Managing Motion for MRI

UCLA Radiology 2018 Fellows' Lectures

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Holden H. Wu, Ph.D.

Magnetic Resonance Research Labs

Department of Radiological Sciences,

University of California, Los Angeles, CA, USA

Outline

- MRI and Motion
- Techniques to Manage Motion
- Managing Cardiac Motion
- Managing Respiratory Motion

MRI and Motion

- MRI is slow (vs. US, CT)
- MRI time scales
  - TR: 1 - 1000 ms
  - image: 100 ms - 10 min

MRI and Motion

- Motion Characteristics
  - voluntary vs. non-voluntary
  - periodic vs. aperiodic
  - rigid vs. non-rigid
    e.g., *translation, rotation, shearing …*
  - inter-voxel vs. intra-voxel
  - inter-view vs. intra-view

MRI and Motion

- Motion Sources, Time Scales, Magnitudes
  - cardiac: ~60 bpm (1 Hz), mm
  - respiratory: ~5 sec/breath (0.2 Hz), mm - cm
  - bulk motion: mm - cm
  - vascular pulsation, CSF pulsation: mm
  - peristalsis: mm
  - swallowing, coughing, twitching: mm - cm

  - blood flow

MRI and Motion

- Effects of Motion on MRI Quality
  - image blurring
  - aliasing artifacts
  - signal dropout
  - other artifacts

Techniques to Manage Motion

- Subject Setup and Communication
- Acquisition Methods
- Reconstruction Methods

Subject Setup and Communication

- Explain Scan Procedures
- Medication (if required)
  - reduce claustrophobia
  - reduce peristalsis
- Coaching (e.g., stay still, breath hold)
- Coil and placement
- ECG and bellows placement
- Reassurance and breaks

Acquisition Methods

- Suppress Signal from Moving Tissues
  - e.g., flow suppression, spatial saturation
- Swap Frequency and Phase Encoding Directions
  - e.g., A/P vs R/L in axial acquisitions
- Multiple Averages
- *Disadvantages?*

Acquisition Methods

- Accelerate the Acquisition
  - partial Fourier
  - parallel imaging
  - multi-slice imaging
  - single-shot EPI
  - single-shot HASTE
- Use Motion-Robust Acquisition
  - gradient moment nulling
  - PROPELLER / BLADE, radial, spiral, etc.
- *Disadvantages?*

Reconstruction Methods

- Reconstruct Undersampled Data
  - partial Fourier
  - parallel imaging
- Motion Compensation
  - may need some motion information
  - reject inconsistent data
  - correct motion-affected data
- *Disadvantages?*

Managing Cardiac Motion

- Cardiac Motion
  - non-voluntary
  - non-rigid
  - quasi-periodic
  - ~60 bpm (1 Hz)
  - mm scale

Managing Cardiac Motion

Cardiac Phases

Phase 1	Phase 2	Phase 3	…	Phase N

Temporal duration of the cardiac phases?
- <50 ms to resolve cardiac motion (i.e., >20 frames/sec)
- depends on sampling parameters (and trade-offs)

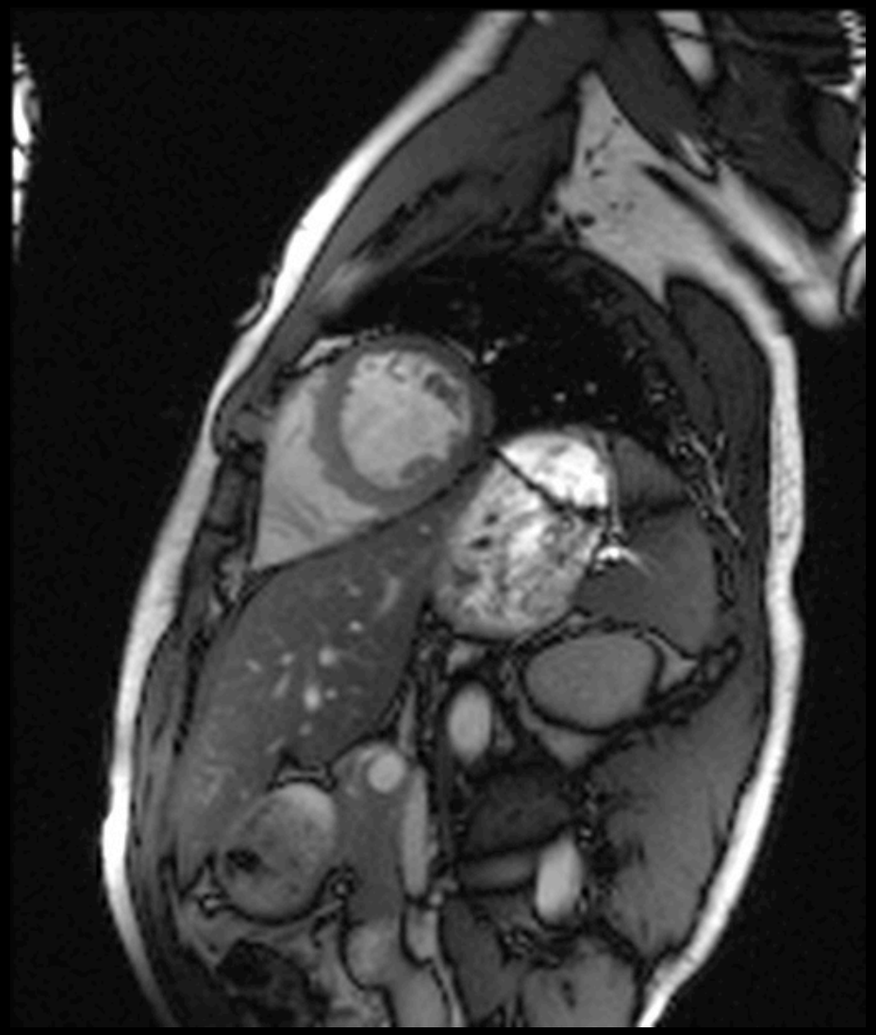
Managing Cardiac Motion

- Real-Time MRI

Phase 1	Phase 2	Phase 3	…	Phase N
MR image 1	MR image 2	MR image 3	…	MR image N

Managing Cardiac Motion

- Real-Time MRI



courtesy of Dr. Daniel Ennis

Managing Cardiac Motion

- Real-Time MRI: Challenges
  - compromises in spatial resolution and/or temporal resolution (i.e., frame rate)
  - typical parameters
    2-3 mm in-plane resolution
    50-200 ms/frame (5-20 frame/sec)
  - may not have high enough spatial resolution and/or frame rate to resolve cardiac motion

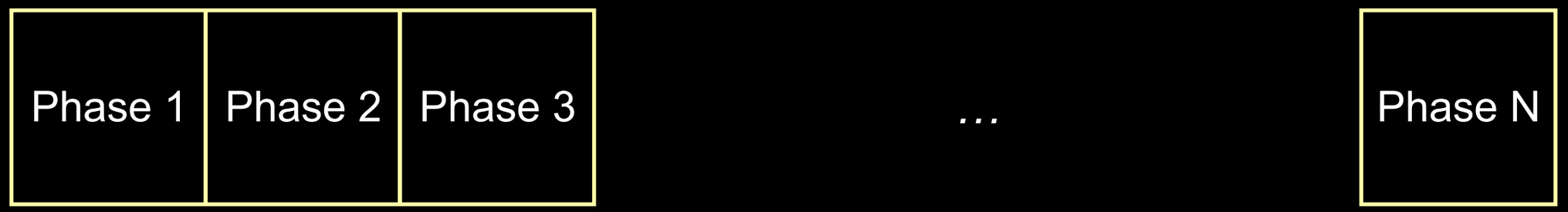
Managing Cardiac Motion

- Cardiac Triggering
  - ECG or pulse ox signal
  - sync scan to cardiac cycle
  - assume steady HR
  - segmented acquisition
    acquire subset of data each HB
    fully acquire data over multiple HBs

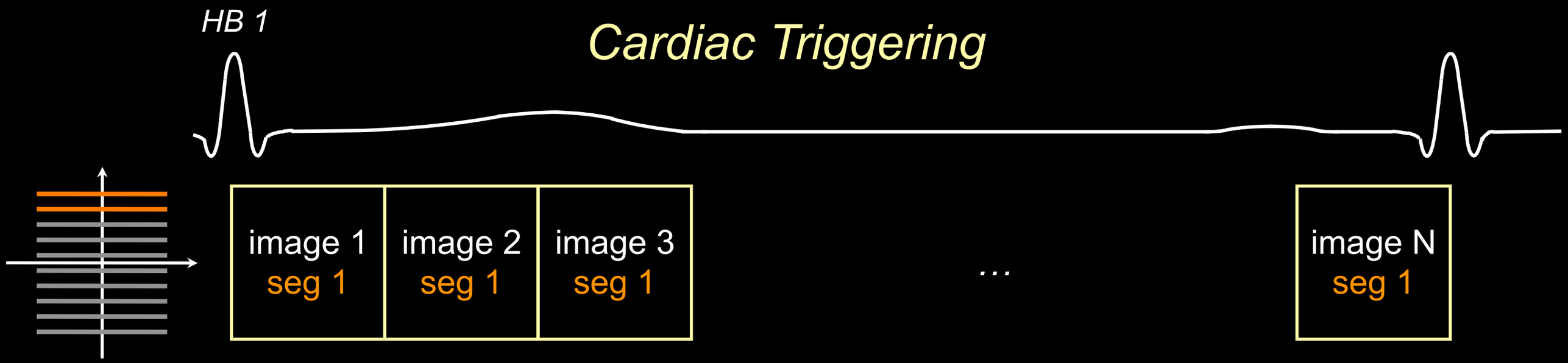
  - Need to manage respiratory motion as well
    e.g., breath holding (BH)

Managing Cardiac Motion

Cardiac Triggering



Managing Cardiac Motion



How many lines per segment?
- LinesPerSeg * TR = temporal duration of “cardiac phase”

Managing Cardiac Motion

HB 1

Cardiac Triggering

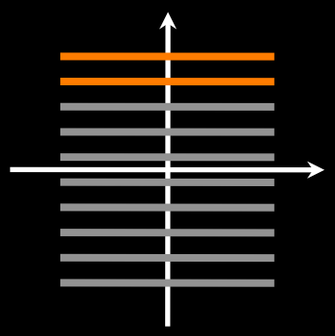


image 1 seg 1	image 2 seg 1	image 3 seg 1	…	image N seg 1

HB 2

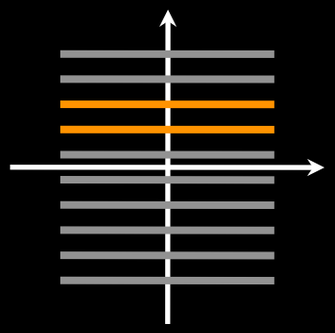


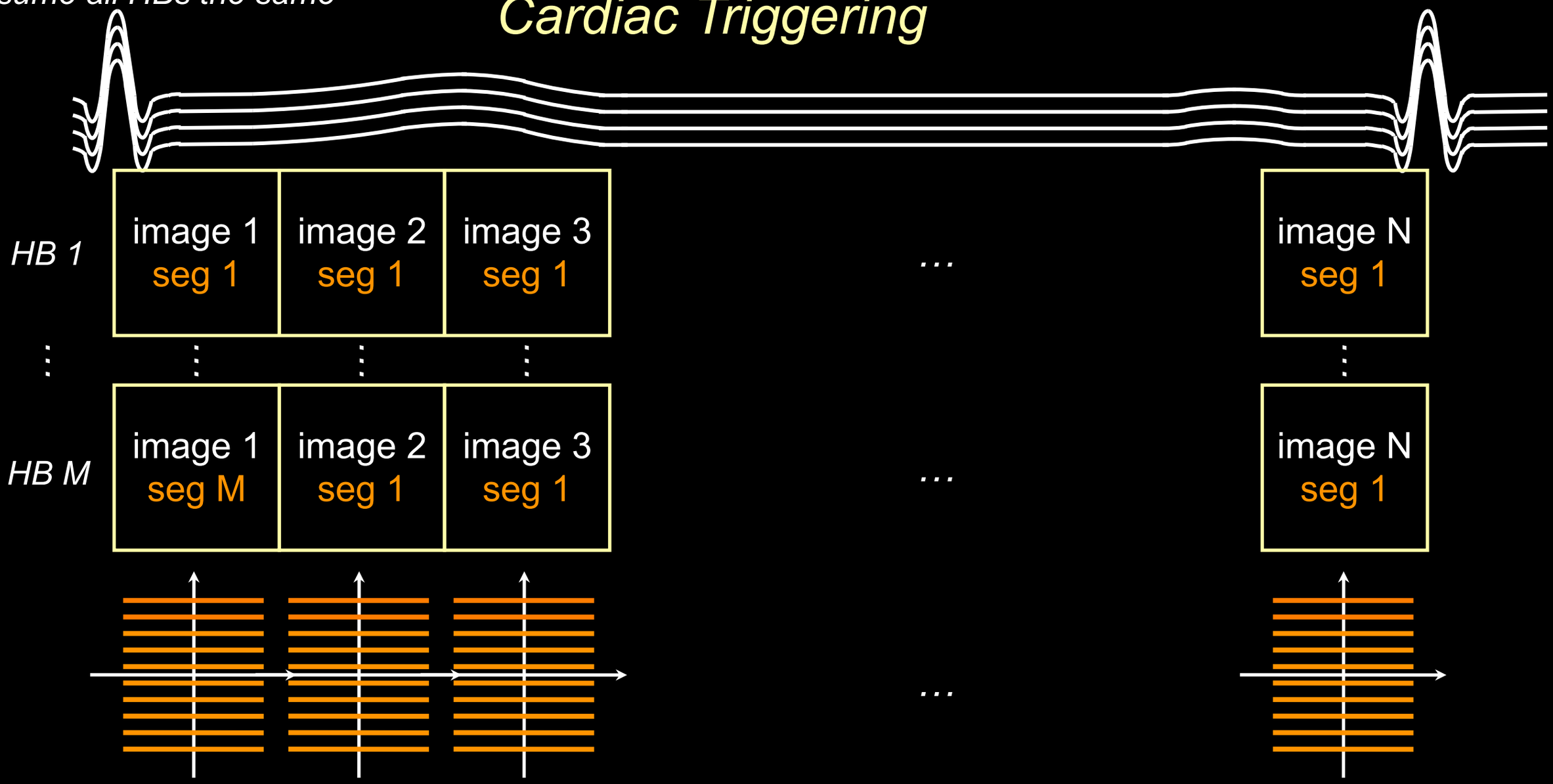
image 1 seg 2	image 2 seg 2	image 3 seg 2	…	image N seg 2

How many heartbeats (HB) needed?
- need M = NumKspLines / LinesPerSeg segments to cover k-space
- If we need M segments to cover k-space, need M heartbeats

Managing Cardiac Motion

Assume all HBs the same

Cardiac Triggering



Managing Cardiac Motion

Cardiac Triggering

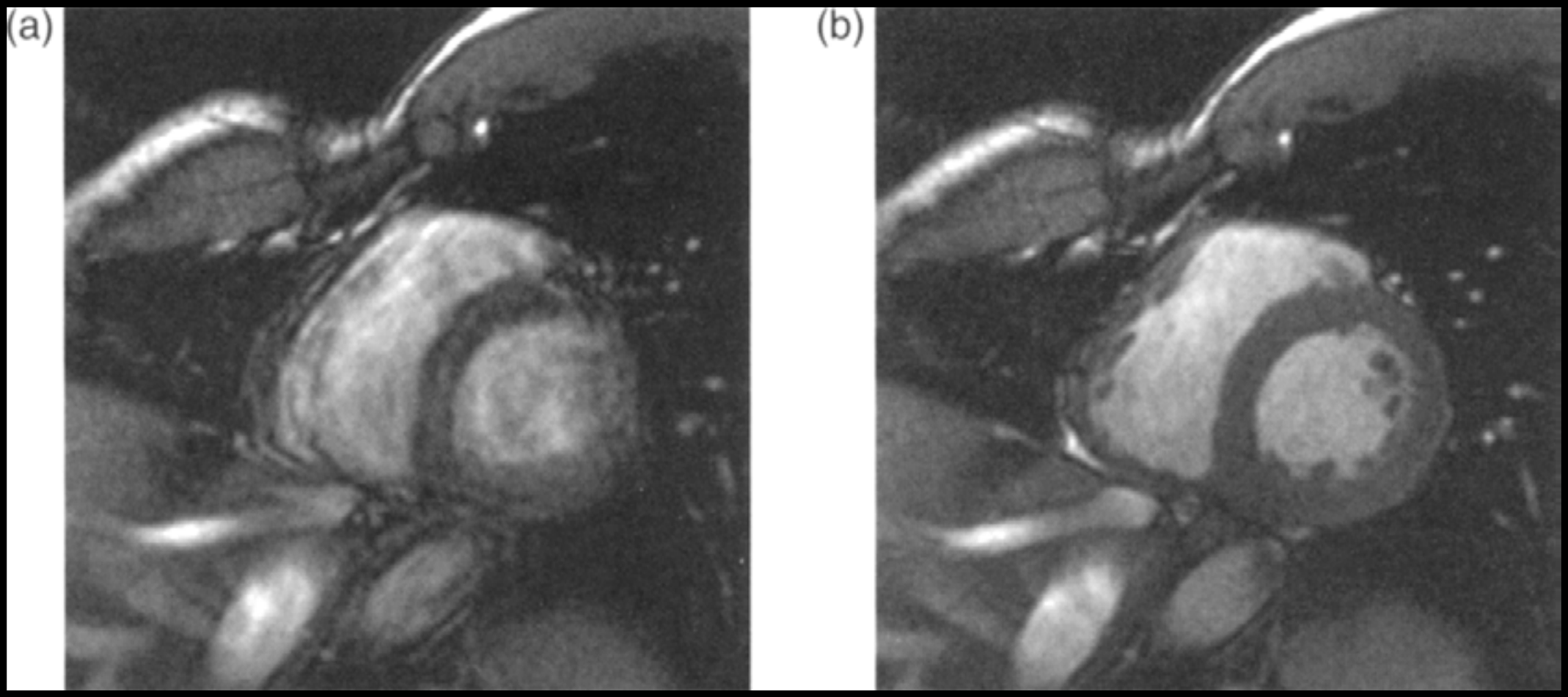
image 1	image 2	image 3	…	image N

Phase 1	Phase 2	Phase 3	…	Phase N

Example
- NumKspLines = 128
- LinesPerSeg = 8; TR = 5 ms
- temporal duration of “cardiac phase” = 40 ms (i.e., 25 phases per sec)
- need M = 128/8 = 16 segments
- need a 16-HB breath hold scan

Managing Cardiac Motion

Cardiac Triggering



No triggering *ECG triggering*

Managing Cardiac Motion

Cardiac Triggering

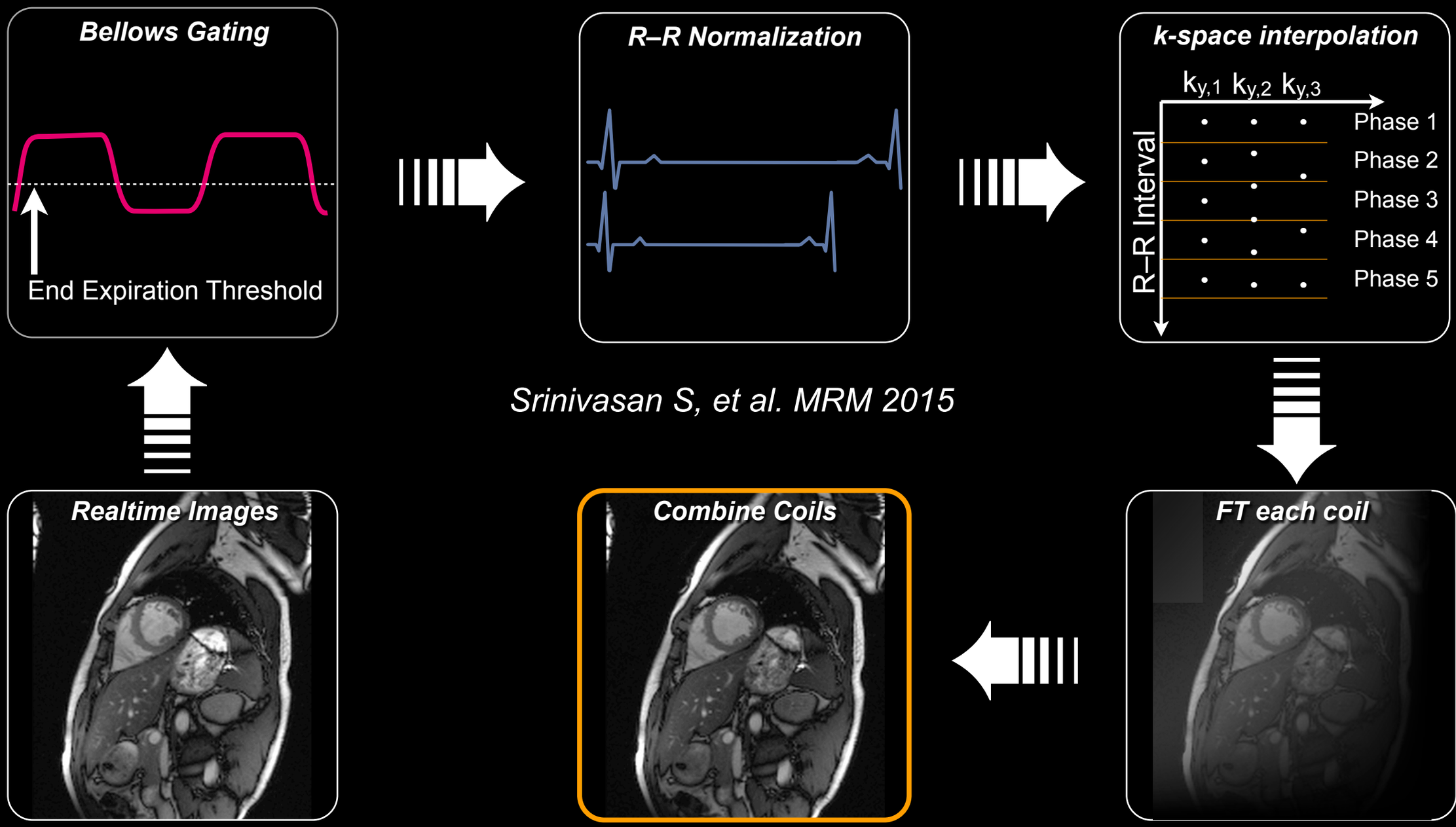
courtesy of Dr. Daniel Ennis

Managing Cardiac Motion

- Cardiac Triggering: Challenges
  - unreliable ECG signal
    especially at higher field ($B_0 \geq 3T$)
  - variations in each HB
  - fast HR; irregular HR
  - BH limits scan duration
    limits # HBs
    limits segmentation and # cardiac phases

Managing Cardiac Motion

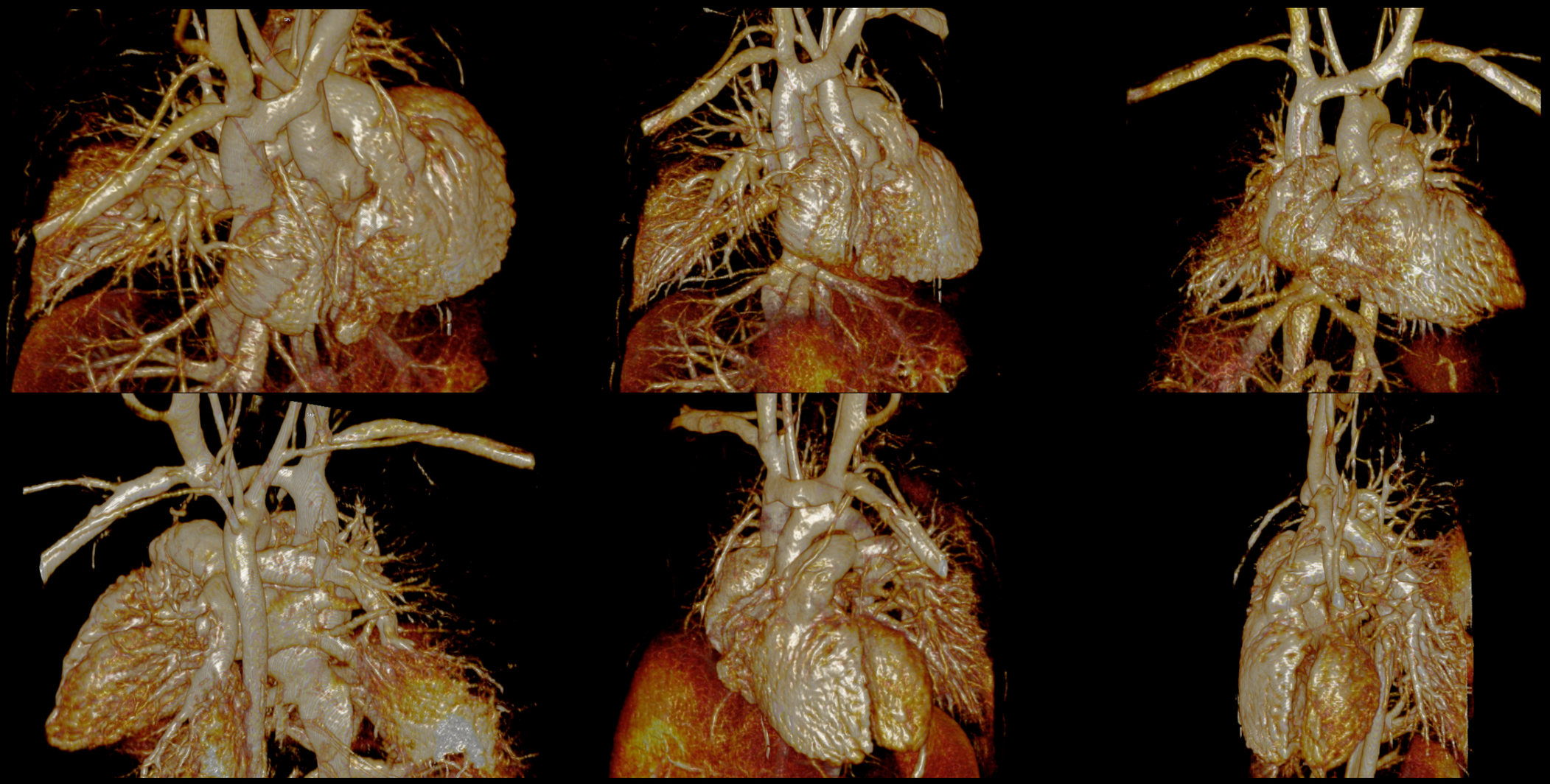
New Techniques: Free-Breathing Cardiac Cine MRI



Srinivasan S, et al. MRM 2015

Managing Cardiac Motion

New Techniques: Free-Breathing 4D Cardiovascular MRI



Han et al. MRM 2017; Zhou et al. NMR Biomed 2017; Han et al. MRM 2015; Nguyen et al JMRI 2017; Nguyen et al JCMR 2017; Finn et al. JMRI 2017

Managing Respiratory Motion

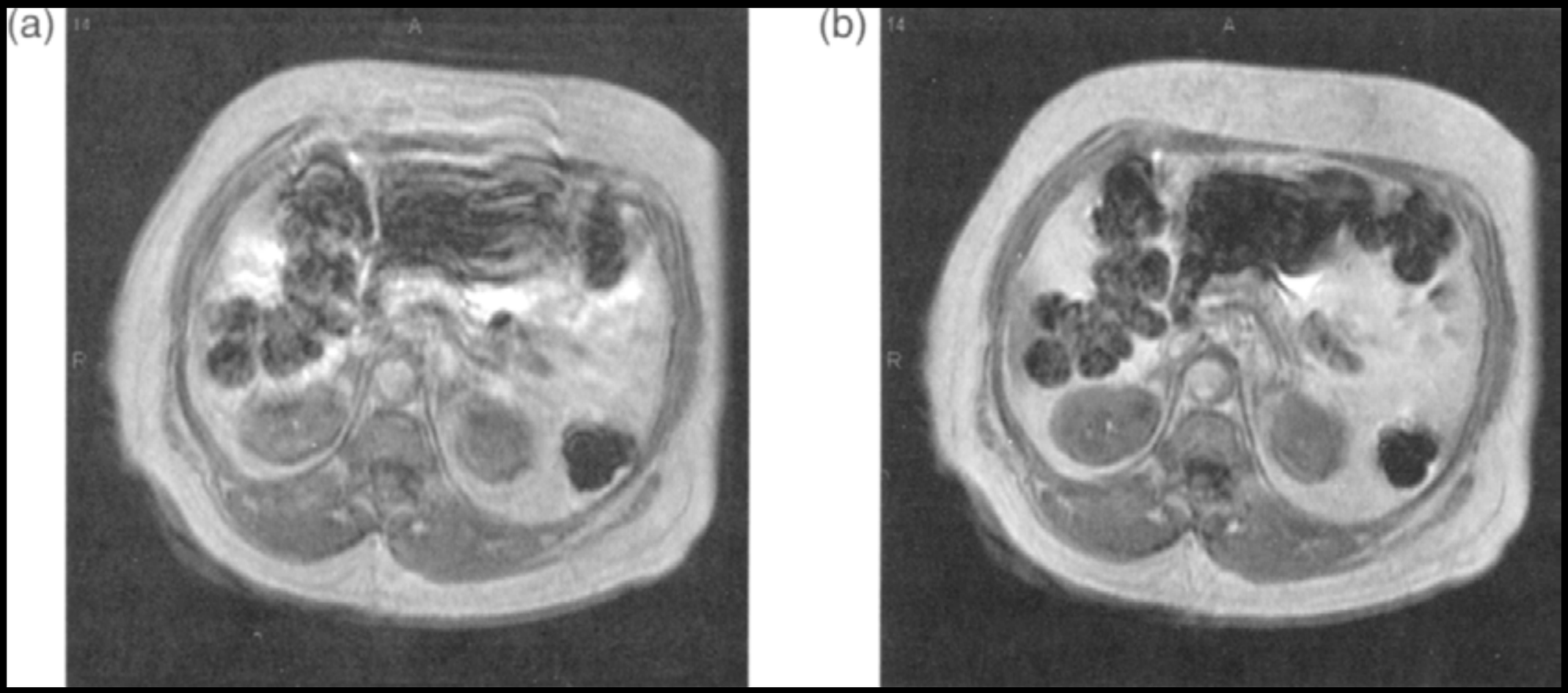
- Respiratory Motion
  - voluntary
  - non-rigid
    mostly S/I
  - quasi-periodic

  - ~5 sec/breath (0.2 Hz)
  - mm - cm scale

Managing Respiratory Motion

- Breath Holding (BH)
  - temporarily suspend respiratory motion
  - usually end expiration or end inspiration
  - 10-20 sec in patients
  - may need multiple BH (sets of slices/slabs)

Managing Respiratory Motion



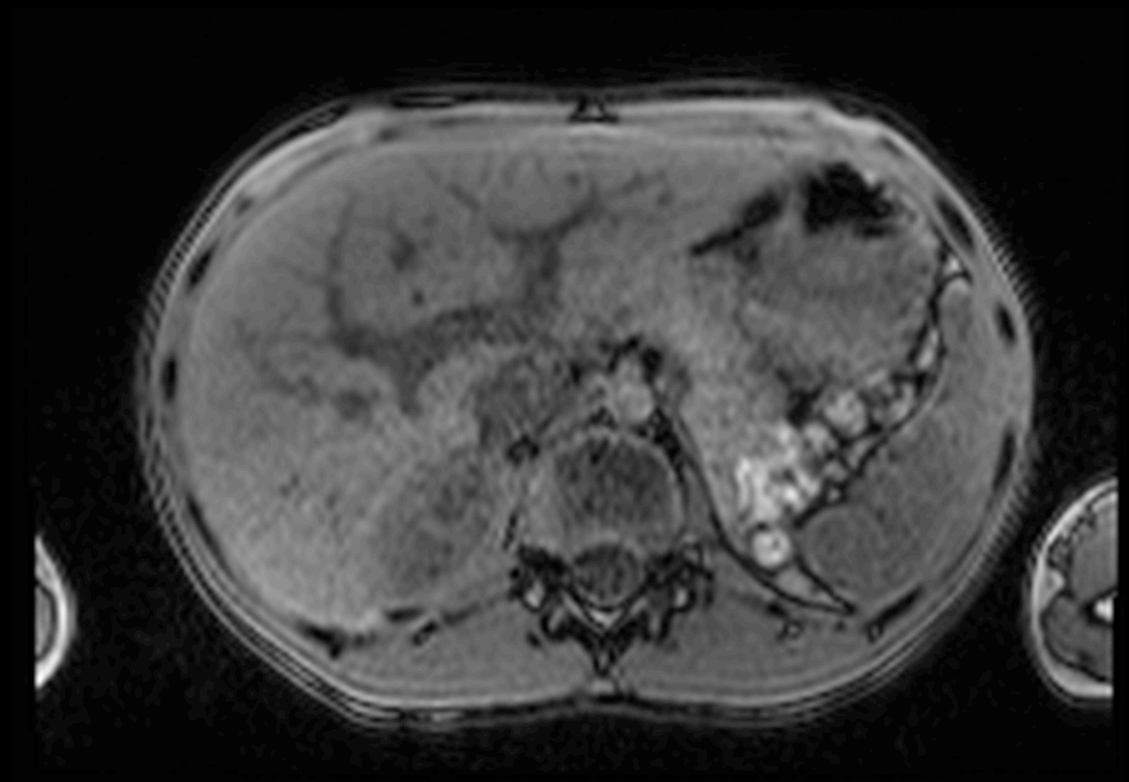
No breath-holding *With breath-holding*

Managing Respiratory Motion

BH T2w HASTE AXL (2D)

BH T2w HASTE COR (2D)

Managing Respiratory Motion



BH T1w VIBE AXL (3D)

BH T1w VIBE COR (3D)

Managing Respiratory Motion

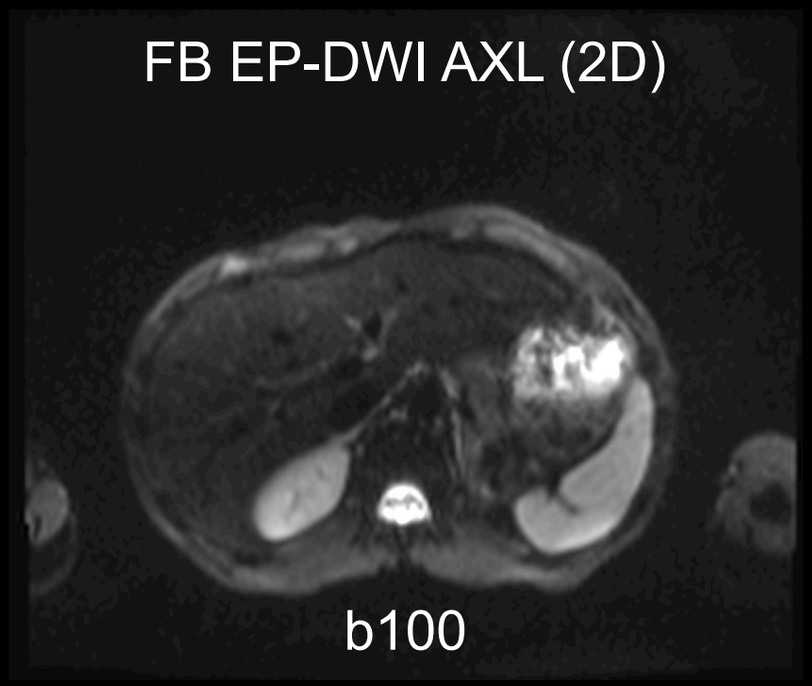
- BH MRI: Challenges
  - short BH duration
    compromises in scan parameters
  - imperfect BH
    residual motion artifacts (e.g., aliasing)
  - multiple BH scans
    wears subject down
    inconsistent BH position
  - patient may be unable to BH

Managing Respiratory Motion

- Free Breathing (FB) + Multiple Averages
  - average out the motion
  - e.g., 3-8 averages
  - can be used for different types of motion

Managing Respiratory Motion

FB EP-DWI AXL (2D)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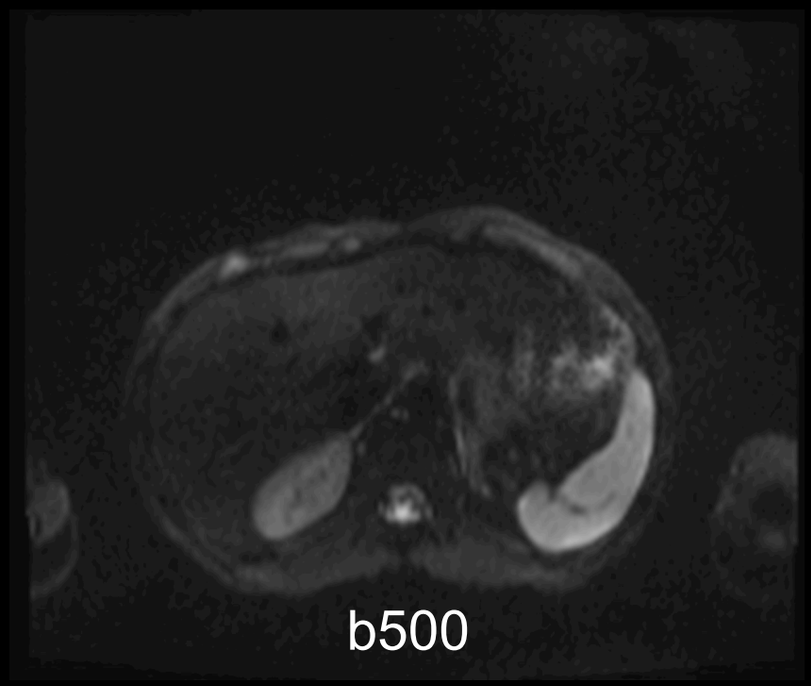
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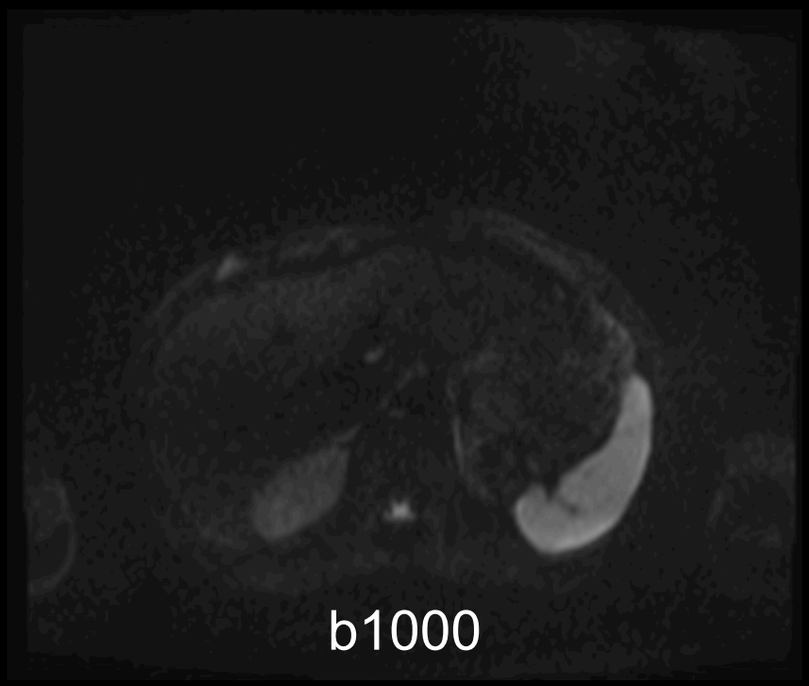
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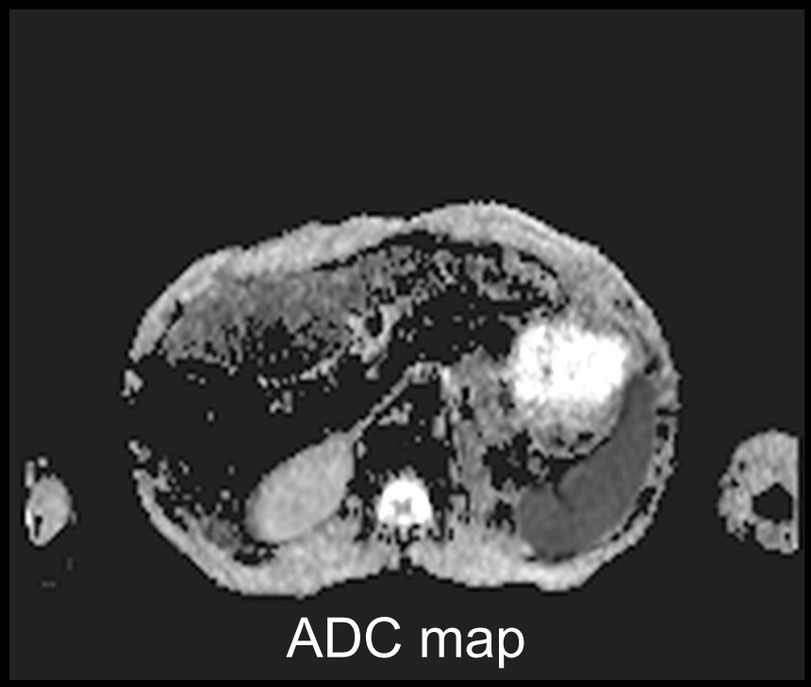

ADC map

Managing Respiratory Motion

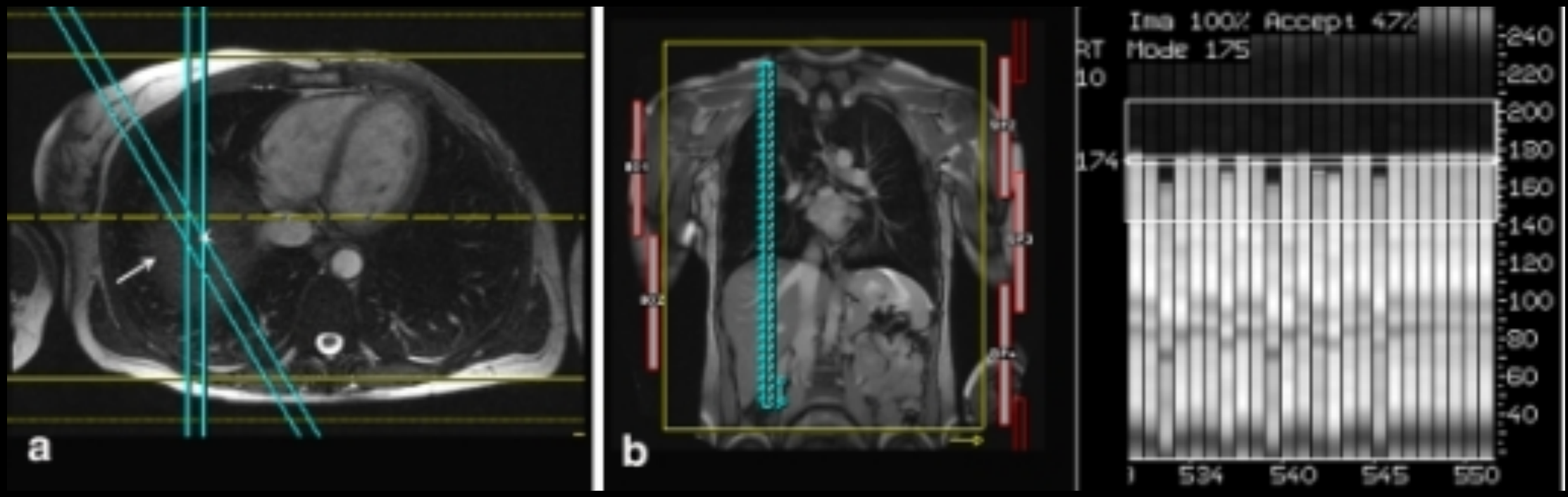
- FB + Multiple Averages: Challenges
  - variations in respiratory pattern
  - image blurring
  - residual artifacts (e.g., aliasing)
  - long scan

Managing Respiratory Motion

- FB + Respiratory Gating
  - measure respiratory status / position
    e.g., bellows, MR navigator signal
  - acquire data when in consistent resp. state
  - fully acquire data over multiple resp. cycles

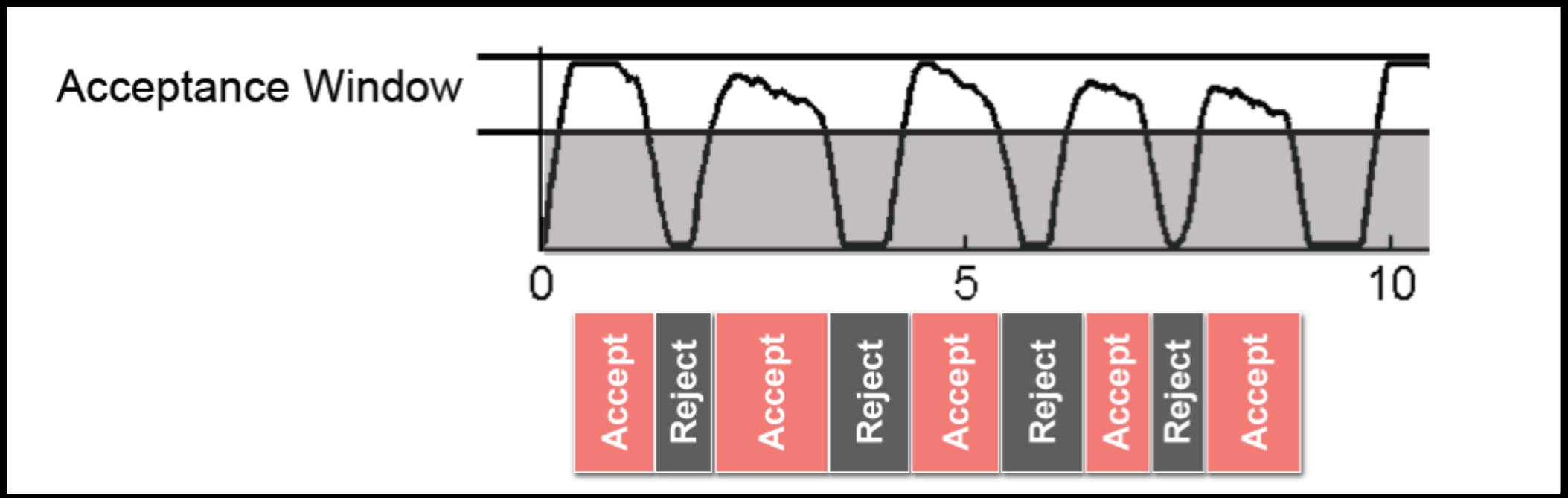
Managing Respiratory Motion

MR Navigator



Managing Respiratory Motion

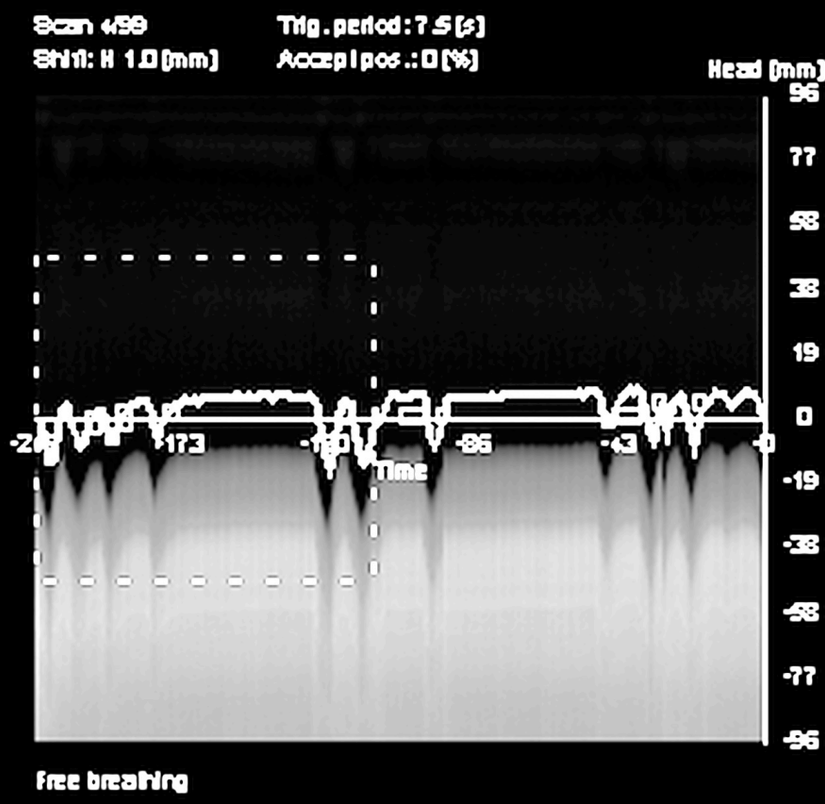
Respiratory Gating

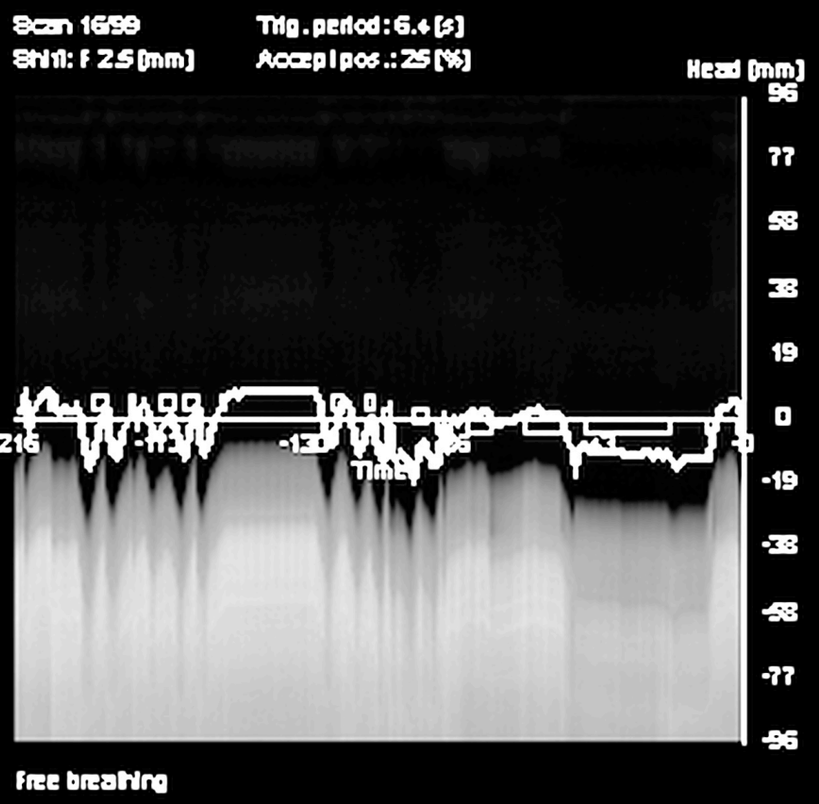


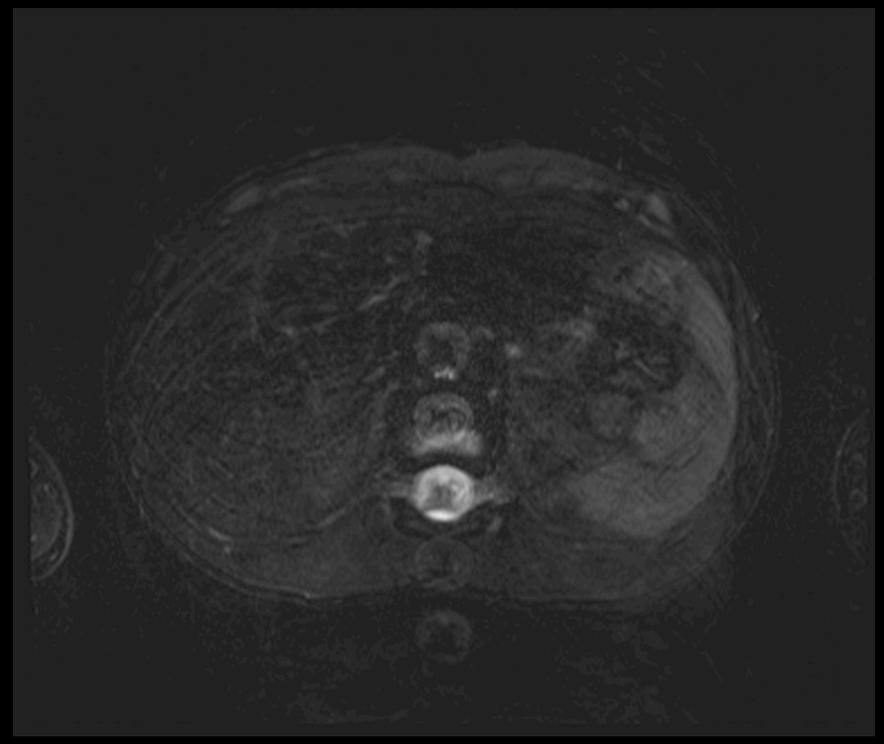
Prospective vs. Retrospective

Managing Respiratory Motion

FB T2w TSE AXL (2D)





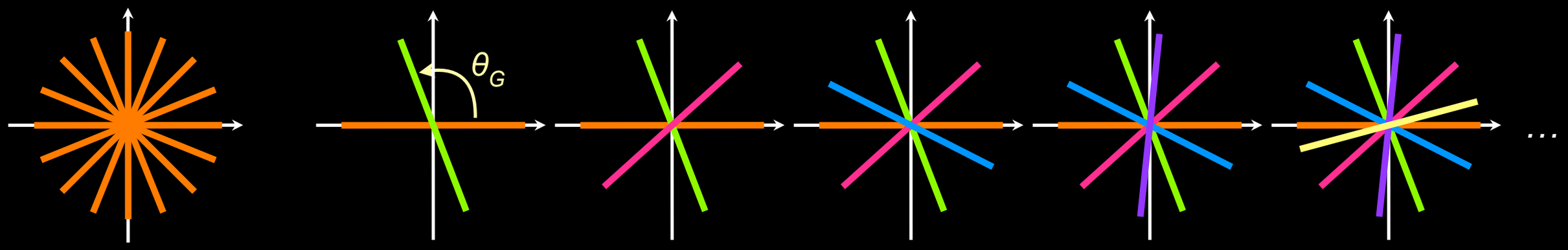


Managing Respiratory Motion

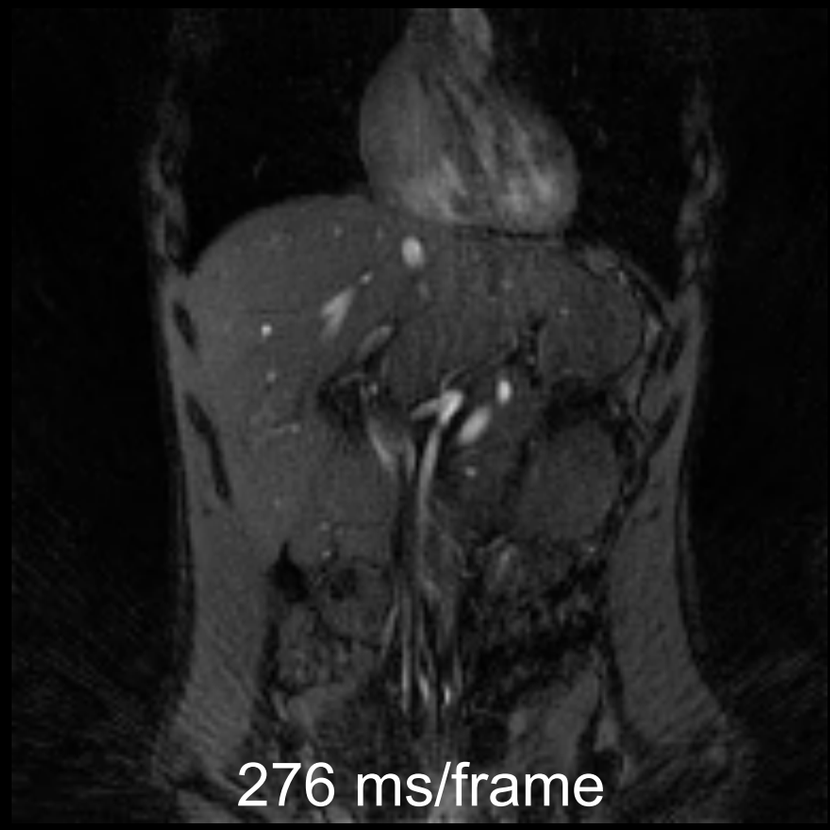
- FB + Respiratory Gating: Challenges
  - inconsistent respiratory pattern
  - residual motion artifacts (e.g., aliasing)
  - can be long scans with unknown duration

Managing Respiratory Motion

New Techniques: Real-Time Non-Cartesian 2D MRI



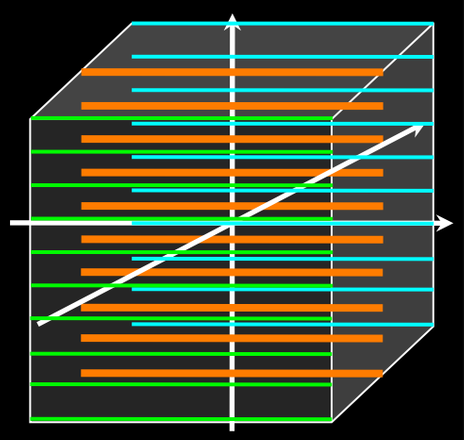
2D Radial Golden angle ordering



Managing Respiratory Motion

New Techniques: FB Non-Cartesian 3D MRI

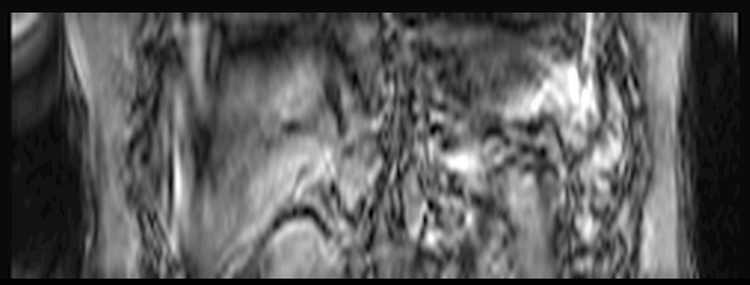
BH 3D Cartesian MRI



3D Cartesian

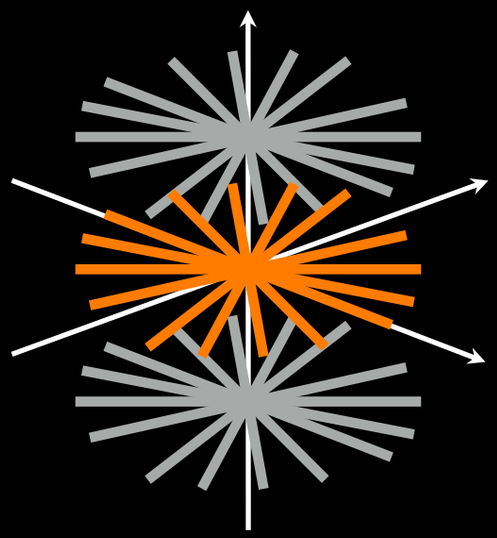
imperfect BH

AXL



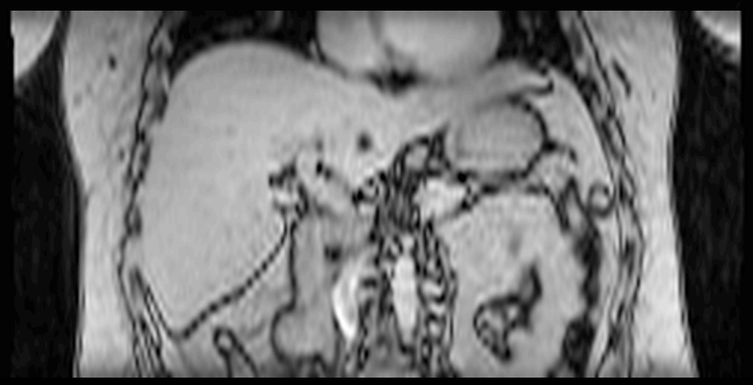
COR reformat

FB 3D Stack-of-Radial MRI



3D Stack of Radial

AXL



COR reformat

Summary

- MRI and Motion
- Techniques to Manage Motion
- Managing Cardiac Motion
- Managing Respiratory Motion

Q&A Time

Acknowledgments

HoldenWu @ mednet.ucla.edu http://mrrl.ucla.edu

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