Historical Developments in Time-Resolved Angiography

Chuck MIstretta
The University of Wisconsin-Madison

1971 Job Interview with John Cameron

Chuck What did you do at for a high energy physics thesis at Harvard?

I measured the radius of the pi meson using electron-proton Scattering

Would you be interested in medical imaging?

What is that?

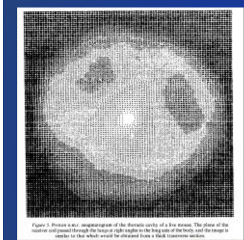
Its X-ray-people scattering

I might be able to do that

Johns advice on how to streamline my teaching career

"Chuck - Give the same final exam each year, just change the answers."

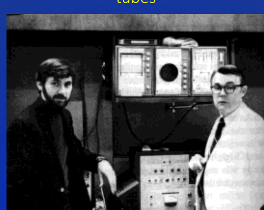
Lauterbur Visit To Madison 1973



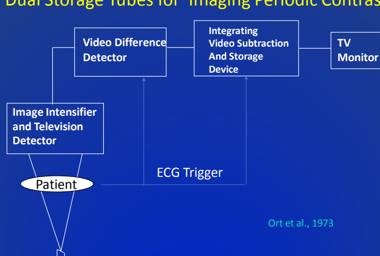
Paul This looks interesting. Perhaps you should pursue it

Chuck Mistretta and Andy Crummy circa 1971

Vascular roadmapping using silicon target storage tubes

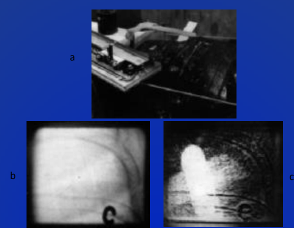


Dual Storage Tubes for Imaging Periodic Contrast



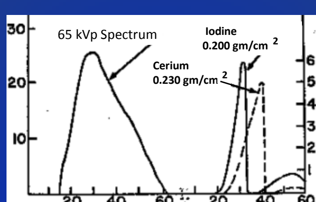
Ort et al., 1973

Enhancement of Periodic Contrast Using Dual Storage Tube Signal Averaging



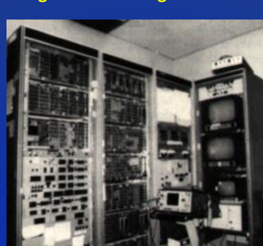
M. Ort Ph.D. Thesis U. of Wisconsin 1973

Formation of Quasi-Monoenergetic Beams Using Filtration



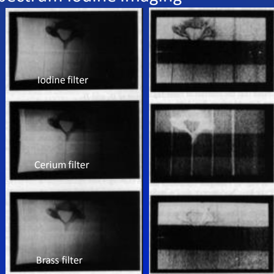
Ort et al. 1973

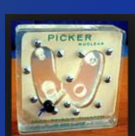
Real Time Digital Video Image Processor --1976



Memory -- 0.25 megabytes

Simultaneous Cancellation of Bone and Soft Tissue in 3-Spectrum Iodine Imaging



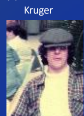


Hounsfield 1971

1973 Article On Generalized Subtraction Imaging

Mistretta C.A. The use of a general description of the radiological transmission image for categorizing imaging enhancement procedures. *Optical Engineering* 13(2):134; 1974.

Kruger



Kalender

Riederer

Pelc

Five Hits

Mom

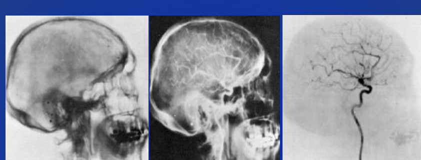
Taylor Expansion of X-ray Transmission Image

$I(x, y,z,E,t) - I(x + \Delta x, y + \Delta y,z + \Delta z,E + \Delta E,t + \Delta t) =$

$(dI /dx)^* \Delta x + (dI /dy)^* \Delta y$	
$+(dI /dE)^* \Delta E$	*dual energy*
$+(dI /dt)\ \Delta t$	*DSA*
$(dI /dz)\ \Delta z$	*CT*
$+(d^2I/dEdz)\Delta E\Delta t$	dual energy CT
$+ (d^2I /dEdt)\ \Delta E\Delta t$	dual energy DSA (Brody)
$+ (d^2I /dzdt)\Delta z\Delta t$	CTA, 4D DSA
$+ (d^3I /dEdzdt)\ \Delta E\Delta t\Delta z$	dual energy 4D DSA

Film Subtraction Angiography

Ziedses des Plantes Circa 1930

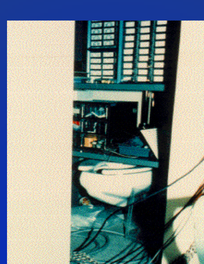


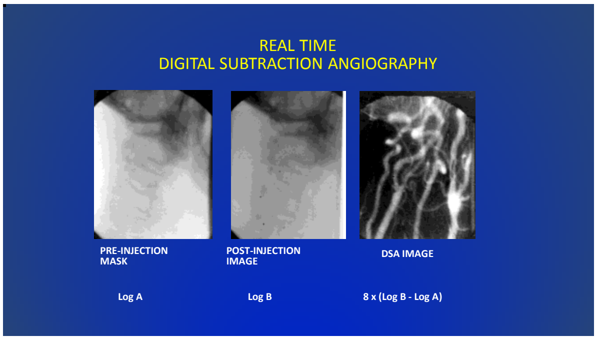
Negative of Pre - Contrast Film

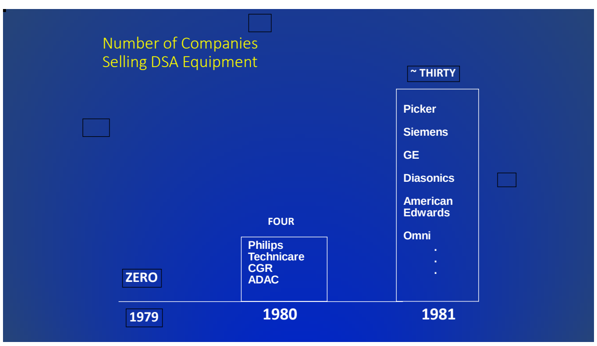
Post - Contrast Positive Film

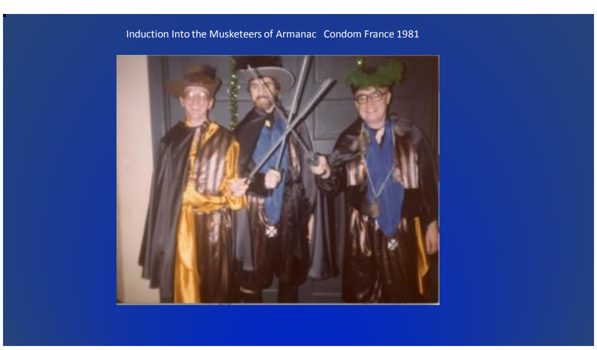
Subtraction Film

View from DVIP Console at New Location in UW Hospital

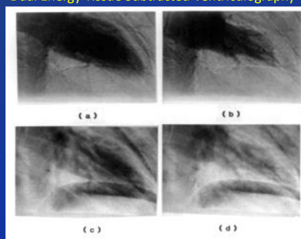



REAL TIME
DIGITAL SUBTRACTION ANGIOGRAPHY
PRE-INJECTION MASK
POST-INJECTION IMAGE
DSA IMAGE
Log A
Log B
8 x (Log B - Log A)


Number of Companies
Selling DSA Equipment
~ THIRTY
Picker
Siemens
GE
Diasonics
American Edwards
Omni
FOUR
Philips
Technicare
CGR
ADAC
ZERO
1979
1980
1981


Induction Into the Musketeers of Armanac Condom France 1981

Dual Energy Tissue Subtracted Ventriculography



Dual Energy DSA

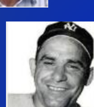
Conventional DSA

Implemented on Philips system. Energy switched between 60 and 120 Kvp at 60 Hz

Molloi S.Y., Mistretta C.A. Scatter-glare corrections in quantitative dual-energy fluoroscopy. *Med Phys* **15**(3):289-297; 1988.

1988
"Willi - CT is dead Let's go learn some MRI"

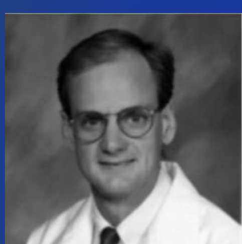
Spiral CT



"It is difficult to make predictions-especially about the future"
Yogi Berra

3D Time-Resolved
Contrast-Enhanced
MR Angiography
(MR-DSA)

Tom Grist
Candidate for Radiology position



k-Space Signal
Distribution

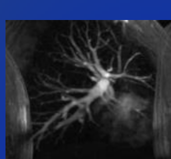
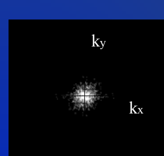
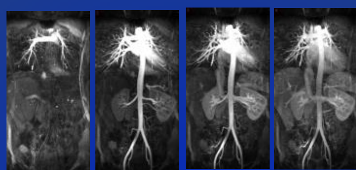


image space



k-space

Time resolved imaging of contrast kinetics (TRICKS) using sub-Nyquist acquisition (4X)



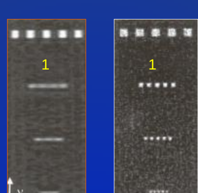
Selected MIP images formed from 3D data sets in a 27 frame time-resolved series. The time for acquisition of each k-space segment was 5.6 seconds. The acquisition matrix was 308x128 x16 zero filled to 512x256x32. FOV = 44x22 cm. Tip/TR/TE= 60 /10.8 / 1.9. Contrast dose = 35 ml Gadodiamide.

Undersampled Acquisition using Radial Sampling

Radial undersampling preserves the central part of the point spread function but causes streak artifacts. However, these are often tolerable.

Cartesian vs Undersampled 2D Radial

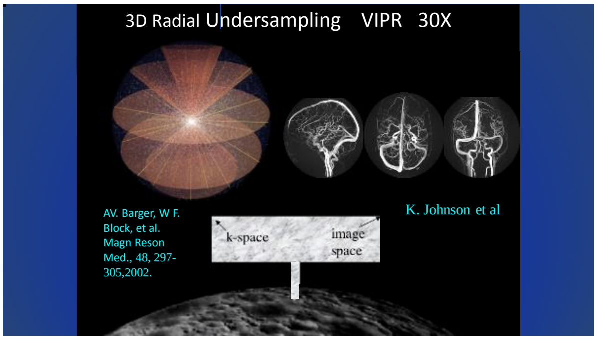
Same scan time

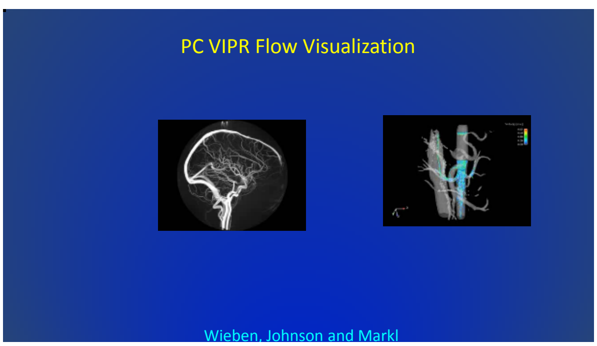


Cartesian 512 x 128

2D Radial 512 x 128

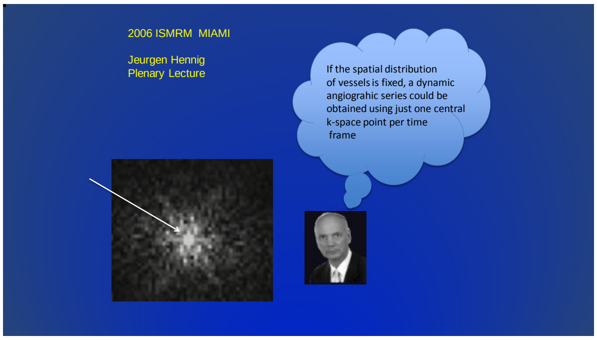
Phase encoding. direction →



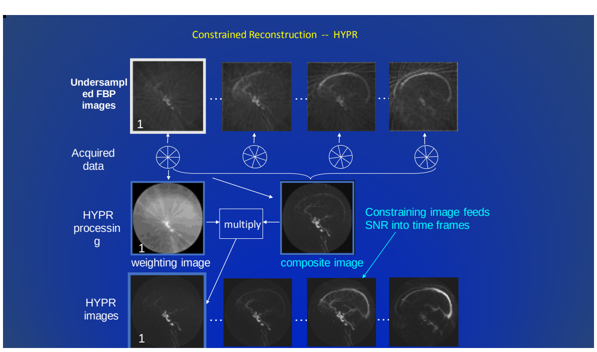


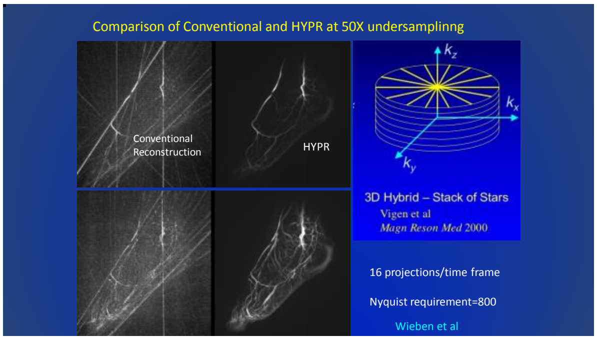
HYPR
Highly Constrained Imaging with Projections

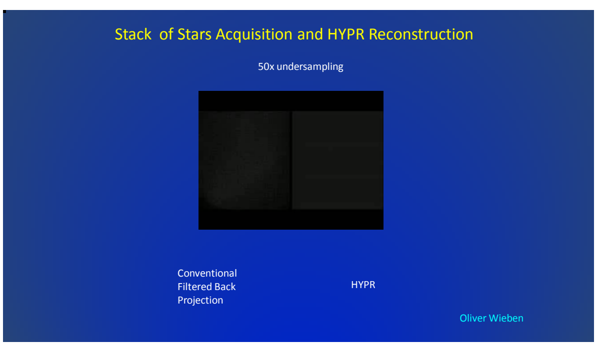
Radial undersampling had brought a factor of 30 acceleration to MRA. The addition of a constrained reconstruction technique called HYPR increased this to a factor of 800 relative to Nyquist

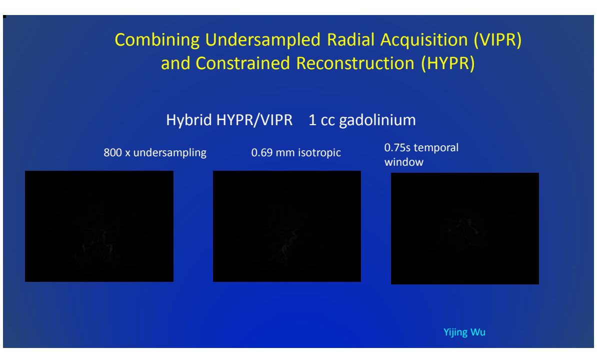

2006 ISMRM MIAMI
Jeurgen Hennig
Plenary Lecture
If the spatial distribution of vessels is fixed, a dynamic angiograhic series could be obtained using just one central k-space point per time frame


The next day
I wonder how many k-space points would be required if the blood vessels were filling into a fixed spatial configuration?
Training Images
Webb, Liang, Magin and Lauterbur
Applications of reduced-encoding MR imaging with generalized-series reconstruction (RIGR). J Magn Reson Imaging. 1993 Nov-Dec;3(6):925-8.
Tsao J., Boesinger P. and Pruessman KP,k-t BLAST and k-t Sense: Dynamic MRI with High Frame Rate Exploiting Spatiotemporal Correlations, Magn Reson Med. 2003; 50 (5):1031-43.
Liang, Madore, Glover and Pelc,
Fast algorithms for GS-model-based image reconstruction in data-sharing Fourier imaging. IEEE Trans Med Imaging. 2003 Aug;22(8):1026-30.


Constrained Reconstruction -- HYPR
Undersampled FBP images
Acquired data
HYPR processing
multiply
weighting image
composite image
Constraining image feeds SNR into time frames
HYPR images


Comparison of Conventional and HYPR at 50X undersamplinng
Conventional Reconstruction
HYPR
3D Hybrid – Stack of Stars
Vigen et al
Magn Reson Med 2000
16 projections/time frame
Nyquist requirement=800
Wieben et al


Stack of Stars Acquisition and HYPR Reconstruction
50x undersampling
Conventional Filtered Back Projection
HYPR
Oliver Wieben

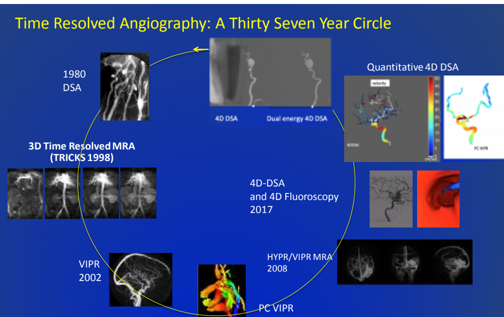

Combining Undersampled Radial Acquisition (VIPR) and Constrained Reconstruction (HYPR)
Hybrid HYPR/VIPR 1 cc gadolinium
800 x undersampling
0.69 mm isotropic
0.75s temporal window
Yijing Wu

The HYPR Swing

Recent work has focused on applying principles developed in our MRA work to X-ray data acquired using C-arm CT acquisition.

The emphasis has been to provide new diagnostic capabilities and device guidance and assistance in the planning and evaluation of interventional procedures.

Time Resolved Angiography: A Thirty Seven Year Circle



Taylor Expansion of X-ray Transmission Image

$I(x, y, z, E, t) - I(x + \Delta x, y + \Delta y, z + \Delta z, E + \Delta E, t + \Delta t) =$

$(dI/dx)^* \Delta x + (dI/dy)^* \Delta y$

$+(dI/dE)^* \Delta E + (dI/dt)\, \Delta t + (dI/dz)\, \Delta z$ — DSA

$+(d^2I/dEdz)\Delta E \Delta t$ — dual energy CT

$+ (d^2I/dEdt)\, \Delta E \Delta t$ — dual energy DSA (Brody)

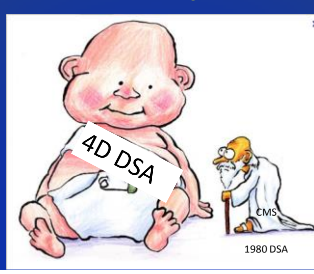
$+ (d^2I/dzdt)\Delta z \Delta t$ — CTA, 4D DSA

$+ (d^3I/dEdzdt)\, \Delta E \Delta t \Delta z$ — dual energy 4D DSA

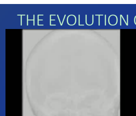
Enabled Using MR Recon Methods

30 yrs

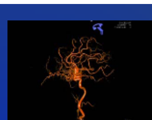
DSA Born Again



THE EVOLUTION OF DSA

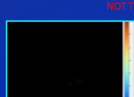


1980 2D DSA
TIME RESOLVED

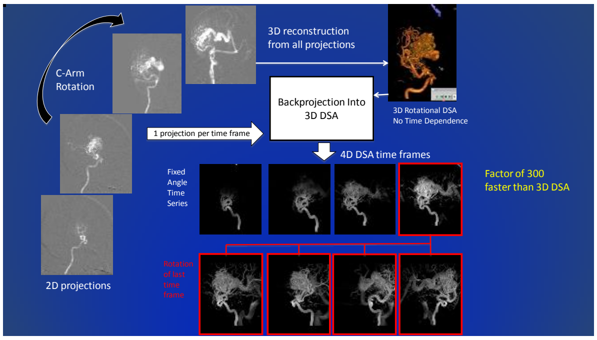


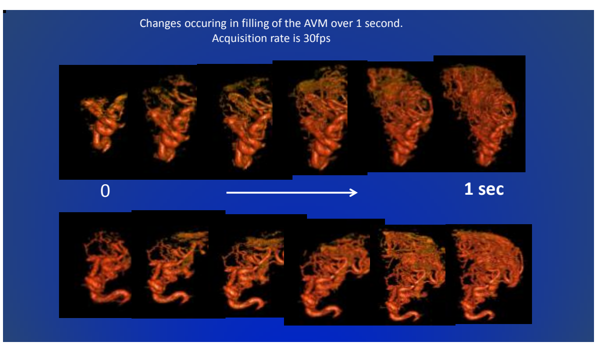
1996 3D DSA
NOT TIME RESOLVED

This slide shows the progression from The 1980 2D DSA to the 1996 3D DSA (C-ARM CT Angio), to the present 4D DSA



2017 4D DSA and 4D Fluoroscopy





Quantitative 4D DSA with Color coded flow

Recently we have developed methods to provide dynamic 4D DSA volumes that are color coded with either velocity or flow and to generate these without operator intervention.

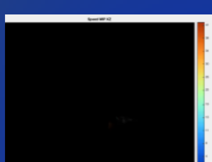
These methods are being validated against PC VIPR and Doppler ultrasound in a number of human and animal studies.

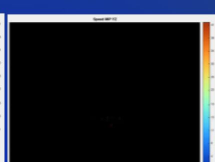
Quantitative Velocity Determination Methods

There are three methods under investigation

1. Fourier phase analysis of temporal waveforms separated by distance along centerline
2. Temporal cross correlation of waveforms separated by distance along centerline
3. Inverse slope of mean transit time (or other arrival measures) vs vessel centerline position

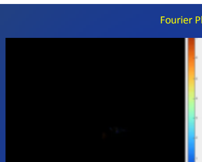
Fourier Phase Method Average speed in each segment





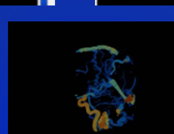
velocity

Fourier Phase Method Flow



4D flow

4D flow

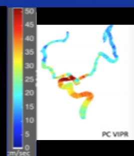


PC VIPR
Flow

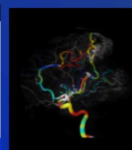
Case 618

Determination of Local Velocity using 4D DSA MTT Method

4D MTT



4D MTT

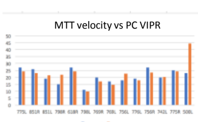


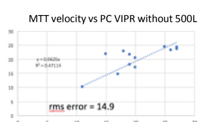
Availability of velocity and flow information promises to help in the planning and evaluation of interventions in the X-ray suite.

Mean Transit Time (MTT) method vs PC VIPR

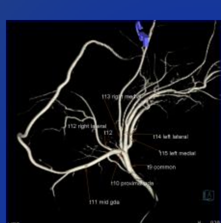
13 clinical cases were compared with PCVIPR. The MTT method worked in all cases and does not require pulsatility. case 500L was excluded because there was I year between DSA and MR acquisitions.

The rms error in the fit was 14.9%. There is a 10% uncertainty in PCVIPR . The other 5% may be attributable to actual variations in velocity for each exam, so not much better can be expected.



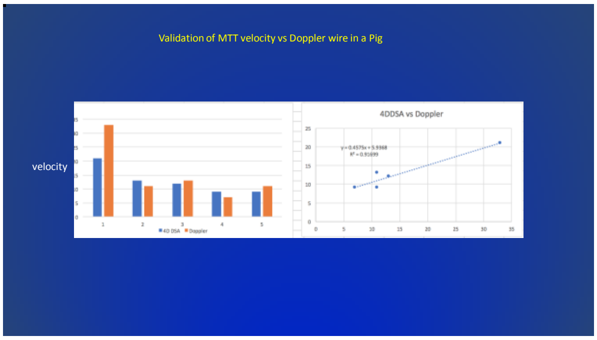


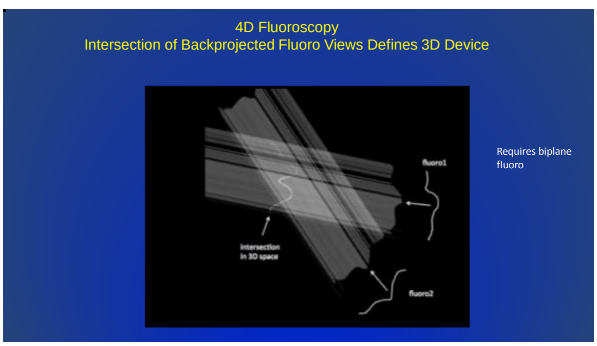
4D-DSA: Correlation w/ intravascular Doppler in a pig

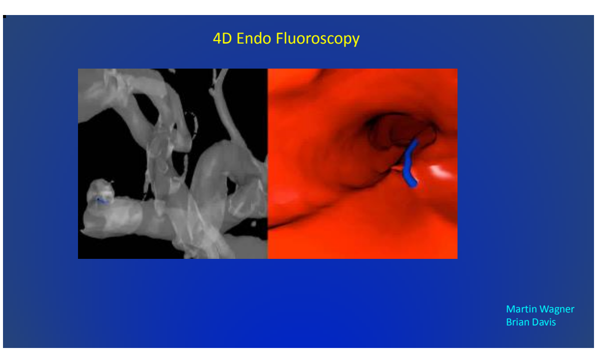


Location	4D-DSA (cm/s)	Flowire (cm/s)
CHA	21	33
Prox. GDA	DVV	18
Mid. GDA	13	11
LL	12	13
LM	9	7
RM	16	25*
RL	9	11

* vasospasm

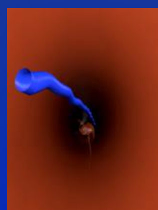

Validation of MTT velocity vs Doppler wire in a Pig
velocity
4D DSA
Doppler
4DDSA vs Doppler
y = 0.4575x + 5.9968
R² = 0.91699


4D Fluoroscopy
Intersection of Backprojected Fluoro Views Defines 3D Device
fluoro1
fluoro2
Intersection in 3D space
Requires biplane fluoro


4D Endo Fluoroscopy
Martin Wagner
Brian Davis

Results: Aneurysm

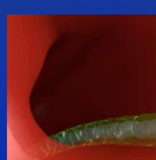
guidewire



Martin Wagner, PhD, University of Wisconsin-Madison 55

Results: Coiling

guiding catherter (green)
microcatheter (white)
coil (blue)



Martin Wagner, PhD, University of Wisconsin-Madison 56

Ongoing Dual Energy Work

- 2 spectrum k-edge
- 3 spectrum k-edge — mid 70's
- Dual energy Ventricuolography
- Dual Energy Phosphor Plates Cassettes — mid 80's
- Dual energy 4D DSA — 2015

Taylor Expansion of X-ray Transmission Image

$I(x, y,z,E,t) - I(x + \Delta x, y + \Delta y,z + \Delta z,E + \Delta E,t + \Delta t) =$

$(dI /dx)^* \Delta x + (dI /dy)^* \Delta y$

$+(dI /dE)^* \Delta E + (dI /dt) \Delta t + (dI /dz) \Delta z$

$+(d^2I/dEdz)\Delta E\Delta t$ dual energy CT

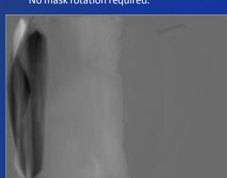
$+ (d^2I /dEdt) \Delta E\Delta t$ dual energy DSA (Brody)

$+ (d^2I /dzdt)\Delta z\Delta t$ CTA, 4D DSA

$+ (d^3I /dEdzdt) \Delta E\Delta t\Delta z$ dual energy 4D DSA

Dual Energy 4DDSA

Form constraining image from energy - subtracted projections
Backproject projections through constraining image to form 30 dual energy volumes/sec
No mask rotation required.



4D DSA

Dual Energy 4D DSA

Speidel and Schaughnessy

67 years with Darlene

Thanks


LOUIS
HAROLD
GRAY
1905
1965
INTERNATIONAL
COMMISSION
ON RADIATION UNITS
AND MEASUREMENTS
L. H. GRAY MEDAL FOR
OUTSTANDING CONTRIBUTION
TO RADIATION SCIENCE
AWARDED TO