Introduction

- Respiration can induce thoracic and abdominal motion.
- Both organs and tumors move with respiration.
- In radiation oncology, to provide sufficient dose to the tumor while reduce radiation to organs-at-risk, knowledge of organ and tumor motion is essential.

Introduction

- 4D imaging can be used to track motion.
- 4DCT has been used in radiotherapy motion management.

Introduction

- Challenges in 4DCT – lack of tissue and tumor contrast.
- May not be a huge issue for lung cancer.
- It is a real problem for abdominal cancer.

Introduction

- Improving tissue and tumor contrast with MRI.
Introduction

• Improving tissue and tumor contrast with MRI.

CT

4DMRI

• Typical 4DMRI image acquisition scheme
  – 2D+t+1D = 4D
  – 3D+t = 4D

Compatible MRI sequences

• Images at different respiratory phases have to be acquired within one respiratory cycle.
• Fast imaging techniques are needed.
• Typical pulse sequences used in 4DMRI
  – Spoiled gradient echo (FLASH, SPGR or T1-FFE)
  – Balanced SSFP (TrueFISP, FIESTA or bFFE)

4DMRI

• 2D+t+1D
  – Temporal resolution: ~4 frames/second
  – Spatial resolution: ~2×2×8mm

• 3D+t
  – Temporal resolution: ~1 frame/second
  – Spatial resolution: ~3×3×4mm
Spoiled gradient echo
• Sequence diagram

Balanced SSFP
• Sequence diagram

Guided 4DMRI acquisition
• Guidance
  – No guidance
  – Prospective
  – Retrospective

4DMRI – no guidance
• 2D Balanced SSFP
4DMRI – no guidance

- 3D Spoiled gradient echo

Prospectively guided 4DMRI

- Need surrogate: internal or external.
- Typical internal surrogate is liver-lung boundary

Prospectively guided 4DMRI

- Acquisition scheme

Prospectively guided 4DMRI

- Results

Prospectively guided 4DMRI

- Respiratory amplitude guided 4DMRI

Prospectively guided 4DMRI

- Images at different respiratory states
Prospectively guided 4DMRI
- Images in reconstructed view

Prospectively guided 4DMRI
- Robust to breathing irregularities

Retrospective guided 4DMRI
- Retrospective sorting using external surrogate

Retrospective guided 4DMRI
- Retrospective sorting using external surrogate

Retrospective guided 4DMRI
- Retrospective sorting using external surrogate

Retrospective guided 4DMRI
- Retrospective sorting using internal surrogate
Conclusion

- A variety of techniques have been developed to acquire 4DMRI.
- 4DMRI is still limited by spatial resolution and temporal resolution compared to 4DCT.
- Future studies should be focused on improving respiratory sorting robustness and accuracy, tumor-tissue contrast, image quality, spatial resolution and temporal resolution.

Acknowledgements

- Washington University in St. Louis
  - Shelton Caruthers, Ph.D.
  - Parag Parikh, M.D.
  - Sasa Mutic, Ph.D.
  - Dennis Hallahan, M.D.
  - Joseph Ackerman, Ph.D.
  - Joel Garbow, Ph.D.
- University of California, Los Angeles
  - Daniel Low, Ph.D.