Beyond 4DCT: It's About Time



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Work Backwards: What Do We Need?

• Sorting artifact-free images

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What Else Do We Need?

- Quantitative understanding of tumor position during treatment
- Time-dependent
- No real-time measurement: need real-time surrogate
- Tumor position prediction
 - How do we plan?
 - Select motion mitigation strategy:
 - Need any?
 - Gating?
 - ITV?



Images: Our Source of Motion Information

- Images provide ability to segment
- Images can be used to measure tumor/organ motion





4DCT

• Commercial methods for acquiring breathing-cycle resolved images



If not 4DCT, What?

- Need to sample many breaths
- NOT multiple 4DCTs (too much dose)
- Rather, examine repeated fast helical scanning
 - Simultaneous surrogate monitoring





Ridiculous?

- Free-breathing CT (FHFBCT)
- Each slice has different breathing state
- Seems ridiculous that it would work
- Image is record of instantaneous tissue positions
- Requirement
 - Couch speed >> lung tissue speed
 - Translate to pitch, rotation time, and CT detector coverage
 - Image time (rotation time/pitch) dictates motion-induced image *blurring*
- Surrogate is record of simultaneous surrogate value





Tie Together Positions and Surrogates

- Need some sort of model that connects positions and surrogate measurements
- Surrogate measures breathing Amplitude
 - Proportional to tidal volume
- Amplitude insufficient to describe breathing motion (hysteresis)
- Hypotheses (quiet respiration):
 - Hysteresis due to internal pressure imbalances
 - Pressure imbalance distribution maintains proportionality
 - Pressure imbalance proportional to airflow at mouth
- Tidal volume and airflow are "phase space" variables
 - Proportional to Surrogate Amplitude and Rate







Equation?

• KISS



Model-based CT: General framework



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5DCT Process Error Estimate



Dou TH, Thomas DH, O'Connell D, Lamb JM, Lee P, Low DA. A method for assessing ground-truth accuracy of the 5DCT technique. International Journal of Radiation Oncology* Biology* Physics. 2015 Nov 15;93(4):925-33.

Example patient-specific report

Scan 02



Scan 03



Abdominal 5DCT



4DCT: Garbage in Garbage Out



Academic Need to Fix This

- 4DCT artifacts and lack of quantitation limit other research and clinical applications
- AAPM abstracts that have or use "4DCT"

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MO-E115-GePD-F5-03 MO-E115-GePD-F9-06 MO-I345-GePD-F4-03 TU-AB-KDBRC-03 TU-AB-205-03 TU-C1030-GePD-F9-03 TU-D-KDBRA1-01 TU-E115-GePD-F5-04 TU-GH-KDBRA1-06 TU-I345-GePD-F7-06 TU-I345-GePD-F8-05 WE-AB-KDBRC-02 WE-AB-KDBRC-05 **TU-AB-205-05** WE-C1000-GePD-F5-06 TU-C1000-GePD-F9-02 TU-C1030-GePD-F9-01 TU-E115-GePD-F5-01 TU-E115-GePD-F5-02 TU-E115-GePD-F9-01 TU-I345-GePD-F3-03 TU-I345-GePD-F8-01 WE-AB-KDBRB1-04 WE-AB-KDBRC-04 WE-AB-KDBRC-07 WE-AB-KDBRC-08 WE-C1000-GePD-F6-03 WE-C1030-GePD-F2-01 WE-C1030-GePD-F2-02 WE-C1030-GePD-F2-04 WE-HI-KDBRB1-09 WE-HI-KDBRB1-10 WE-J-KDBRC-01 **TH-AB-KDBRC-06** TH-D-KDBRA2-00 TH-EF-KDBRA1-07

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- 2019 AAPM abstracts that have or use "4DCT", "4D-CT", "4DCBCT"

SU-E-SAN2-04 SU-F-221AB-01 SU-F-304-05 SU-I330-GePD-F5-06 TH-A-SAN2-04 TH-A-225BCD-03 TH-A-221AB-08 TH-D-304-02 MO-E115-GePD-F5-03 MO-E115-GePD-F5-05 PO-GePV-T-350 PO-GePV-T-351 PO-GePV-T-374 PO-GePV-T-381 SU-I330-GePD-F7-01 SU-I430-GePD-F5-02 SU-L-SAN2-03 SU-L-221CD-08 MO-I345-GePD-F4-01 TU-C1030-GePD-F9-03 TU-J345-GePD-F2-01 MO-E115-GePD-F5-01 MO-E115-GePD-F5-06 MO-E115-GePD-F7-01 MO-K-221AB-02 TU-AB-221AB-02 TU-C1030-GePD-F3-02 TU-C1030-GePD-F3-03 TU-C1030-GePD-F5-03 TU-C1030-GePD-F5-04 TU-C1030-GePD-F5-04 TU-C1030-GePD-F5-02

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