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

- Pencil Beam (PB)
- Superposition/Convolution (SC)
- Monte Carlo (MC)

Calculation Speed

Calculation Accuracy

Typical IMRT Process

1. Create Leaf Sequence
2. “Deliverable” Dose Calculation (DD)
3. Initial Intensity (II(x,y))
4. Evaluate Plan Objective
5. Converged? Adjust I(x,y)
6. Compute Dose (DO)
7. Optimized Intensity (IO(x,y)) and Dose DO
8. No
9. Yes

Commercial Systems

May 2004

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<thead>
<tr>
<th>System</th>
<th>Optimization</th>
<th>Dose Algorithm</th>
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What is a Dose Prediction Error?

- Predicted ≠ Actual

Dose Prediction Error

Actual Dose Received by Patient
- Predicted Dose (Computed)

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
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
Monte Carlo and IMRT
ASTRO 2003
Jeffrey V. Siebers, VCU

Measurement of $DPE_{\text{hetero}}$

- Anthopomorpic phantoms

Fluence

- $DPE_{\text{fluence}}$: 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$_{\text{fluence}}$ Measurement
Phantom Dose Verification

Beams on Patient  Beams on Phantom

Sample Film Dosimetry Results

Other Analysis
Distance to Agreement
Gamma
...
Monte Carlo and IMRT
ASTRO 2003
Jeffrey V. Siebers, VCU

DPE\textsubscript{fluence} SC to Measurement Comparison

54% of points have a dose difference <2\% or a DTA <2 mm

DPE\textsubscript{fluence} MC to Measurement Comparison

97% within 2\%, 2 mm

DPE\textsubscript{hetero} MC compared to SC, Same fluence

66 Gy Hot-Spot

DPE\textsubscript{hetero} + DPE\textsubscript{fluence} MC compared to SC, MC transport through MLC

66 Gy Hot-Spot

57 Gy line not cover PTV
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

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DPE_{hetero} + DPE_{fluence}
DPE Consequences & Solutions

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

Reoptimize with accurate (SC) algorithm

Reduce effect of DPE influence
Monte Carlo and IMRT
ASTRO 2003
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Deliverable optimized to reduce effect of DPE\textsubscript{fluence}

- Original SC\textsubscript{opt}
- Deliverable Plan SC
- MC of Deliverable
- MC\textsubscript{opt} (deliverable)

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

Patient Positioning (setup errors)

- DPE\textsubscript{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\textsubscript{patientPosition}: Head and Neck

75 70.8 65 60 54 45 30
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