Four-dimensional dose calculations

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Educational Objectives

At the conclusion of this presentation, the participant will be able to answer the following questions:

1. What are 4D dose calculations?
2. Do we need to do 4D dose calculations?
3. Can 4D dose calculations be done on a routine basis in the clinic?
4. What questions remain to be answered?

What are 4D dose calculations?

- Dose calculations that account for motion
  - Respiratory motion, in particular
  - Could also account for interfractional variations
    - Adaptive calculations
  - Focus on accounting for intrafractional respiratory motion in dose calculations

What are 4D dose calculations?

- 4D dose calculations, not 4D treatment planning
  - Recall transition from 2D to 3D
    - Start with setting beams on single transverse plane – 2D data set
    - Calculate and view dose in other planes – “2.5D planning”
    - Eventually plan on 3D data set

What are 4D dose calculations?

- 4D dose calculations, not 4D treatment planning
  - We do “3.5D treatment planning”
    - Start with planning on single phase of 4D data set – 3D data set
    - Calculate and view dose in other phases
    - We do not yet plan on 4D data set

What are 4D dose calculations?

- Plan on single phase – reference phase
- Copy beams onto remaining phases of 4D data set and calculate doses
- Deform 3D dose grid from reference phase to other phases – deformable image registration
- Compute doses to deformed reference dose grid
- Sum doses over phases

Do we need to do 4D dose calculations?

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PHYSICS CONTRIBUTION

POTENTIAL DOSIMETRIC BENEFITS OF FOUR-DIMENSIONAL RADIATION TREATMENT PLANNING

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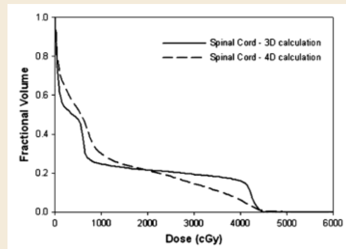
- 15 pts with Stage III NSCLC
- Compared 3D with 4D dose calculations

Do we need to do 4D dose calculations?

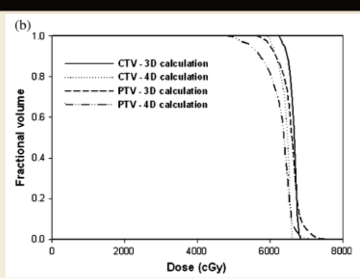
- Patients planned in 3D
  - Used MIP to generate PTV
  - Used AVG for dose calculations
- Beams and weights copied onto 4D data set
- Examined DVHs for PTV, GTV, total lung, heart, cord

Do we need to do 4D dose calculations?



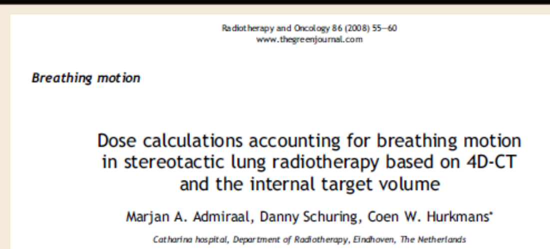
- Negligible difference in dose to normal anatomic structures

Do we need to do 4D dose calculations?



- CTV coverage – 4/15 showed differences
- PTV coverage – 8/15 showed differences

Do we need to do 4D dose calculations?


Radiotherapy and Oncology 86 (2008) 55–60
www.thegreenjournal.com

Breathing motion

Dose calculations accounting for breathing motion in stereotactic lung radiotherapy based on 4D-CT and the internal target volume

Marjan A. Admiraal, Danny Schuring, Coen W. Hurkmans*

Catharina hospital, Department of Radiotherapy, Eindhoven, The Netherlands

- 10 pts with Stage I lung tumors
- Negligible difference between 3D and 4D

Can 4D dose calculations be done on a routine basis in the clinic?

- For now, not likely
  - Time-consuming and resource-intensive
- In the future
  - Tasks can be scripted so minimal user intervention is required
  - Faster hardware and greater memory may make calculations feasible

Observation

- The time needed to calculate a dose distribution is independent of the speed of the hardware
  - Faster hardware results in more sophisticated models, which require more time to execute

What questions remain to be answered?

1. How accurate is deformable registration?
2. How accurate are 4D dose calculations?
3. Can we predict the need for 4D dose calculations?

How accurate is deformable registration?

Brock, et al, Med Phys 32, 1647 (2005)

- Used finite element model to effect deformations
- Compared locations of visible bifurcations
- Vector magnitude of deformations to be 4 mm for explicitly deformed organs and 3 mm for implicitly deformed organs

How accurate is deformable registration?

Castillo, et al, Red Journal 72, S452 (2008)

- Compared spatial accuracy of surface-based vs volume-based deformable algorithms for lung
- Average magnitude of error was 4 mm for surface-based and 2 mm for volume-based

How accurate are 4D dose calculations?

Vinogradskiy, et al, Med Phys 36, 3438 (2009)

- Used deformable phantom with programmed motion
- Compared 4D calculations with film and TL dosimetry
- Calculation and TLD in agreement within 3%
- Calculation and film met 5%/3 mm criteria in 42/48 cases – differences occurred when motion was irregular

How accurate are 4D dose calculations?

Vinogradskiy, et al, Med Phys 36, 5000 (2009)

- Compared 3D and 4D calculations with measurements
- Found 4D to be more accurate – greater percentage of points met 5%/3 mm criteria

Can we predict the need for 4D dose calculations?

- To be determined

Take-home message

- 4D dose calculations explicitly account for respiratory motion
- 4D dose calculations can be done using present technologies, although more powerful hardware can make them clinically routine
- Additional studies are needed to determine the accuracy and the circumstances for which 4D calculations are desirable

What action is not included in a 4D dose calculation?

25%	1. Accumulating the doses to the reference dose grid over all phases of the 4D data set
25%	2. Copying beams from the reference phase and calculating doses in the other phases of a 4D data set
25%	3. Deforming the 3D dose grid from the reference phase to the other phases in a 4D data set
25%	4. Optimizing beam arrangements and weights on each phase of a 4D data set

10
Countdown

What action is not included in a 4D dose calculation?

4. Optimizing beam arrangements and weights on each phase of a 4D data set

Ref: Starkschall, et al, "Potential dosimetric benefits of four-dimensional radiation treatment planning," IJROBP 73:1560-1565 (2009)

Which statement regarding the use of 4D dose calculations for lung tumors is the most correct?

25%	1. 4D dose calculations are not needed under any circumstances
25%	2. 4D dose calculations may be needed for planning treatment of early stage lung tumors
25%	3. 4D dose calculations may be needed for planning treatment of advanced lung tumors
25%	4. 4D dose calculations may be needed for planning treatment of all lung tumors

10
Countdown

Which statement regarding the use of 4D dose calculations for lung tumors is the most correct?

3. 4D dose calculations may be needed for planning treatment of advanced lung tumors

Ref: Starkschall, et al, "Potential dosimetric benefits of four-dimensional radiation treatment planning," IJROBP 73:1560-1565 (2009); Admiraal, et al, "Dose calculation accounting for breathing motion in stereotactic lung radiotherapy based on 4D-CT and the internal target volume," Radiotherapy and Oncology 86:55-60 (2008)

Which of the following statements regarding 4D dose calculations is false?

25%	1.	4D dose calculations are more accurate when respiratory motion is regular
25%	2.	4D dose calculations have been shown to agree with TL measurements to within 3%
25%	3.	Surface-based deformable image registration appears to be accurate to within 2 mm
25%	4.	We are not yet able to predict for which cases 4D dose calculations are needed

10
Countdown

Which of the following statements regarding 4D dose calculations is false?

3. Surface-based deformable image registration appears to be accurate to within 2 mm

Ref: Brock et al, "Accuracy of finite element model-based multi-organ deformable image registration" Med Phys 32:1647-1659 (2005); Vinogradskiy et al,"Verification of four-dimensional photon dose calculations", Med Phys 36:3438-3447(2009)