


# Dimensionality in MRI





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## 2D Imaging

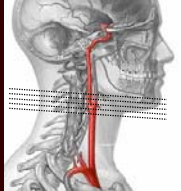
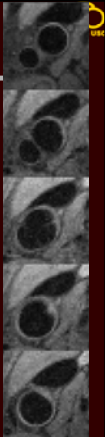
- A thin slice is excited
- Two spatial dimensions ( $x,y$ ) are acquired
- Acquired space:  $k_x, k_y$

brain                      knee

## Multi-slice 2D imaging


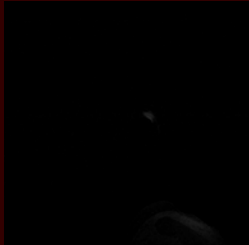
- Multiple slices are excited
- Two spatial dimensions ( $x,y$ ) are acquired for each slice
- Acquired space:  $k_x, k_y, z$

carotid bifurcation (neck)

## Multi-slice 2D imaging

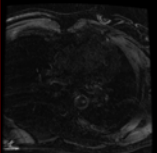
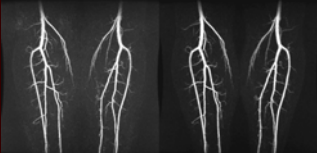
- Other example

brain vasculature

## 3D Imaging

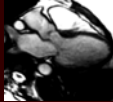

- A thick slice is excited
- Three spatial dimensions ( $x,y,z$ ) are acquired
- Acquired space:  $k_x, k_y, k_z$

coronary artery (heart)                      angiography (legs)

## Time-resolved 2D

- Thin slice, 2D acquisition
- Dimensions:  $k_x, k_y, t$
- Cine x real-time

cardiac (cine)                      USC    SPAN  
vocal tract (real-time)

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## Time-resolved multi-slice 2D

- Multiple thin slices, 2D acquisitions
- Cine acquisitions
- Dimensions:  $k_x, k_y, z, t$

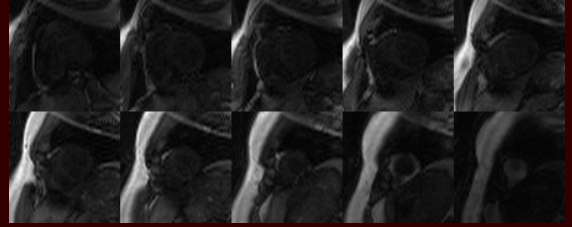


left-ventricle (heart)

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## Time-resolved 3D

- Thick slice, 3D acquisitions
- Cine acquisitions
- Dimensions:  $k_x, k_y, k_z, t$

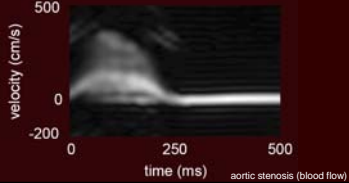


myocardial perfusion (heart)

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## Velocity-encoded MRI (FVE)

- Thin slice, two spatial dimensions ( $x, y$ )
- Velocity distribution ( $v$ )
- Temporal dimension ( $t$ )
- Acquired data:  $k_x, k_y, k_v, t$

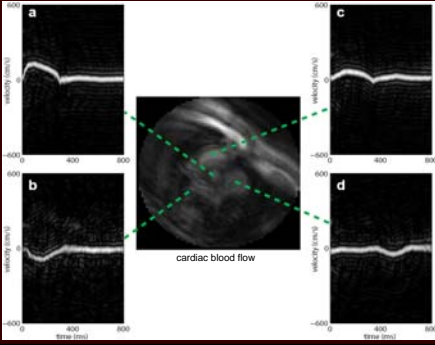


velocity (cm/s)

time (ms) aortic stenosis (blood flow)

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## Velocity-encoded MRI



cardiac blood flow

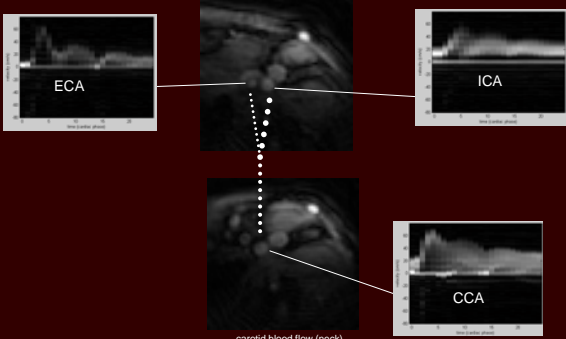
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## Multi-slice or 3D FVE

- Multi-slice FVE
  - Multiple thin slices, two spatial dimensions ( $x, y$ )
  - Acquired data:  $k_x, k_y, k_v, z, t$
- 3D FVE
  - Thick slice, three spatial dimensions ( $x, y, z$ )
  - Acquired data:  $k_x, k_y, k_z, k_v, t$

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## Multi-slice FVE



ECA

ICA

CCA

carotid blood flow (neck)

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## 7D Flow

- Thick slice, 3D imaging ( $x, y, z$ )
- Temporally resolved
- 3D velocity encoding ( $v_x, v_y, v_z$ )

velocity [m/s]  
0.75  
0.56  
0.38  
0.19  
0.00

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## Dimensionality facts

- Increased dimensionality typically implies longer scan times
- SNR is typically higher in high-dimensional imaging
- Higher acceleration factors can be achieved

Kozzerke MRM 52:19, 2004  
Carvalho ISMRM 15:588, 2007  
Lustig MRM 58:1182, 2007  
Gamper MRM 59:365, 2008

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## Compressed Sensing in MRI

- The more dimensions, the more sparse
- Readout direction ( $x$ ) not undersampled
- 2D images
  - Perturbed spirals, 2D wavelet transform along  $x, y^1$
  - Variable-density spirals, 2D total variation<sup>2</sup>
- Multi-slice or 3DFT<sup>3</sup>
  - 2D wavelet transform along  $y, z$
- Time-resolved 2D<sup>4,5</sup>
  - Fourier transform along  $t$
- Velocity-encoded (FVE)<sup>5</sup>
  - Fourier transform along  $t$

[1] Lustig ISMRM 13:685, 2005  
[2] Kim ISMRM 16:422, 2008  
[3] Lustig MRM 58:1182, 2007  
[4] Lustig ISMRM 14:2420, 2006  
[5] Gamper MRM 59:365, 2008

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## CS-MRI: never demonstrated

- Time-resolved multi-slice or 3D ( $x, y, z, t$ )
- Stack-of-spirals 3D ( $x, y, z$ )
- Time-resolved stack-of-spirals ( $x, y, z, t$ )
- Multi-slice or 3D FVE ( $x, y, z, v, t$ )
- Spiral FVE ( $x, y, v, t$ )
- Multi-slice or 3D spiral FVE ( $x, y, z, v, t$ )

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## CS-MRI: reconstruction time

- Highest dimensional CS demonstrated:
  - Velocity-encoded (FVE):  $x, y, v, t$  Gamper MRM 59:365, 2008
- Non-Cartesian FT is slow
  - Stack-of-spirals
  - Spiral FVE
- Cartesian is faster (FFT)
  - Time-resolved multi-slice or 3D ( $x, y, z, t$ )
  - Multi-slice or 3D FVE ( $x, y, z, v, t$ )

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## Acknowledgement

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  - Taehoon Shin (perfusion)
  - Erik Bresch (vocal tract)
  - Joao Carvalho (velocity-encoded)
  - Michael Markl (7D flow)
  - Google Images (other)

**The End**



**<http://mrel.usc.edu>**

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