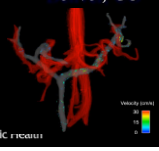
Development and Clinical Applications of Time-Resolved Magnetic Resonance Angiography

Thomas M. Grist, MD, FACR
ICRU Gray Symposium
AAPM 2017
Denver, CO

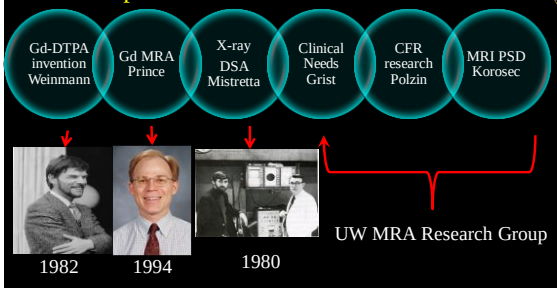


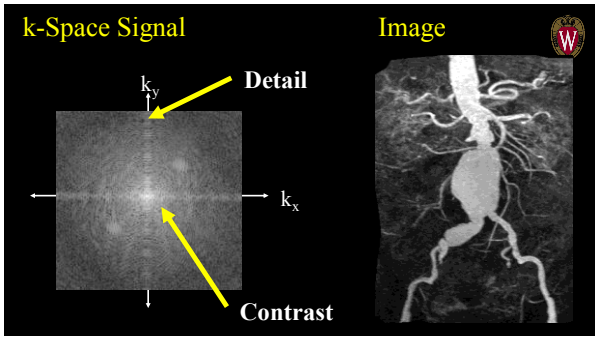
DEPARTMENT OF RADIOLOGY
University of Wisconsin
School of Medicine and Public Health

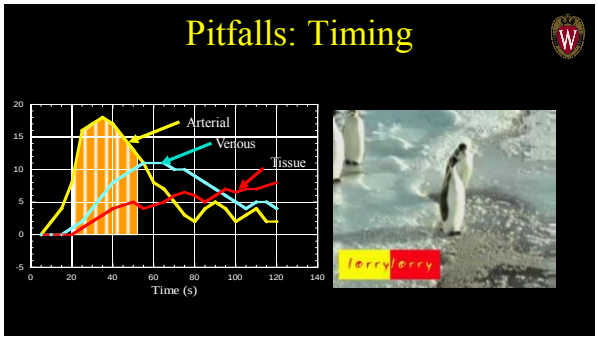
Objectives and Outline

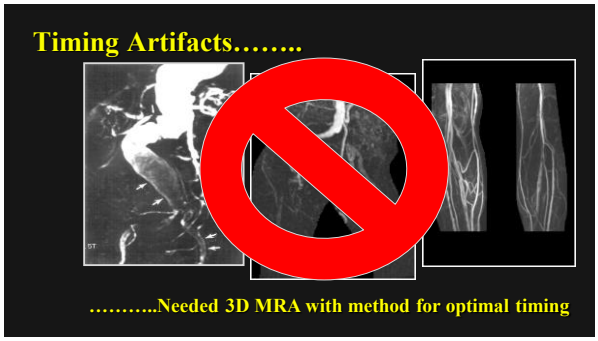
- Objectives:
  - Share some key developments in MRA conceived by Chuck Mistretta, PhD
  - Describe the clinical impact of the innovations
- Part 1: Time-resolved MRA during passage of contrast
- Part 2: Time-resolved MRA during cardiac cycle

Development of the MRA version of DSA

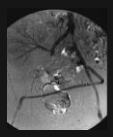


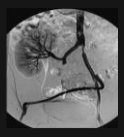

k-Space Signal
Image
k_y
Detail
k_x
Contrast


Pitfalls: Timing
Arterial
Venous
Tissue
Time (s)
20
15
10
5
0
-5
0
20
40
60
80
100
120
140
larry larry


Timing Artifacts……..
……..Needed 3D MRA with method for optimal timing

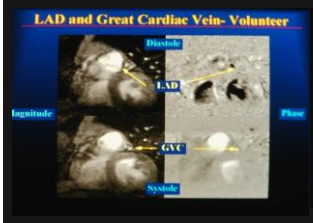
Mistretta and Crummy: Digital Subtraction Angiography (DSA)

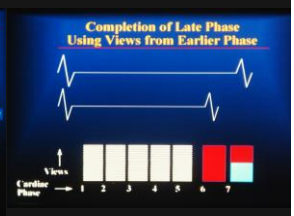




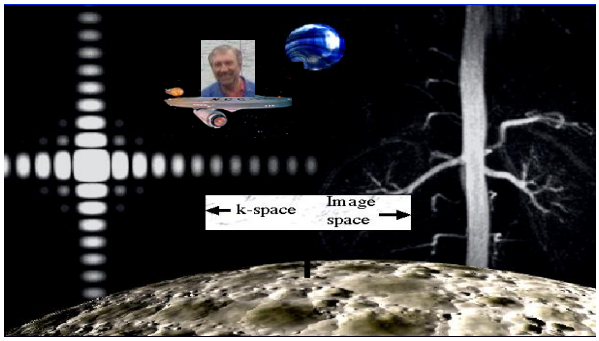
IV DSA IA DSA

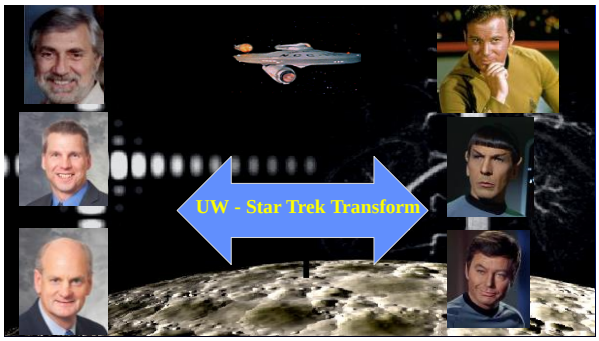
Coronary Flow and Flow Reserve by 2D PC

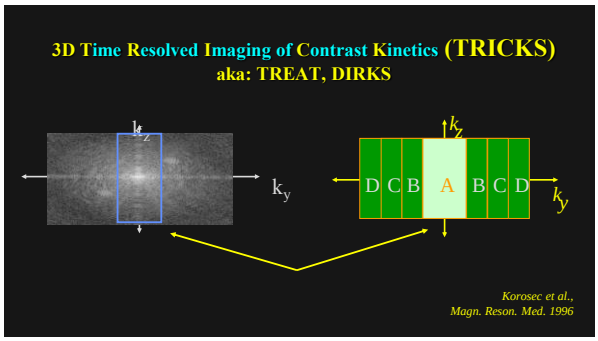


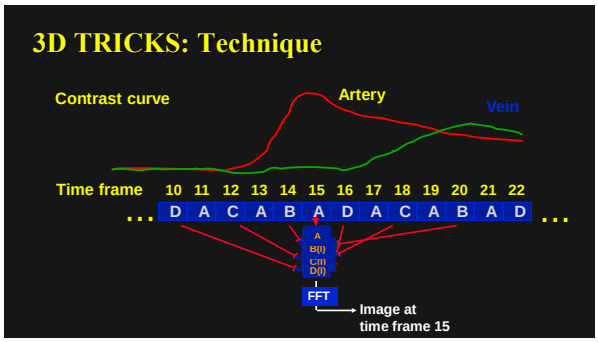


Grist TM, Polzin JA, Bianco JA, Foo TKF, Bernstein MA, Mistretta CM
Measurement of Coronary Blood Flow and Flow Reserve Using Magnetic Resonance Imaging
Cardiology 1997 88, (1),

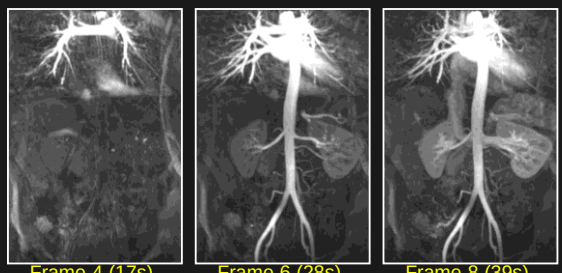



UW - Star Trek Transform

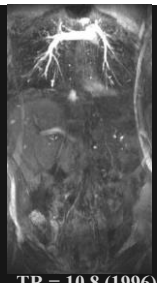

3D Time Resolved Imaging of Contrast Kinetics (TRICKS)
aka: TREAT, DIRKS
k_z
k_y
D C B A B C D
k_z
k_y
Korosec et al.,
Magn. Reson. Med. 1996


3D TRICKS: Technique
Contrast curve
Artery
Vein
Time frame 10 11 12 13 14 15 16 17 18 19 20 21 22
... D A C A B A D A C A B A D ...
A
B(t)
C(t)
D(t)
FFT
Image at
time frame 15

TRICKs – Time-Resolved CE 3D MRA



Frame 4 (17s) Frame 6 (28s) Frame 8 (39s)



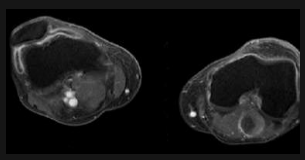
3D TRICKS
Korosec et al
Mag Res Med
1996

TR = 10.8 (1996) 512 x 128 x16 Frame Time 5.6 s

Reconstruction: 6 hours + 1 graduate student

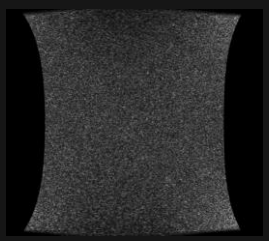
Time resolved digital vascular imaging

Benefits of time-resolved imaging

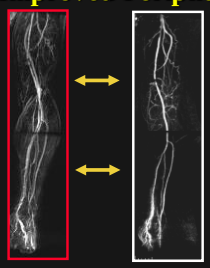


Left Popliteal Occlusion

Benefits of time-resolved imaging



Improved Peripheral MRA



Smartstep

TRICKS

- Significantly more arteries diagnostic with TRICKS
- Significantly more venous contamination with moving SmartStep in lower station
- n=20, $p < 0.05$

Hany TF, et al
Radiology 2001;221:266-272.

TRICKS: Peripheral MRA

Accuracy:

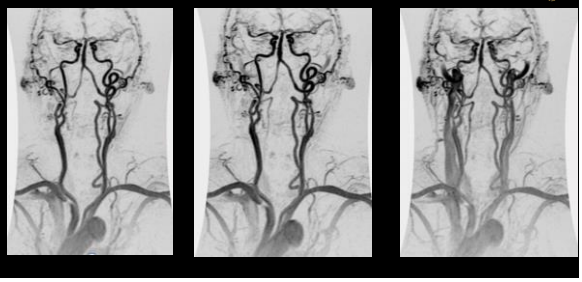
SN = 93%

SP = 86%

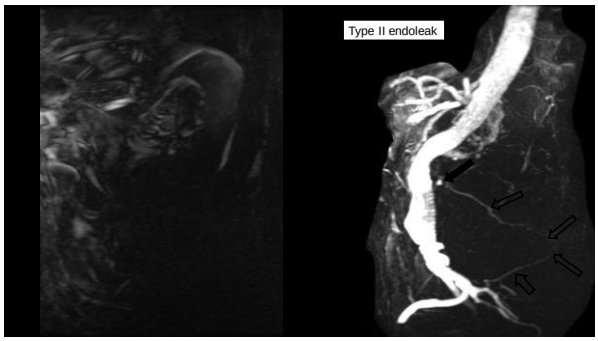
n = 68

Swan JS, et al
Radiology 2002
225; 435-52

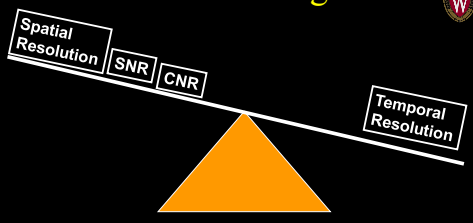
70 y/o had fainting spell while welding overhead



"Subclavian Steal" Syndrome

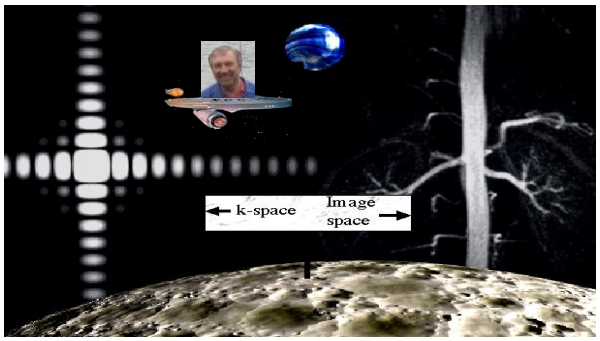


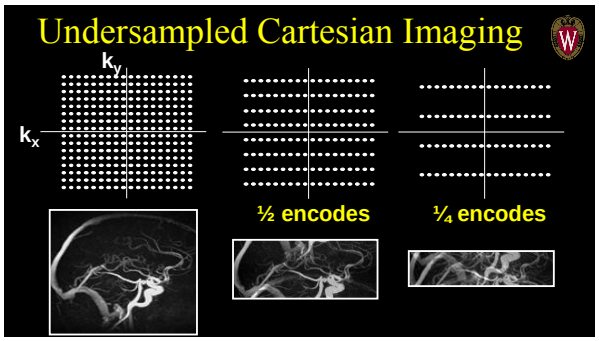
MRA Remains A Balancing Act

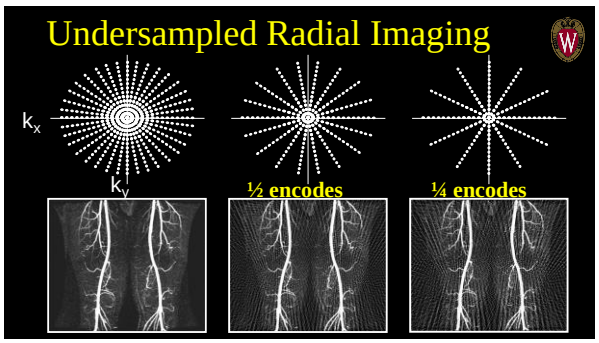


→ k-space sampling and image reconstruction strategies help to achieve high spatial resolution time-resolved MR angiograms.

Innovating at the UW Fishing Meeting


k-space
Image space

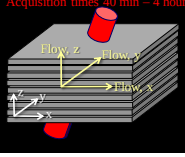

Undersampled Cartesian Imaging
k_y
k_x
½ encodes
¼ encodes

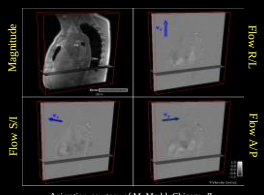

Undersampled Radial Imaging
k_x
k_y
½ encodes
¼ encodes

Time-resolved 3-dimensional 3-directional Velocity-encoded MRI

Acquisition:

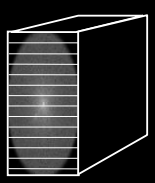
- Volumetric coverage with conventional cartesian encoding
- 3-directional flow encoding
- ECG gating
- Respiratory correction
- Clinically Impractical
  - Acquisition times 40 min – 4 hours



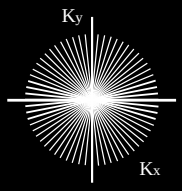


Animation courtesy of M. Markl, Chicago, IL

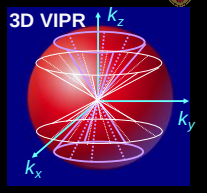
3D RADIAL ACQUISITIONS



Cartesian



Radial - SOS

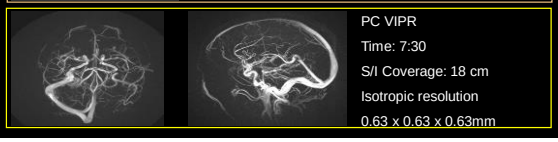


Barger AV et al. Time-resolved contrast-enhanced imaging with isotropic resolution and broad coverage using an undersampled 3D projection trajectory. Magn Reson Med, 2002; 48: 297–305.

PC VIPR vs 3D Cartesian PC

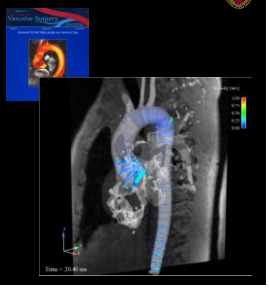
Acceleration Factor 30 With Contrast

Cartesian 3D PC
Time: 7:22
S/I Coverage: 4 cm
Through-plane resolution 2mm
0.94 x 0.94mm



PC VIPR
Time: 7:30
S/I Coverage: 18 cm
Isotropic resolution
0.63 x 0.63 x 0.63mm

4D Flow: Visualization



Too much data?

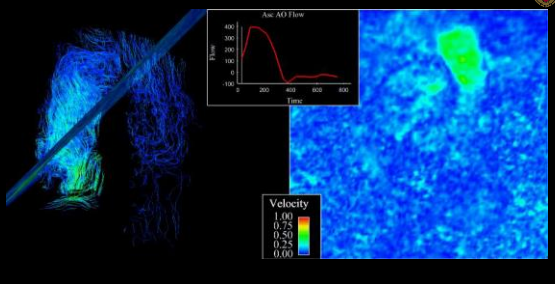
Need for advanced visualization.

Animation courtesy of M. Markl PhD, Freiburg, and Chicago, IL

- Patient presents with persistent pain despite HTN treatment
- MRA Flow analysis for further evaluation

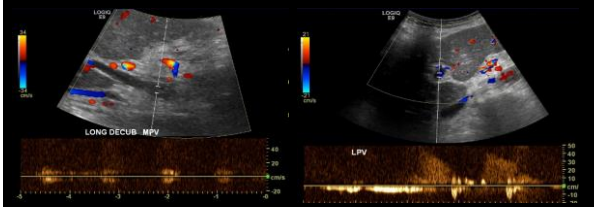
Cases – Thoracic

PC VIPR acute aortic dissection



66 yo F with portal HTN

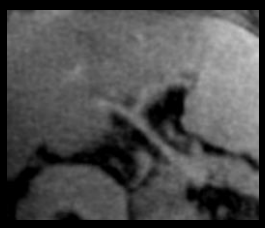
- No flow in MPV - ? thrombus
- Reversed flow in LPV



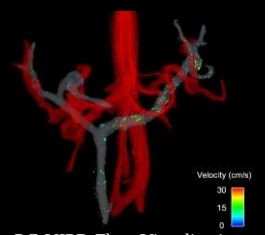
66 yo F with portal HTN

- Stomal varices draining from SMV
- Patent portal vein (no thrombus)

66 yo F with portal HTN



PC-VIPR Magnitude

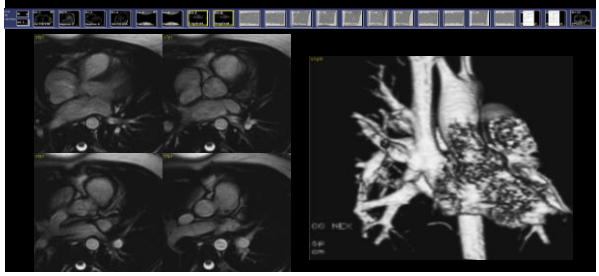


PC-VIPR Flow Visualization

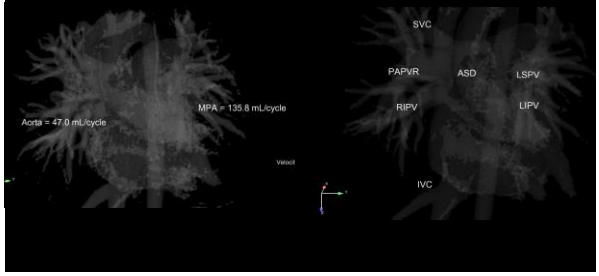
PAPVR: Value of MRI with 4D flow

- Chest pain, dizziness.
- Right sided cardiac enlargement
- History of palpitations.
- Patient had TEE which showed possible shunt.

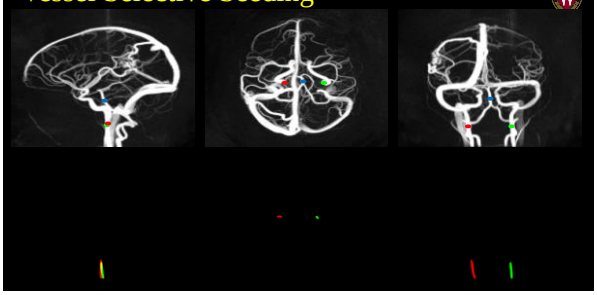
PAPVR: Value of MRI with 4D flow



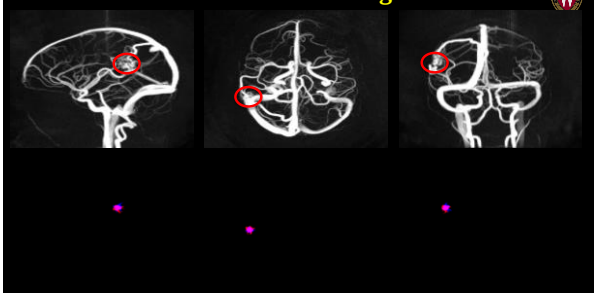
PAPVR: Value of MRI with 4D flow



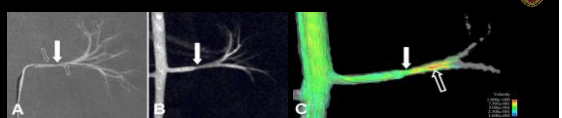
Vessel Selective Seeding

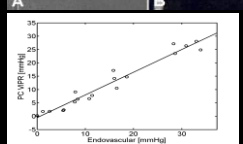


Patient with AVM: Nidus seeding + Reverse



4D Flow: Quantitative Hemodynamics





$$\nabla P = -\rho \frac{\partial \vec{V}}{\partial t} + (\vec{V} \bullet \nabla)\vec{V} + \rho \vec{g} + \mu \nabla^2 \vec{V}$$

Pearson Correlation

r = 0.977; p < 0.001

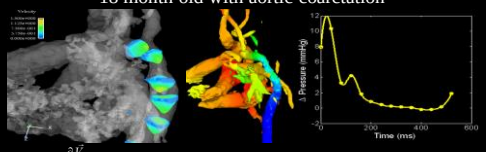
95% CI: 0.939- 0.991

Animal model of renal artery stenosis[1]

[1]Bley TA, et al. Radiology 2011

Quantitative flow analysis: Measuring pressure gradient

18 month old with aortic coarctation



$$\nabla P = -\rho \frac{\partial \vec{V}}{\partial t} + (\vec{V} \bullet \nabla)\vec{V} + \rho \vec{g} + \mu \nabla^2 \vec{V}$$

P = pressure **V = velocity**

μ = viscosity (centipoise) **g = gravitation**

ρ = density kg/m^3

Summary: Time-resolved MRA

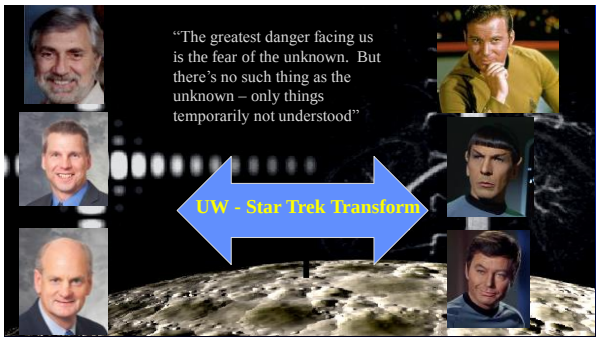
- Time-resolved MRA during contrast passage
  - "Can't miss" approach to timing
  - Window into functional significance of stenosis
- Time-resolved during cardiac cycle
  - Clinically practical using under-sampling
  - Demonstrates complex flow patterns
  - Provides quantitative hemodynamics

1. Michael Ort, M.D., Ph.D. – 1975
2. Frederick Kelcz, M.D., Ph.D. – 1976
3. Robert Kruger, Ph.D. – 1978
4. Willi Kalendar, Ph.D. – 1979
5. Stephen Riederer, Ph.D. – 1979
6. ChorngGang Shaw, Ph.D. - 1981
7. David Ergun, Ph.D. - 1982
8. Michael Van Lysel, Ph.D. - 1983
9. Bruce Hasegawa, Ph.D. – 1984
10. James Dobbins III, Ph.D. - 1985
11. Ching-Shan Lee, Ph.D. - 1986
12. Shaikh Naimuddin, Ph.D. – 1986
13. Sabee Molloi, Ph.D. - 1987
14. Nick Hangiandreou, Ph.D. - 1990
15. David Weber, Ph.D. - 1990
16. Cynthia Mc Collough, Ph.D. - 1991
17. Frank Korosec, Ph.D. – 1991
18. Frank Zink, Ph.D. - 1992
19. Yi Wang, Ph.D. - 1994

Mistretta's Impact

Trainees!

What impact have they had, and what will they do in the future?


"The greatest danger facing us is the fear of the unknown. But there's no such thing as the unknown – only things temporarily not understood"
UW - Star Trek Transform