Advances in Radiological Neuro-Endovascular Interventional Imaging

S Rudin

Topic Groups

- Improved Imaging Methods
  (decrease dose, increase resolution)
- Evaluation Methods
  (dose, imaging, simulated procedures)

Topics

- Improved Imaging Methods
  - Decreased radiation dose with **ROI Fluoroscopy**
  - Better resolution with Micro-Angiographic Fluoroscope (**MAF**)
  - Scatter reduction and reduced **grid artifacts**
  - Increased **small focal spot output**
- Evaluation Methods
  - Monitoring radiation dose with Dose Tracking System (**DTS**)
  - New metrics family such as Relative Object Detectability (**ROD**)
  - Testing with **3D printed Vascular Phantoms**

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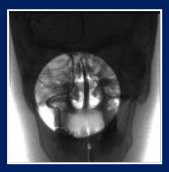
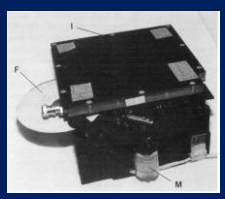
ROI Fluoroscopy

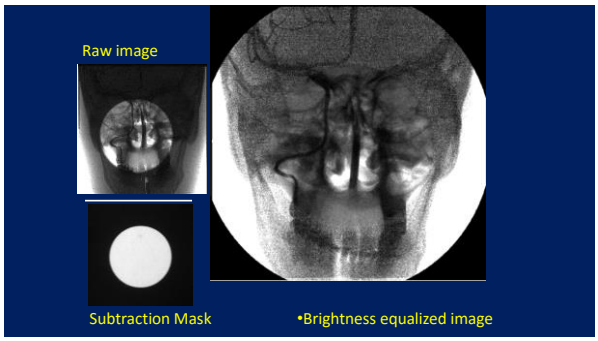
- Attenuation outside ROI (10-20%dose)
- Less scatter to ROI

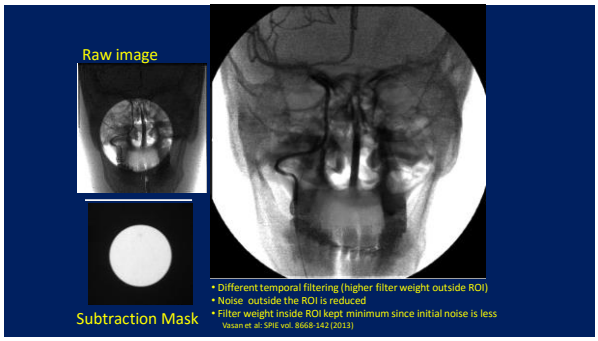


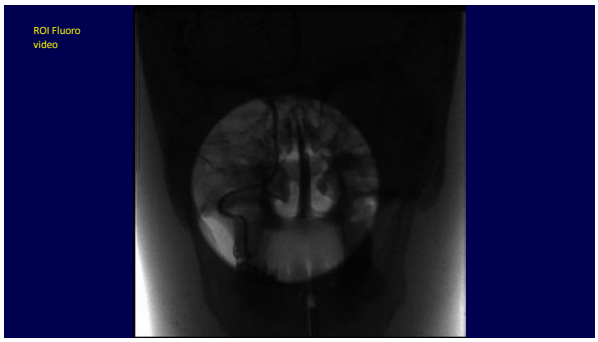
Raw output image

Rudin and Bednarek: Med Phys 19(5):1183-1139(1992)




Raw image
Subtraction Mask
•Brightness equalized image


Raw image
Subtraction Mask
• Different temporal filtering (higher filter weight outside ROI)
• Noise outside the ROI is reduced
• Filter weight inside ROI kept minimum since initial noise is less
Vasan et al: SPIE vol. 8668-142 (2013)


ROI Fluoro
video

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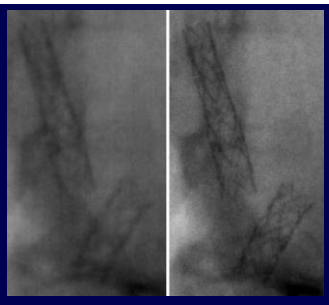


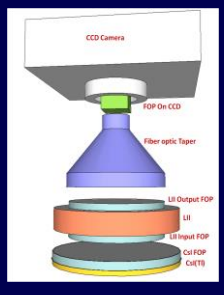
Flat Panel Detector (FPD)

MAF Detector

MAF below FPD

Motorized MAF changer on biplane gantry

MAF



Pixel size compared:
MAF: 35 µm
FPD: 150-200 µm
XII: 120-200 µm
MAF FOV: 4cm

MAF-CMOS

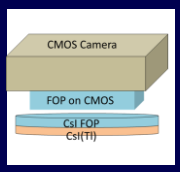


Table 1: CMOS Detector Specifications	
Pixel Size	75 micron
Image Matrix Size	1116 x 864, 7cm x 12cm
Full Well Capacity (FWC)	8.5K M and 1.5K electrons
Frame Rate	60 fps (2x2 binning)
Noise	20 and 102 electrons
Scintillator	CsI(Tl) 600 micron HR type
Binning Modes	1 x 1, 2 x 2, 3 x 3, 4 x 4

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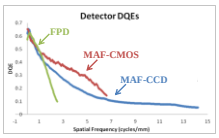
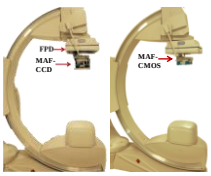
Detector Pairs

Three existing detectors were used for comparisons:

- Micro-angiographic fluoroscope (MAF-CCD)
  - Pixel size 35µm, f_N = 14.2 cycles/mm
- Dexela 1207 CMOS (MAF-CMOS)
  - Pixel size 75µm, f_N = 6.6 cycles/mm
- Paxscan 2020 flat panel detector (FPD)
  - Pixel size 194µm, f_N = 2.5 cycles/mm



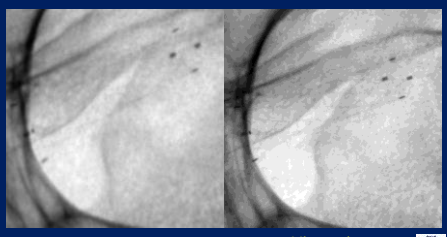


FPD

MAF

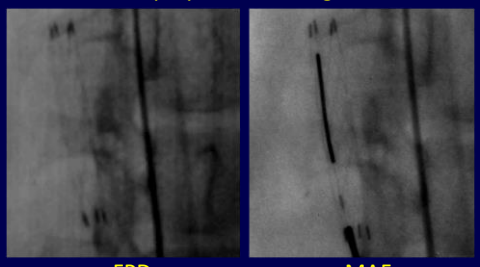
Comparison of Neuroform stent in skull w. 4” acrylic

C. Ionita, et al



XII Microangio

Deployed Stent Images

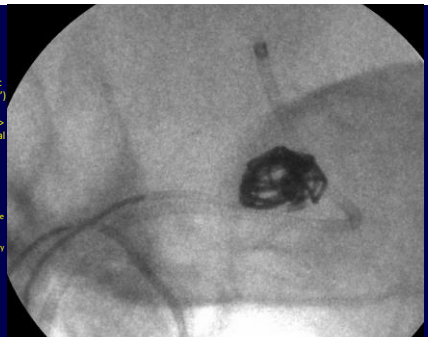


FPD MAF

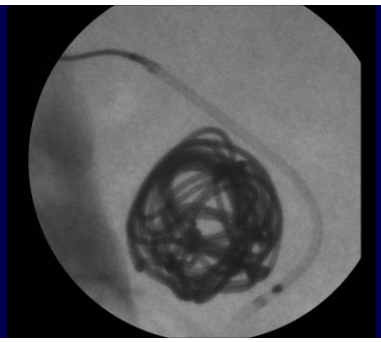
MAF clinical Video (Youtube: "Micro-Angiographic Fluoroscope")

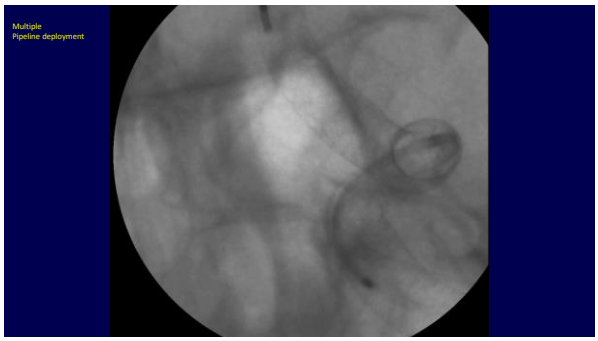
Smaller FOV> lower integral dose.

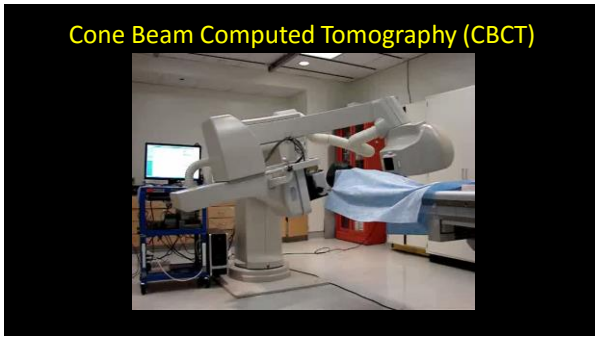
Case 5: Right middle cerebral artery Occlusion and an Anterior com. Artery Aneurysm.

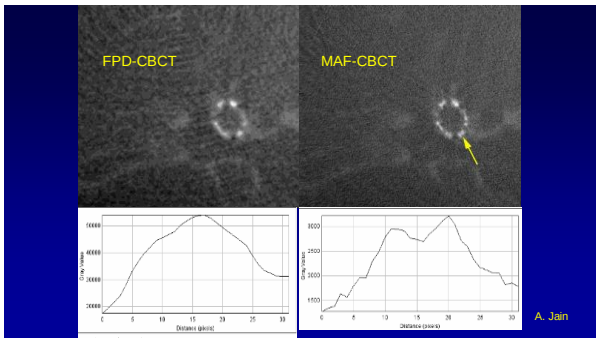


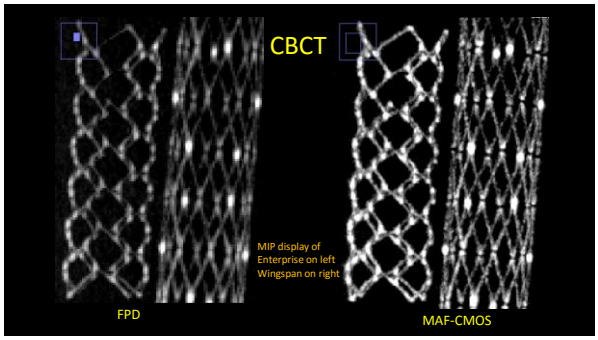
MAF clinical video: stenting of coiled aneurysm




Multiple
Pipeline deployment


Cone Beam Computed Tomography (CBCT)


FPD-CBCT
MAF-CBCT
A. Jain



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Effect of scatter on contrast reduction

Standard scatter reduction method: grid

- Sacrifice some primary
- Could increase patient dose
- Grid line artifacts

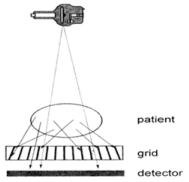
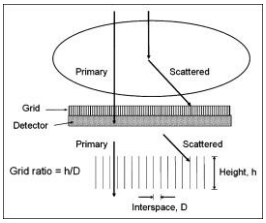
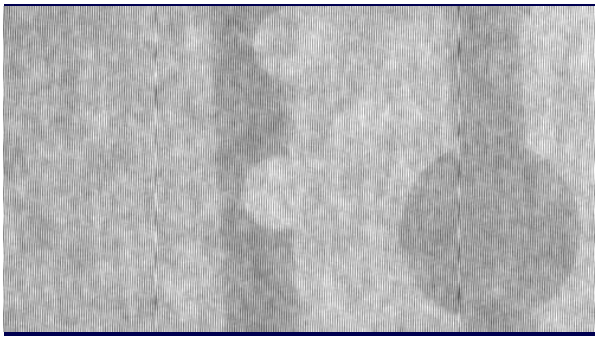


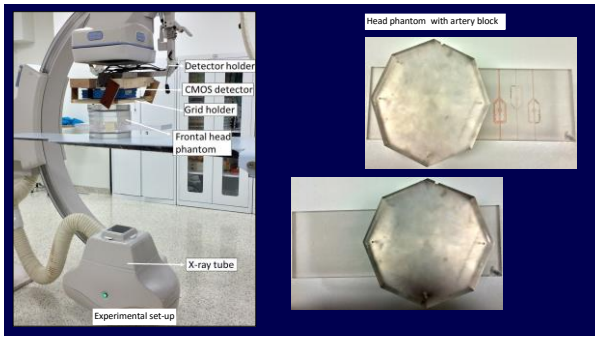
Fig. 4, Scatter elimination in grid

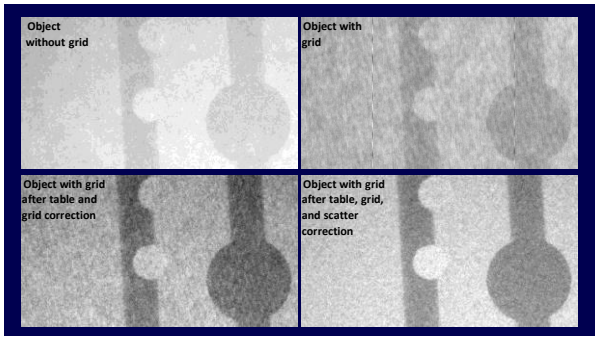


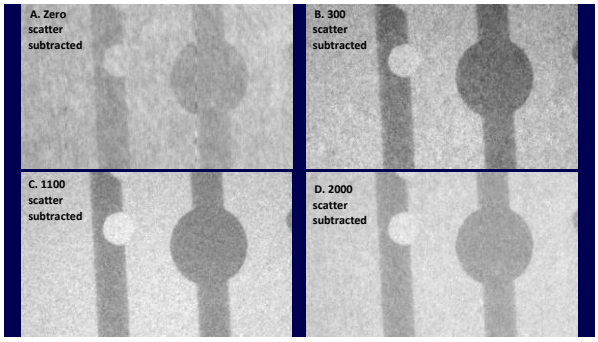


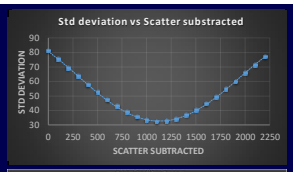
How to get rid of grid-line artifacts and blochs:
Step 1: record grid-line pattern w/o object but with patient table
Step 2: subtract estimate of scatter from image of object w grid
Step 3: divide by grid-line pattern image

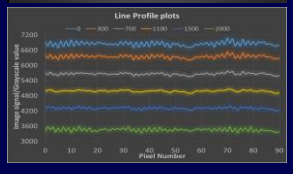
R. Rana et al: AAPM 2016, SU-C-209-3


Detector holder
CMOS detector
Grid holder
Frontal head phantom
X-ray tube
Experimental set-up
Head phantom with artery block

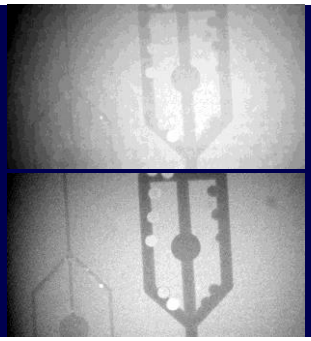

Object without grid
Object with grid
Object with grid after table and grid correction
Object with grid after table, grid, and scatter correction


A. Zero scatter subtracted
B. 300 scatter subtracted
C. 1100 scatter subtracted
D. 2000 scatter subtracted





R. Rana et al:
AAPM 2015, WE-G-204-6



Improved contrast
No blotches
No grid-lines
Improved S/N

R. Rana et al:
AAPM 2016, SU-C-209-3

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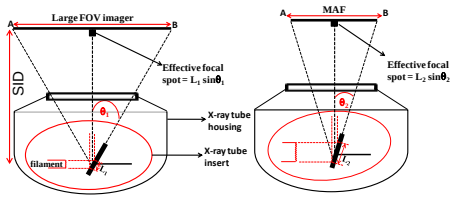
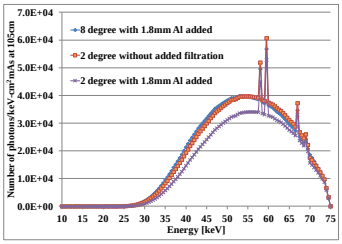


Large: anode angle & FOV. Small: anode angle & FOV.
(Same effective focal spot size, ~4x output)

Gupta S et al: SPIE 2012 8313_192, p. 831358-1-11



X-ray spectra of tungsten anode with and without added filtration with head phantom in the beam

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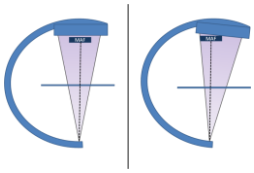
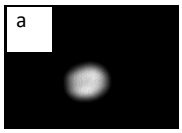
Experimental Apparatus

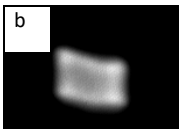
- The MAF-CMOS detector was used to acquire images of a neurovascular stent
- C-arm tilted to 6 degrees caudal (maximum angle achievable with 12" FOV)
- MAF was aligned with perpendicular incident x-ray beam to minimize x-ray obliquity



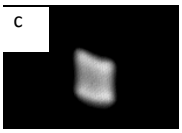
Russ M et al: AAPM 2016, TU-EF-209-5



Small FS, Central Axis



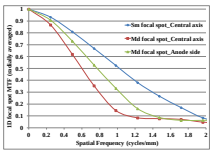
Medium FS, Central Axis



Medium FS, Tilted

X-ray pin-hole images:
(a) small focal spot (nom. size 0.3 mm) at the center
(b) Medium focal spot (nom. size 0.5 mm) at the center
(c) Medium focal spot tilted at the anode side.

Output of medium FS toward anode is 2.85X that of central small FS (Toshiba Infinix tube)



MTFs in plane of the anode

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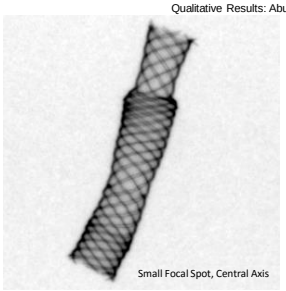
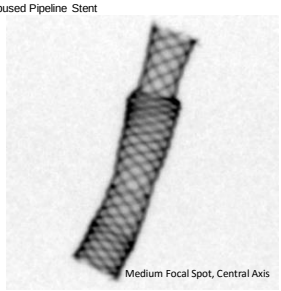
Qualitative Results: Abused Pipeline Stent



Small Focal Spot, Central Axis



Medium Focal Spot, Central Axis

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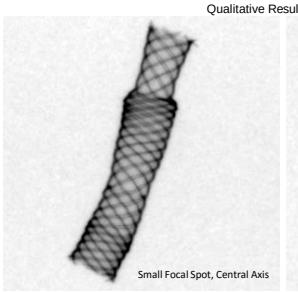
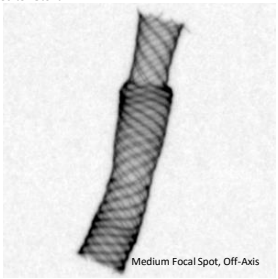
Qualitative Results: Stent

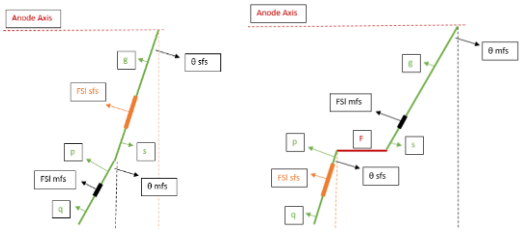


Small Focal Spot, Central Axis



Medium Focal Spot, Off-Axis

Non-offset Design **Offset Design**



Freund E et al: AAPM 2016 SU-G-IeP3-3

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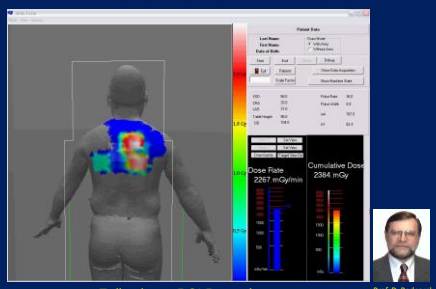
Dose Tracking System (DTS) Real-Time Display



Following a PCI Procedure

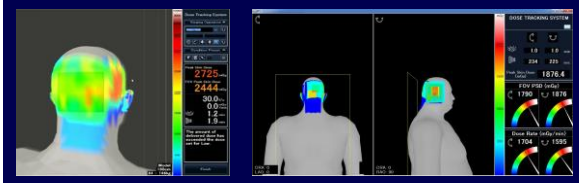
Prof. D. Bednarek

DTS Real-Time Display with Improved Graphics

Neuro-interventional Procedure Simulation

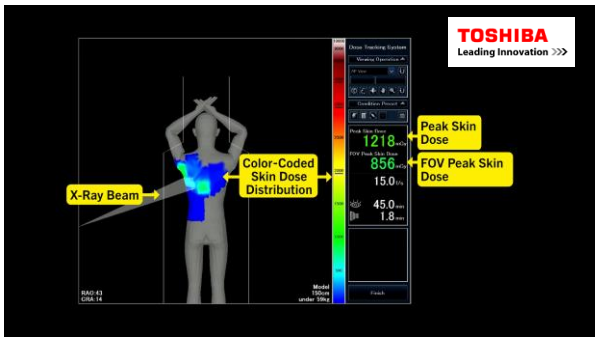
Bednarek et al

Dose Tracking System (DTS)

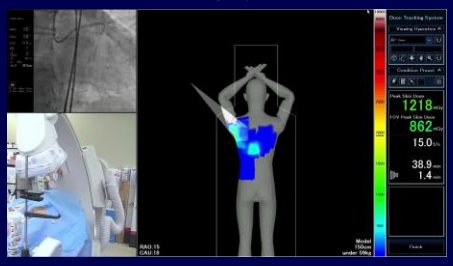


Single plane DTS

Bi-plane DTS



Dose Tracking System (DTS)



Selected (out of 27) by trade organization as Best New Radiology Software of 2014:

Dose Tracking System (DTS), Toshiba America Medical Systems

Vijayan S et al: AAPM 2016; MO-FG-CAMPUS-IeP-4, TU-D-209-2
Xiong Z et al: AAPM 2016; TU-D-209-5, SU-G206-5
Oines A et al: AAPM 2016; TU-D-209-3

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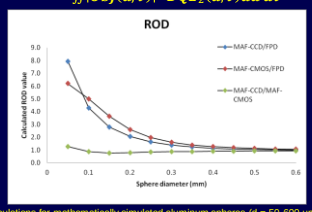
  - Monitoring radiation dose with Dose Tracking System (**DTS**)
  - New metrics family such as Relative Object Detectability (**ROD**)
  - Testing with **3D printed Vascular Phantoms**

Relative Object Detectability (ROD)

$$ROD = \frac{\iint |Obj(u,v)|^2 \, DQE_1(u,v)\,du\,dv}{\iint |Obj(u,v)|^2 \, DQE_2(u,v)\,du\,dv}$$



- Calculations for mathematically simulated aluminum spheres (d = 50-600 µm)
- All detectors trend toward the ratio of the detector DQE for the largest sphere size

More RODs*

Relative Obj. Det. (ROD):

$$ROD = \frac{\iint |Obj(u,v)|^2 \, DQE_1(u,v)\,du\,dv}{\iint |Obj(u,v)|^2 \, DQE_2(u,v)\,du\,dv}$$

Referenced ROD:

$$R-ROD = \frac{\iint |OBJ(u,v)|^2 \, DQE_1(u,v)\,du\,dv}{\iint |OBJ(u,v)|^2 \, DQE_R(u,v)\,du\,dv}$$

Generalized ROD:

$$G-ROD(\rho,X,m) = \frac{\iint |OBJ(u,v)|^2 \, GDQE_1(u,v,\rho,X,m)\,du\,dv}{\iint |OBJ(u,v)|^2 \, GDQE_2(u,v,\rho,X,m)\,du\,dv}$$

ρ scatter fraction; X exposure; m magnification

Generalized-Measured ROD:

$$GM-ROD = \frac{\left[\iint \frac{|OBJ(u,v)_{meas}|^2}{GNNPS(u,v)_2}\,du\,dv\right]_1}{\left[\iint \frac{|OBJ(u,v)_{meas}|^2}{GNNPS(u,v)_1}\,du\,dv\right]_2}$$

*Russ M, et al. SPIE vol. 9412-45, 2015; Pre-Whitened Matched Filter (PWMF, Ideal) observer assumed.
For additional NPWMF observer G-ROD see Russ M, et al. SPIE vol. 9783-128, 2016

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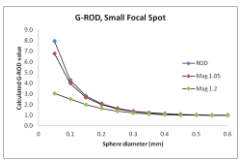
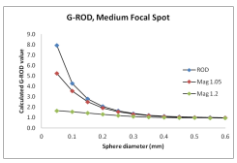
G-ROD Wire Results

MAF-CCD vs. FPD

$$G-ROD = \frac{\iint |Obj(u,v)|^2 \, GDQE_1(u,v)\,du\,dv}{\iint |Obj(u,v)|^2 \, GDQE_2(u,v)\,du\,dv}$$





Russ M et al: SPIE 2015

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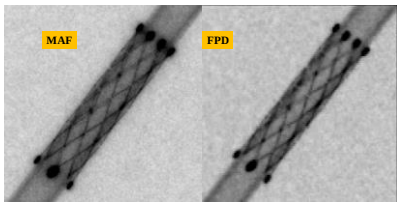
Generalized Measured-ROD Introduction

GM-ROD can be used to compare performance of two detector systems using only experimentally obtained data, doesn't need explicitly defined MTF or DQE



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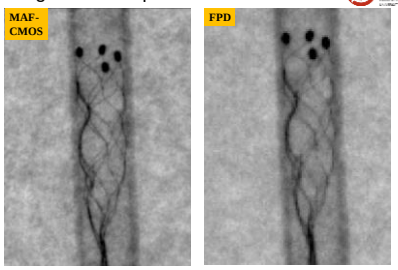
Images for Comparison



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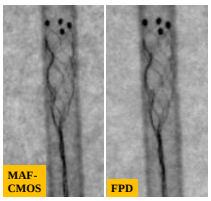
GM-ROD Definition



$$GM\text{-}ROD = \frac{\left[\iint \frac{|OBJ(u,v)_{meas}|^2}{NNPS(u,v)_1} du\, dv\right]}{\left[\iint \frac{|OBJ(u,v)_{meas}|^2}{NNPS(u,v)_2} du\, dv\right]}$$

- Neurovascular stent imaged with MAF-CMOS and FPD detectors
- Aluminum block used to simulate attenuation
- All imaging conditions held constant for both detectors
- NNPS taken from flat field and dark field corrected images of background

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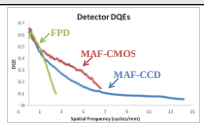
GM-ROD Calculation Results

- GM-ROD calculates the signal-to-noise^2 ratio at all spatial frequencies (including the real and aliased components of signal and noise)
- Lower bound of integration increased to emphasize higher frequencies in calculation
- Increase in GM-ROD value indicates MAF-CMOS detection superiority in higher frequency regime

Integration Bounds (cycles/mm)	GM-ROD (for MAF-CMOS/FPD)
Full range (0.1 to Nyquist)	3.5
0.5 to Nyquist	3.4
1.0 to Nyquist	3.4
1.5 to Nyquist	3.7
2.0 to Nyquist	5.3



Topics

- Improved Imaging Methods
  - Decreased radiation dose with **ROI Fluoroscopy**
  - Better resolution with Micro-Angiographic Fluoroscope (**MAF**)
  - Scatter reduction and reduced **grid artifacts**
  - Increased **small focal spot output**
- Evaluation Methods
  - Monitoring radiation dose with Dose Tracking System (**DTS**)
  - New metrics family such as Relative Object Detectability (**ROD**)
  - Testing with **3D printed Vascular Phantoms**

Objet Eden260V™ — The 16-Micron-layer 3D Printing System

Technical Specifications

Layer Thickness (Z-axis)
Horizontal build layers down to 16-micron

Tray Size (X×Y×Z)
260×260×200 mm

Net Build Size (X×Y×Z)
255×252×200 mm

Build Resolution
X-axis: 600 dpi
Y-axis: 600 dpi
Z-axis: 1600 dpi

Printing Modes
High Quality (HQ): 16-micron
High Speed (HS): 30-micron

Typical Accuracy
20-85 um for features below 50mm
Up to 200um for full model size
(for rigid materials only, depending on geometry, build parameters and model orientation)

Material Supported
- Objet FullCure®720: transparent material
- Objet VeroClear: transparent clear material
- Objet Vero family: rigide opaque material
- Objet DurusWhite: polypropylene-like material
- Objet Tango family: rubber-like material
- Objet RGD525: high temperature resistant material

Support Type
- Objet FullCure®705 Support
- Non-toxic gel-like photopolymer support easily removed by WaterJet

Materials Cartridges
Sealed 4×3.6 kg cartridges
Automatic switching between cartridges
Easily and instantly replaced through a front-loading door

Power Requirements
110–240 VAC 50/60 Hz
1.5 KW single phase

Machine Dimensions (W×D×H)
870×735×1200 mm

Machine Weight
Net 410 kg
Gross (in crate) 500 kg

Software
Objet Studio™ features:
- Suggested build orientation and speed, Autoplacement
- Optimax-printing optimization package
- Automatic real time support structure generation
- Slice on the fly
- PolyJet™ Materials Management
- Network version

Input Format
STL and SLC File

Operational Environment
Temperature 18°C–25°C
Relative Humidity 30–70 %

Special Facility Requirements
None

Jetting Heads
SHR (Single Head Replacement), 8 units

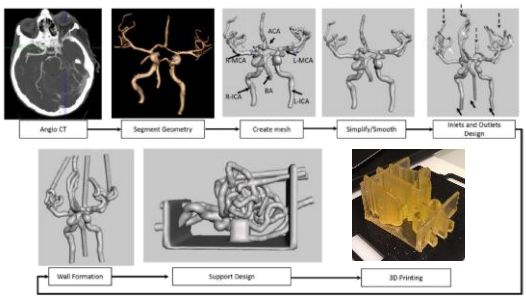
Network Communication
LAN–TCP/IP

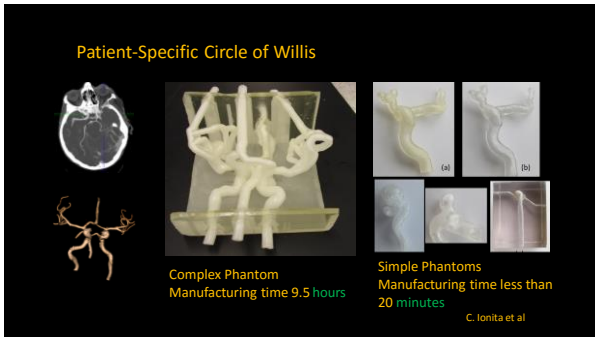
Compatibility
Windows XP, Windows 2000

Other Features
- Removable tray for high productivity

*All specification are subject to change without notice

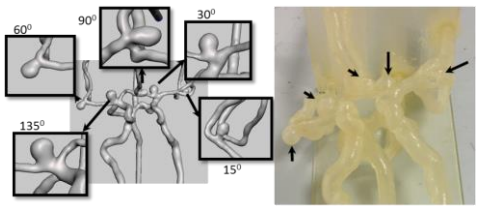
Prof. C. Ionita


ACA
L-MCA
R-ICA
BA
L-ICA
Angio CT
Segment Geometry
Create mesh
Simplify/Smooth
Inlets and Outlets Design
Wall Formation
Support Design
3D Printing

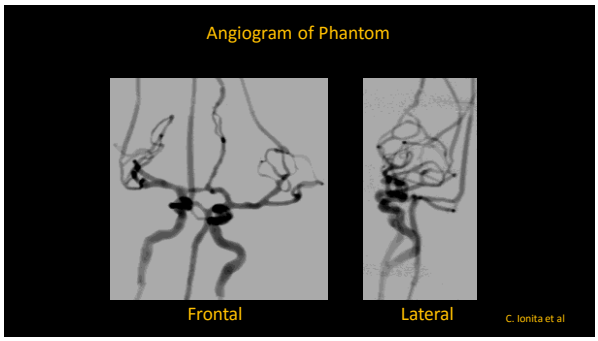

Patient-Specific Circle of Willis
Complex Phantom
Manufacturing time 9.5 hours
Simple Phantoms
Manufacturing time less than
20 minutes
C. Ionita et al


Circle of Willis I

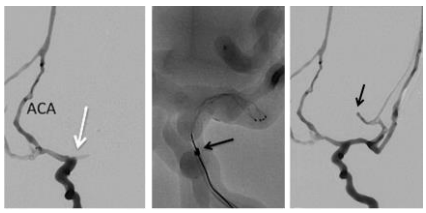

Coronary Arteries



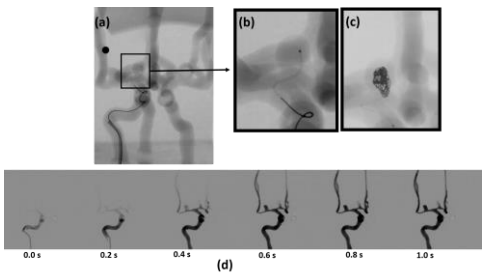
Circle of Willis Phantom II with added aneurysms



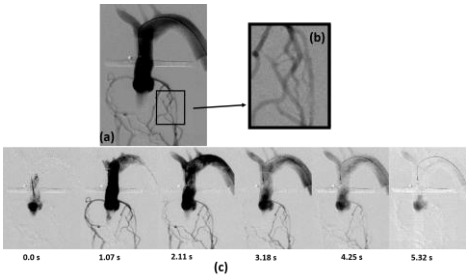
Testing clot retrieval device



DSA: Clot location | Fluoro: Solitaire FR stent retriever | DSA: Clot retrieved



Aneurysm Coiling in Circle of Willis Phantom II



Coronary Angiogram in Phantom

First Place, SPIE 2015 Medical Imaging Conference (1st of 51)

Methods for Improving Imaging in Neuro-EIGIs

- Improved Imaging Methods
  - Decreased radiation dose with **ROI Fluoroscopy**
  - Better resolution with Micro-Angiographic Fluoroscope (**MAF**)
  - Scatter reduction and reduced **grid artifacts**
  - Increased **small focal spot output**
- Evaluation Methods
  - Monitoring radiation dose with Dose Tracking System (**DTS**)
  - New metrics family such as Relative Object Detectability (**ROD**)
  - Testing with **3D printed Vascular Phantoms**

Advances in Radiological Neuro-Endovascular Interventional Imaging

Expectation for advances to continue!

Acknowledgments:
DR Bednarek, CN Ionita, A Jain,
graduate students and staff of the UB-TSVRC

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- NIH-NIBIB Grant R01-EB002873
- Toshiba Medical Systems Corp.

Thank you

Generalizing Metrics

The performance of a detector is influenced by system parameters when it becomes a part of the imaging chain in a clinical setting. Pre-existing metrics can be generalized to describe this change, including the GMTF and GDQE

$$GMTF(f,\rho,m) = \left[(1-\rho)MTF_f\left(\frac{m-1}{m}f\right) + \rho MTF_s\left(\frac{f}{m}\right)\right] MTF_d$$

where f is focal spot size, ρ is scatter fraction, m is magnification, MTF_f is focal spot blur and geometric unsharpness MTF, and MTF_s is scatter blur MTF

$$GDQE(f,\rho,X,m) = \frac{GMTF(f,\rho,m)^2}{m^2 \varphi_{in} GNNPS(f,X,m)}$$

where X is exposure, φ is x-ray fluence, and GNNPS is the normalized noise power spectrum scaled for magnification.

I.S. Kyprianou, S. Rudin, D. Bednarek, K. Hoffman, "Generalizing the MTF and DQE to include x-ray scatter and focal spot unsharpness: application to a new microangiographic system", Medical Physics 03/2005; 32(2):613-26.

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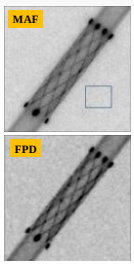
GM-ROD Definition



$$GM-ROD = \frac{\left[\iint \frac{|OBJ(u,v)_{mask}|^2}{GNNPS(u,v)_2}\,du\,dv\right]_1}{\left[\iint \frac{|OBJ(u,v)_{mask}|^2}{GNNPS(u,v)_1}\,du\,dv\right]_2}$$

- Boston Scientific Wingspan Stent imaged with FPD and MAF
- Modified ANSI head phantom used for attenuation
- All imaging conditions held constant for both detectors
- NNPS taken from flat field and dark field corrected images of background

Russ M, et al. SPIE vol. 9412-45, 2015

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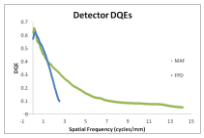
GM-ROD Results

- GM-ROD calculates the signal-to-noise ratio at all spatial frequencies, including the real and aliased components of signal and noise
- Lower bound of integration increased to emphasize higher frequencies in calculation
- Increase in GM-ROD value indicates MAF detection superiority in higher frequency regime

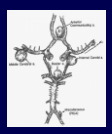
Integration Bounds (cycles/mm) (in two dimensions)	GM-ROD (for MAF/FPD)
Full range (0 to Nyquist)	4.80
0.56 to Nyquist	3.43
1.0 to Nyquist	5.45
1.5 to Nyquist	10.06
2.0 to Nyquist	24.42



Focus: Replacement of invasive surgery with minimally invasive endovascular image-guided interventions (EIGI) for vascular pathologies where small vessels and details of devices are important to visualize. . .

- Neurovasculature pathologies:
  - Aneurysms (hemorrhagic): clip vs coil/stent
  - Stenoses (ischemic): endarterectomy vs stent
  - AVMs





Circle of Willis


Stent

. . . hence high spatial resolution imaging is needed.