4D-MRI: Developments and Applications

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Strategies for 4D-MRI

Real time 4D-MRI
- ultra-fast 3D MR sequence
- fast gradient, multi-coils, parallel processing
- inadequate image quality (3-4 mm, 0.7 f/s)

Retrospective 4D-MRI
- fast 2D MR sequence
- breathing signal from surrogate
- adequate image quality (1.5x1.5x3 mm, 3 f/s)

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Retrospective 4D-MRI

Image Acquisition	Respiratory Signal
Fast 2D cine MR	Surrogates
Multiple slices	- External
Cine duration > 1 cycle	- Internal/Image-based
Frame rate: ~3 f/s	Signal processing
Slice thickness: 3-5 mm	Phase determination
Pixel size: 1-2 mm	Retrospective sorting

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Fast MR Sequences

- TrueFISP/FIESTA (balanced steady state gradient echo)
  - T2*/T1, sensitive to fluid, band artifacts from long TR
- HASTE/SSFSE (single shot fast spin echo)
  - T2, good CNR, signal decay from lung echo train, blurring
- FLASH/Fast SPGR (fast spoiled gradient echo)
  - T1 (poor), tumor hypo-intensity
- EPI (echo-planner imaging)
  - GE-EPI (T2*), SE-EPI (T2), IR-EPI (T1)
  - susceptibility, ghosting, chemical shift, fat suppression

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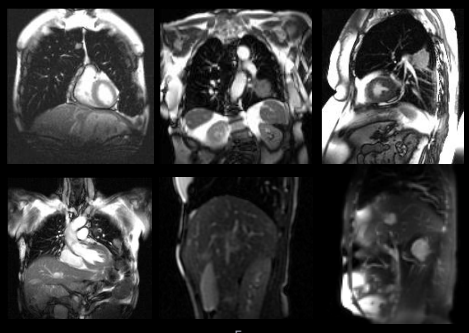
Fast MRI: Examples



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Fast MR Sequences

- HASTE and TrueFISP both can monitor respiratory motion during free breathing.
- Tumor contrast and image artifacts depend upon tumor characterizations.
- HASTE images show better tumor contrast than TrueFISP images.
- HASTE has local blurring artifact; TrueFISP has motion artifacts in the phase encoding direction.

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Internal/image-based Surrogates

- Implanted markers
- Diaphragm
- Air content
- Lung area
- Lung density
- Fourier transform
- Body area (axial, sagittal)
- Normalized cross correlation
- Deformable image registration

- Simpler process, lower cost, more efficient
- Potentially better correlation with tumor motion

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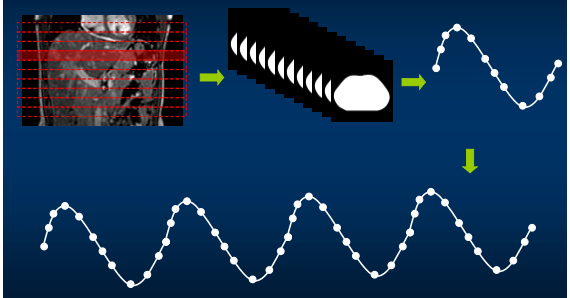
Slice Body Area (SBA): Axial



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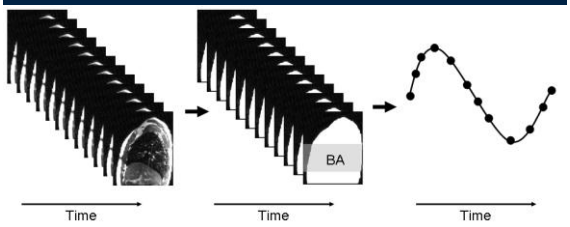
Slice Body Area (SBA): Sagittal



- Respiratory motion is mostly in SI and AP directions
- Potentially better correlation with tumor motion

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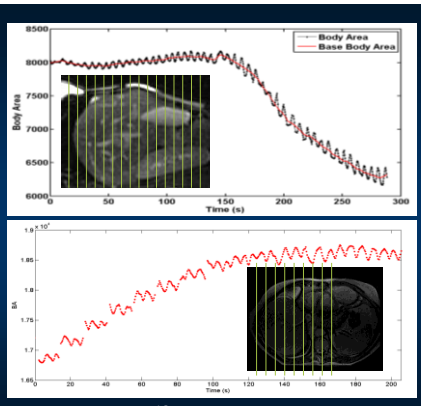
Axial SBA / Sagittal SBA



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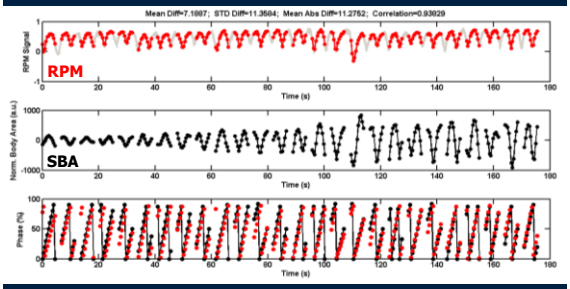
Axial SBA ~ RPM: Example



- Correlation (R), absolute phase difference (D_A)

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Axial SBA ~ RPM: Summary

Patient	P	T (s)	V_T	A (mm)	V_A	R	D	D_A	F (s)	S_{BA}	S_{RPM}
Lung Cancer Patients (n=17)											
Mean	L2	3.4	0.18	6.5	0.20	0.90	-5.1	13.8	0.47	3.1	2.6
Abdominal Cancer Patients (n=14)											
Mean	L2	3.7	0.19	6.8	0.21	0.94	-1.3	8.5	0.32	2.8	2.6
All Patients (n=31)											
Mean	L2	3.6	0.19	6.6	0.20	0.92	-3.3	11.4	0.40	2.9	2.6

- Good correlation in the abdomen (R=0.94).
- Phase shifts observed in some lung patients.

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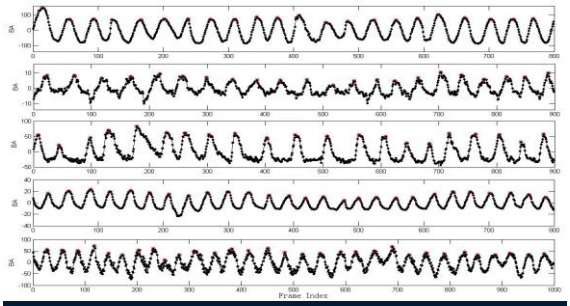
Sagittal SBA: Single Slice



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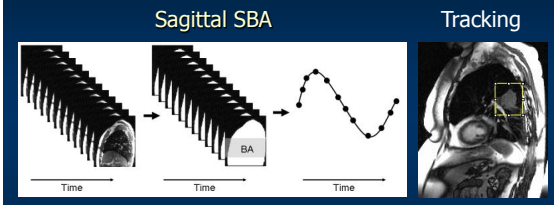
Sagittal SBA ~ Motion Tracking



- Respiratory signal (SBA v.s. ROI tracking)
- Motion tracking: cross-correlation algorithm

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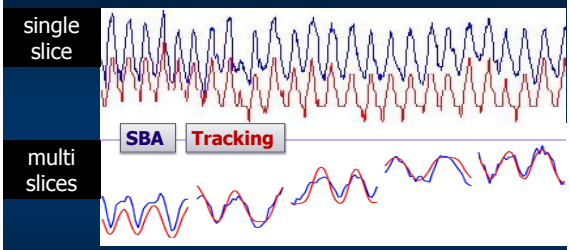
Sagittal SBA ~ Motion Tracking



- 7 Subjects, 5 single slice, 2 multi-slice
- Small phase difference in peaks (5.8%)

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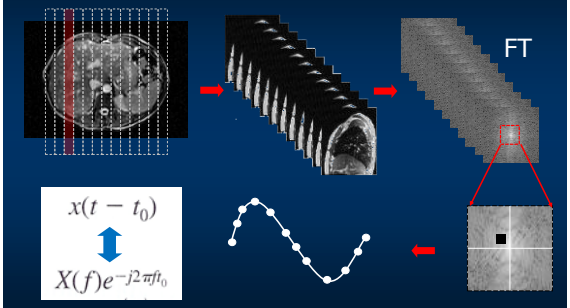
Surrogate: Fourier Transform



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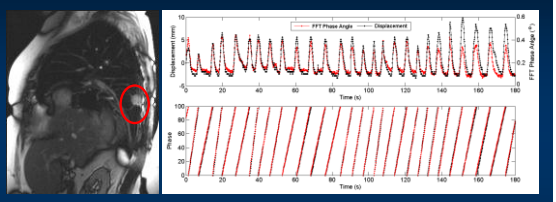
Validation: FT ~ Tracking



- 10 Subjects, 2 min scan, sagittal / coronal
- Small phase difference (-3.1±4.8%)
- High correlation (r^2=0.97±0.02)

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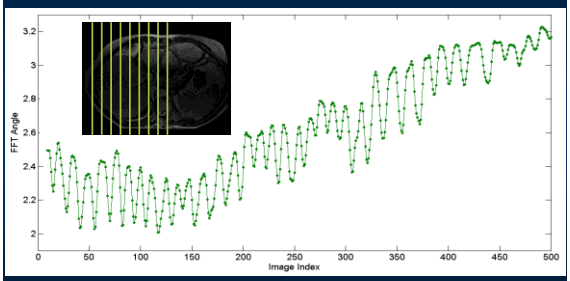
Sagittal FT : multi-slice, patient



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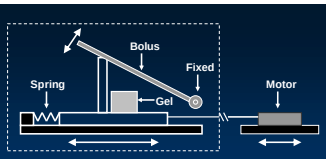
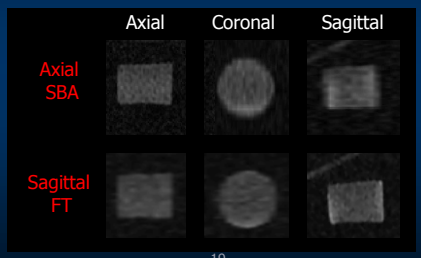
Phantom Validation





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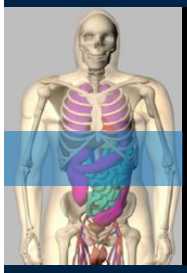
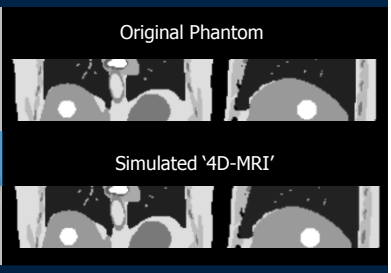
4D Digital Human Phantom





Segars, et al. Med Phys, 2008

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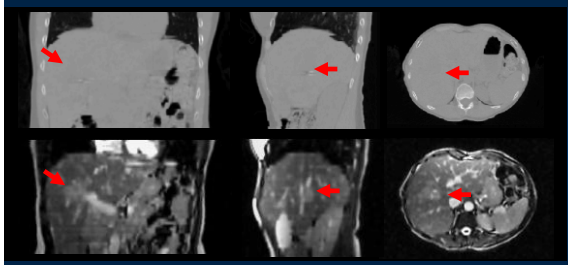
4D-MRI: Patient Example



- Tumor CNR: 20.1 in 4D-MRI, 2.5 in 4D-CT.

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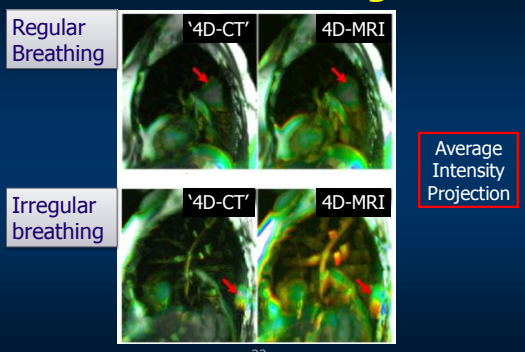
4D-MRI for lung?



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Summary

- 4D-MRI using internal surrogates is feasible.
- Slice body area and Fourier Transform are potential robust internal respiratory surrogates.
- Validation is crucial when using internal respiratory surrogate for 4D-MRI technique.

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