MR Imaging for Real Time Radiotherapy Guidance

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Why MRI?

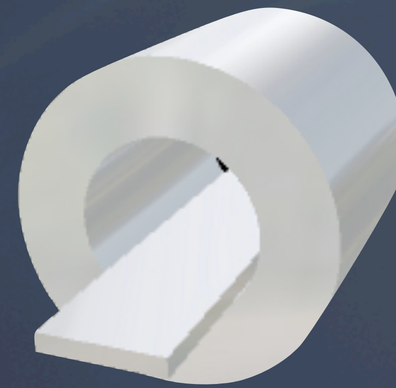
Lung cancer 15% Cancer cases

- Exquisite soft tissue contrast
- 3D imaging capability
- lack of radiation dose

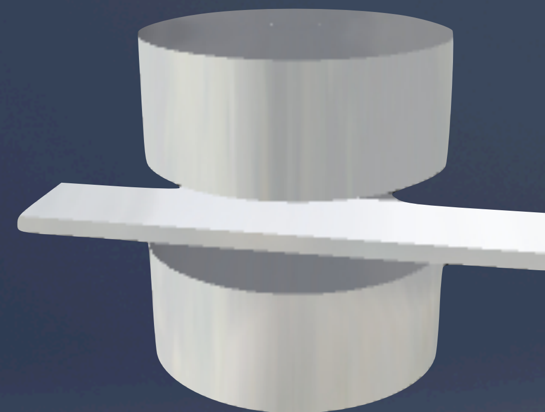
Hatabu et al. MR imaging of pulmonary parenchyma... Eur J Radiol, 1999

System Geometries

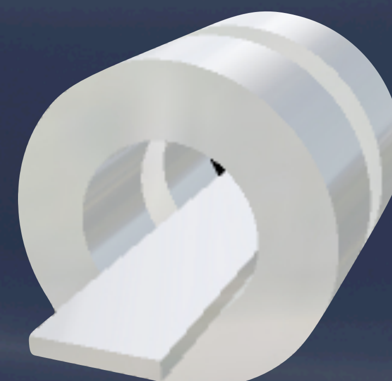
SNR α B_0
B_0 homogeneity
Gradient performance



Magnetic Field Effects on
Dose Distribution (Talk #2)



Integration of the two
devices (Talks #3 and #4)



Outline

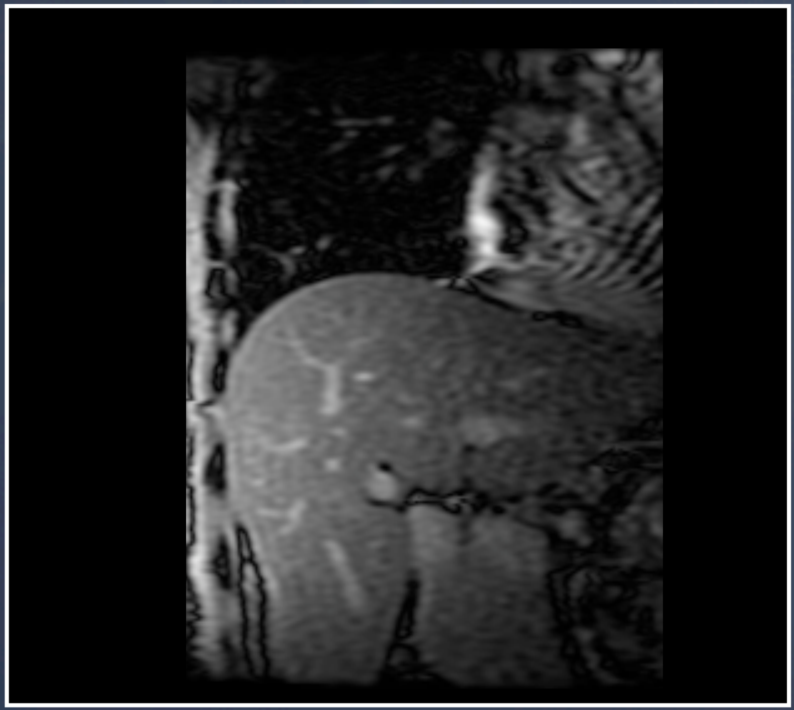
Tradeoffs in

- imaging speed
- motion artifacts
- SNR

Imaging strategies

- capture motion
- beam rotating around body

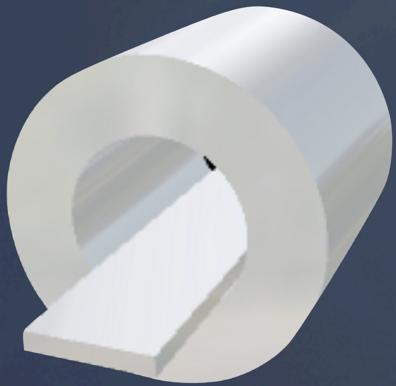
X-ray Compatible MR coils



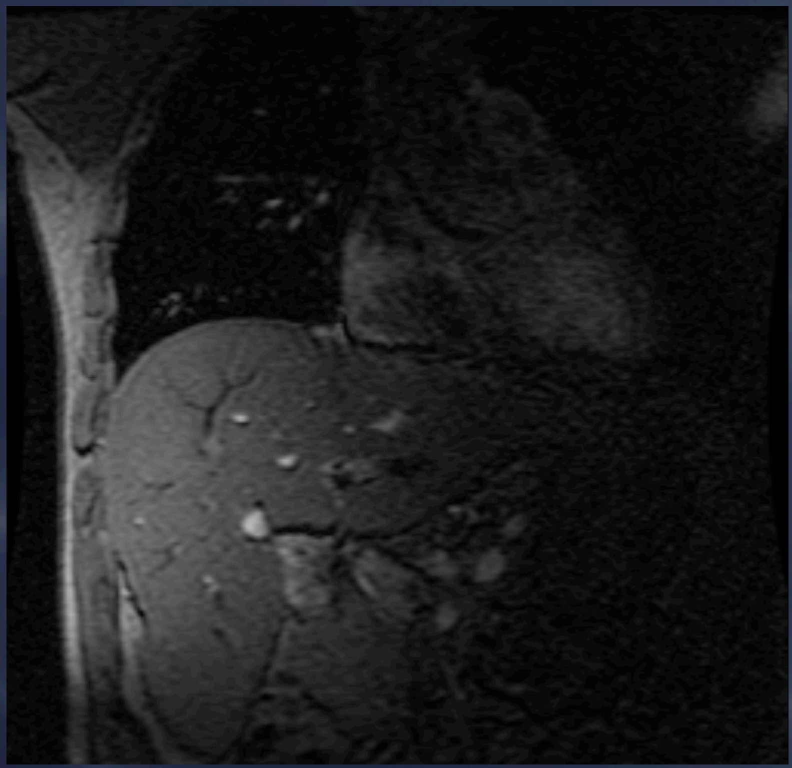
Lung/Liver tumors may move 20 mm at 10 mm/s

Experimental Setup

1.5T GE MRI System
human volunteers



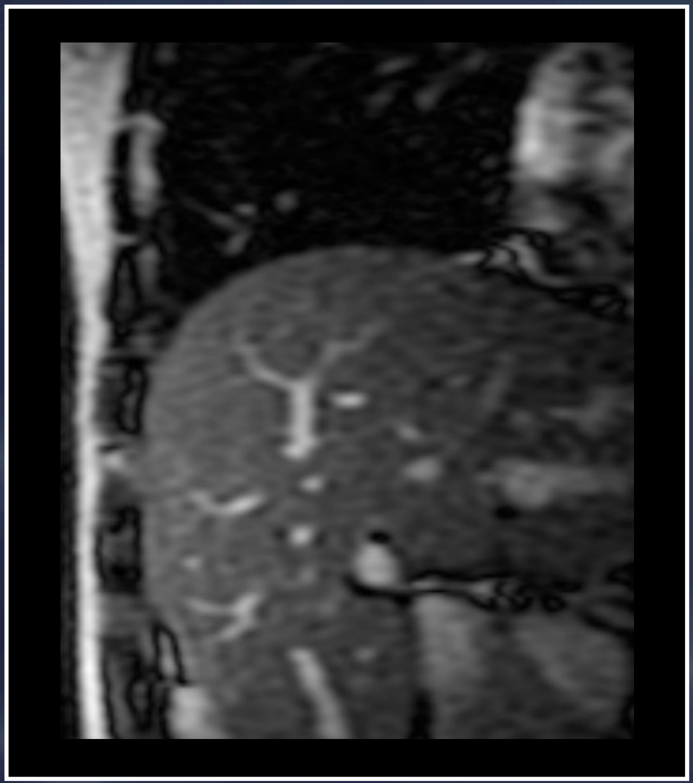
diaphragm as surrogate for tumor



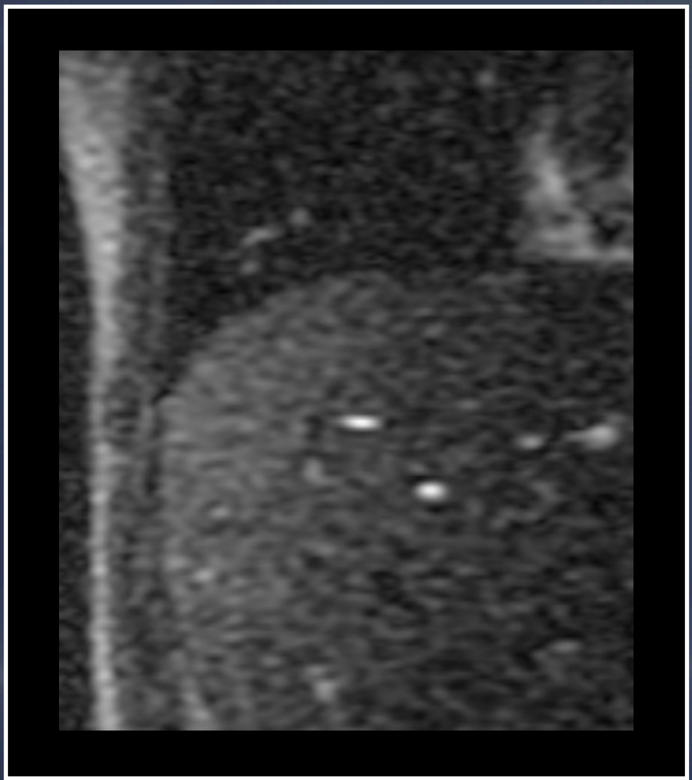
4 channel hip coil for reduced FOV

Imaging Consideration 1: Pulse Sequence

bSSFP =
FIESTA =
True FISP



bSSFP
TE/TR = 1.6/3.2 ms

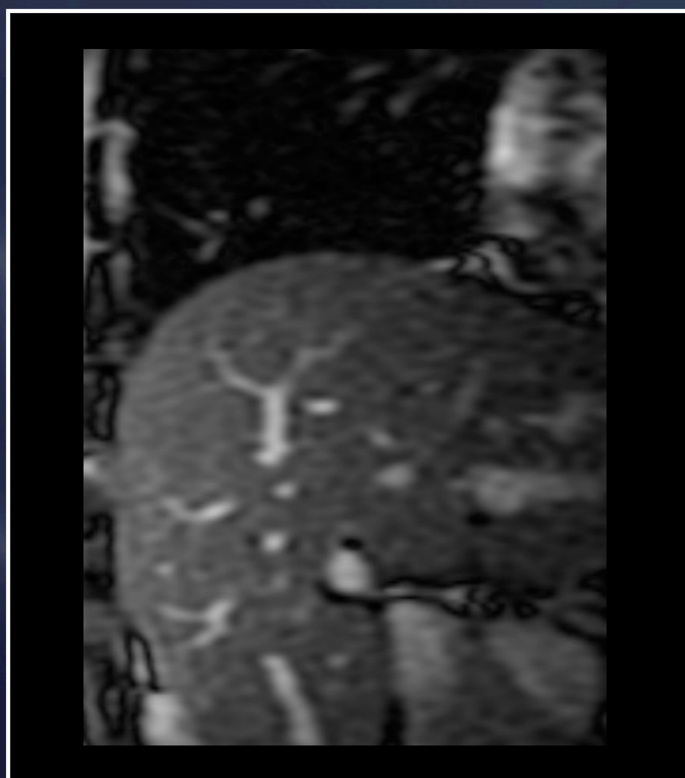


SPGR
TE/TR = 1.4/2.9 ms

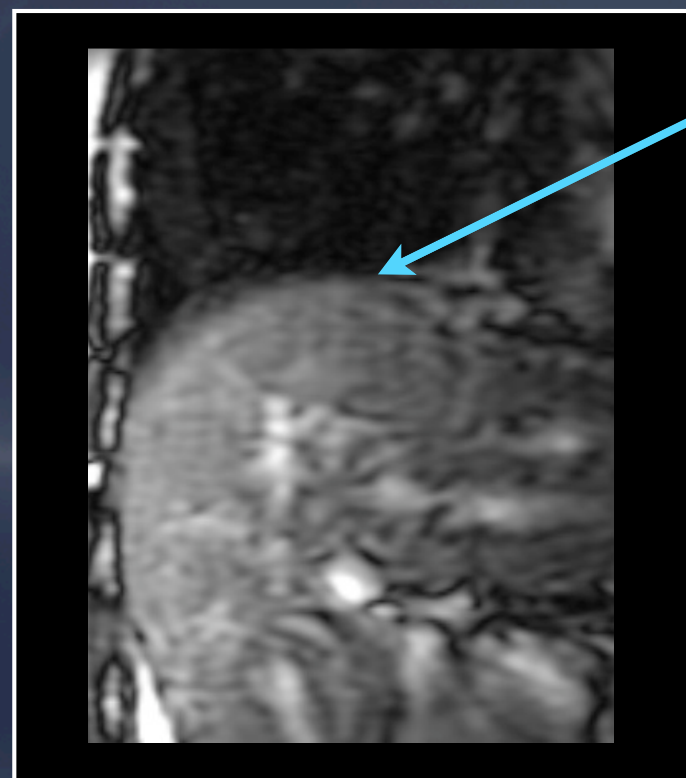
At short TRs, fully balanced SSFP gives much better results.

Imaging Requirements Introduction

Rapid imaging
- to eliminate motion blurring
- to track motion in real-time



$T_{scan} = 0.14$ s

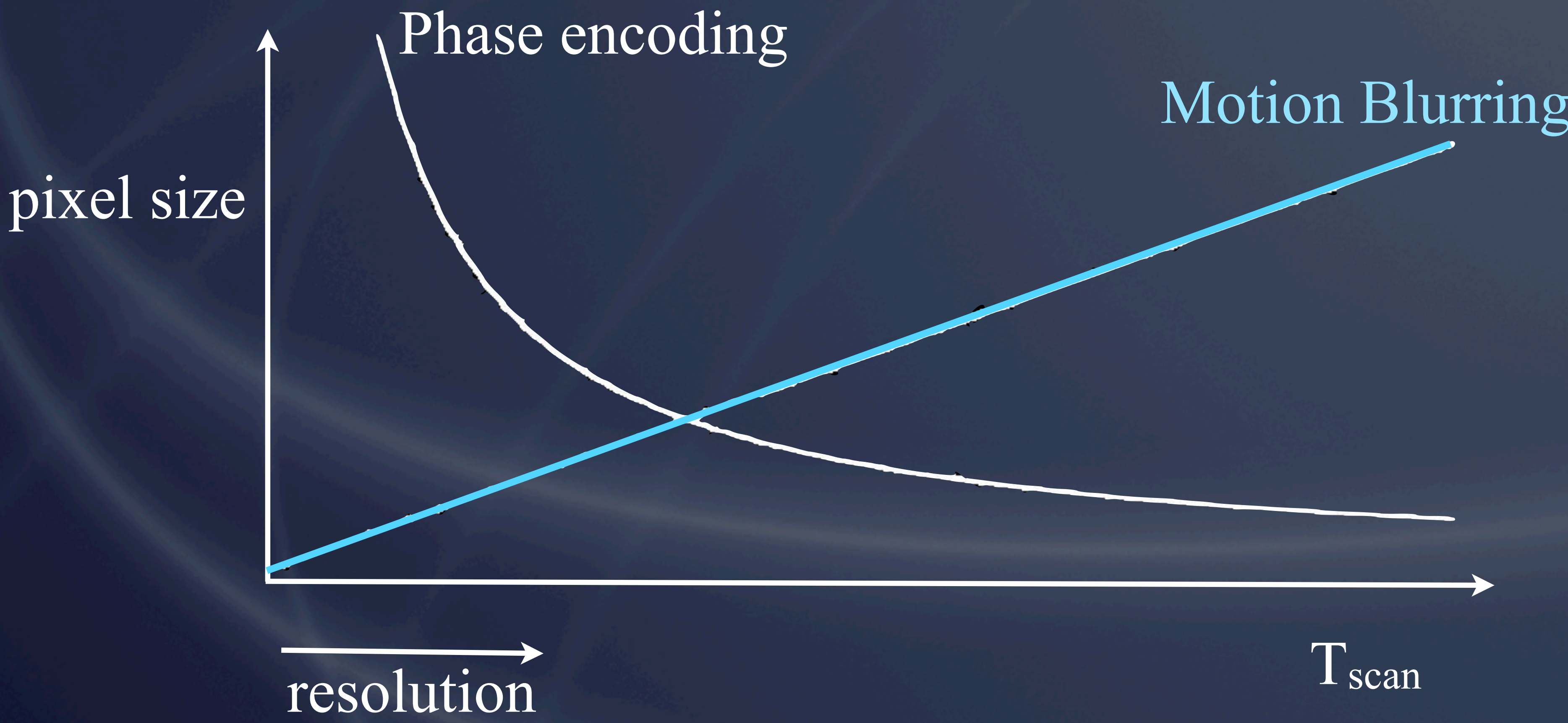


Edge Blur

$T_{scan} = 2$ s

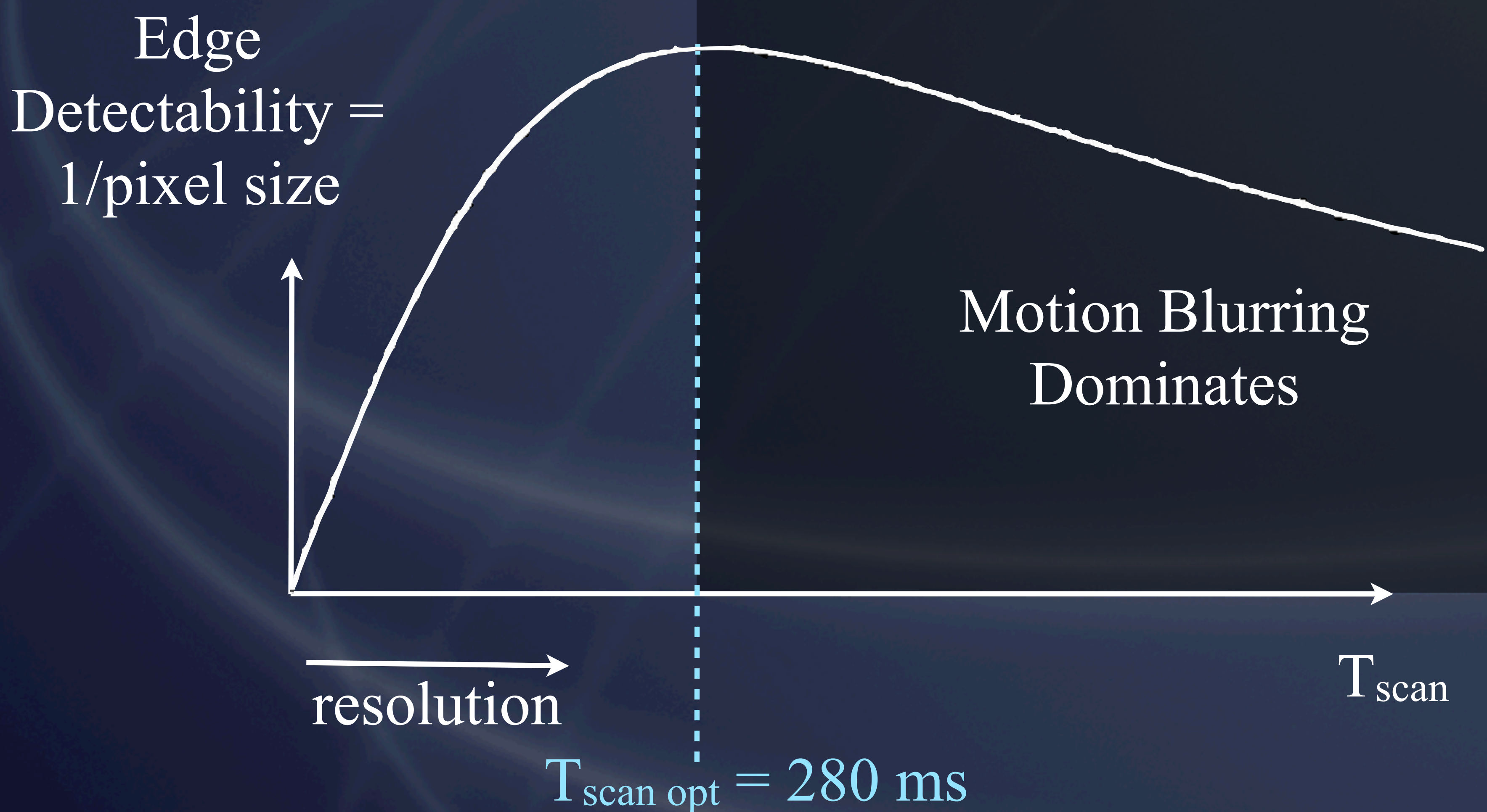
Optimization

Assumptions
v = 10 mm/s
FOV = 26
adequate SNR



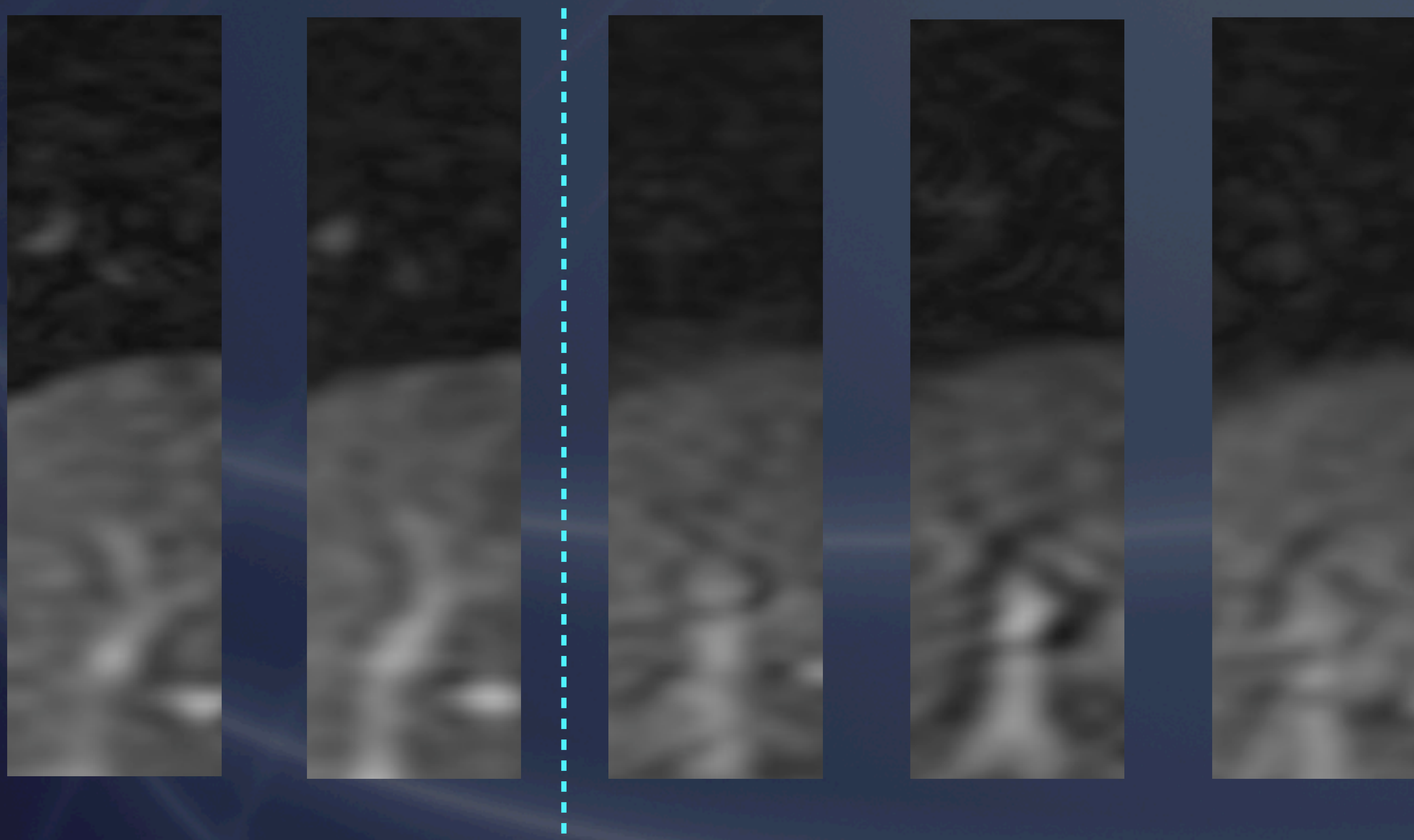
Optimal Scan Time

Assumptions
v = 10 mm/s
FOV = 26
adequate SNR



Rapid Scan Required

$T_{scan} =$ 0.14s 0.24s 0.7s 1.2s 2.1s

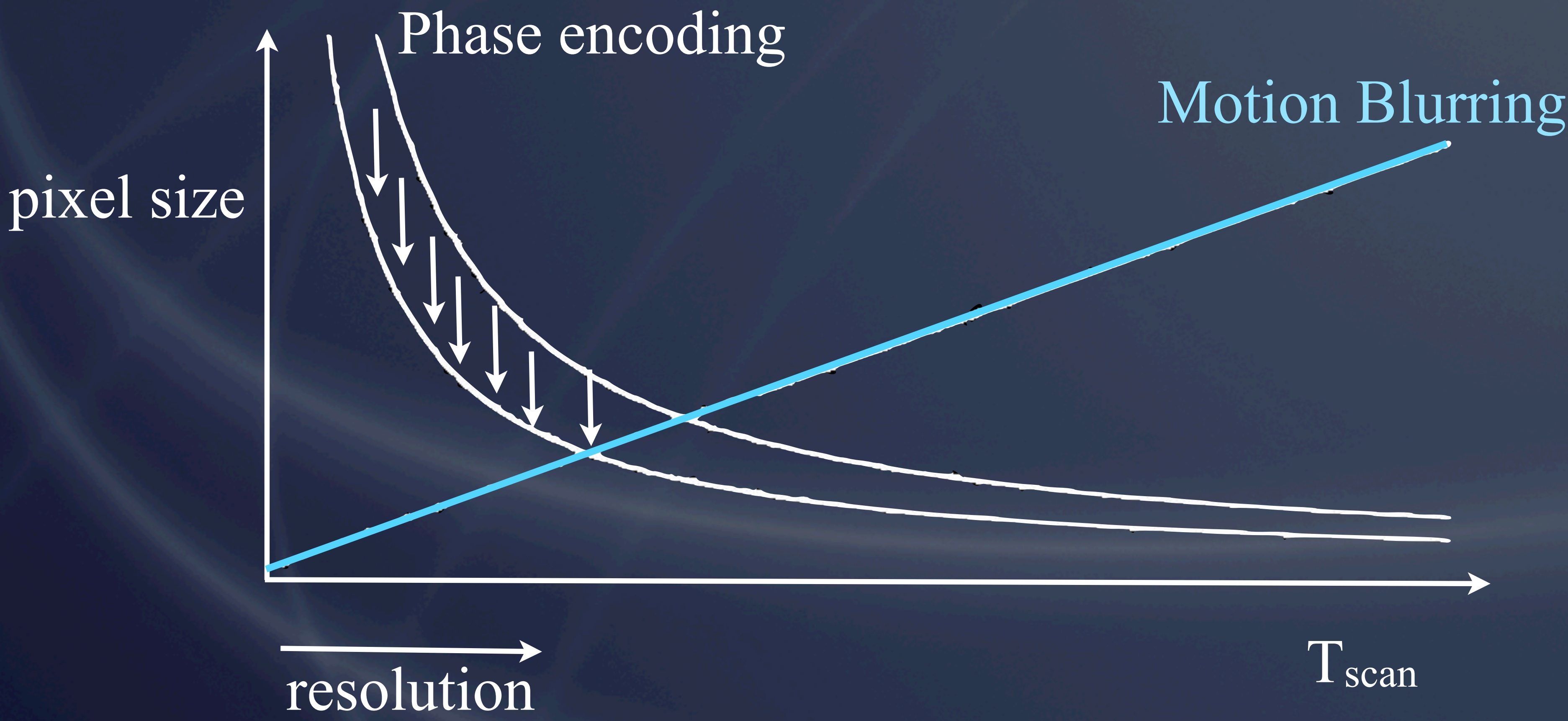


$T_{scan\ opt} = 280$ ms

We can already acquire at twice the required frame rate.

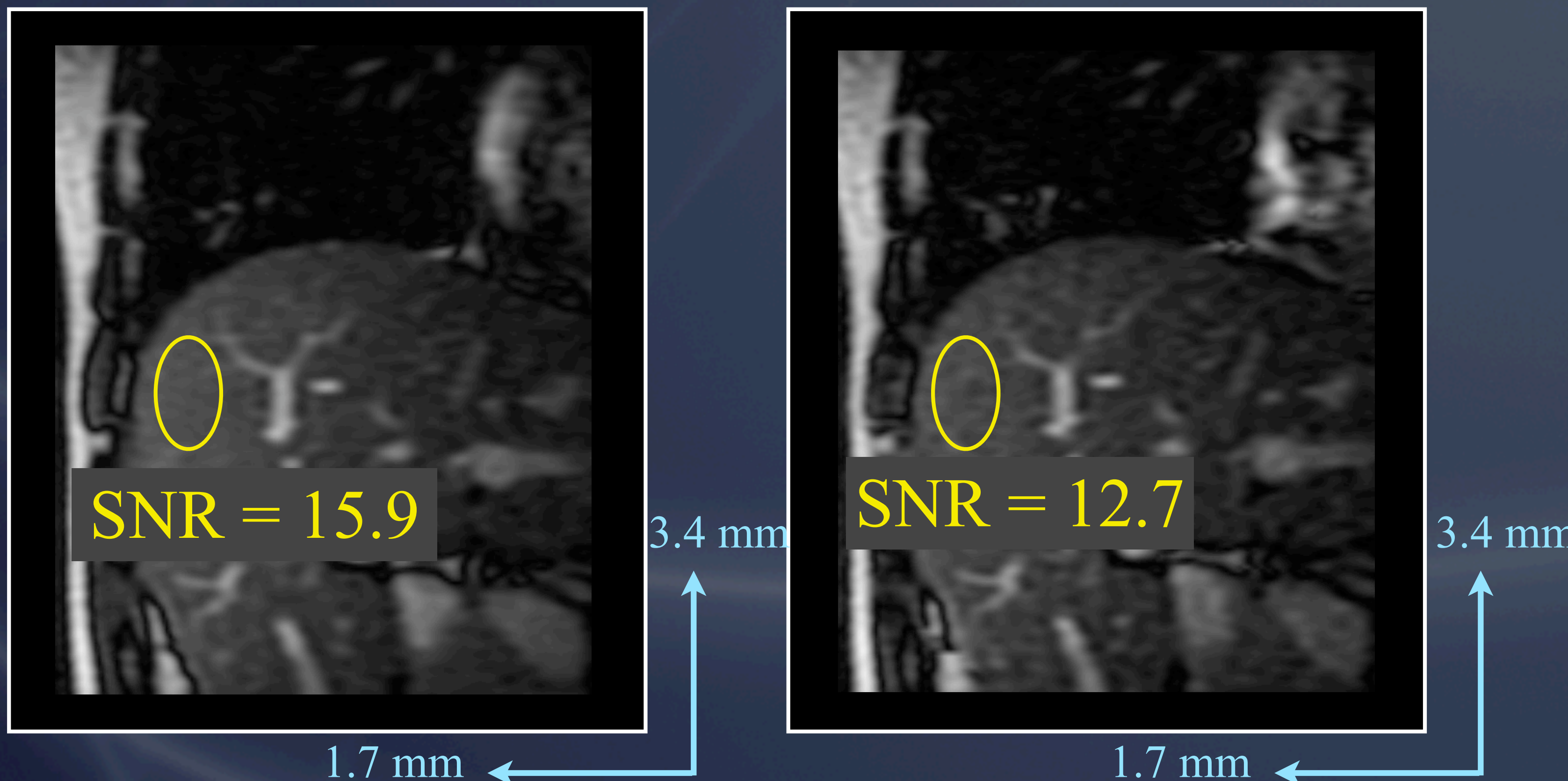
If we have extra SNR, you can scan faster

Assumptions
v = 10 mm/s
FOV = 26
adequate SNR



Imaging Consideration 2: SNR

$$SNR \propto B_0 \; \Delta x \Delta y \Delta z \; \sqrt{T_{scan}}$$



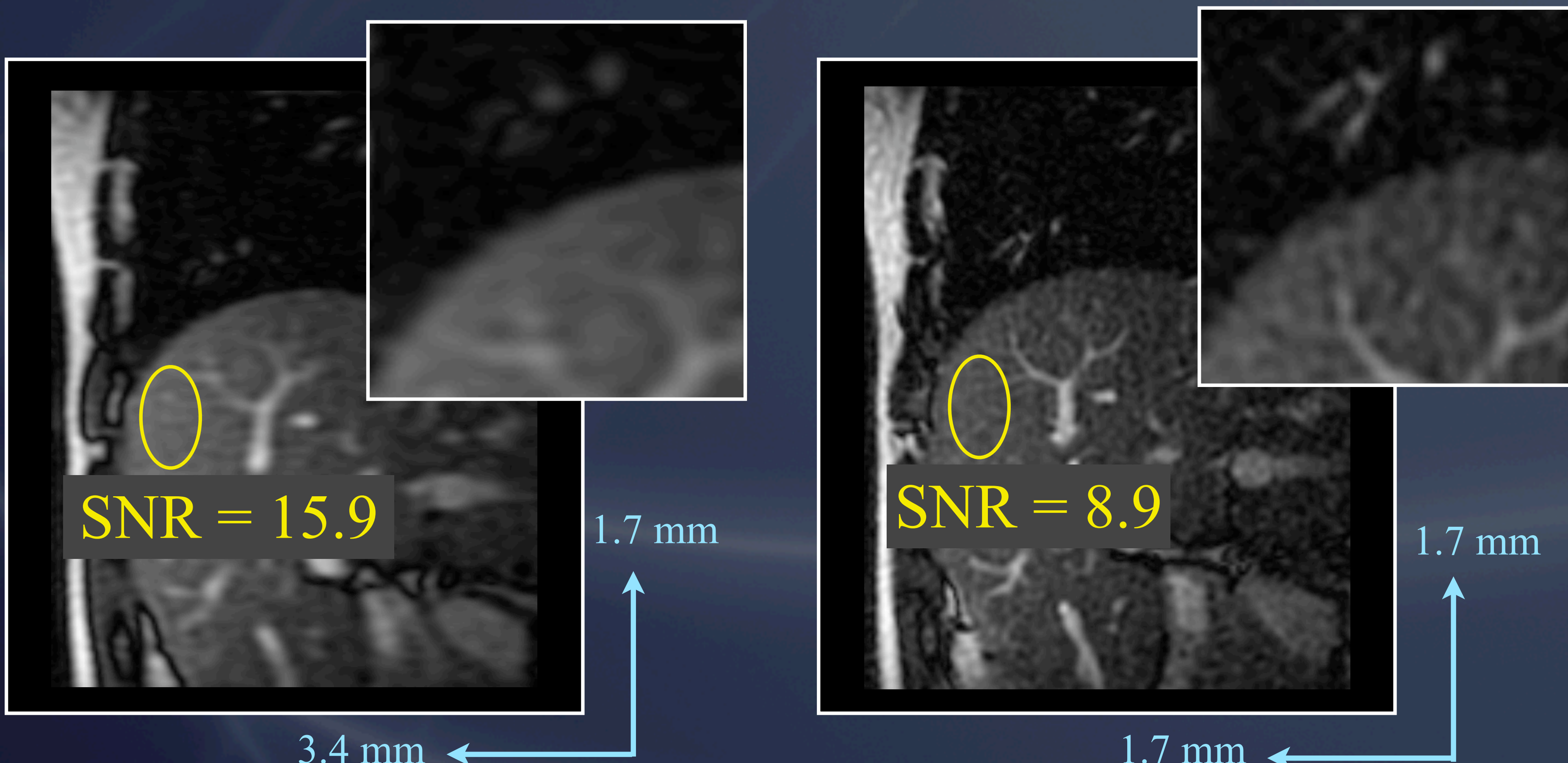
$T_{scan} = 0.24$ s

$T_{scan} = 0.14$ s

SNR is proportional to √scan time

Imaging Consideration 2: SNR

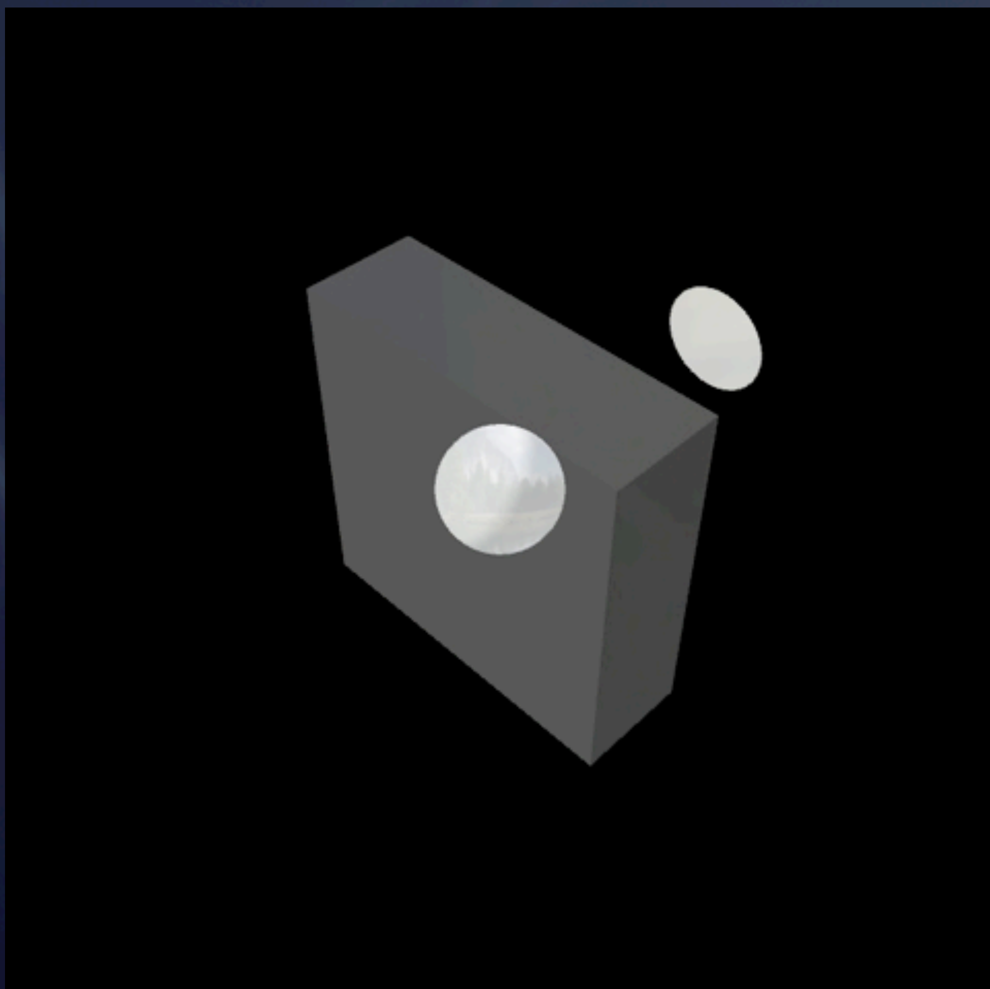
$$SNR \propto B_0 \underline{\Delta x \Delta y \Delta z} \sqrt{T_{scan}}$$



— T_{scan} = 0.24 s —

Improvements in resolution cost us in SNR.
This can reduce our edge detection capabilities.

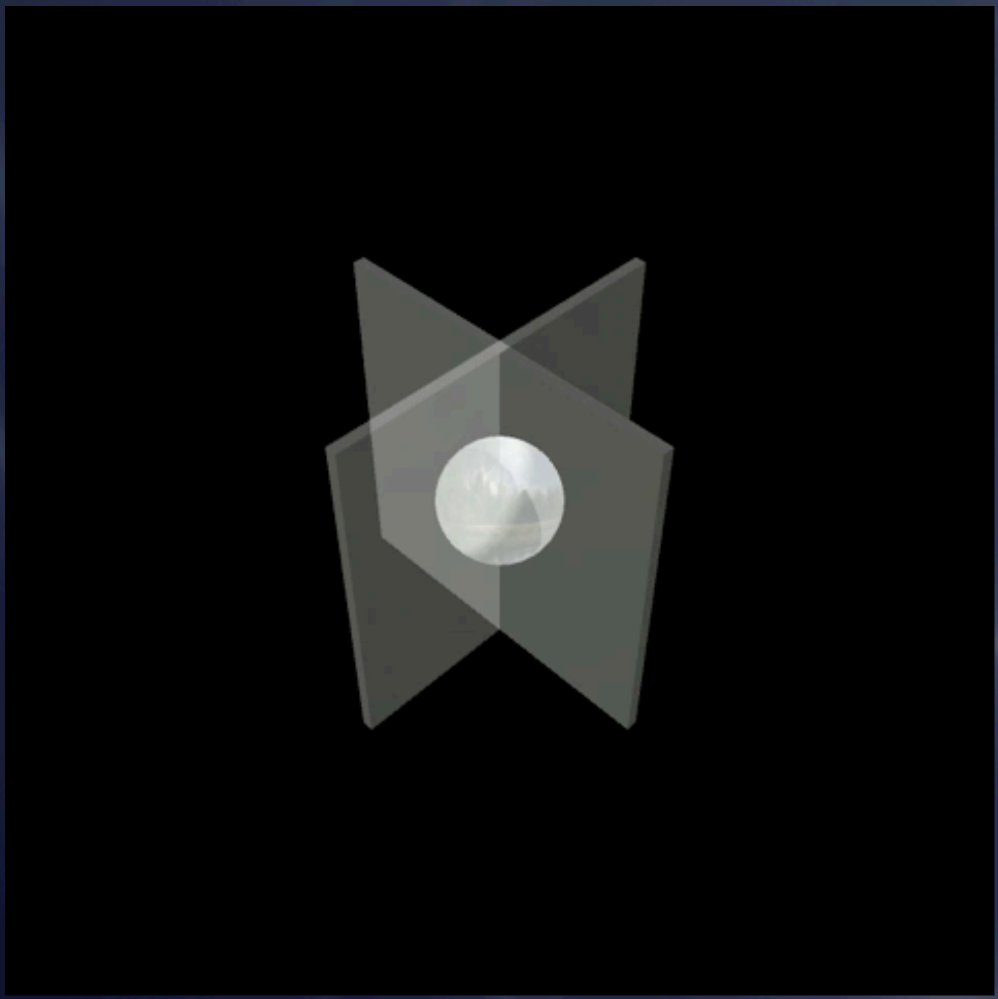
Imaging Strategies

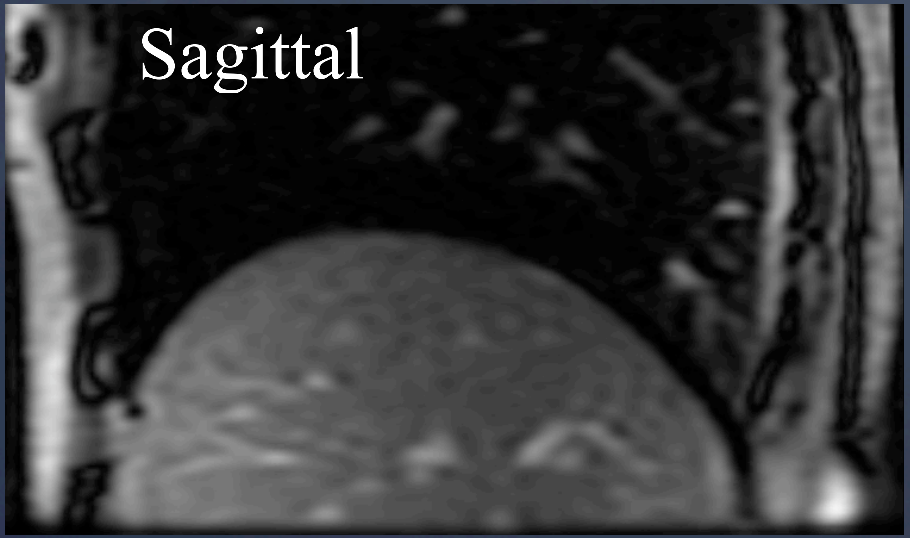


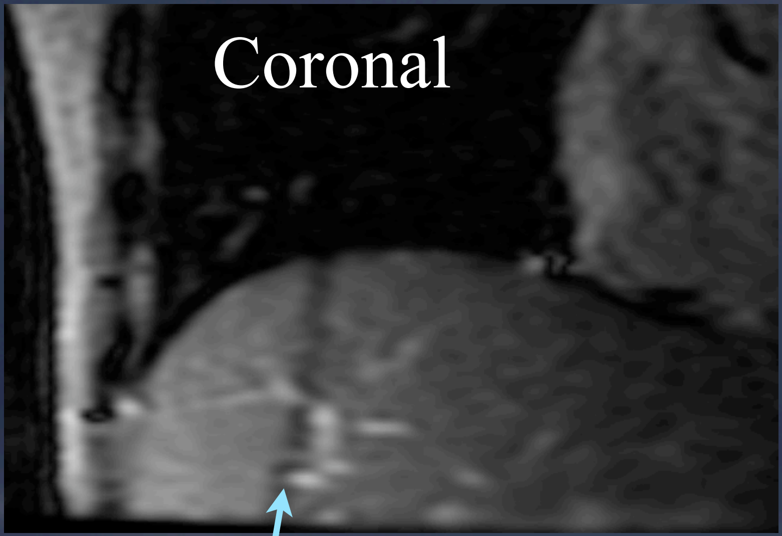
- Currently capable
- Real time
- Simple

Two Orthogonal Scan Planes

More motion information needed?





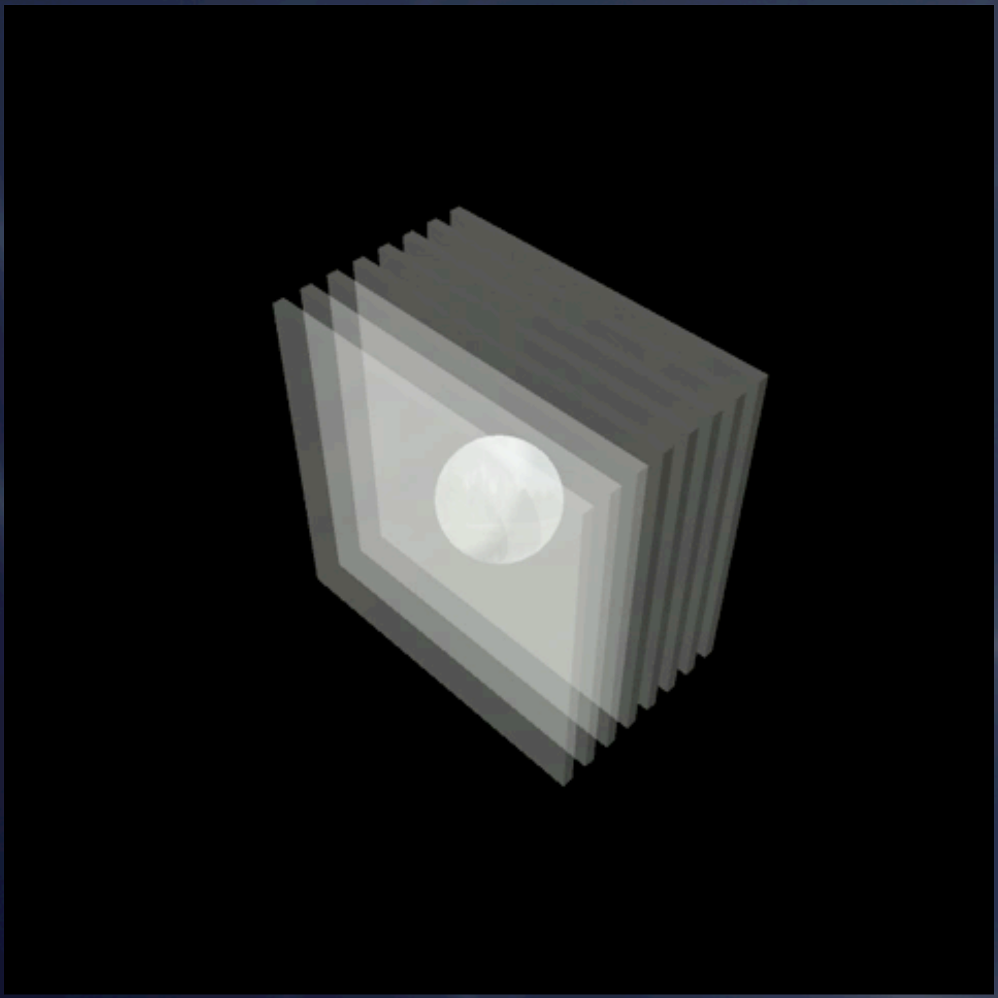


Saturation from sagittal slice

- Currently capable

2D vs 3D?

Even more motion information needed?

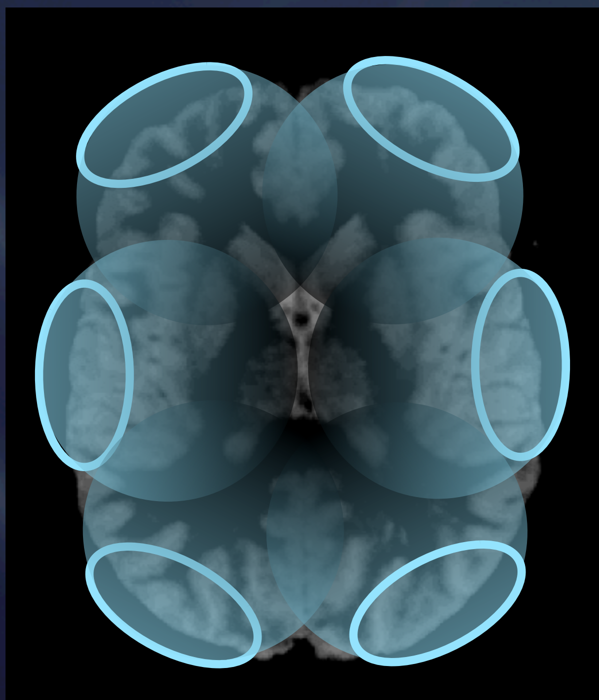


T_{scan} is increased by at least a factor of 8.

Motion Blur!

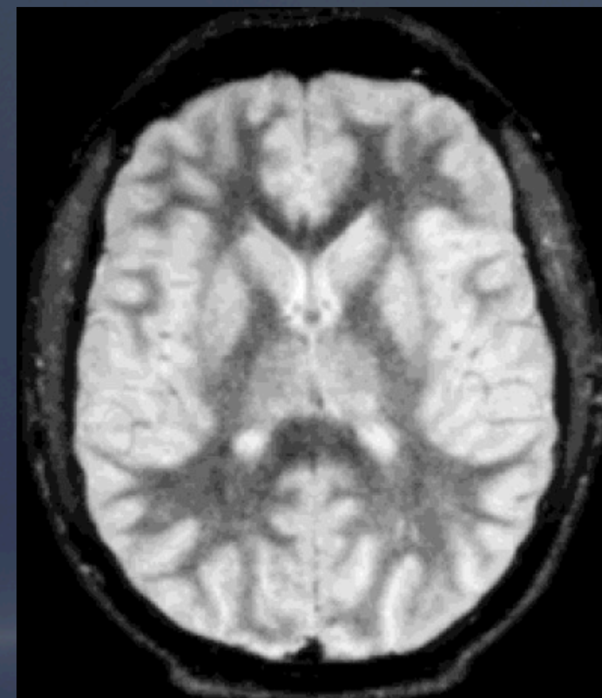
Unless we can decrease T_{scan} by 4-fold to get to our desired $T_{scan} \leq 280$ ms.

Add in Parallel Imaging



The coil sensitivity provides extra information...

...that is used to unwrapped an undersampled image.

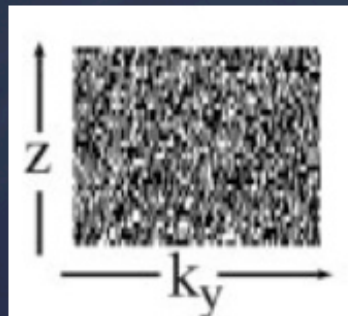


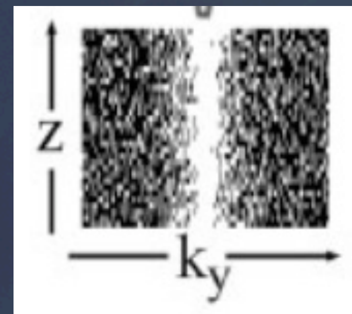
Essentially trade SNR for scan time.

Pruessmann K, et a., SENSE: Sensitivity Encoding for Fast MRI, MRM 1999

With compressed sensing, *k space* is undersampled.

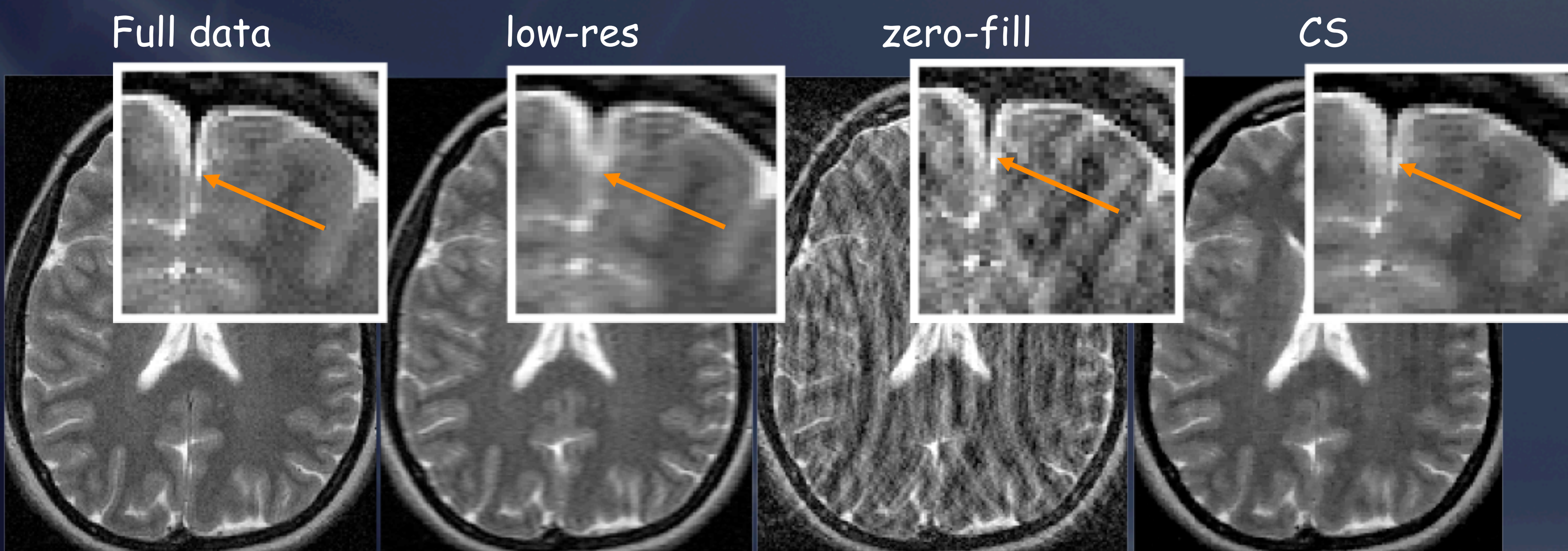
random undersampling





random undersampling proportional to the power spectrum

- Scan reduction: x2.4



Lustig M, Sparse MRI: The Application of Compressed Sensing, MRM, 58:p1182 2007

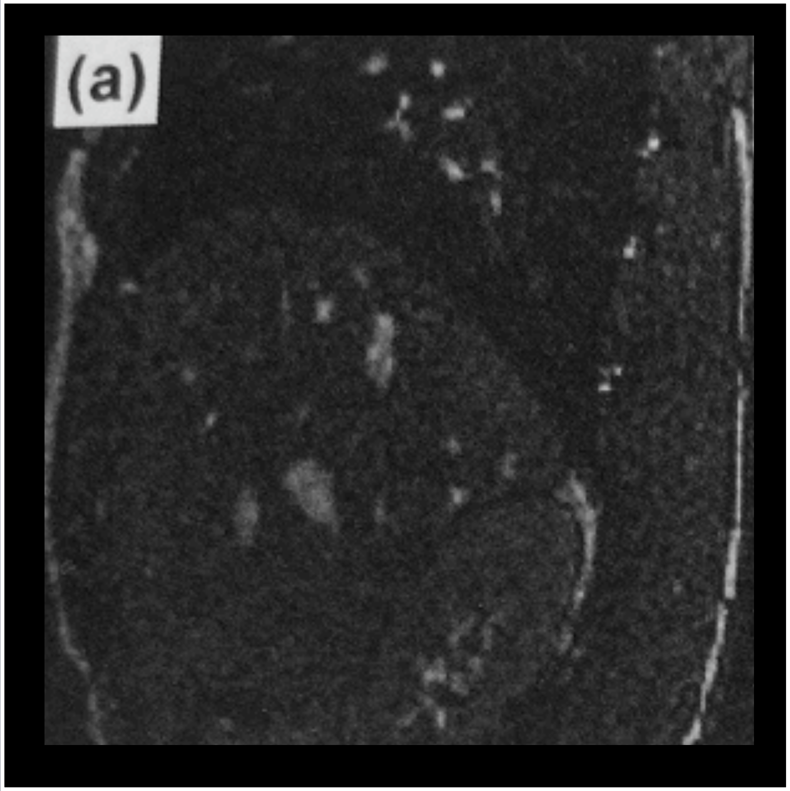
Add in Parallel Imaging and Compressed Sensing

$$SNR \propto B_0 \, \Delta x \Delta y \Delta z \, \sqrt{T_{scan} \; 8 \; \frac{1}{8}}$$

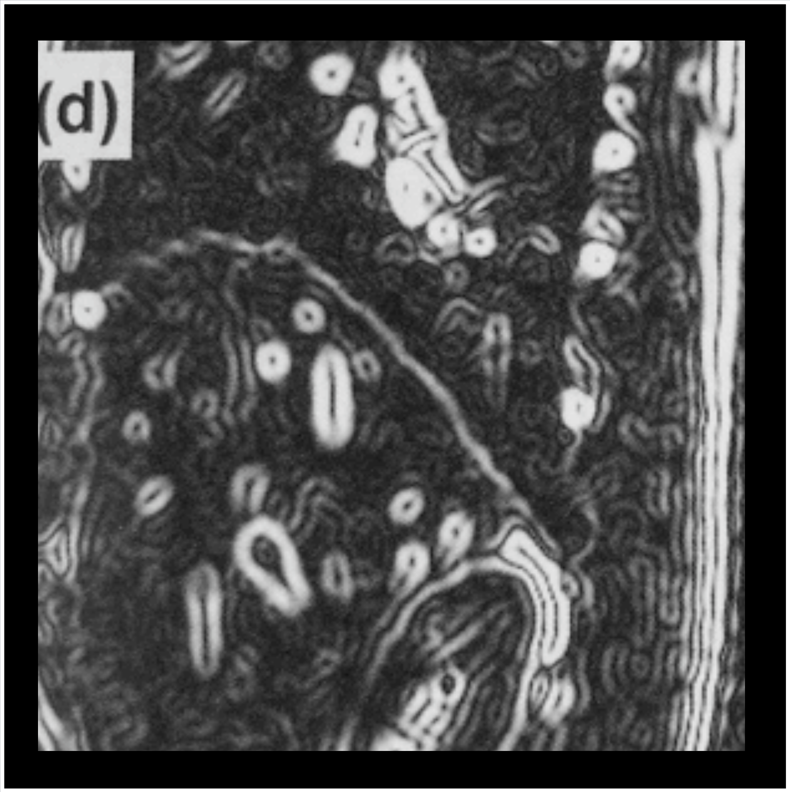
- T_{scan} increase by 8 (8 slices)
- T_{scan} decrease by 4 (combination of PI and CS), plus some additional losses (gfactor and CS)

=> 3D, same scan time, same SNR

Let's think out of the box



Conventional
bSSFP



High Spatial
Frequencies Only

Kuroda K, A Target Tracking Technique... Thermal Medicine 23(4) Dec 2007 p181.
Sawant A, Real-Time Imaging Strategies, AAPM, Tuesday

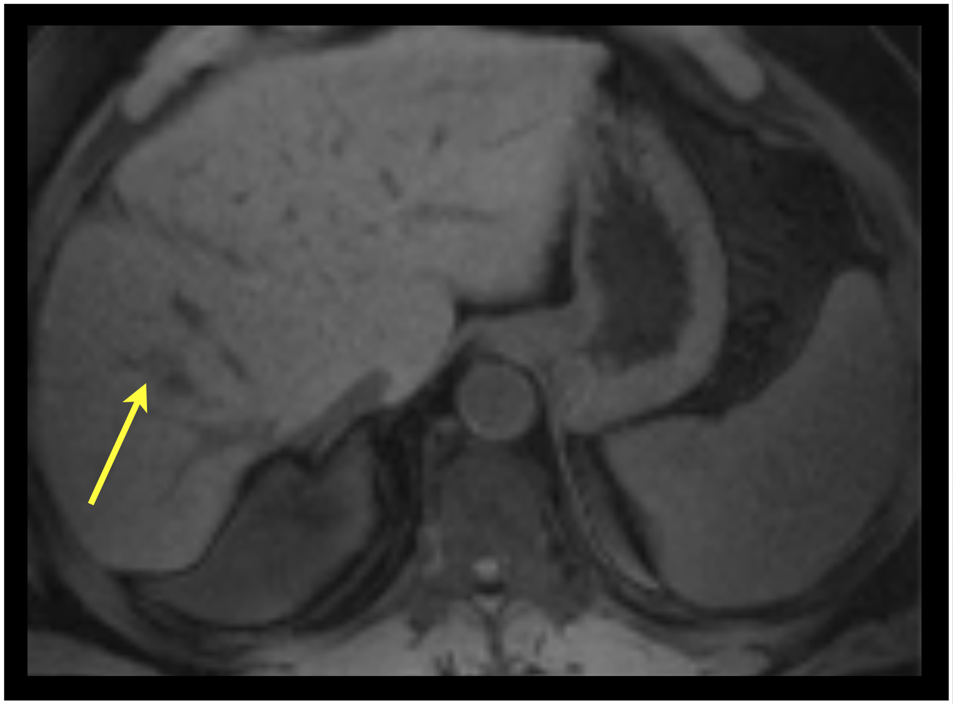
Lung Tumors

Relatively straightforward from an imaging standpoint: Tumor against a low signal background.

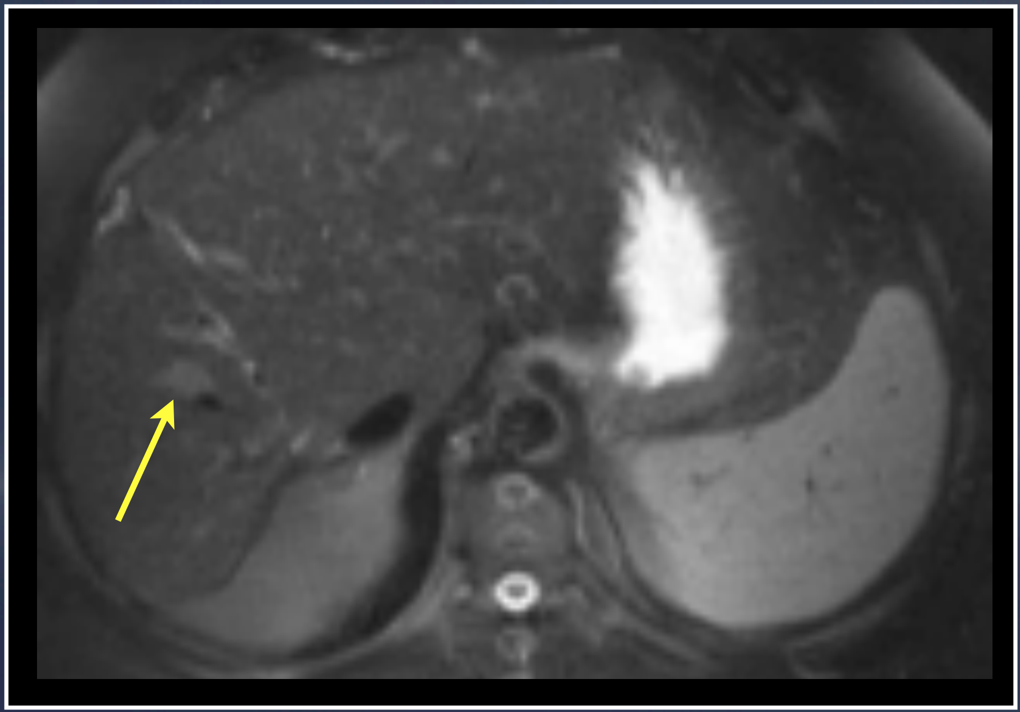
Hatabu et al. MR imaging of pulmonary parenchyma... Eur J Radiol, 1999

Liver Tumors

All of the above requirements hold, plus need to think about contrast against a tissue background.



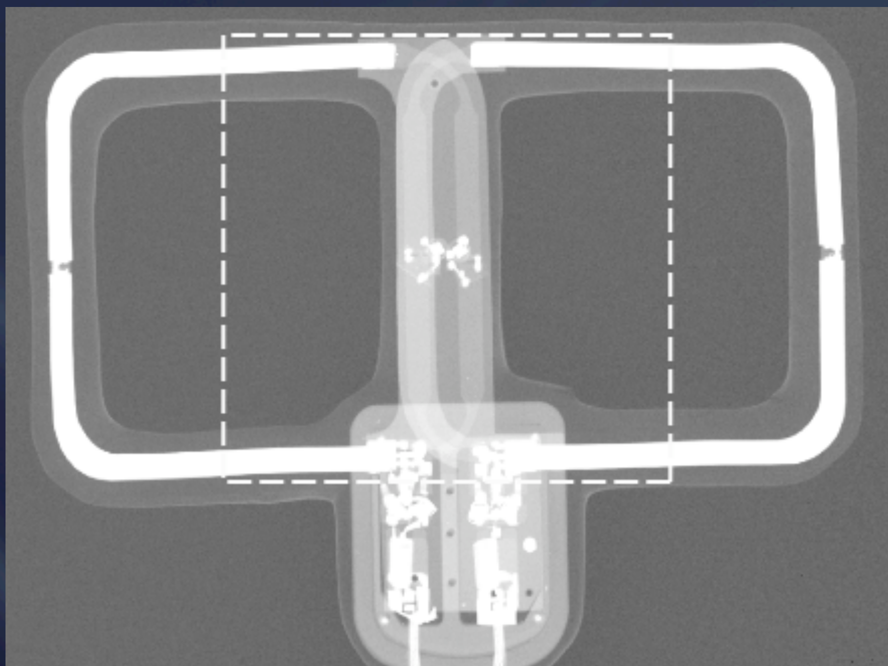
T1



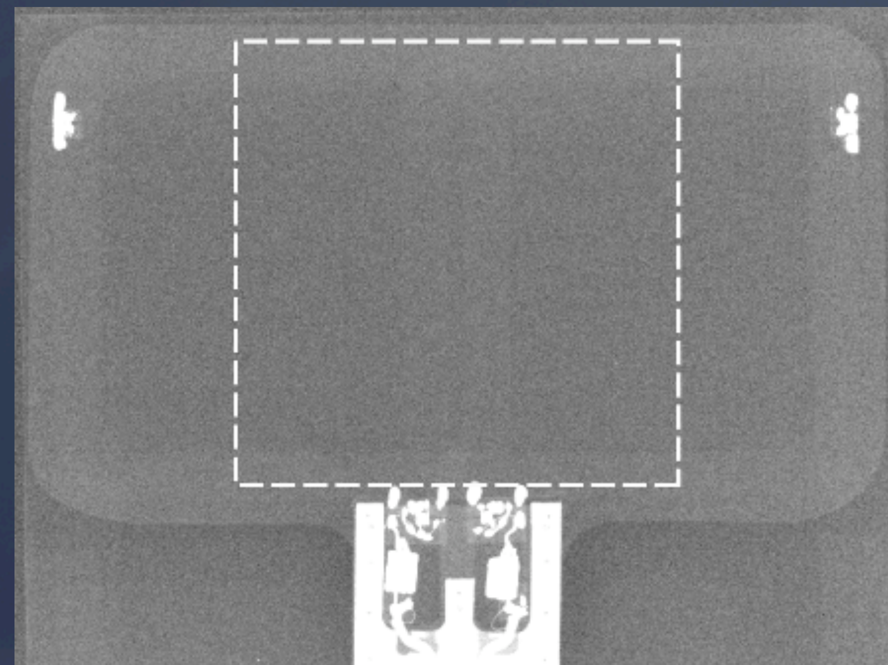
T2

Digumarthy et al., MRI in detection of hepatocellular carcinoma (HCC), Cancer Imaging. 2005; 5(1): 20–24

Radiation Transparent RF Coils



Conventional PA Coil



X-ray Compatible PA Coil

- 4 - channel phased array for abdominal imaging
- only low x-ray attenuating material in beam path
  - loop capacitors to be placed outside beam path or moved into detuning circuit
  - detuning circuit outside beam path

Rieke V, Butts K, et al. X-ray compatible RF coil... MRM 2005

Summary

Real-time MRI monitoring for radiotherapy guidance is doable on current imaging systems: 1.5T cylindrical system.

Need to investigate the role of noise:
- impact of noise on accuracy of lesion tracking
- how low a magnetic field can we use

Acknowledgements

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