van Herk Formulae: M = 2.5(Σ) + 0.7(σ)
* Assume precise implementation

PTV Margin Reduction

- Under IMRT-IGRT, abundant evidence demonstrated that PTV margins are reduced and normal tissue toxicity are decreased. Example: reduced rectal toxicity in prostate cancer; preserve parotid function in H&N cancer.
- The question is: Why 4D-IMRT?

Clinical Requirements of 4D IMRT

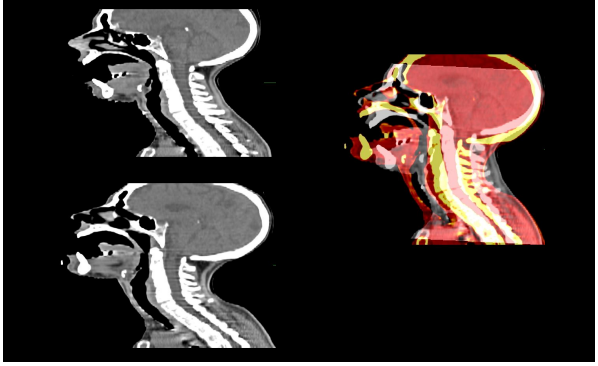
Organ movements and anatomic changes in patients require us to explicitly include the time variable into both planning and delivery.



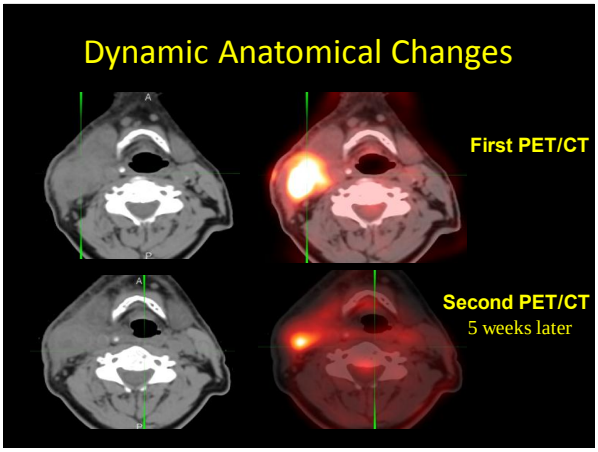
Positional Correction Is Not Enough

- With abundant information gather from daily IGRT, we recognize that positional correction is not enough.
- The non-rigid patient's positional changes and dynamic anatomical changes require adaptive RT.
- 4D IMRT allows us to take these changes into clinical considerations.

Non-Rigid Positional Changes



Dynamic Anatomical Changes



4D IMRT – Online or Offline?

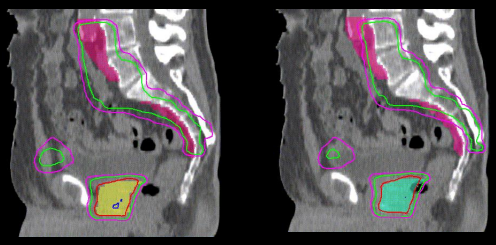
Offline 4D IMRT

- Offline 4D IMRT is the first logical step.
- Offline 4D IMRT can correct for systematic changes – slow tumor volume changes or systematic positional changes
- Offline 4D IMRT permits a streamline workflow, less demanding on resources.

Offline or Online 4D IMRT?

- Offline 4D IMRT can not account for daily non-rigid anatomic changes - rectal or bladder changes in the prostate cancer
- Offline 4D IMRT can not account for daily deformable positional changes – flexible neck positions in H&N cancer
- Online 4D IMRT can correct for random positional errors

Independent Organ Movements

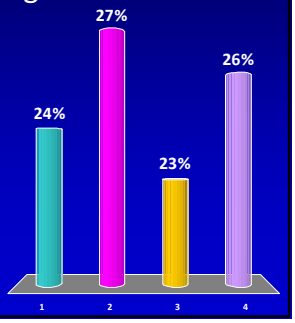


Original Plan iso-shift

60 Gy, 54 Gy, 45 Gy, 40 Gy

What percentage of patients treated in your clinic receive adaptive planning?

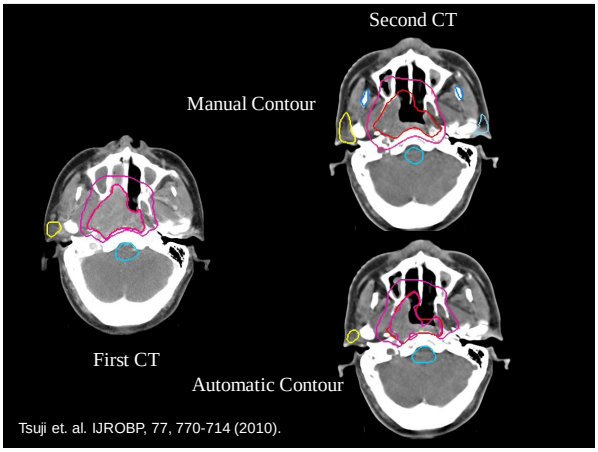
1. 50%
2. 25%
3. 10%
4. none



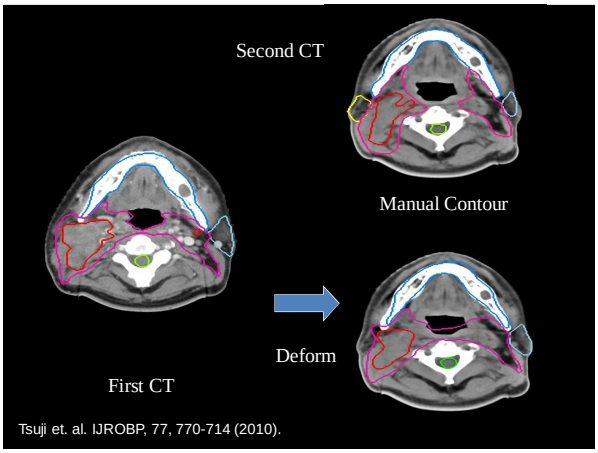
4D IMRT Today

Offline 4D-IMRT Work Flow

- Acquire a new planning CT – 10 minutes.
- Deform all contours (including tumor volume and sensitive structures) the initial planning CT to the new planning CT – 2 minutes.
- Physician review and edit the tumor volume – (10 - 30 minutes).
- Replan by applying the initial planning objectives to the new plan and fine tuning the plan – 2 hours



Tsuji et. al. IJROBP, 77, 770-714 (2010).



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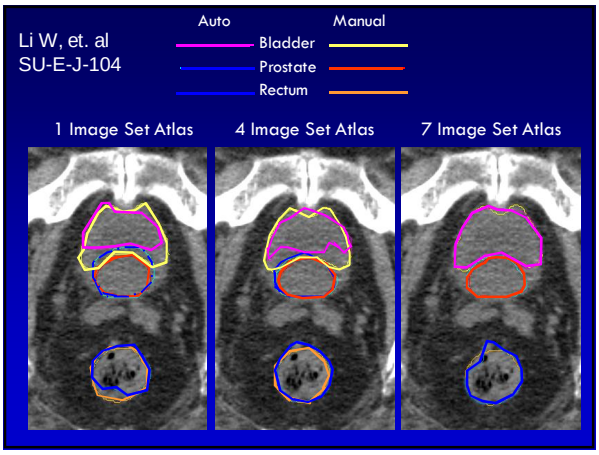
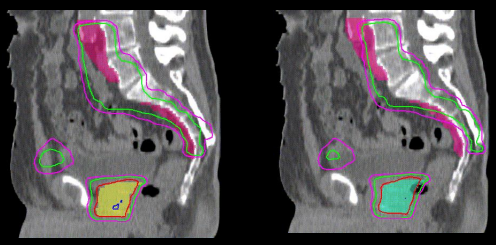


Multiple Plan Pools For 4D IMRT

Independent Organ Movements



Original Plan

iso-shift

60 Gy, 54 Gy, 45 Gy, 40 Gy

Poor Man 4D-IMRT Strategies

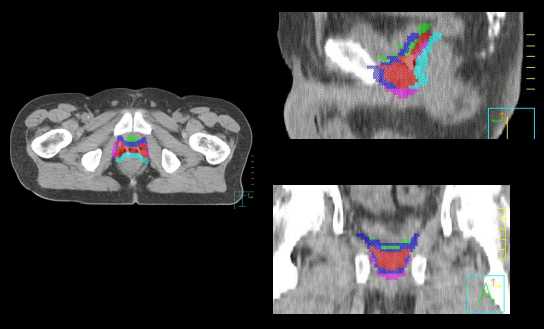
- Re-plan every day – not Ready
- Adjust IMRT segments online - not ready yet
- Create multiple adaptive IMRT plans – Pseudo-4D IMRT

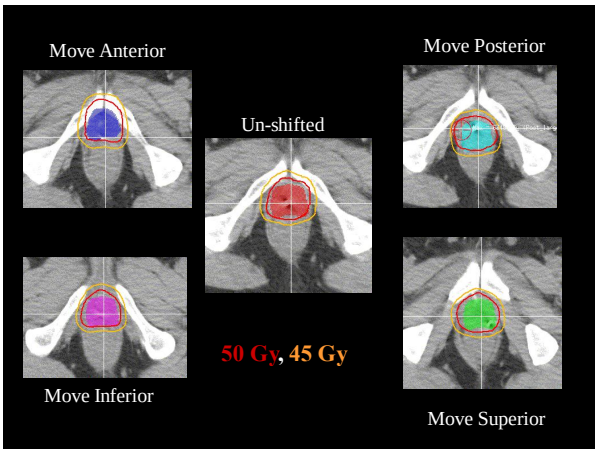
Xia P, et. al, Med. Phys, 37(9) 2010, 5006-5-13

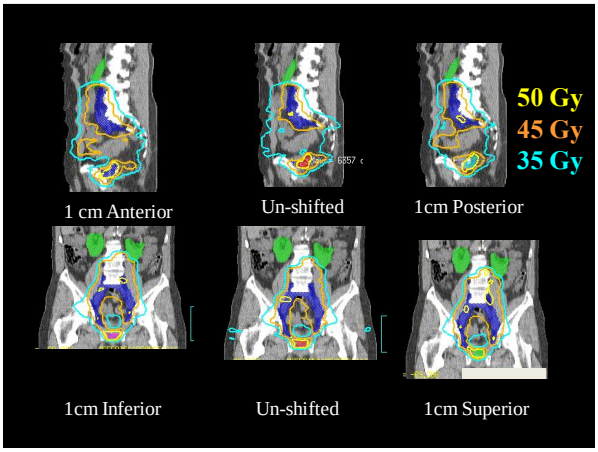
Multiple Adaptive IMRT Plans

- Create a set of IMRT plans with a series of presumed prostate positions while keeping the pelvic lymph nodes stationary.
- Use IGRT to detect the prostate position in relative to the pelvic bony anatomy.
- Choose an IMRT plan that best matches the prostate position of the day.

Prepare Possible Instances







Treatment Procedure For Multiple Adaptive Plan IMRT

- MV-CBCT was first aligned to the pelvic bone, and then aligned to implanted markers.
- The patient setup error (shifts from bone alignment) was corrected.
- The prostate movement was determined by the differences of shifts obtained from the two image registrations.
- A proper IMRT plan was chosen for treatment according to the detected prostate position.

Tomorrow's 4D IMRT

4D IMRT Is Required From Clinical Necessitates

- 4D-IMRT is required from clinical necessitates
  - because of non-rigid positional changes.
  - because of dynamic anatomical changes.
  - because of highly conformal dose distributions.
  - because of increasing use of hypo-fractionation.
- 4D-IMRT allows us to
  - correct both systematic and random errors.
  - use smaller or zero planning margin.
  - Achieve high precision delivery

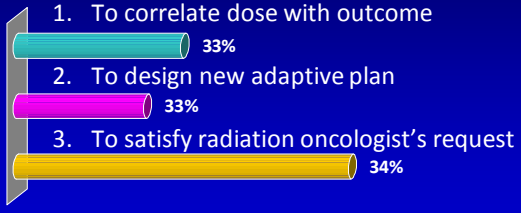
Is Online (Real Time) Planning a Reality?

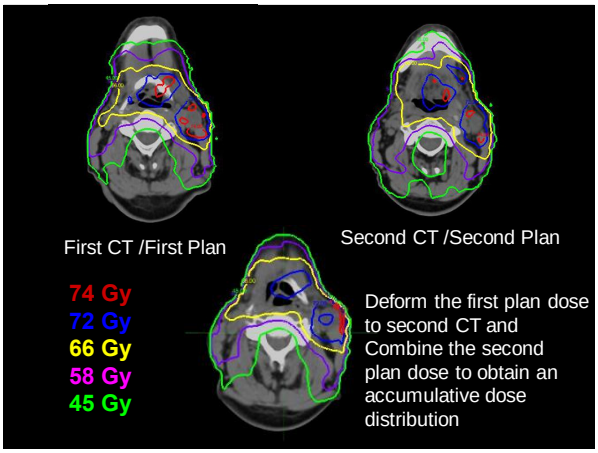
- Real time planning will become technically feasible:
  - with a CT unit in the treatment room.
  - with fast computational power (GPU) (~100 times fast)
  - with robust automatic contouring tools.
  - with remote planning and viewing tools.
  - with ability to accumulate total dose.
- Real time planning demands efficient workflow.

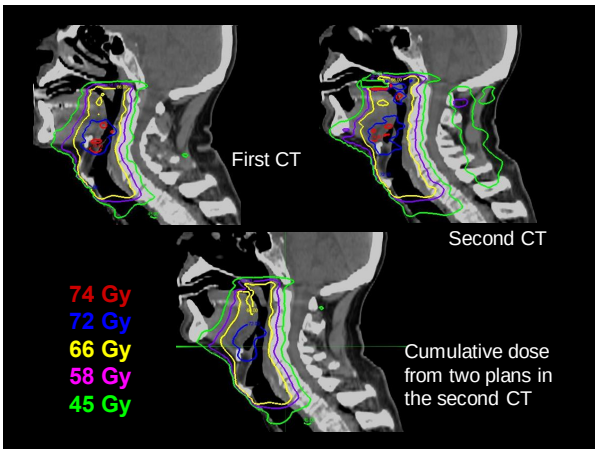
Cumulative Dose Distributions

- Researchers are actively developing a way to display accumulative dose distributions from multiple planning CTs.
- One can use deformable imaging registration method, but it is not perfect.
- Why we need cumulative dose distributions?

Why We Need Cumulative Dose?







Summary

- 4D IMRT will be the future of radiotherapy, especially with increasing use of hypofraction treatment
- 4D IMRT can accommodate systematic and random changes in patient anatomy and treatment position.
- 4D IMRT requires efficient and effective IGRT tools, and tools to facilitate real time planning such as deformable image registration, fast real time planning.
- With these tools, adaptive treatment is clinical feasible and practical.