VCU The Department of Radiation Oncology

The Influence of Dose Modeling on IMRT

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Outline

- Define Dose Prediction Error (DPE)
- DPE sources
- Impact on plan quality / optimality
- Role of IMRT QA to detect DPEs
- Incorporating better dose predictions into IMRT optimization

The dose calculation problem

(external photon beams)

- For a given radiation fluence incident upon the patient geometry, determine the energy absorbed (the absorbed dose) within the patient as a function of position.

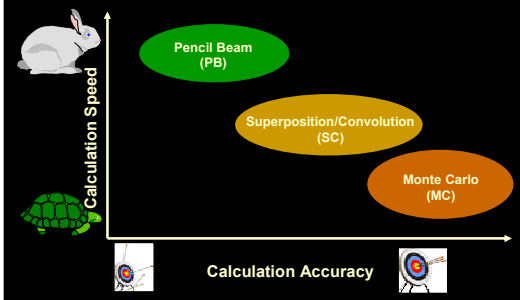
- When we "compute dose" we are really just *predicting* what the dose will be to the patient

Dose algorithms can be inaccurate for

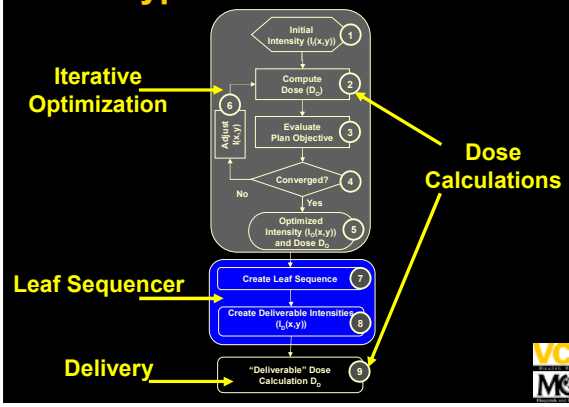
- Small fields
- Regions of dose gradients (radiation disequilibrium)
- Heterogeneous conditions

IMRT is typically delivered through a sequence of small static fields or with a dynamically moving aperture with a small width. Dose gradients are common place in IMRT fields.

Dose Calculation Algorithms



Typical IMRT Process



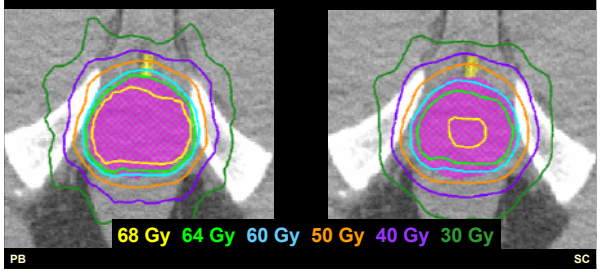
Commercial Systems

May 2004

System	Optimization Dose Algorithm
Corvus 5.0	Pencil Beam (PB)
Eclipse 7.1.67	Fast 3D Superposition
CMS Xio 4.2	Fast 3D PB Superposition
KonRad 2.1	PB
Pinnacle 7.4	PB with SC corrections
Plato	PB
Oncentra 1.3	PB

What is a Dose Prediction Error?

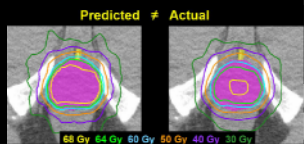
Predicted ≠ Actual



Dose Prediction Error

Actual Dose Received by Patient
– Predicted Dose (Computed)

Dose Prediction Error

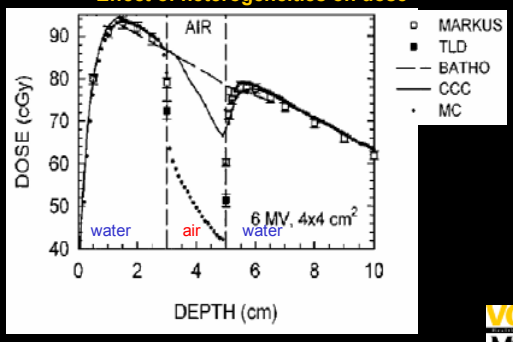


How estimate DPE?

- Compare with
  - Measurements
    - Restricted to simple geometries
  - Computation with "more accurate" algorithm
    - Algorithm must be well benchmarked

Example DPE

Effect of heterogeneities on dose



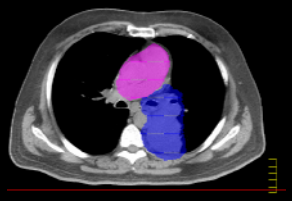
Arnfield et al., Med. Phys, 27 (6) 2000

Sources of Dose Prediction Errors

- Planning system input data
- Planning system algorithm
  - Fluence
  - Heterogeneities
- Patient geometry
  - Setup position
  - Organ motion and deformation
- Dose delivery

Heterogeneities

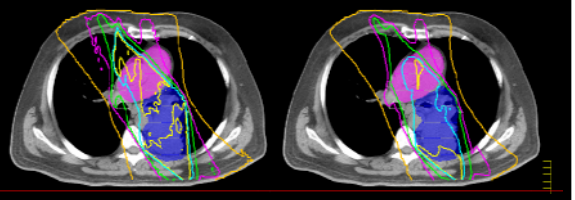
- DPE_{hetero}: due to (miss) handling of heterogeneities by the treatment planning algorithm



DPE_{hetero}: Lung IMRT Plan

6 MV, 6-field dynamic MLC plan

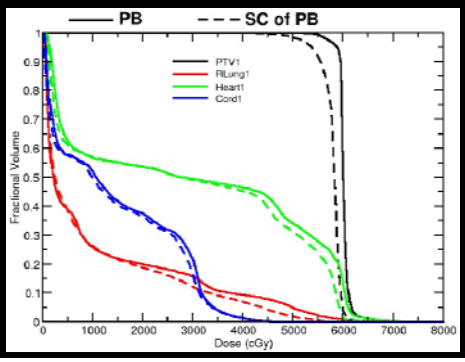
Pencil Beam Optimized | Recomputed with Superposition



60 58 50 45 20

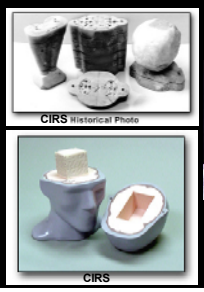
DPE_{hetero}: Lung IMRT Plan

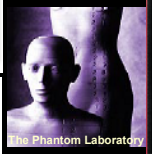
6 MV, 6-field dynamic MLC plan

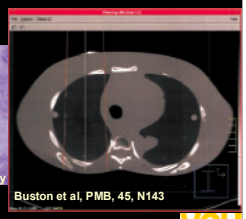


Measurement of DPE_{hetero}

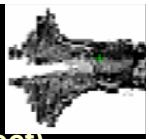
- Anthopomorpic phantoms







Fluence

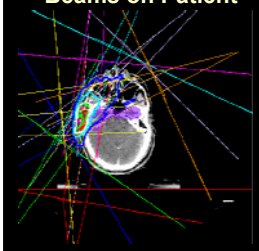


- $DPE_{fluence}$: due to (incorrect) prediction of fluence delivered to the patient
  - Algorithmic prediction of the effect of MLC on beam delivery
  - Fluence delivery errors
    - Inability of machine to deliver desired fluence pattern
    - Random or systematic delivery errors

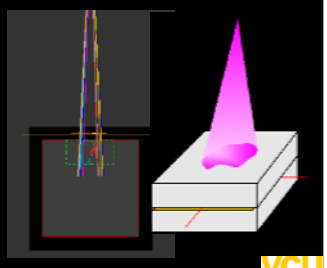
$DPE_{fluence}$ Measurement

Phantom Dose Verification

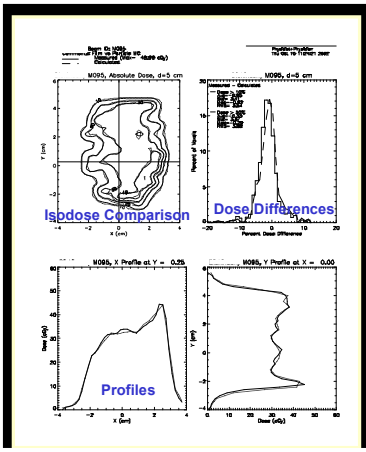
Beams on Patient



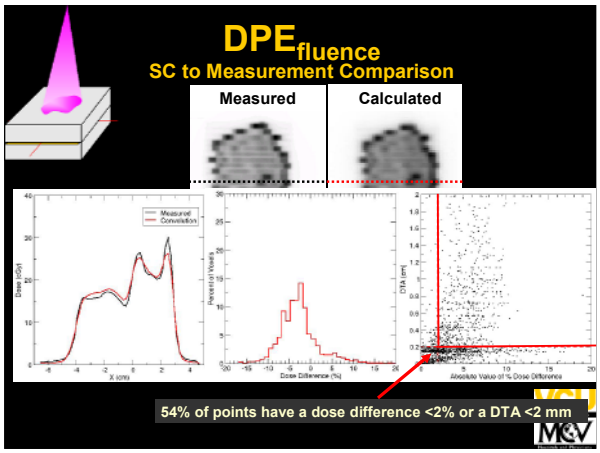
Beams on Phantom

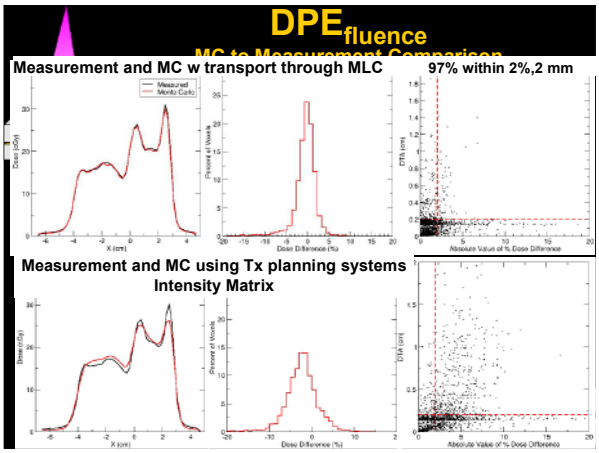


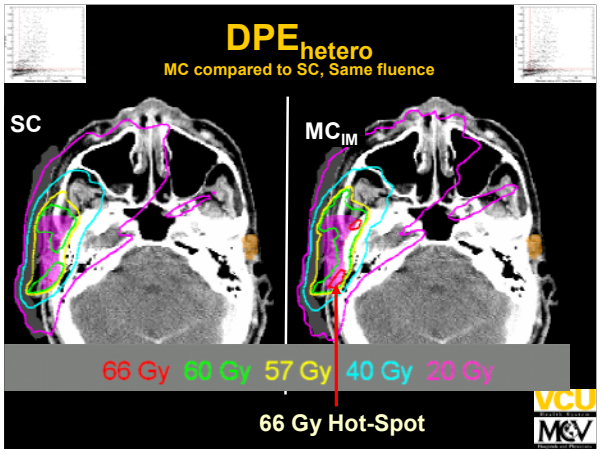
Sample Film Dosimetry Results

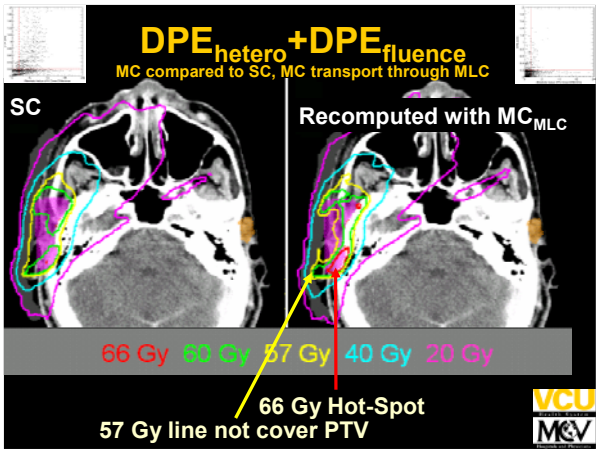


Other Analysis
- Distance to Agreement
- Gamma
- …

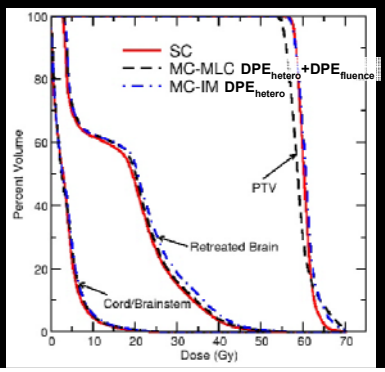

DPE fluence
SC to Measurement Comparison
Measured
Calculated
54% of points have a dose difference <2% or a DTA <2 mm


DPE fluence
Measurement and MC w transport through MLC
97% within 2%,2 mm
Measurement and MC using Tx planning systems
Intensity Matrix


DPE hetero
MC compared to SC, Same fluence
SC
MC IM
66 Gy 60 Gy 57 Gy 40 Gy 20 Gy
66 Gy Hot-Spot


DPE hetero +DPE fluence
MC compared to SC, MC transport through MLC
SC
Recomputed with MC MLC
66 Gy 60 Gy 57 Gy 40 Gy 20 Gy
66 Gy Hot-Spot
57 Gy line not cover PTV

DPE_{hetero}+$DPE_{fluence}$



DPE Consequences & Solutions

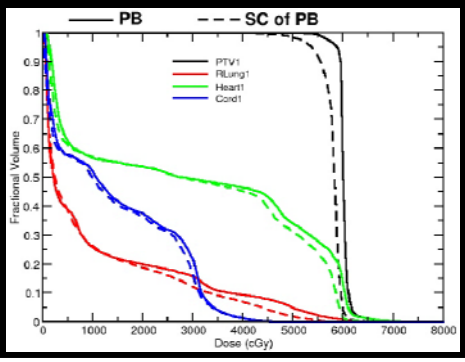
- Incorrect dose predicted for patient
  - Recalculate with more accurate algorithms
  - Scale MUs to get desired coverage
- Sub-optimal dose distribution
  - (Re)optimize with more accurate algorithms

Commercial Systems

System	Optimization Dose Algorithm	Post Optimization Dose Algorithm
Corvus 5.0	PB	MC (optional)
Eclipse 7.1.67	Fast 3D Superposition	PB
CMS Xio 4.2	Fast 3D Superposition	SC (Superposition)
KonRad 2.1	PB	PB
Pinnacle 7.4	PB with SC corrections	SC
Plato	PB	PB
Oncentra 1.3	PB	PB or SC

DPE_{hetero}: Lung IMRT Plan

6 MV, 6-field dynamic MLC plan



DPE_{hetero}: Lung IMRT Plan

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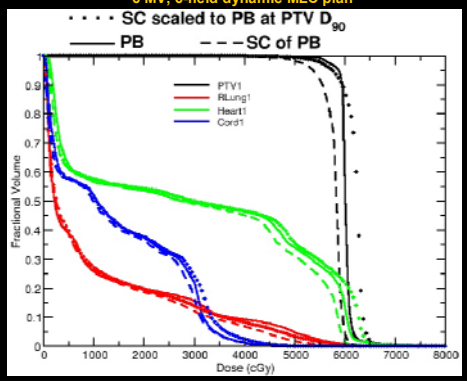

DPE Consequences & Solutions

- Incorrect dose predicted for patient
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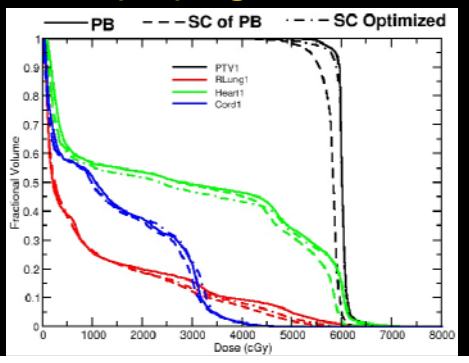
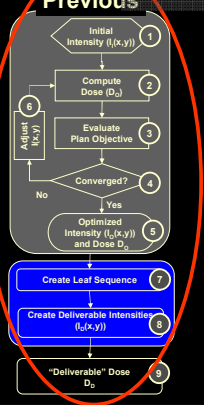
Reoptimize with accurate (SC) algorithm

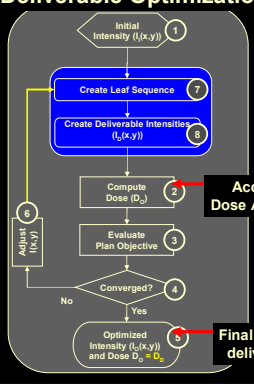


Reduce effect of $DPE_{fluence}$

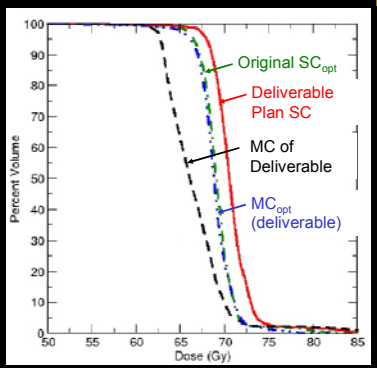
Previous



Deliverable Optimization



Deliverable optimized to reduce effect of $DPE_{fluence}$



Head and Neck IMRT plan

Deliverable optimization can restore original optimized plan

Optimization with more accurate algorithms

- Reproduces (previously unachievable) optimized dose distribution with different intensity patterns and MUs
- IMRT can compensate for
  - Dose perturbations due to heterogeneities
  - Fluence delivery limitations

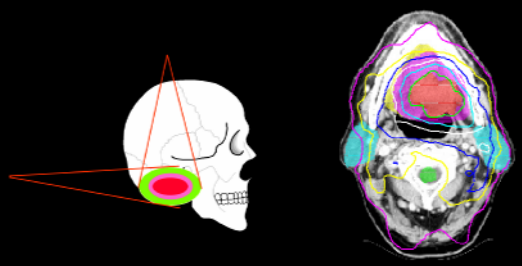
To Summary

Patient Positioning

(setup errors)

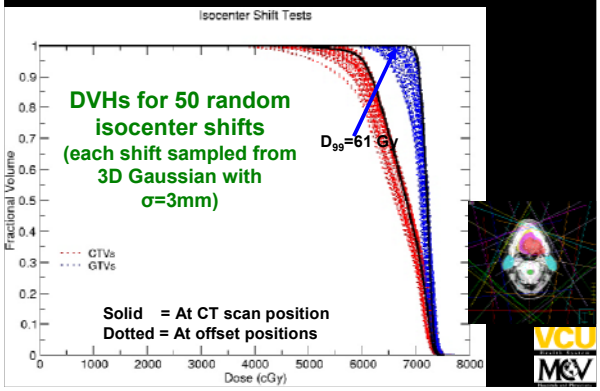
- $DPE_{patientPosition}$: due to (inadequate) prediction of patient position
  - Systematic setup errors
  - Random setup errors
  - Intra-fraction organ motion
  - Inter-fraction organ motion
  - Organ deformation

$DPE_{patientPosition}$: Head and Neck



75 70.8 65 60 54 45 30

$DPE_{patientPosition}$: Head and Neck



Summary
Influence of Dose Modeling on IMRT

- Dose calculation is a prediction process
- Difference wrt actual = Dose Prediction Error
  - Sources
    - Heterogeneities
    - Fluence
    - Patient Positioning
  - Impact on IMRT plans
  - Avoid clinical consequences by re-computing with better algorithms after optimization
  - Better plans available if optimize using accurate algorithm

The END