Clinical Implementation of MR-based motion management

57th AAPM Annual Meeting
Session Program: Therapy Education

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Disclosures

- Henry Ford Health Systems hold a research agreement with Philips Healthcare
- Equipment evaluation agreement with Medspira
- If you see Mickey Mouse, pay attention

TG-76: Patient-specific, large variability

Table 3. Abdominal motion data. The mean range of motion and the (minimum–maximum) ranges in millimeters for each site and each cohort of subjects. The motion is in the superior–inferior (SI) direction.

Site	Observer	Breathing mode	
		Shallow	Deep
Pancreas	Suramo et al.[74]	20 (10–30)	43 (20–80)
Live			
			–80)
			–57)
Kidne			–70)
	Davies et al.[68]	11 (5–16)	--

<u>AAPM TG-76 Recommendation:</u>

Manage patient-specific motion for tumor excursion > 5 mm in any direction

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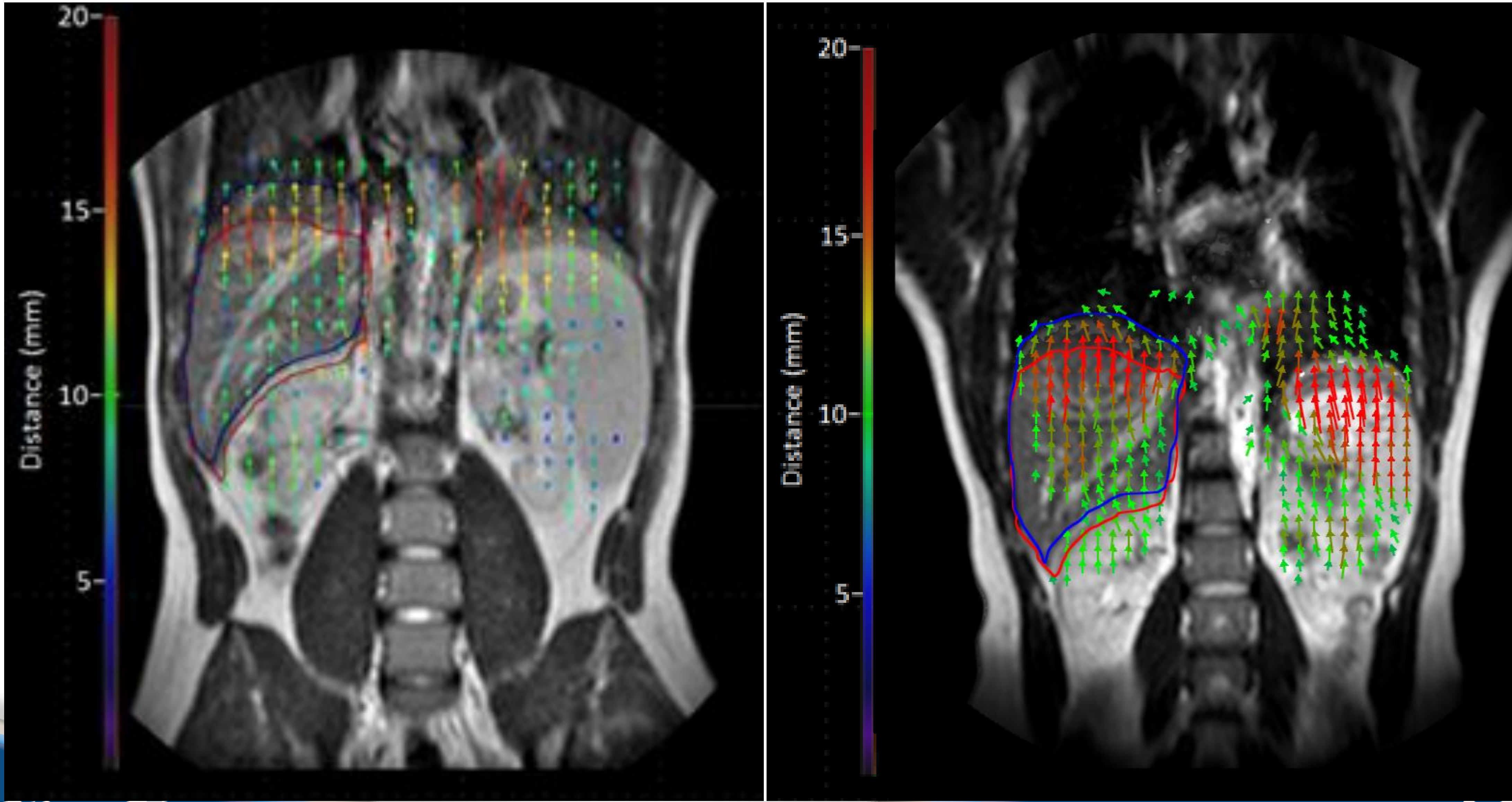
Patient-specific, multi-dimensional



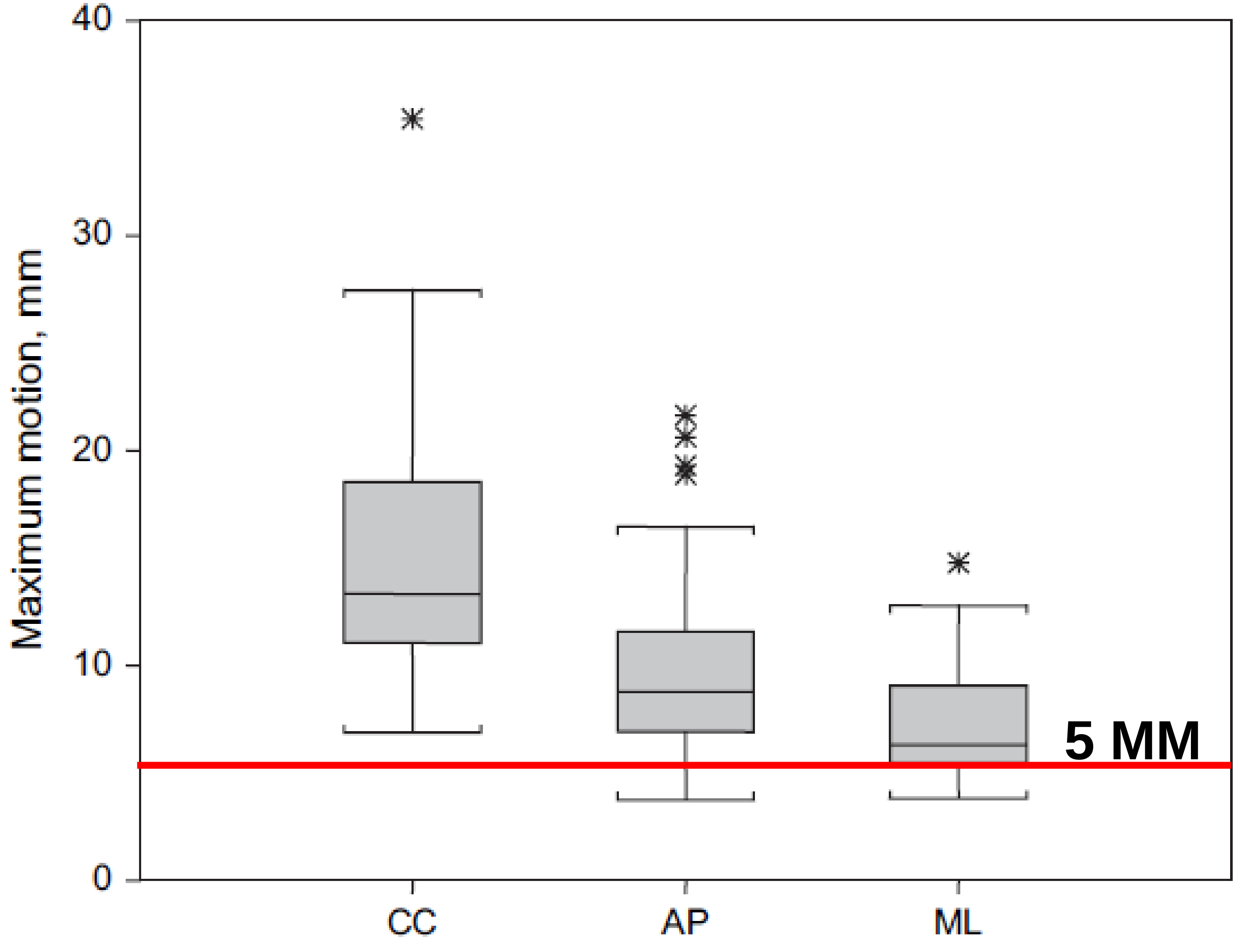
Clinically available MRI options

- Triggering: EE from external surrogate
- Internal navigator: EE from internal surrogate (typically liver/lung interface)
- Breath-hold (BH): can get you EE/EI, BUT…
  - Often deep inspiration/exhalation (not natural)
  - MRI scan times >>>CT scan times →many BHs for patients
- We need a clinically useable solution to properly determine the 3D target volume

MRI Cine Imaging

- Single slice acquisition
  - Axial, sagittal, coronal
- Can interleave but they are still not acquired at the exact same time
- High temporal resolution (~1-10 fps)
- Can image over many breathing cycles
- Typically not susceptible to motion artifacts
- Yield overall excursion, but not out of plane motion

Cine-MRI liver motion



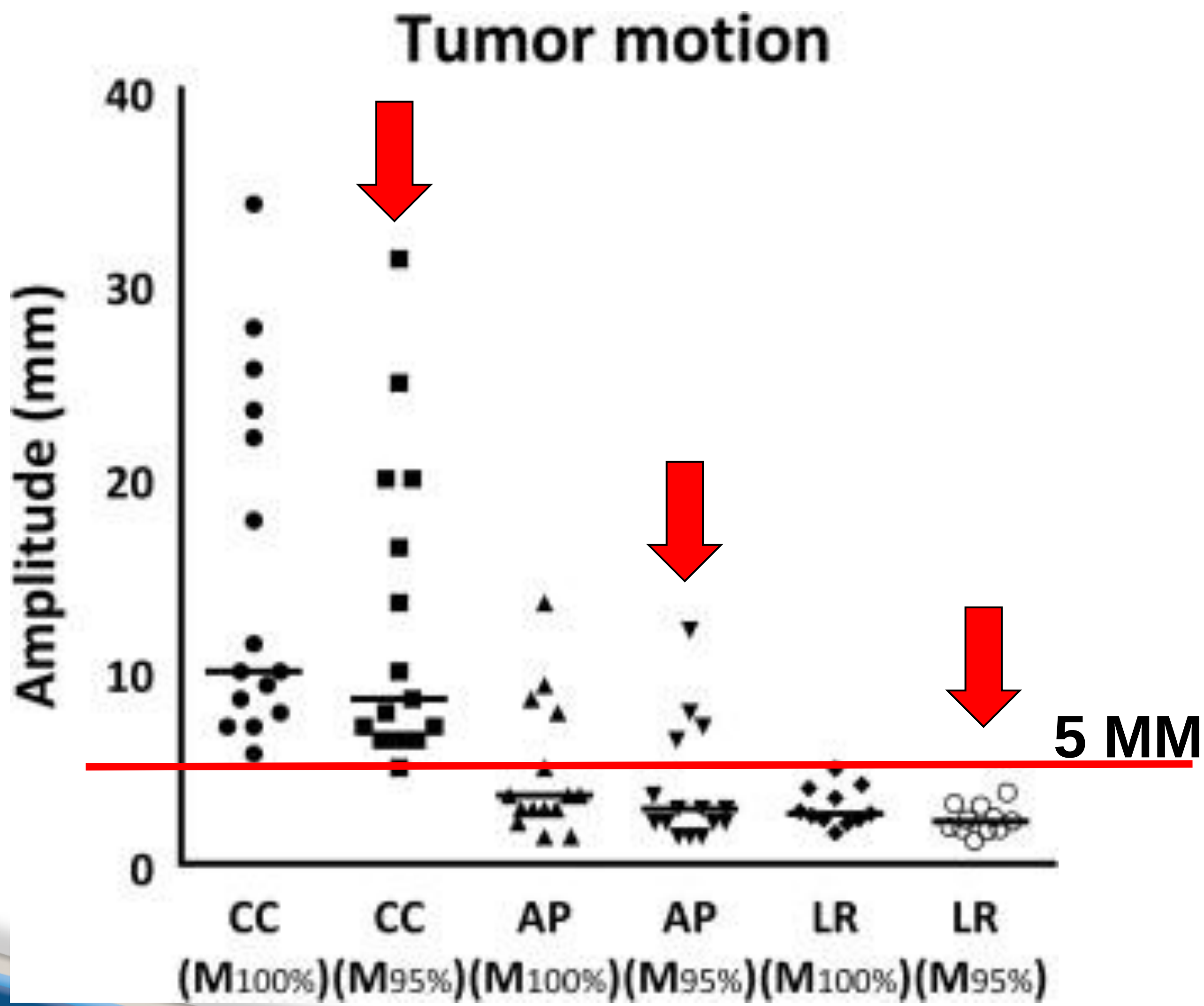
- Axial/sagittal/coronal
- 5 mm thick T2-W
- 1 fps over 60 s
- Resolution: 1.6-2.5 mm

<u>Median motion</u>

✓CC: 13.3 mm
✓AP: 9.2 mm
✓ML: 6.9 mm

Kirilova, A., Lockwood, G., Choi, P., Bana, N., Haider, M. A., Brock, K. K., ... & Dawson, L. A. (2008). Three-dimensional motion of liver tumors using cine-magnetic resonance imaging. *International Journal of Radiation Oncology* Biology* Physics*, *71*(4), 1189-1195.

Cine-MRI pancreas motion



- **Sagittal & coronal**
- **7 mm thick T2-W, 2 fps over 60 s**
- **In-plane resolution: 1.5-2.0 mm**

✓ Coronal plane angulated so primary motion positioned in scan plane

✓ Removed outliers w/95%

Heerkens, Hanne D., et al. "MRI-based tumor motion characterization and gating schemes for radiation therapy of pancreatic cancer." *Radiotherapy and Oncology* 111.2 (2014): 252-257.

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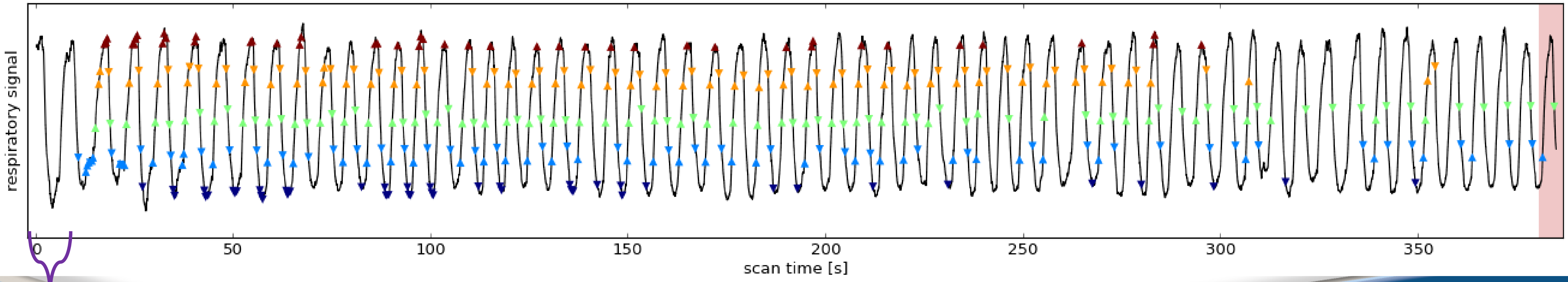
Other Limitations: State of the Art

- MR-compatible equipment
- Similar to 4DCT: external surrogates
- Internal navigators being evaluated
  – No current correlation to clinically available 4DCT
- Subject to sorting artifacts
- MRI scan time >> CT scan time
- Currently evaluating 4DMRI for clinical use

4DMRI Acquisition

- Single shot T2W-TSE 2DMS
- Prospective amplitude-based triggering[1]
  - External surrogate (air-filled cushion)
  - Acquires images at specific phases
- Implementing on 1.0T Open Magnet



Magnet prep + training

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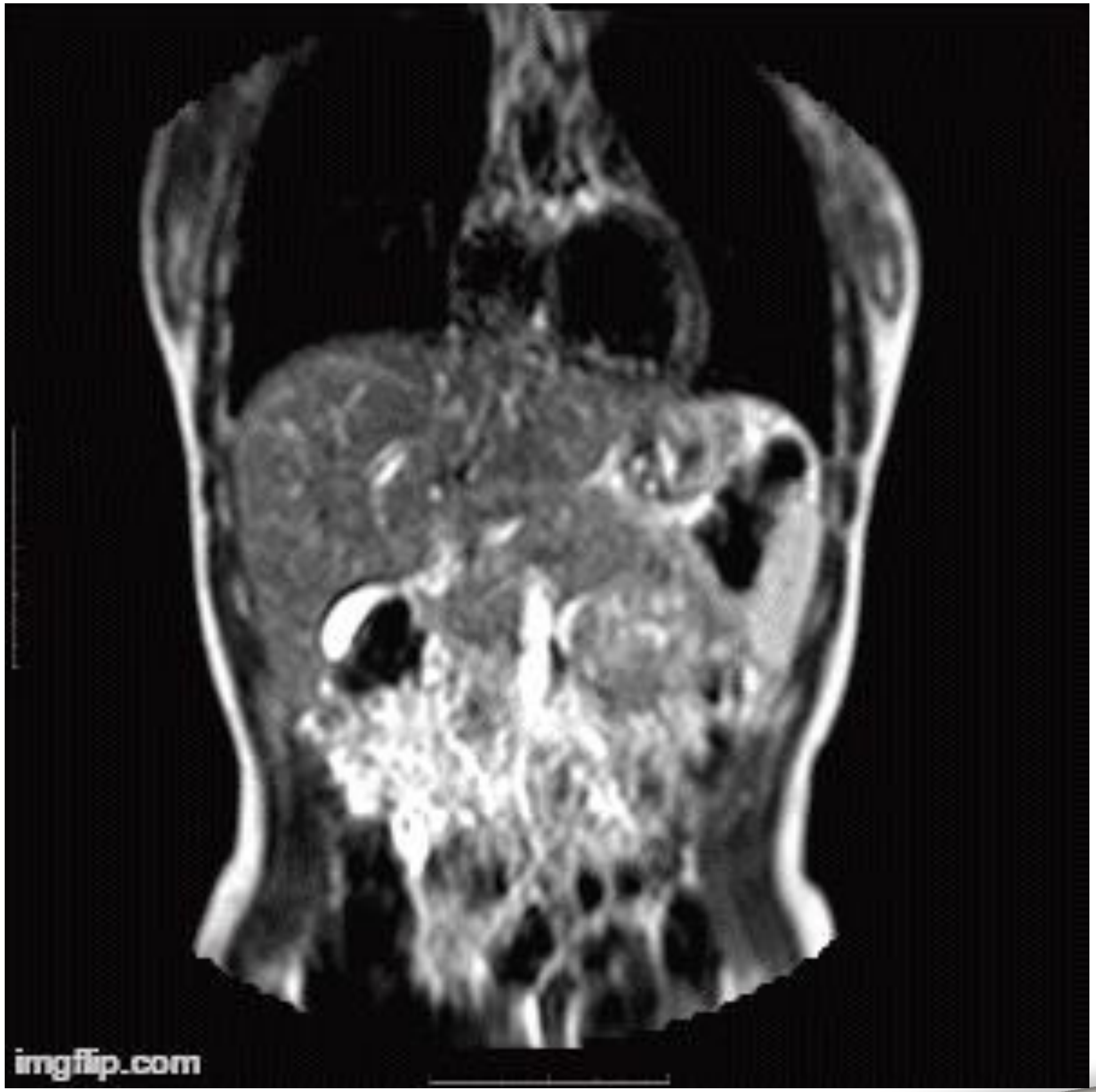
Y. Hu, S. D. Caruthers, D. A. Low, P. J. Parikh, and S. Mutic, "Respiratory Amplitude Guided 4-Dimensional Magnetic Resonance Imaging," International Journal of Radiation Oncology*Biology*Physics **86**, 198-204 (2013).[1]

Coronal 4D-MRI



Clinical Questions

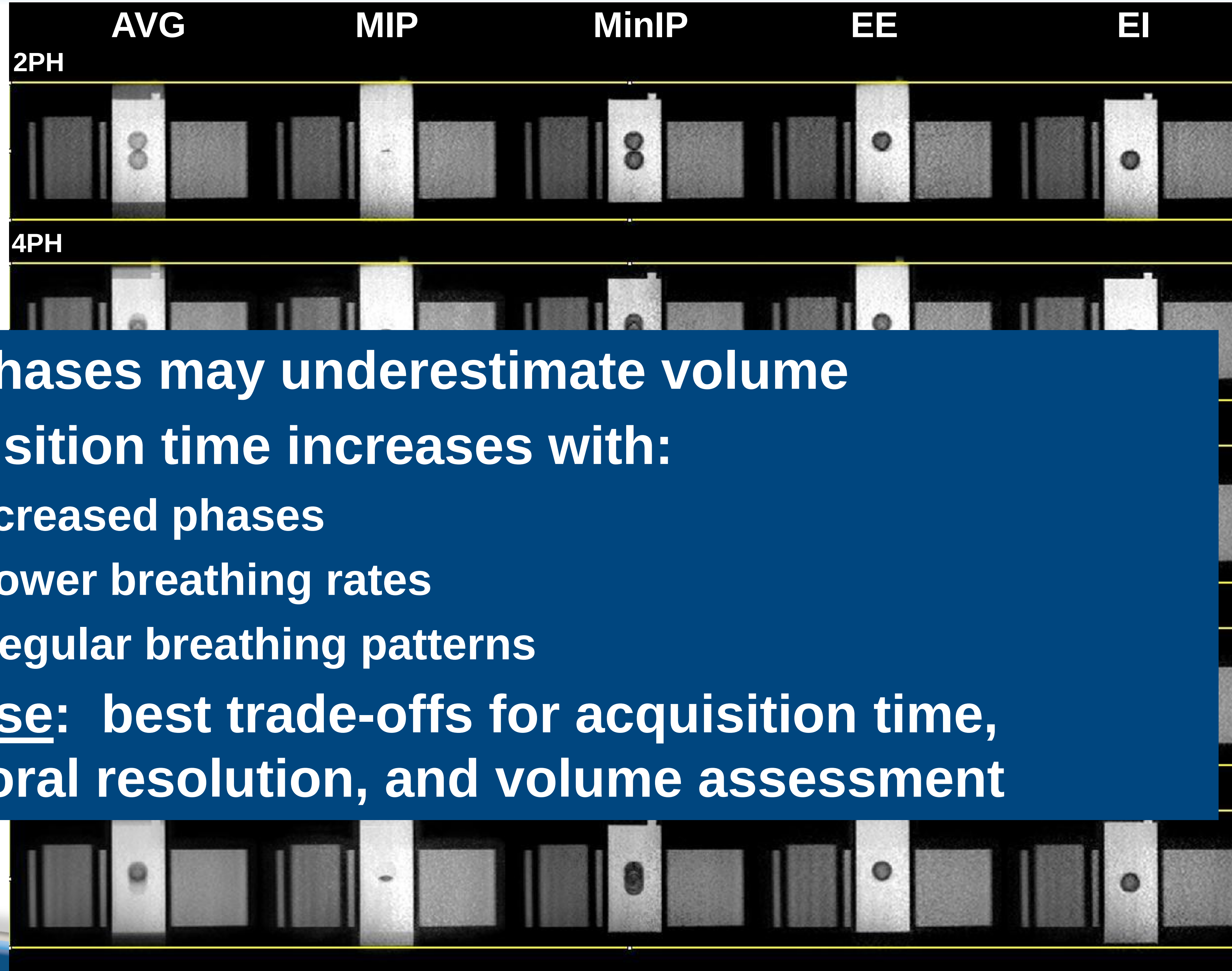
- How many 4DMRI phases do we need?
- Is the algorithm reproducible & robust?
- Is it efficient enough for the clinic, and if not, how can we improve the efficiency?

Initial Evaluation: Equipment

In-house Lego™ Phantom

QUASAR™ MRI-Compatible Respiratory Motion Phantom

Glide-Hurst, C. K., Kim, J. P., To, D., Hu, Y., Kadbi, M., Nielsen, T., & Chetty, I. J. (2015). 4DMRI Optimization and Implementation for MRI Simulation. Accepted, *Practical Radiation Oncology* (2015).



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- 2, 4 phases may underestimate volume
- Acquisition time increases with:
  - Increased phases
  - Slower breathing rates
  - Irregular breathing patterns
- 8 phase: best trade-offs for acquisition time, temporal resolution, and volume assessment

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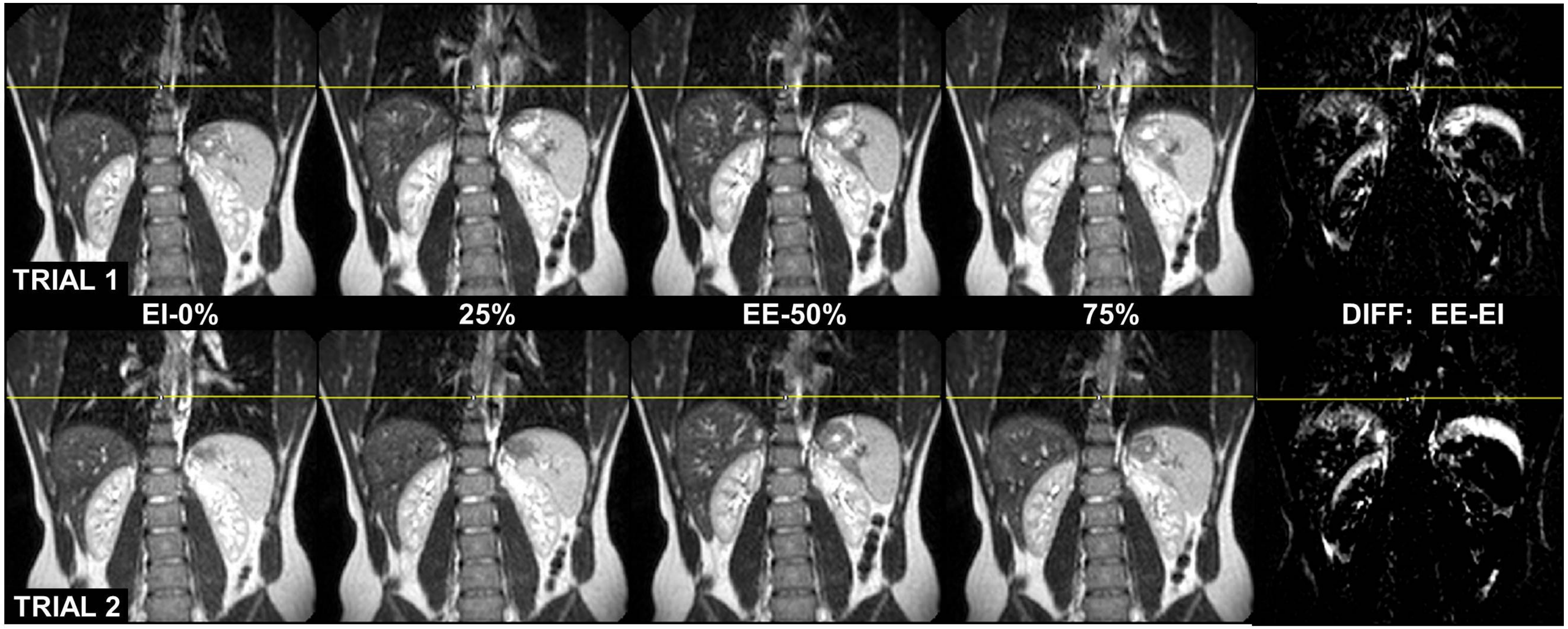
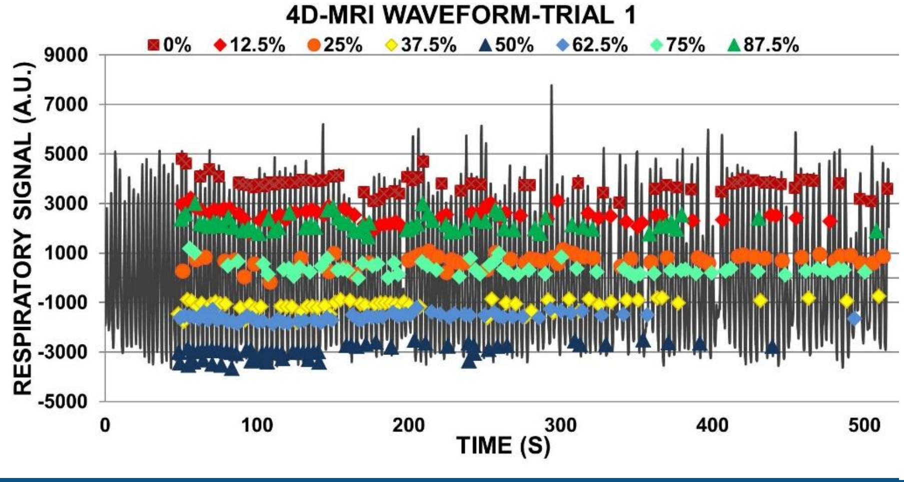
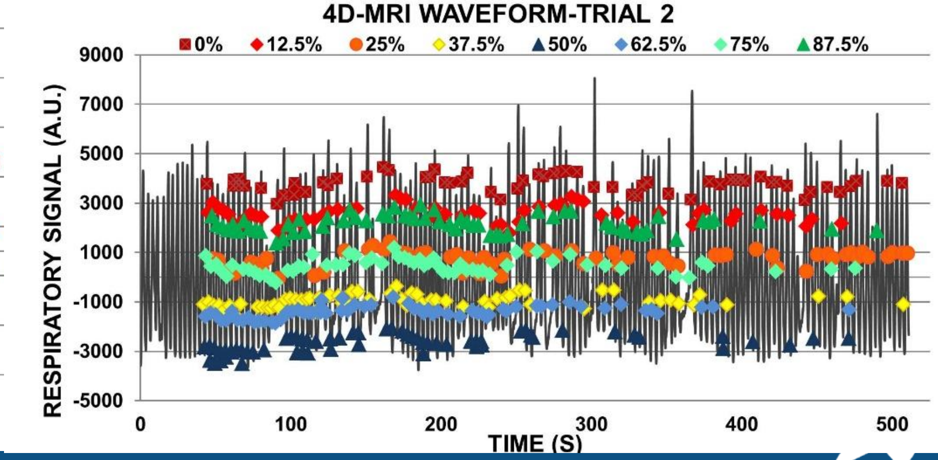
Reproducible, 8 phases, ~8 minutes







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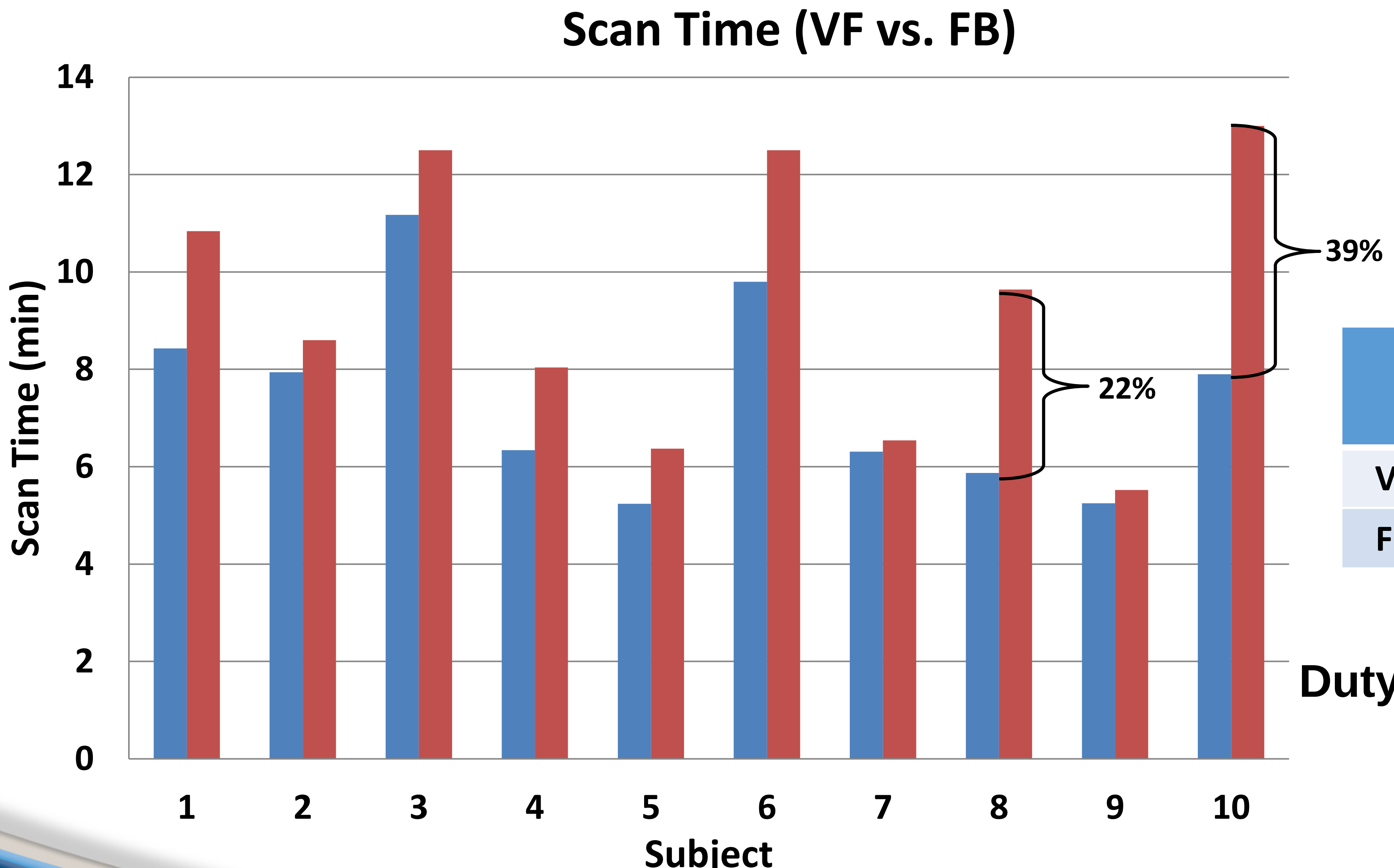
Incorporating Visual Feedback (VF)

- Efficiency & regularity evaluation in 10 volunteers with and without VF

Slide courtesy of David To, M.S.

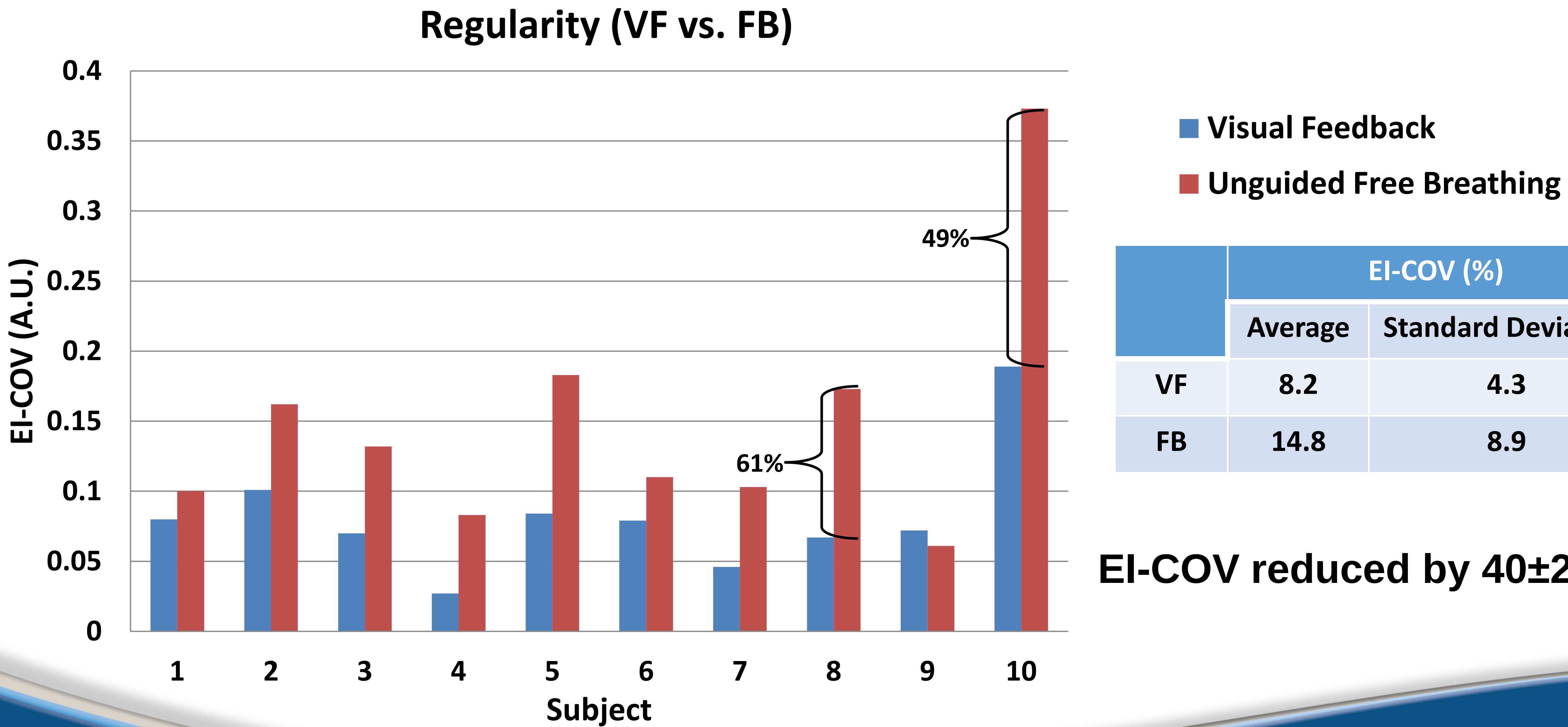
Results: Scan Efficiency



	Scan Time (min)	
	Average	Standard Deviation
VF	7.43	1.99
FB	9.36	2.77

Duty Cycle improved by 27±22%

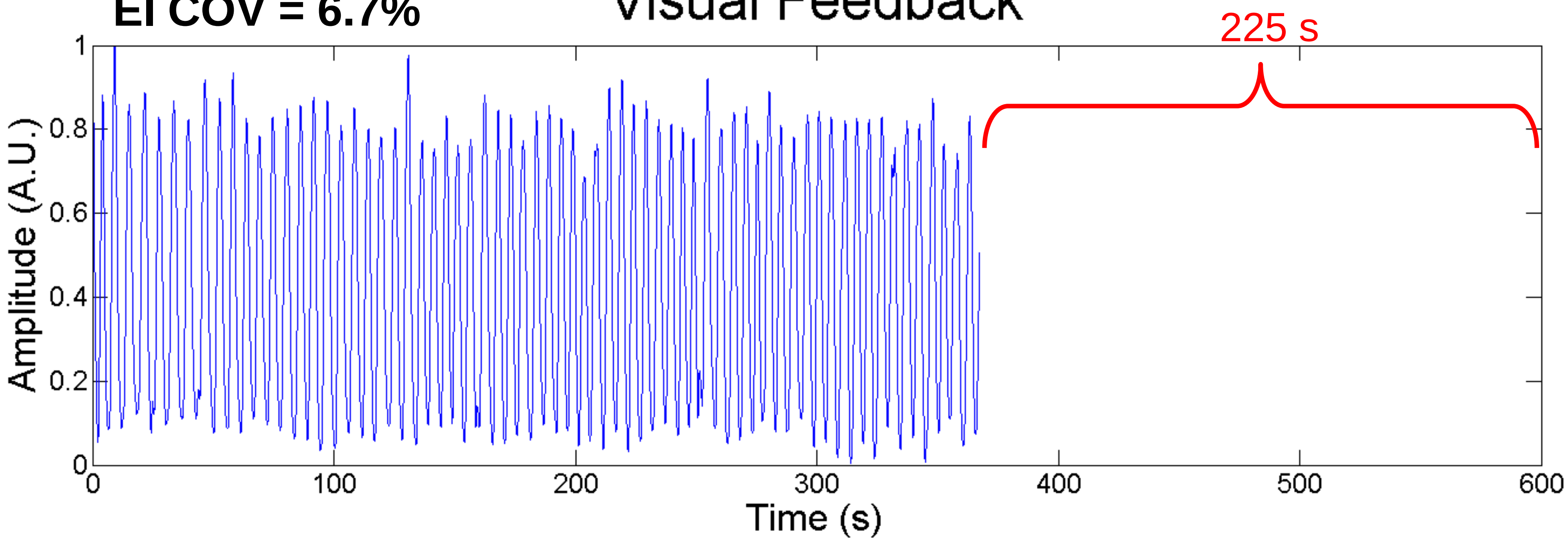
Results: Regularity



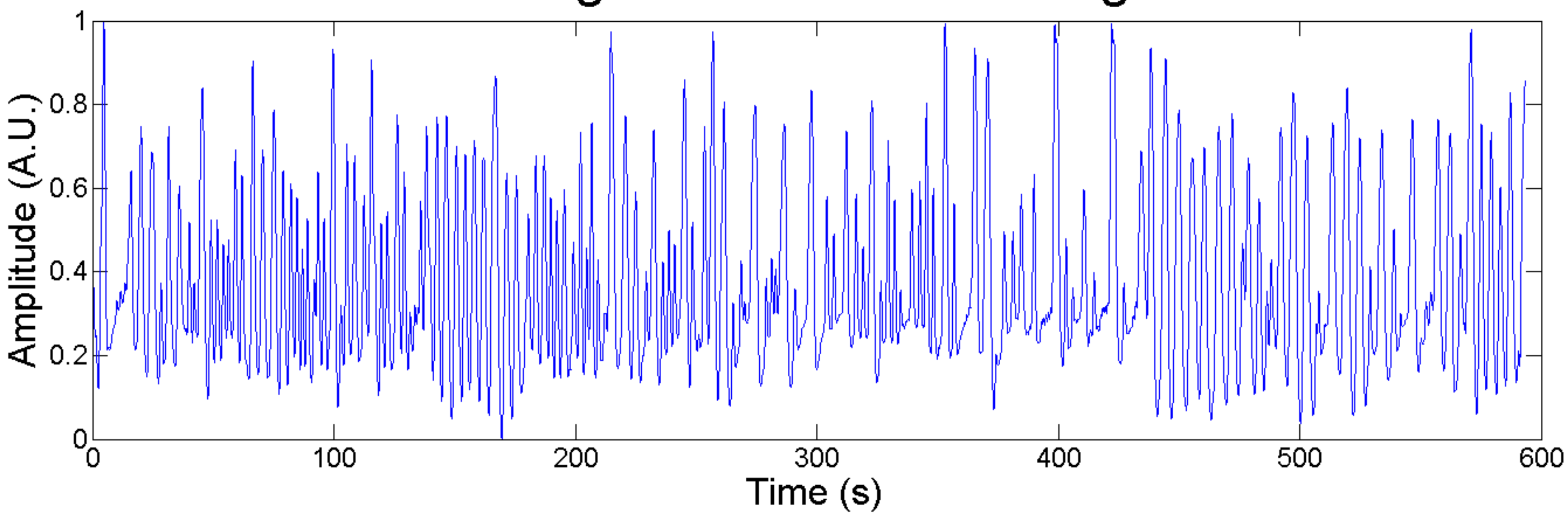
	EI-COV (%)	
	Average	Standard Deviation
VF	8.2	4.3
FB	14.8	8.9

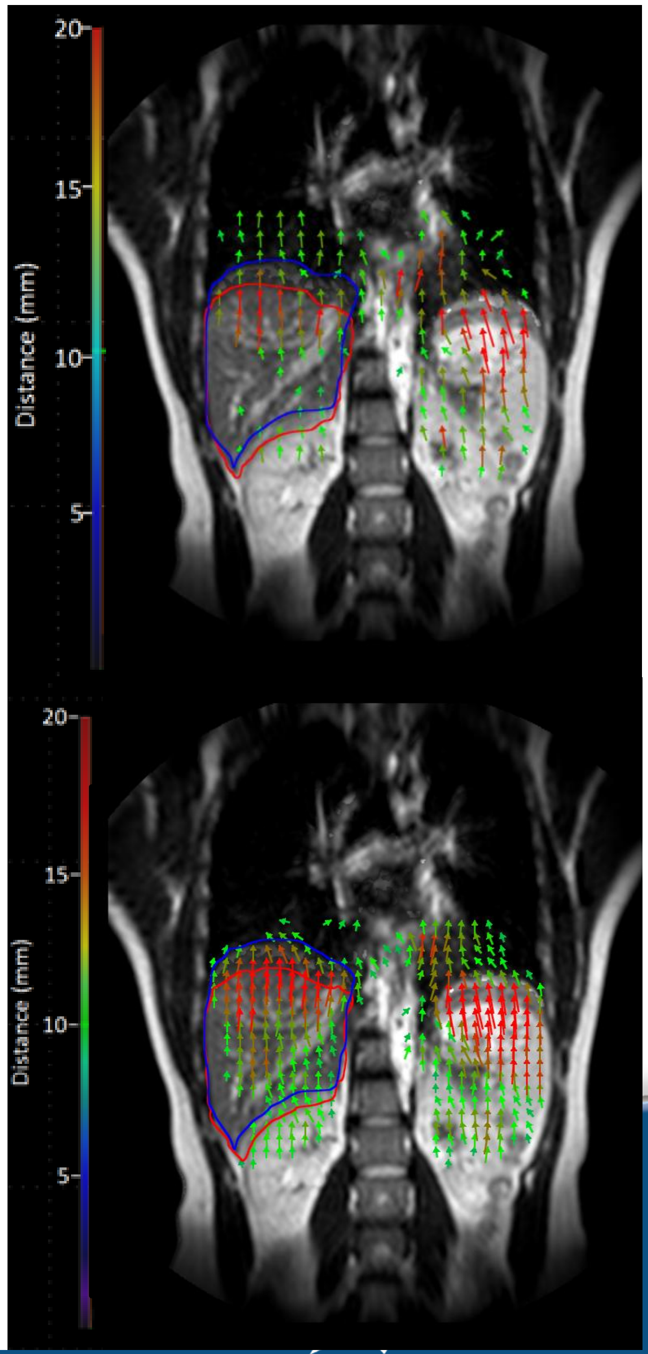
EI-COV reduced by 40±25%

EI COV = 6.7% Visual Feedback

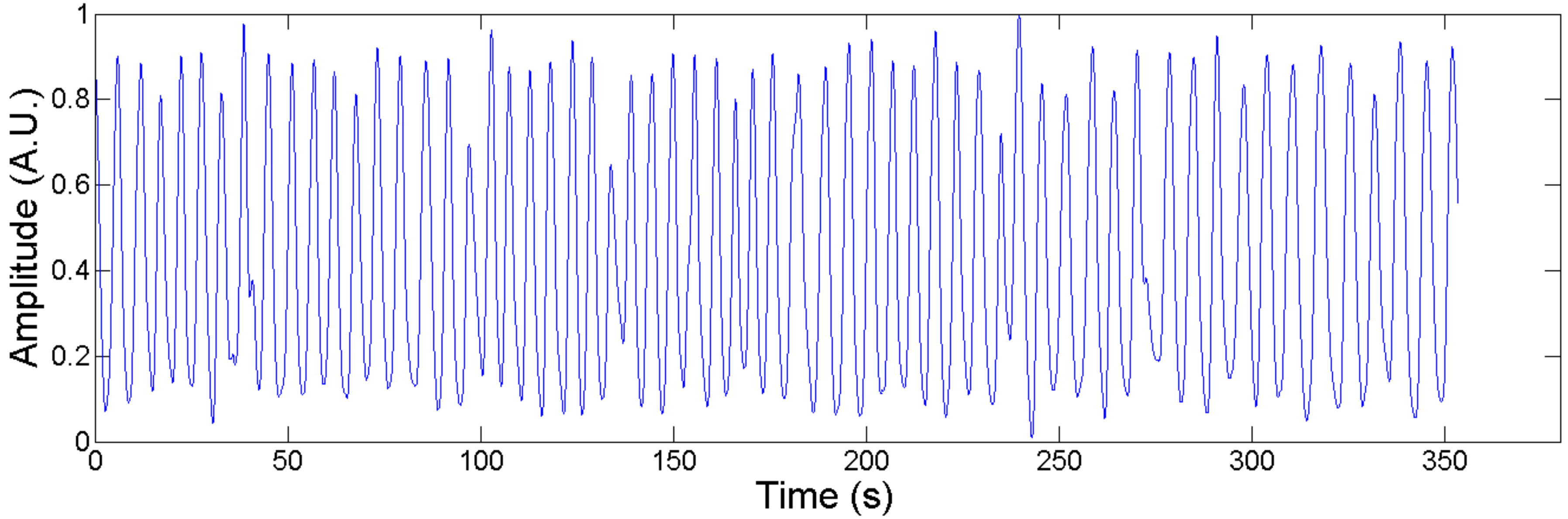


EI COV = 17.3% Unguided Free Breathing

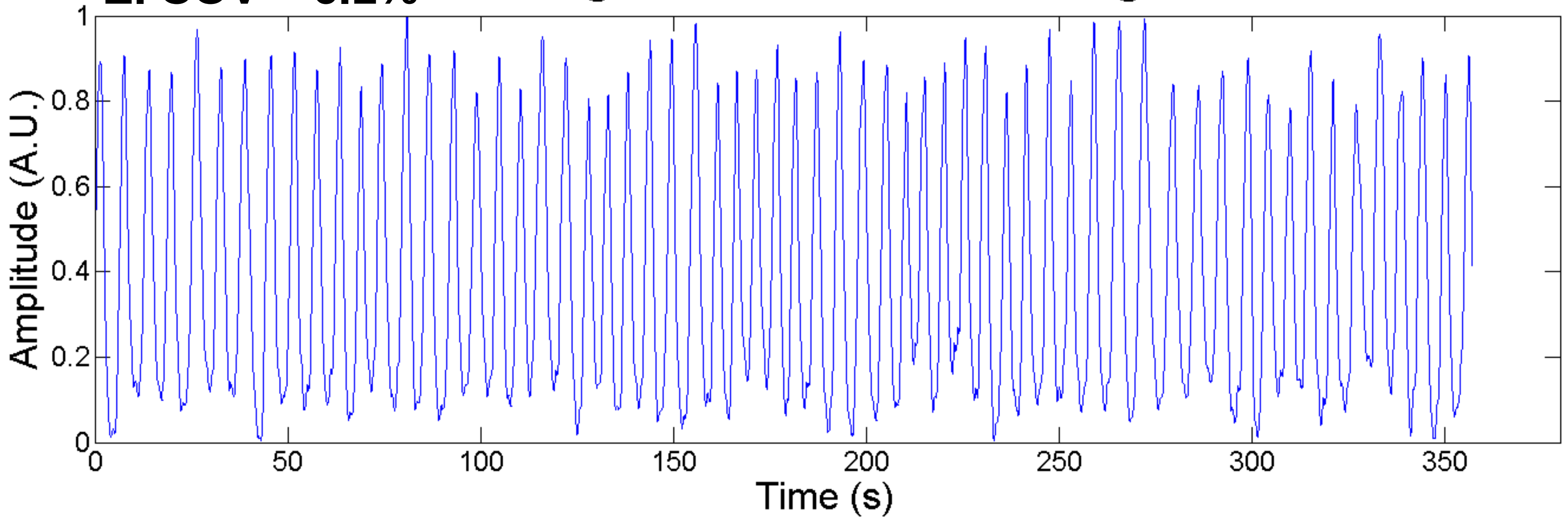


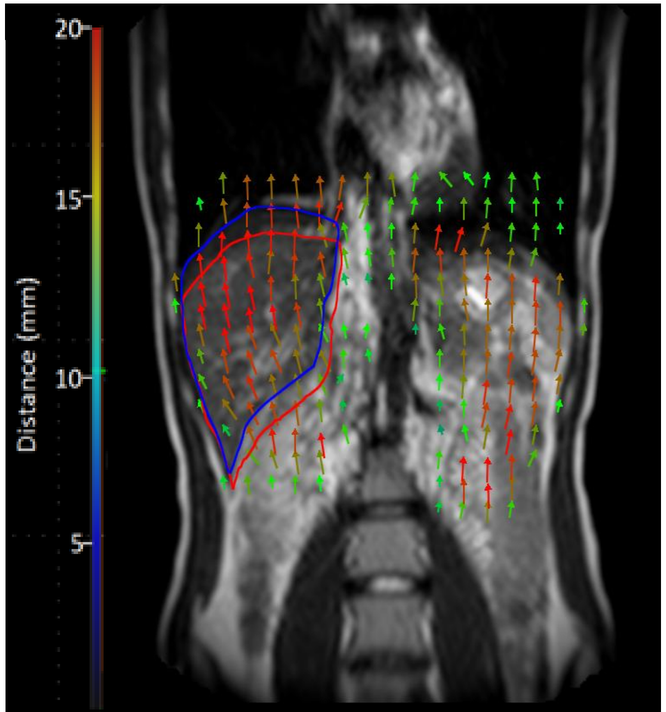


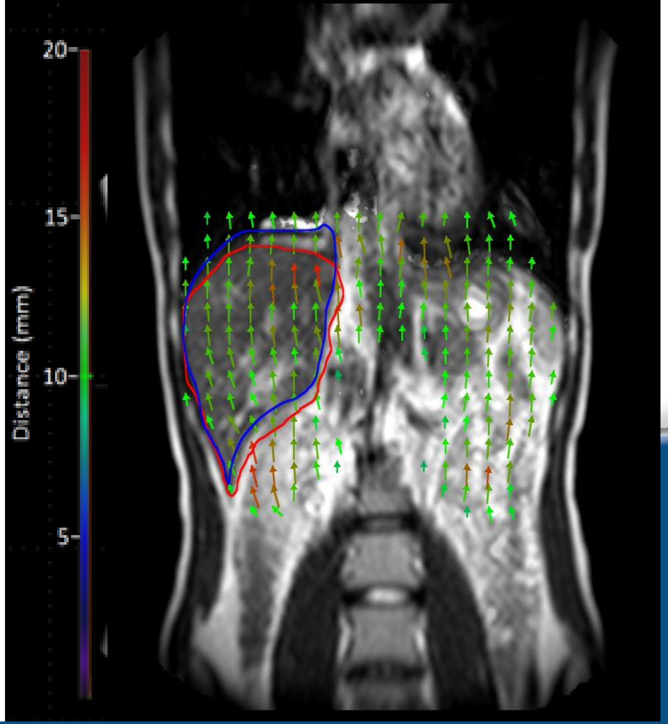
EI COV = 7.2% Visual Feedback



EI COV = 6.1% Unguided Free Breathing



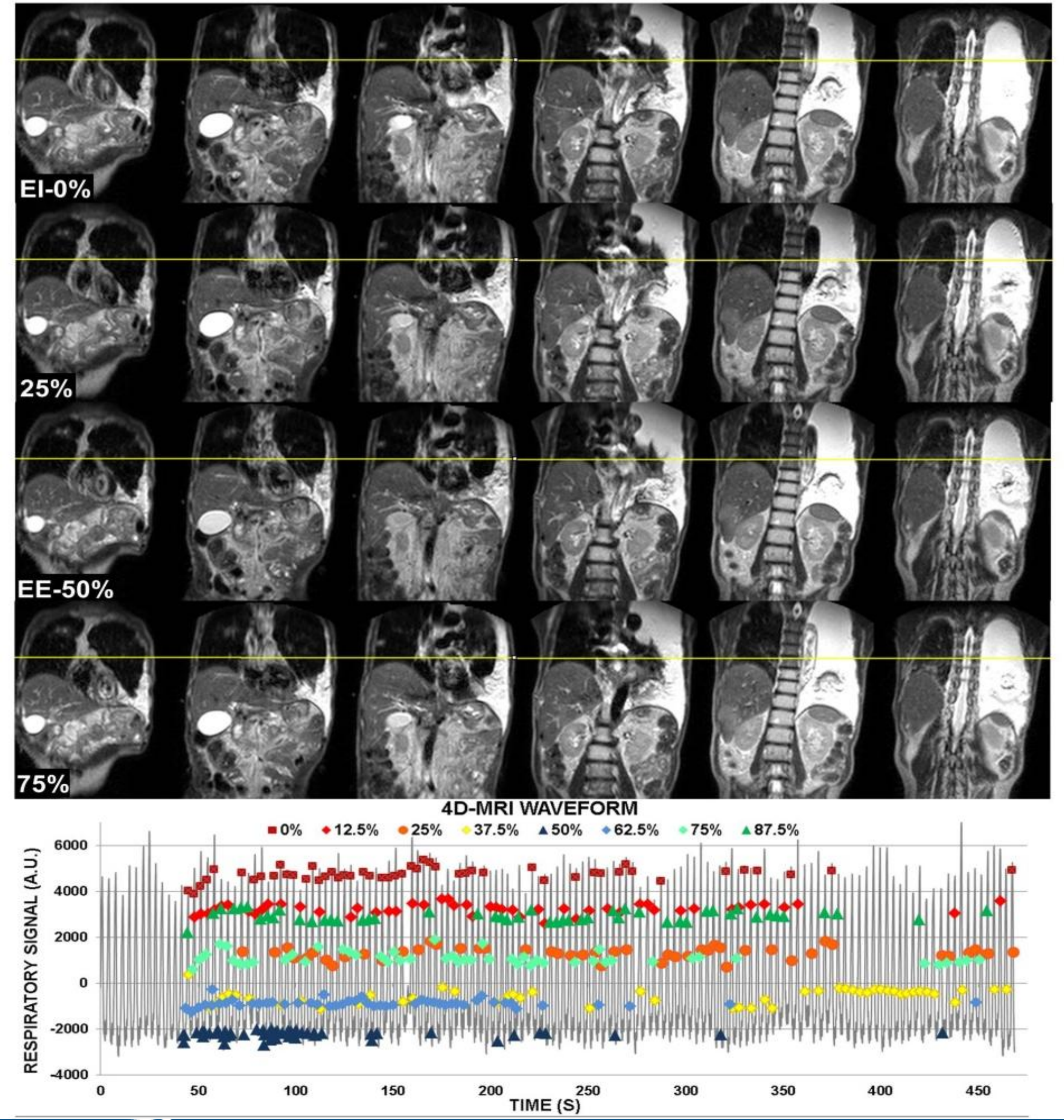




CAUTION: Liver excursion increased with VF

- Centroid to centroid analysis to extract liver excursion
- Will require integration throughout the clinical workflow

	Average Liver Excursion (mm) (Range)		
	S-I	**A-P**	**L-R**
VF	13.7 ± 5.4 (8.3-20.6)	4.6 ± 1.9 (1.5-8.2)	1.3 ± 1.1 (0.1-3.1)
FB	12.4 ± 5.6 (6.8-24.1)	3.8 ± 2.2 (1.2-7.8)	1.2 ± 1.3 (0-3.7)



Patient 4DMRI

- Good image quality
- ~7 minutes
- Tagging acceptable

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Remaining Challenges

- Much like 4DCT, 4DMRI requires patient-specific assessment for candidacy
- Patients with irregular breathing patterns may require audio/visual coaching
- Efforts to improve acquisition efficiency are desirable

Ways to improve efficiency

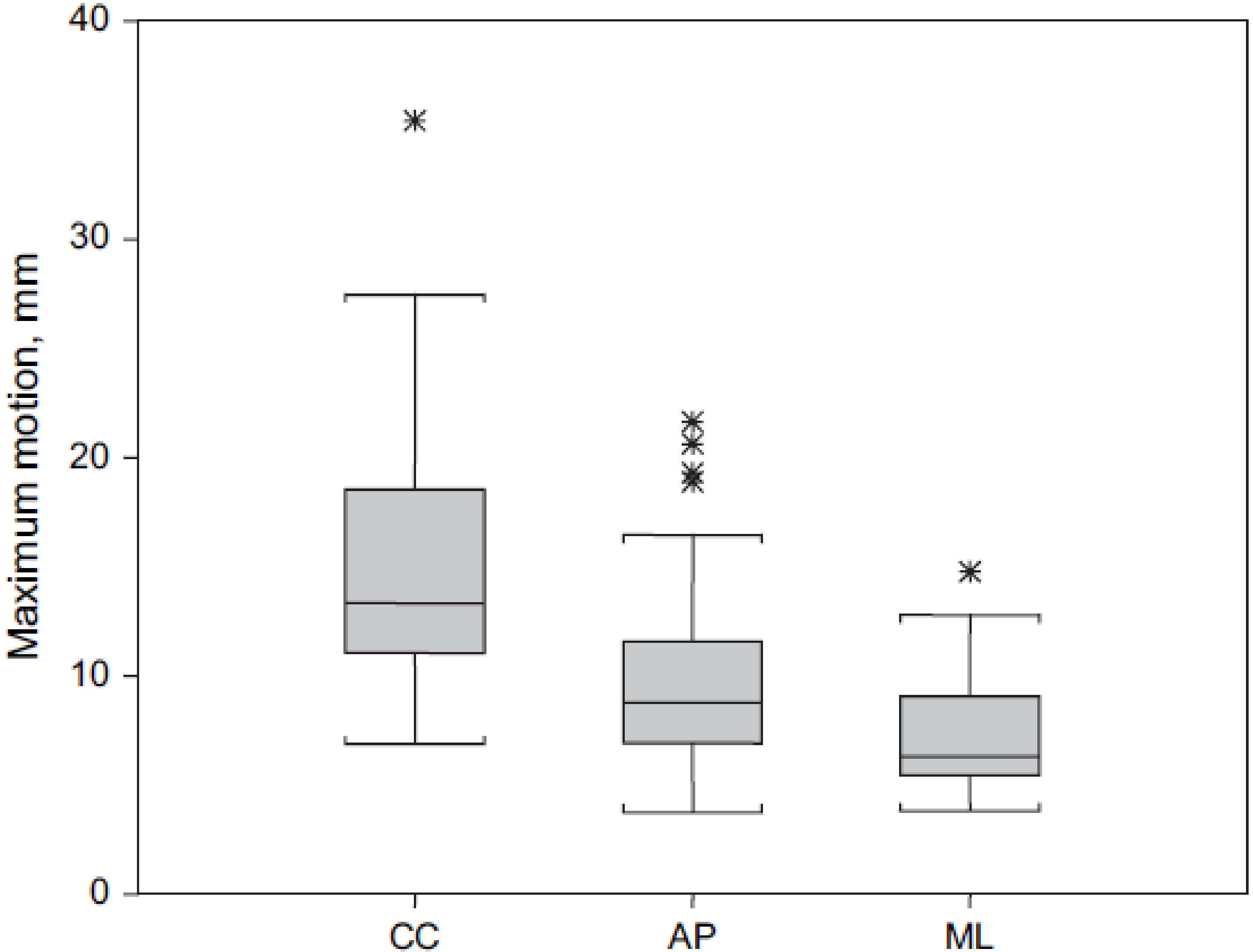
- Use higher field strengths: increase SNR/CNR
- Parallel imaging: reduce data in phase-encode direction
  - Decreases acquisition time 2-3X via combined signal from several coil arrays
- Compressed sensing (undersampling)
- Interleaving planar cine sequences
  - Not acquired at same instance but improves robustness compared to sequential acquisitions

Oh boy! Get out your clickers!

Which technique is most appropriate for assessment of liver cancer motion?

5%	1.	4DCT
8%	2.	Axial plane cine-MRI images
44%	3.	Coronal plane cine-MRI images
43%	4.	4DMRI
1%	5.	Fluoroscopy

Answer 4: 4DMRI



- Adequate liver tumor motion requires <u>soft tissue characterization</u> in all <u>three dimensions</u>, which is possible with 4DMRI
- Single plane cine images will not allow for out-of-plane motion assessment

Kirilova, A., Lockwood, G., Choi, P., Bana, N., Haider, M. A., Brock, K. K., ... & Dawson, L. A. (2008). Three-dimensional motion of liver tumors using cine-magnetic resonance imaging. *International Journal of Radiation Oncology* Biology* Physics*, *71*(4), 1189-1195.

What is an advantage of cine MRI?

20% 1. Multi-planar acquisition

52% 2. No sorting artifacts

19% 3. Can measure out of plane motion

4% 4. Slow acquisition frame rate

5% 5. Requires a breathing waveform

Answer: 2

- Cine images do not require a breathing waveform and thus will not be susceptible to sorting artifacts.
- References:

- Eccles, C. L., Patel, R., Simeonov, A. K., Lockwood, G., Haider, M., & Dawson, L. A. (2011). Comparison of liver tumor motion with and without abdominal compression using cine-magnetic resonance imaging. *International Journal of Radiation Oncology* Biology* Physics*, *79*(2), 602-608.
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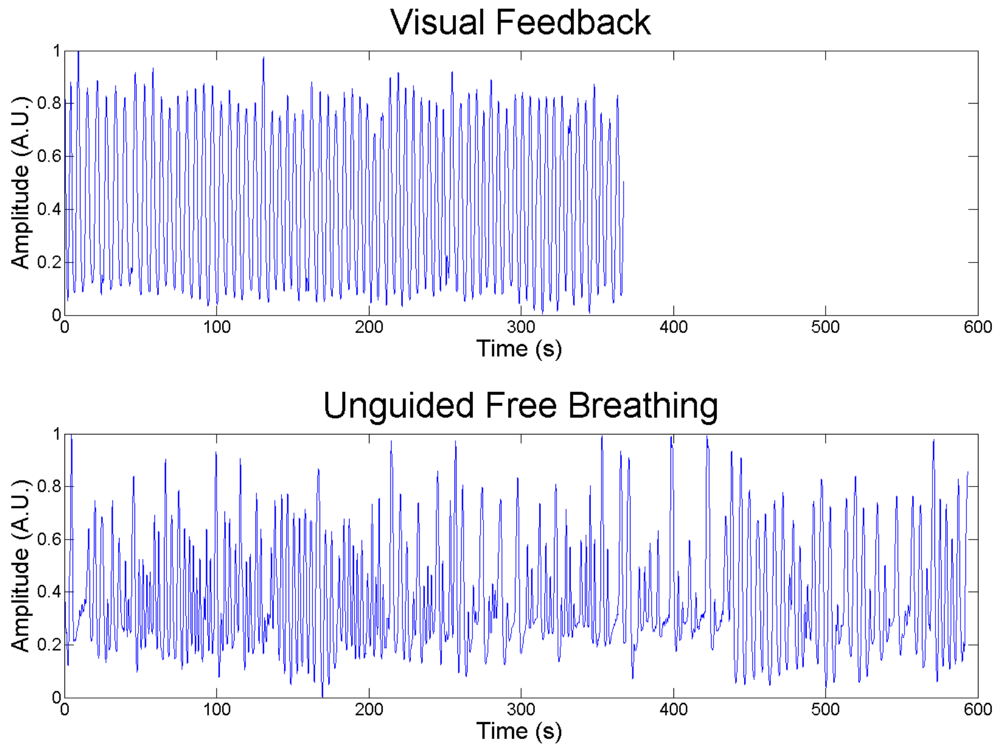
Prospective 4DMRI acquisition efficiency is decreased by:

78%	1.	Irregular breathing patterns
1%	2.	Applying compressed sensing
8%	3.	Faster respiratory rate
9%	4.	Incorporating visual feedback
4%	5.	Using higher field strength MRIs

Answer: 1

Because prospective 4DMRI triggers off of the respiratory waveform, irregular breathing decreases acquisition efficiency.



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- Hu, Y., Caruthers, S. D., Low, D. A., Parikh, P. J., & Mutic, S. (2013). Respiratory amplitude guided 4-dimensional magnetic resonance imaging. *Int Journal of Radiation Oncology* Biology* Physics*, *86*(1), 198-204.
- Du, D., Caruthers, S. D., Glide-Hurst, C., Low, D. A., Li, H. H., Mutic, S., & Hu, Y. (2015). High-Quality T2-Weighted 4-Dimensional Magnetic Resonance Imaging for Radiation Therapy Applications. *Int Journal of Radiation Oncology* Biology* Physics*, *92*(2), 430-437.

Thank you!