3RD CT DOSE SUMMIT:
STRATEGIES FOR CT SCAN PARAMETER OPTIMIZATION
MARCH 15 - 16, 2013 • PHOENIX, ARIZONA

100% Dose | 50% Dose 20s Later | 50% Dose Denoising

WHAT WE CAN LEARN FROM CURRENT CARDIAC CT TECHNOLOGY AND WHAT'S NEXT FOR CARDIAC?

Gilbert Raff, MD

Director of Advanced Cardiovascular Imaging

Oakland University William Beaumont Medical School

DISCLOSURES

- Research grant: Siemens
- I will be presenting state-of-the-art technology with slides graciously provided by
  - Philips
  - GE
  - Toshiba
  - Siemens
- I am responsible for all mistakes in describing these technologies, my only excuse being that I am only a humble clinician, not a physicist!

Achieving "Real-Life" Major Dose Reduction

- There has been a ~70% drop in the median radiation dose in the Michigan cardiac CTA quality improvement registry since 2007. This includes over 39,000 scans.
- Dose reduction depends not only on advancing technology but improving skills in using that technology, as well as monitoring dose and providing feedback.
- Future of dose reduction depends on:
  - Faster temporal resolution
  - Advanced detector technology
  - Automated dose reporting to quality improvement registries

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Appropriate Indications for cardiac CTA

- Emergency or inpatient diagnosis of acute chest pain
- Outpatients with non-acute symptoms
  - After equivocal or nondiagnostic stress tests
  - Alternative to stress tests
  - Bypass and stent graft patency
  - Congenital heart disease
  - Pre-op planning for arrhythmia ablation and transcutaneous valve implants

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JAMA®

Online article and related content
current as of October 26, 2009.

Radiation Dose From Cardiac Computed Tomography Before and After Implementation of Radiation Dose Reduction Techniques

Gilbert L. Raff; Kavitha M. Chinnaiyan; David A. Share; et al.

JAMA. 2009;301(22):2340-2348 (doi:10.1001/jama.2009.814)

Objectives To determine whether a collaborative radiation dose–reduction program would be associated with reduced radiation dose in patients undergoing CCTA in a statewide registry over a 1-year period and to define its effect on image quality.

Design, Setting, and Patients A prospective, controlled, nonrandomized study conducted during a control period (July-August 2007), an intervention period (September 2007-April 2008), and a follow-up period (May-June 2008) at 15 hospital imaging centers participating in the Advanced Cardiovascular Imaging Consortium in Michigan, which included small community hospitals and large academic medical centers. A total of 4995 sequential patients undergoing CCTA for suspected coronary artery disease were enrolled; 4862 patients (97.3%) had complete radiation data for analysis.

Beaumont Hospital- Grosse Pointe
Beaumont Hospital- RO
Beaumont Hospital- Troy
Borgess Medical Center
Bronson Methodist Hospital
Chippewa County War Memorial
Covenant Healthcare
Crittenton Hospital Medical Center
DMC Huron Valley-Sinai
Garden City Hospital
Harper University Hospital
Henry Ford Cottage
Henry Ford Health System
Henry Ford West Bloomfield
Henry Ford Wyandotte
Heritage (Oakwood) Hospital
Hillsdale Community Health Center
Lapeer Regional Medical Center

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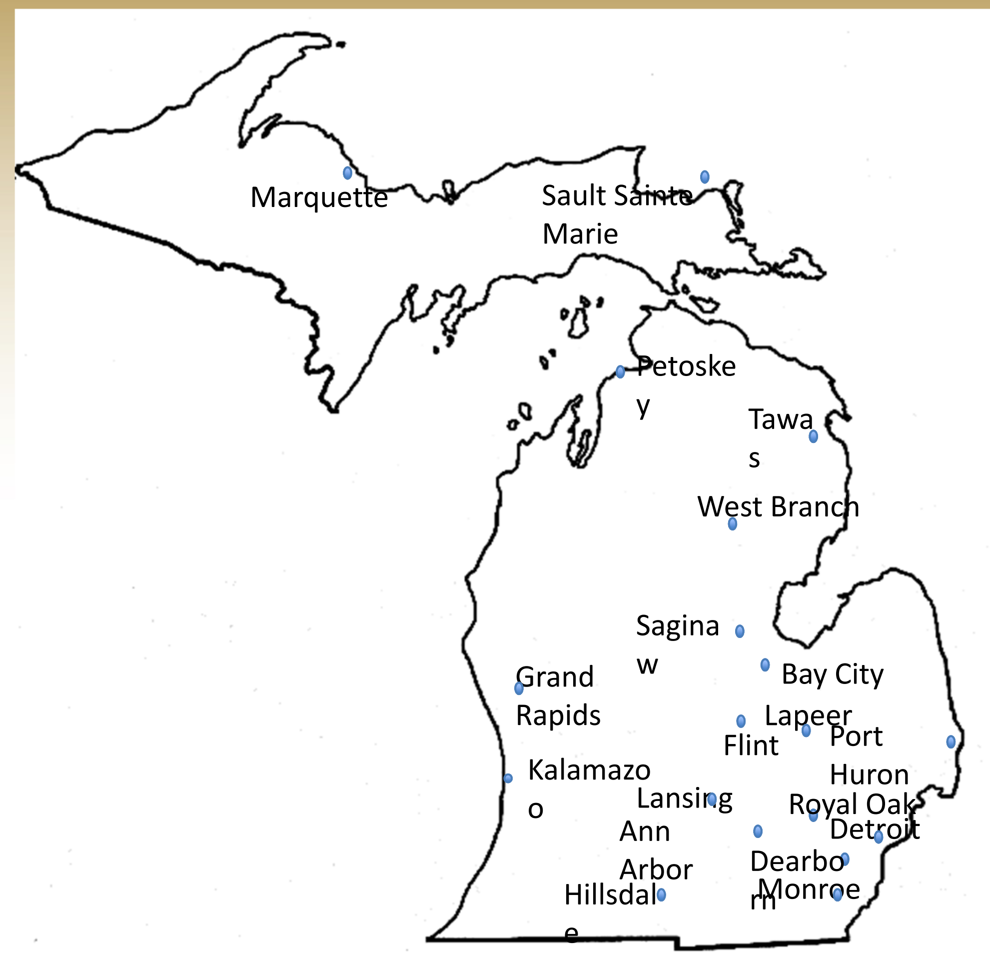
Marquette General Health System
McLaren Bay Region
McLaren Flint
McLaren Macomb
Mercy Memorial
Michigan Heart, P.C.
North Ottawa Community Hospital
McLaren Northern
Oakwood Hospital
Premier Imaging Center
Southgate Radiology
Sparrow Health System
St. John Hospital Medical Center
St. John Macomb-Oakland
St. John Providence Hospital
St. Joseph Health- Tawas
St. Joseph Mercy Ann Arbor
St. Joseph Mercy Oakland
University of Michigan
West Branch Regional Medical Center



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Online article and related content current as of January 8, 2010.

Radiation Dose From Cardiac Computed Tomography Before and After Implementation of Radiation Dose Reduction Techniques

Gilbert L. Raff; Kavitha M. Chinnaiyan; David A. Share; et al.

JAMA. 2009;301(22):2340-2348 (doi:10.1001/jama.2009.814)

Results Compared with the control period, patients' estimated median radiation dose in the follow-up period was reduced by 53.3% (dose-length product decreased from 1493 mGy × cm [interquartile range {IQR}, 855-1823 mGy × cm] to 697 mGy × cm [IQR, 407-1163 mGy × cm]; *P* < .001) and effective dose from 21 mSv (IQR, 12-26 mSv) to 10 mSv (IQR, 6-16 mSv) (*P* < .001). The greatest reduction in dose occurred at low-volume sites.

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Further reductions 2008-2010

Progressive Radiation Dose Reduction from Coronary Computed Tomography Angiography in a Statewide Collaborative Quality Improvement Program: Results from the Advanced Cardiovascular Imaging Consortium (ACIC)

Kavitha M. Chinnaiyan[*], MD, Judith A. Boura[*], MS, Ann DePetris[*], RN, Ralph Gentry[*], RT(R)(CT)(MR), Aiden Abidov[†], MD, PhD, David A. Share[‡], MD, MPH, Gilbert L. Raff, MD[*] and the Advanced Cardiovascular Imaging Consortium Co-Investigators.

*William Beaumont Hospital, Cardiology Division, Royal Oak, MI, [†]Sarver Heart Center, College of Medicine University of Arizona, Tucson, AZ, [‡]Department of Family Medicine, University of Michigan Health System

In review

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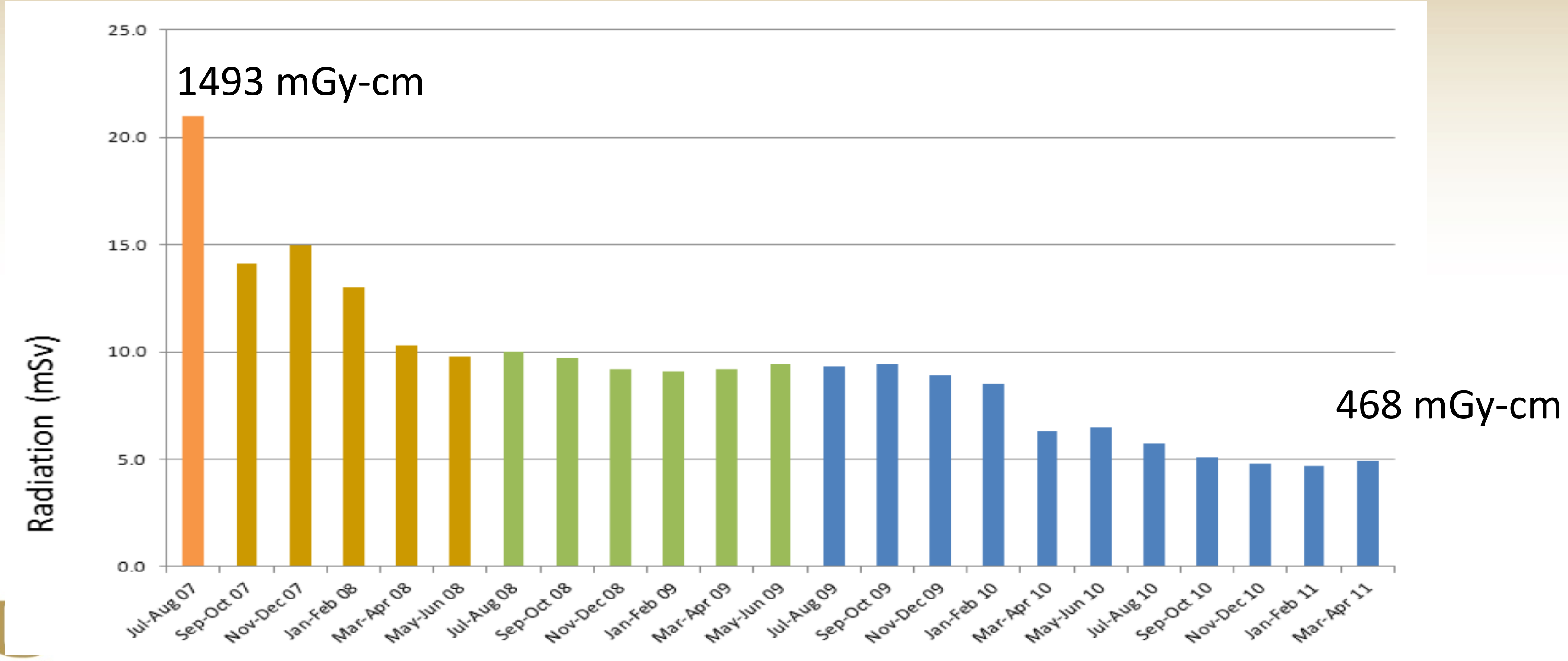
2007-2011 Dose Reduction: 69%



The KEY element

- The single most important element in reducing dose was providing sites with their “report card”.

- If a site’s median dose was considerably higher than average, it was tremendously motivated to get help to improve.

Case Study

- 71 yo female presented to the ER with several hours of chest pain
- Complex history: chronic atypical pneumonia, cough, peripheral venous disease
- EKG/cardiac enzymes non-diagnostic but nuclear stress testing positive
- Cardiac cath recommended but patient refused
- Cardiologist ordered “triple rule out” (TRO): full thorax CT angiography to simultaneously exclude coronary disease, pulmonary embolism and aortic dissection
- In the past, this triple procedure involved radiation doses of ~1700 mGy-cm and compromised image quality

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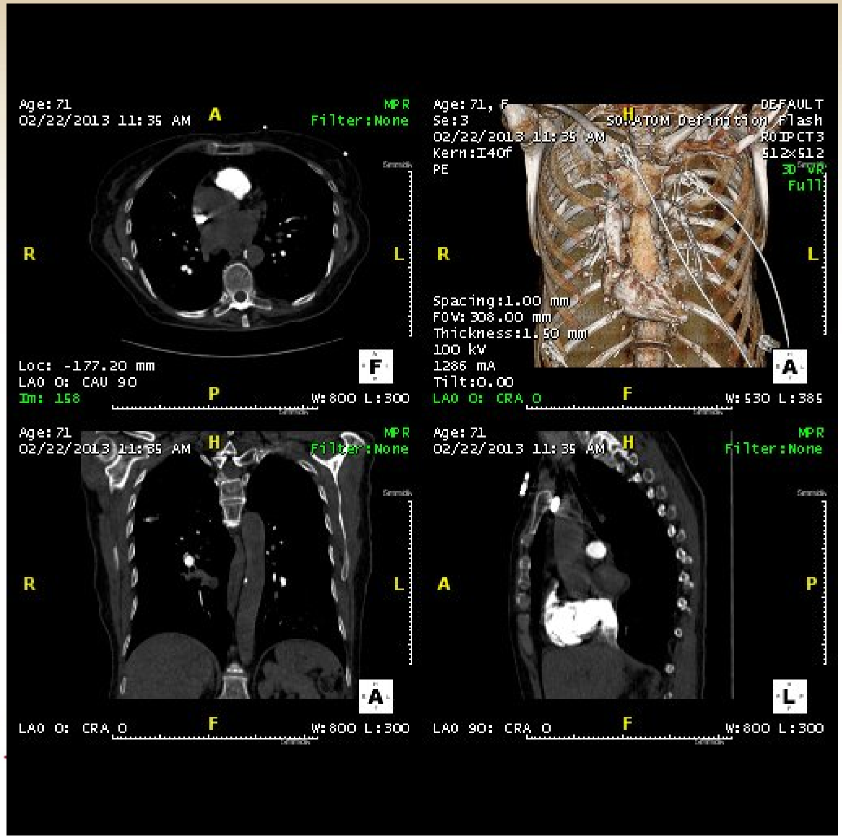
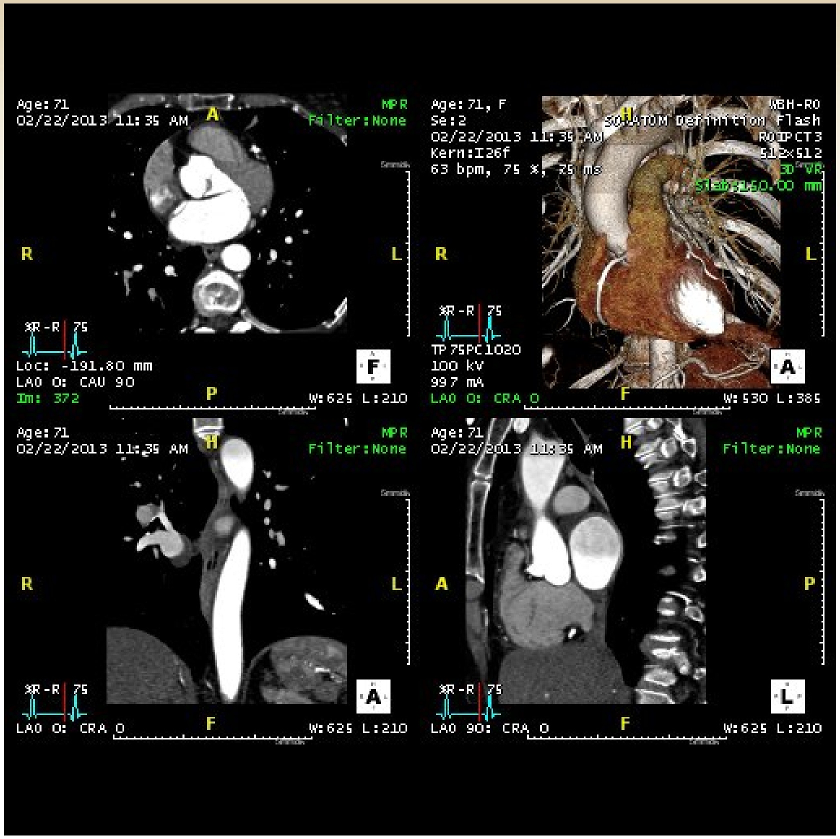
Scan quality good – scan range excessive

PE study



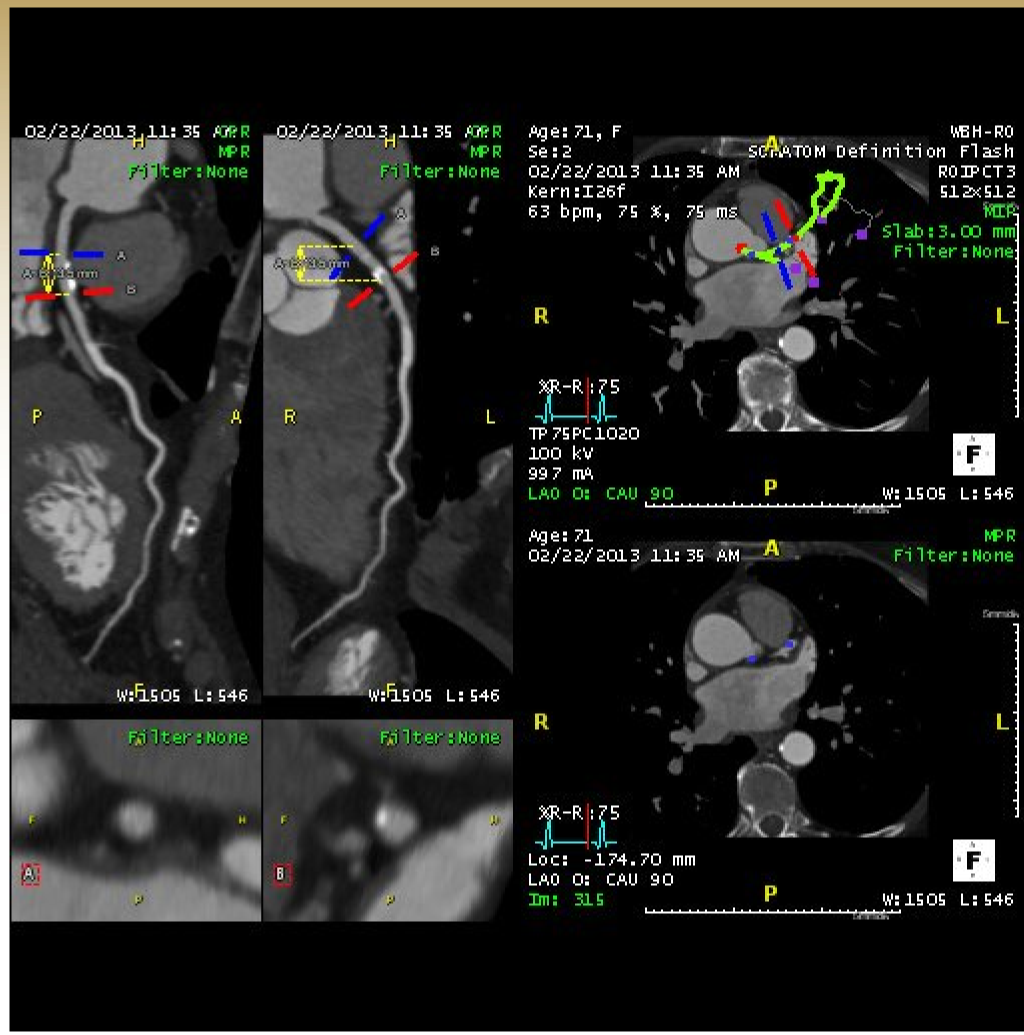
Coronary study



Mild, non-obstructive coronary disease

No cath needed

Stress test was a false positive



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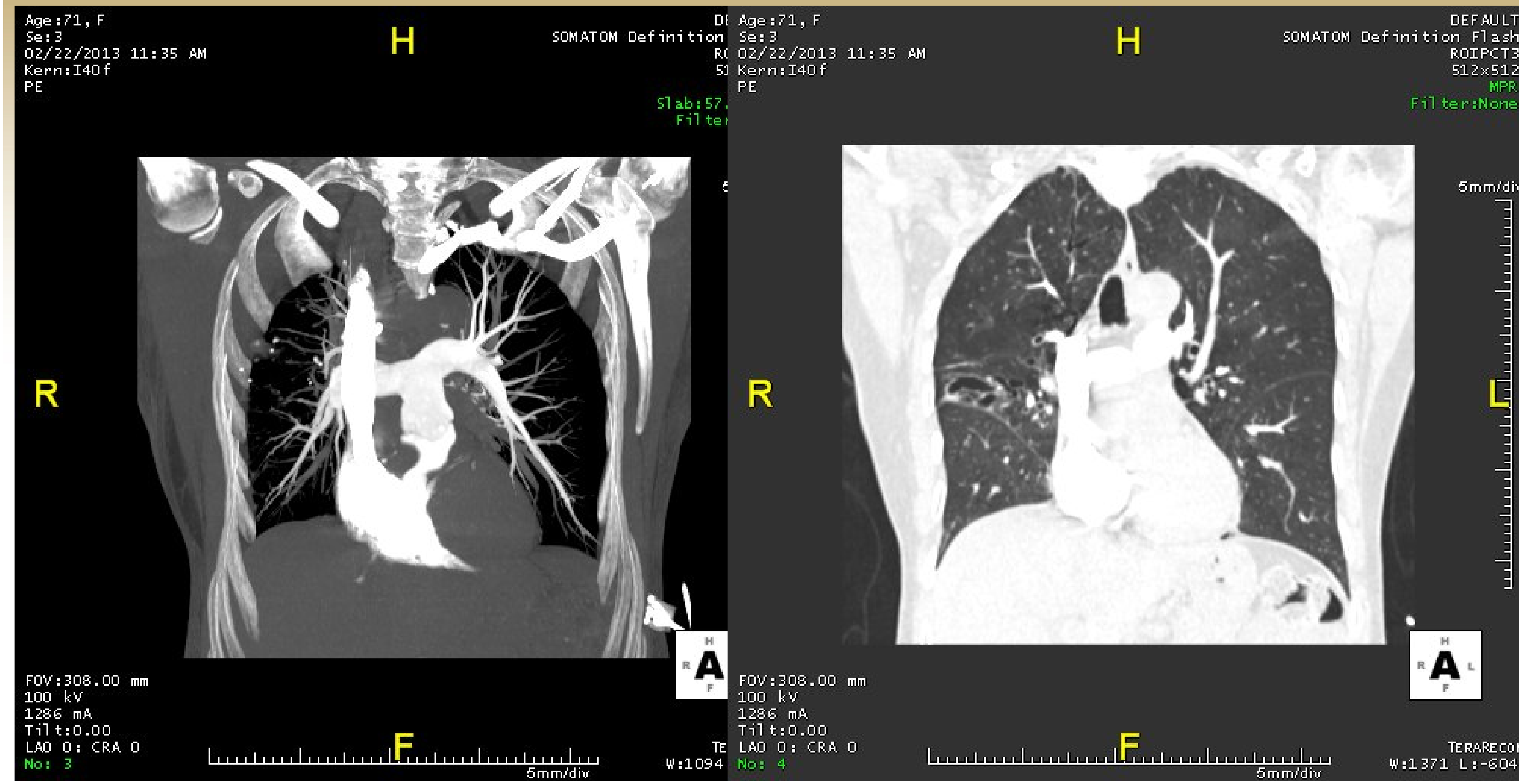
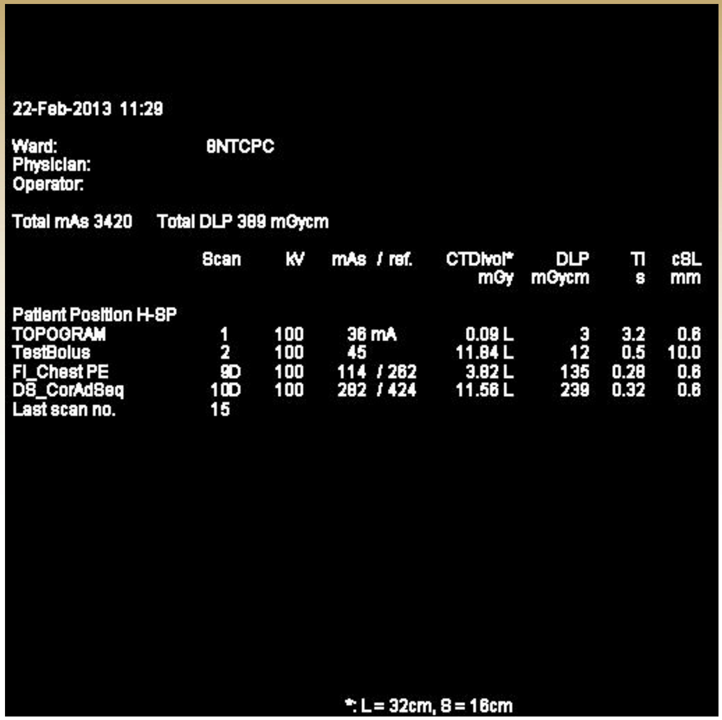
Normal pulmonary angiogram. Focal emphysema, bilateral pulmonary nodules





22-Feb-2013 11:29

Ward: 8NTCPC
Physician:
Operator:

Total mAs 3420 Total DLP 389 mGycm

	Scan	KV	mAs / ref.	CTDIvol* mGy	DLP mGycm	TI s	cSL mm
Patient Position H-SP							
TOPOGRAM	1	100	36 mA	0.09 L	3	3.2	0.6
TestBolus	2	100	45	11.84 L	12	0.5	10.0
Fl_Chest PE	9D	100	114 / 262	3.82 L	135	0.28	0.6
DS_CorAdSeq	10D	100	282 / 424	11.56 L	239	0.32	0.6
Last scan no.	15						

*: L = 32cm, S = 16cm

In the past TRO total dose ranged from 1200-1800 mGy-cm
In this case the total DLP = 389 mGy-cm
How was this achieved?

CCTA SCAN SPECIFICATIONS

Scanner Type: Definition Flash
Aquisition type: Adaptive Sequence
Scan Length (cm): 20
kVp: 100
mAs: 282

Type of Gating: Prospective
Triple Rule-Out: Yes
Dose Modulation (EKG Pulsing): No
Other dose reduction method: Yes
Comment: flash pe, sequence heart, 100kv
244 Radiation (Total DLP x 0.014) (mSv): 5.446
Contrast Rate and Concentration (mg/mL): Isovue 370
Total contrast volume for CTA acquisition (mL): 90
Injection Rate (mL / sec): 6.0
Specify CTA image recon: Multiple

Stent: No
CABG: No
Dye Allergy Prep: No
Dye Allergy Antihistamines:
Dye Allergy Steroids:
Patient's rhythm during scan: Sinus Rhythm
Average HR during CTA: 58
Heart lowering meds used: Yes

Beta Blockers: Yes
Beta Blocker Delivery: Oral **Comments:** 25mg Metoprolol

Sublingual NTG: Yes

BMI: 15
Multiphase recon: Yes

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Specific dose reduction in this case

1. 100 kV tube potential
2. “care-dose” active mA adjustment from topogram
3. High-pitch spiral PE protocol: cranial-caudal followed by
4. Sequential CCTA protocol: caudal-cranial
5. Iterative recon level 2 with 20% mA reduction
6. We will review each of these methods in detail

Best-practice use of technology available in 2011

SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT

Sandra S. Halliburton, PhD[a,*], Suhny Abbara, MD[b], Marcus Y. Chen, MD[c], Ralph Gentry, RT(R) (MR) (CT)[d], Mahadevappa Mahesh, MS, PhD[e], Gilbert L. Raff, MD[d], Leslee J. Shaw, PhD[f], Jörg Hausleiter, MD[g]

Journal of Cardiovascular Computed Tomography (2011) 5, 198–224

Journal of Cardiovascular Computed Tomography

Instructions to the referring physician

- Be specific about the clinical question
- Counsel and prep the patient in advance
- Consult with imaging MD if desired
- All this is vital because the exam may define the protocol and rad dose:
  - e.g., If pulmonary veins are all that is required, coronary protocol is not necessary and very low dose protocol can be done without beta blockers.

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Protocol variations by clinical questions

- Congenital heart disease – coronaries rarely diseased, can use aggressive low dose protocols
- Preoperative pulmonary vein ablation – also very low dose protocols
- Triple rule-out (CAD, PE, Ao) exams increase dose due to larger field of view. Recent advances minimize the problem
- Transcutaneous valve planning very high dose unless the field of view is minimized for the valve and high-pitch (or wide detector array) scanning is used for thorax-abdomen-pelvis runoff

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Instructions to the patient

- Do not use caffeine but take plenty of fluids
- Take usual medications
- Be prepared with names of medicines, medical conditions, allergies
- Understand:
  - Will be receiving radiation
  - Will be receiving contrast
  - Will need to hold still and hold breath
  - These all prevent wasted need for repeat studies

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Evaluation and preparation of PTs

- Nurse assesses baseline vital signs: HR, BP, rhythm, BMI
- If heart rate low (<65) use a handgrip stress to define acceleration
- Proceed to exam only if target heart rate met
- Baseline dose of beta blocker usually 100 mg (metoprolol). This is larger than used in many beginning centers, resulting in image artifacts and repeat exams.
- Call MD for additional measures if not at target
- Communicate with technologists about difficult patients
- MDs MUST be available for collaboration!

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Patient-specific parameters

- Because dose increases with the square of the tube potential, this is the single most important factor in adjusting patient-specific parameters.
- Body mass index (BMI) determines the kVp required to avoid severe noise. Simple height and weight charts are used to specify kVp = 120, 100 or 80.
- U.S. patients tend to be more obese: half the cardiac patients have BMI > 30 and require 120 kVp.
- Unfortunately patients with BMI >40 (morbid obesity) often have no alternatives to CTA and require kVp of 140 and high dose protocols.
- There is no simple way to adjust tube current by BMI, but engineered current modulation from topogram is commonly available.

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STATEGIES TO LIMIT EXPOSURE

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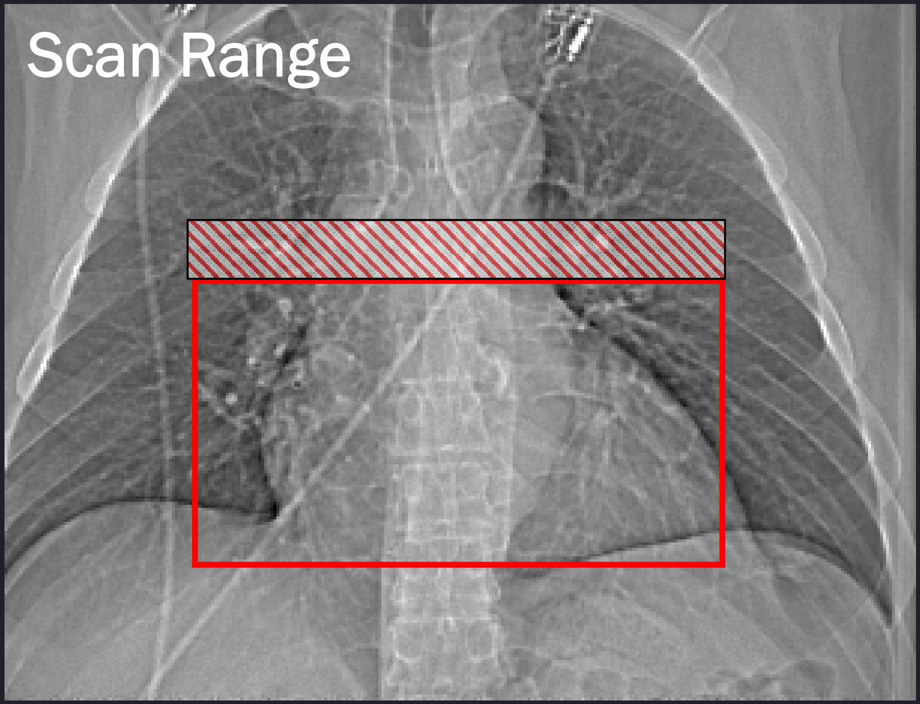
Journal of Cardiovascular Computed Tomography (2011) 5, 198–224

Journal of Cardiovascular Computed Tomography

Slides in blue courtesy of
Dr Stephen Achenbach
Keynote lecture SCCT 2011

STATEGIES TO LIMIT EXPOSURE*



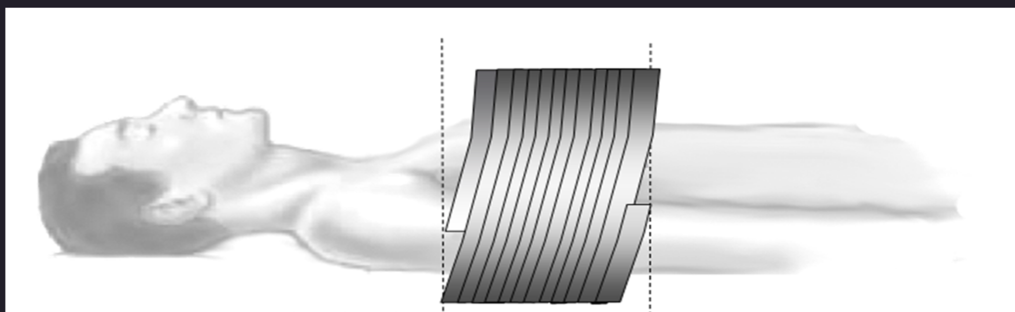
* Slides courtesy of
Dr Stephen Achenbach
Keynote lecture SCCT 2011

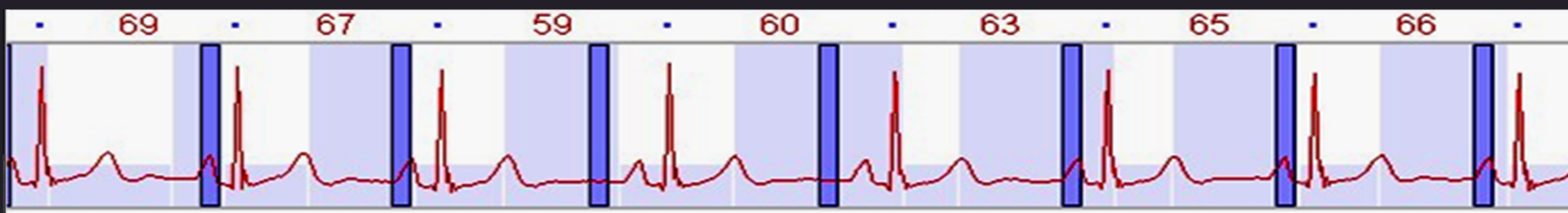
STATEGIES TO LIMIT EXPOSURE

1. Beyond the time necessary to reconstruct an image, irradiate as short a segment of the cardiac cycle as possible

2. Use less photons per cross-sectional image

Scan Protocols

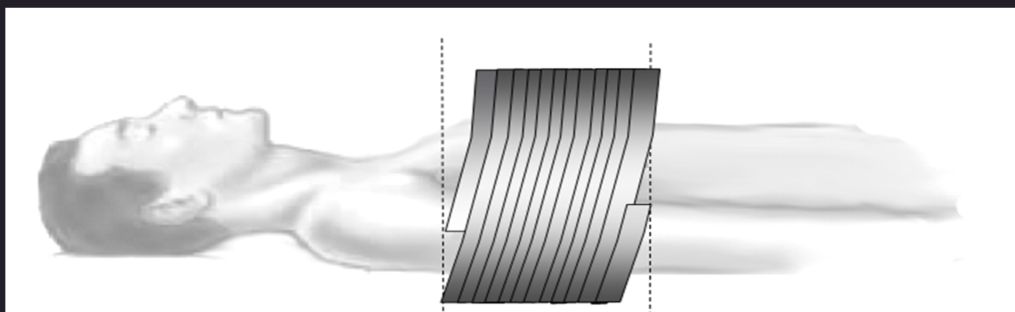




SPIRAL/HELICAL Scan

„ECG pulsing" – 40 to 50% reduction of dose

Scan Protocols



SPIRAL/HELICAL Scan

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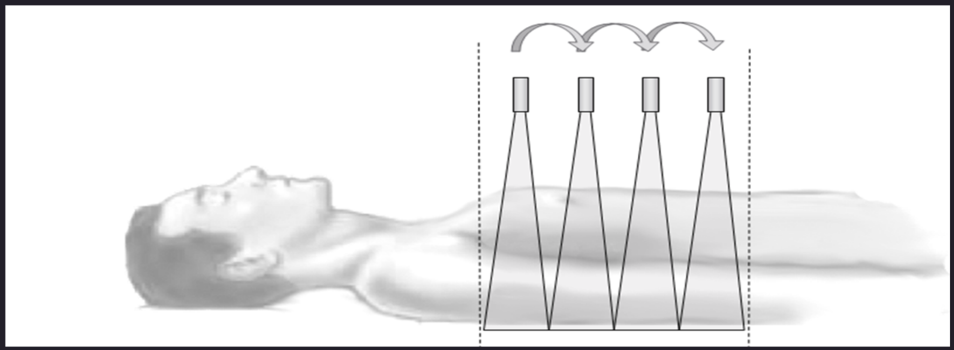
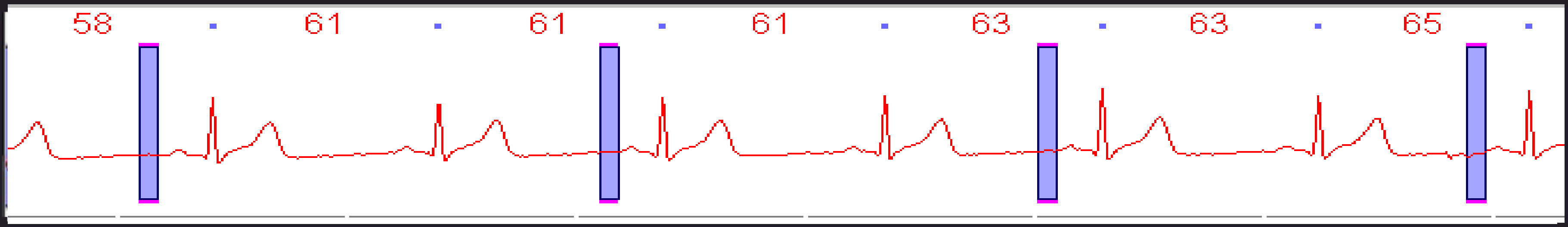
Scan Protocols





PROSPECTIVELY TRIGGERED SCAN

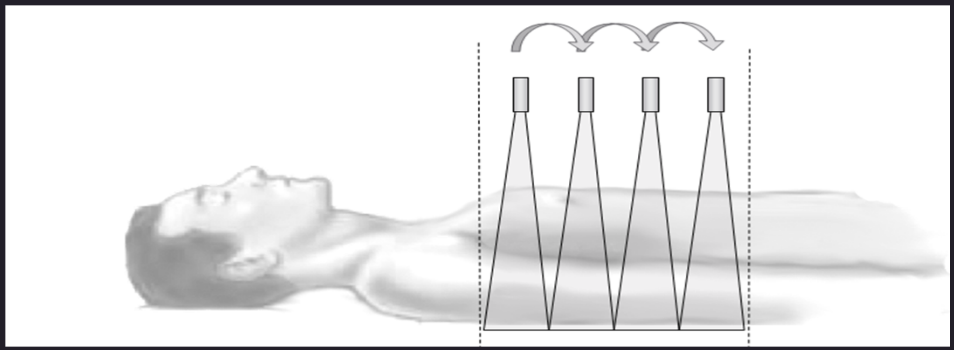
64 slice: ~ 6-8 steps

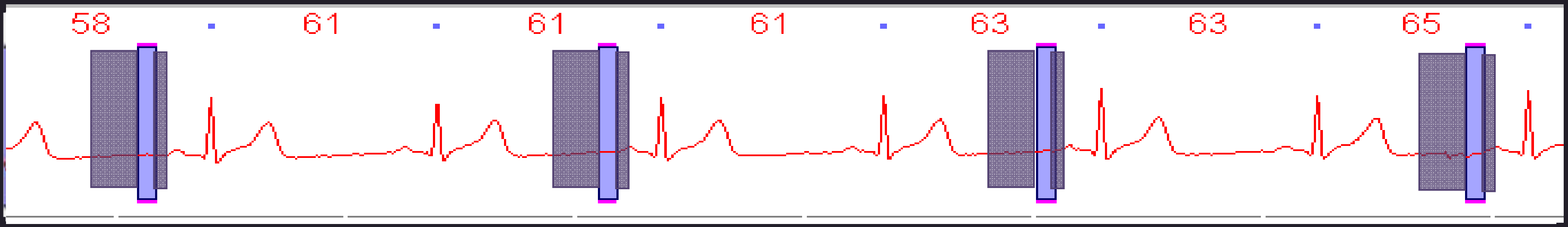
128 slice: ~ 3-4 steps

256 slice: ~ 2 steps

320 slice: ~ 1 step

Scan Protocols

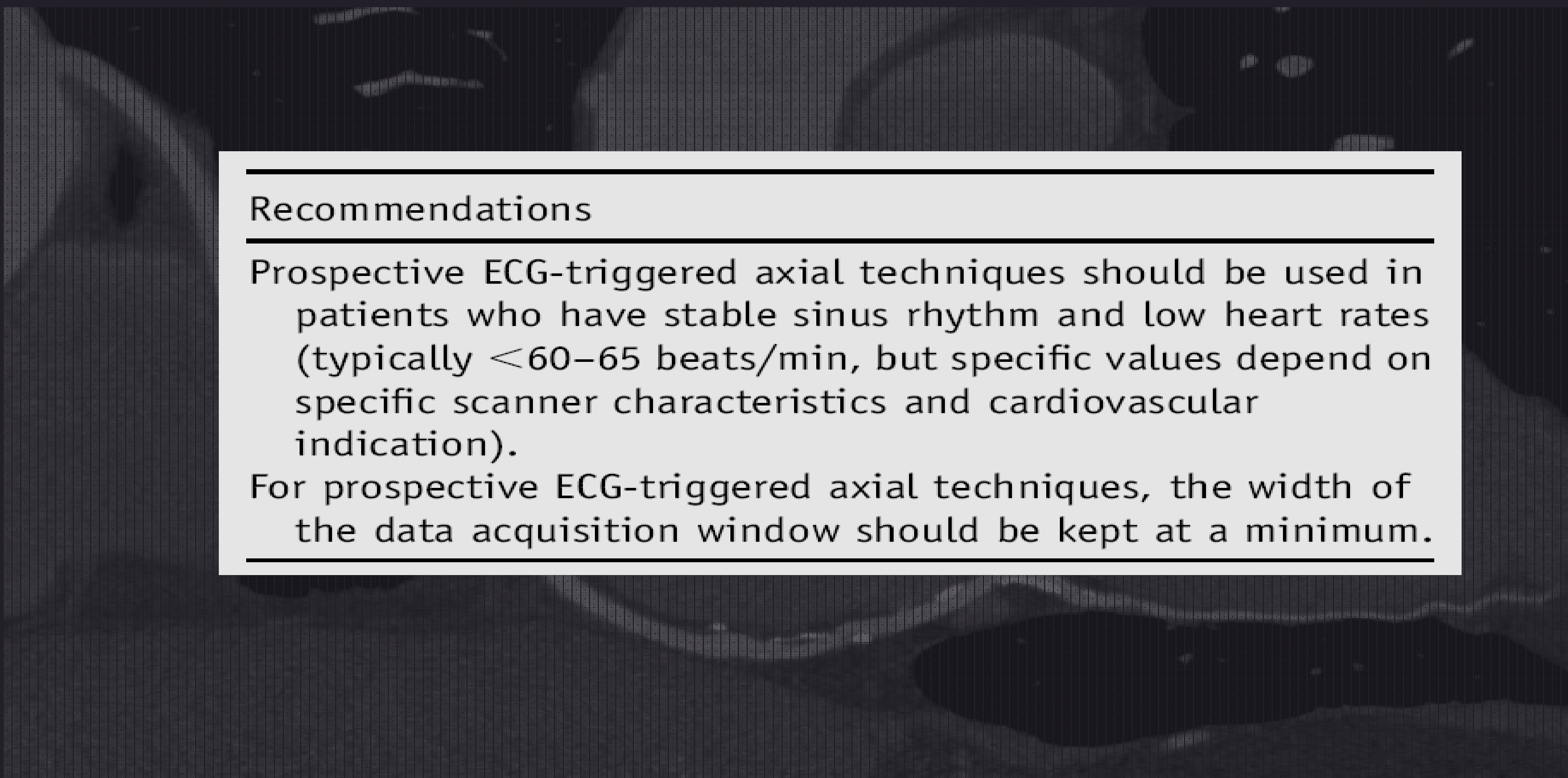




PROSPECTIVELY TRIGGERED SCAN

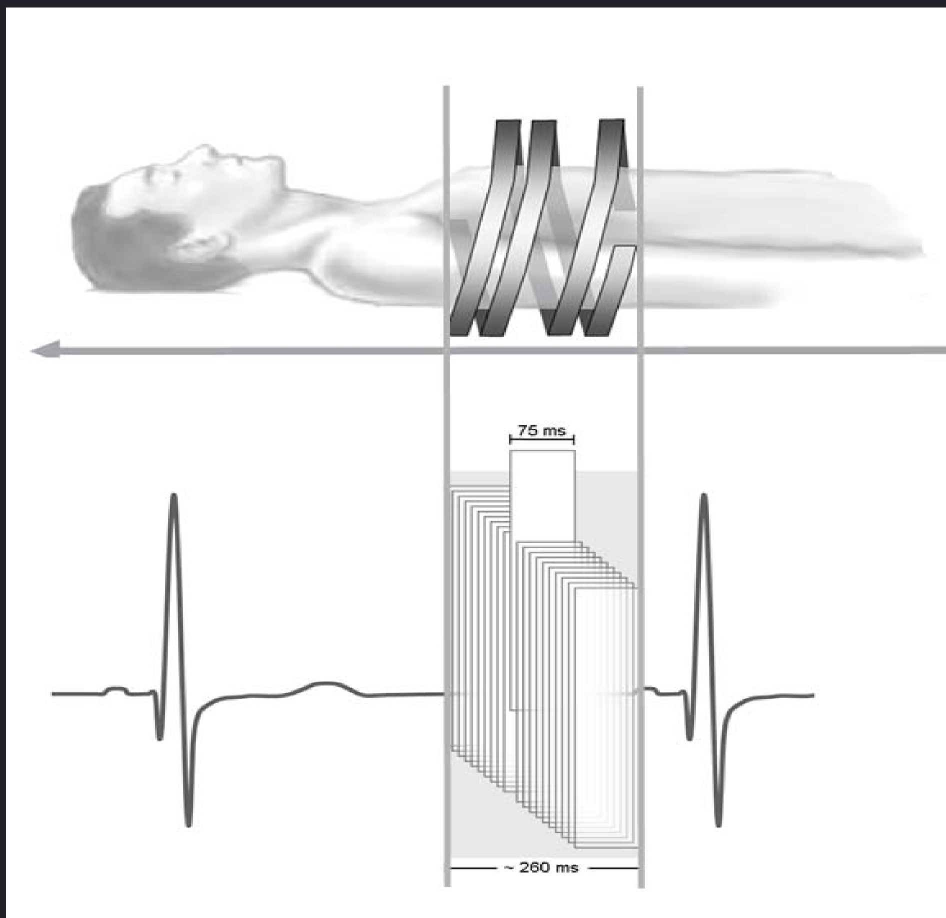
"Padding"

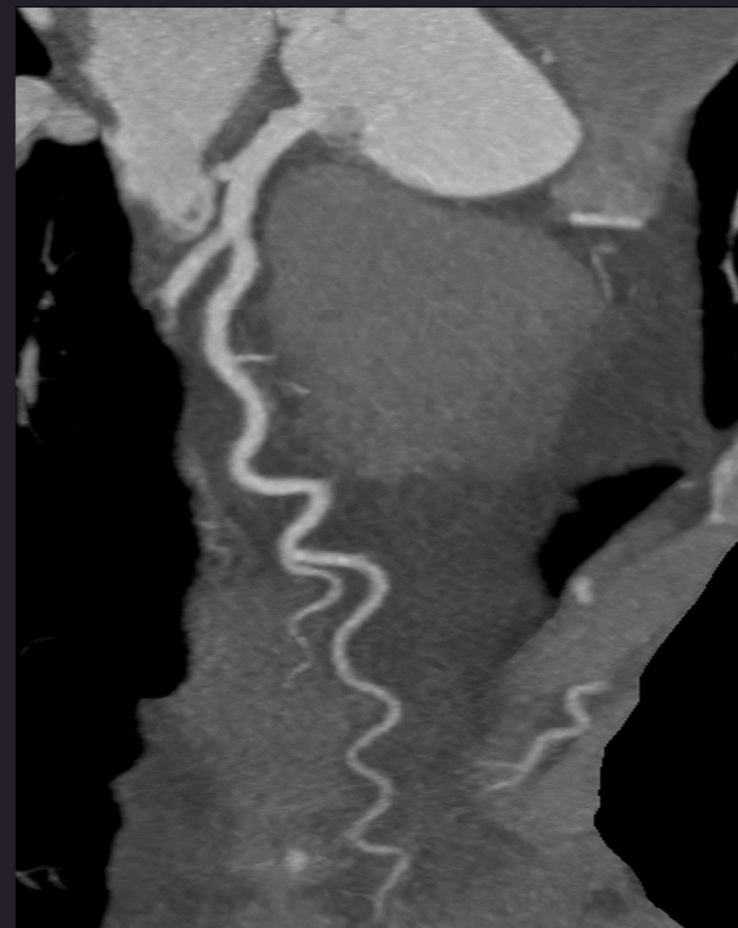
“Step and Shoot” and high-pitch or wide detector single beat: all depend on HR



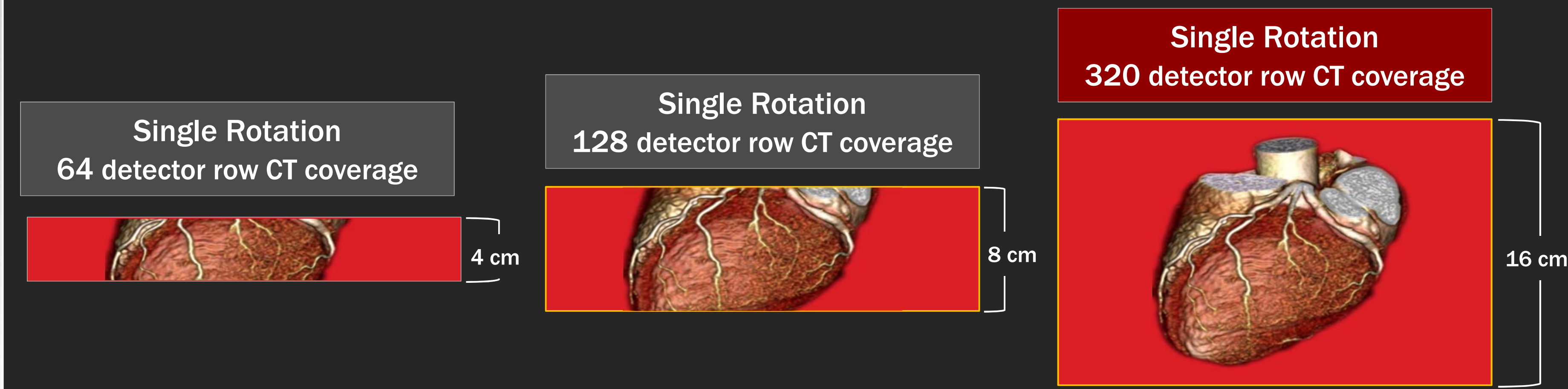
Recommendations
Prospective ECG-triggered axial techniques should be used in patients who have stable sinus rhythm and low heart rates (typically <60–65 beats/min, but specific values depend on specific scanner characteristics and cardiovascular indication).
For prospective ECG-triggered axial techniques, the width of the data acquisition window should be kept at a minimum.

“Prospectively Triggered High Pitch Spiral“





Low Dose Cardiovascular CT for All Patients



“Dial a Dose“

	120 kV
Spiral, No pulsing	~ 25 mSv
Spiral, Pulsing	~13 mSv
Spiral, Aggressive Pulsing	~ 5 mSv
Prospective Trigger	~3 mSv
High Pitch Spiral	~ 1.4 mSv

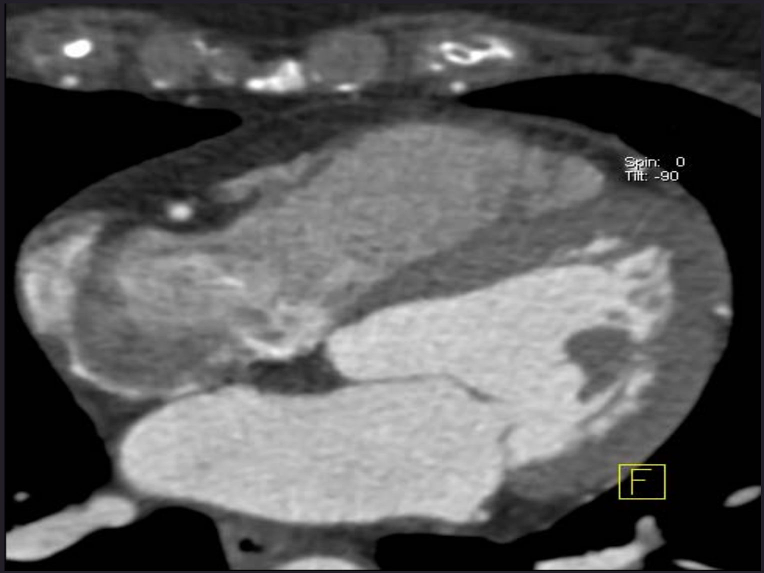
Photons per Image

Less Photons per Image

- Tube voltage (tube potential)
- Tube current

Linear to dose

1/√ to noise: 20% reduction of tube current => 12 % increase in noise



Less Photons per Image

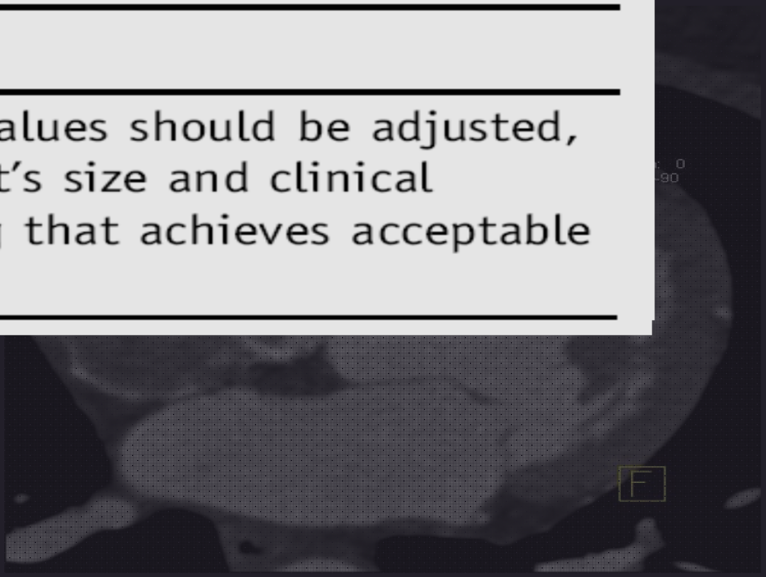
Recommendations
The scanner default tube current values should be adjusted, based on each individual patient's size and clinical indication, to the lowest setting that achieves acceptable image noise.

- Tu

- Tube current

  Linear to dose

  1/√ to noise: 20% reduction of tube current => 12 % increase in noise



Tube Voltage

When to use 100 kV tube current?

< 85 kg (Gopal et al, Int J Cardiovasc Imag 2009)

BMI < 25 kg/m² (Herzog et al, Acad Radiol 2009)

BMI < 30 kg/m² (LaBounty et al, Am J Cardiol 2010)

< 85 kg and BMI < 30 kg/m² (Raff et al, JAMA 2009)

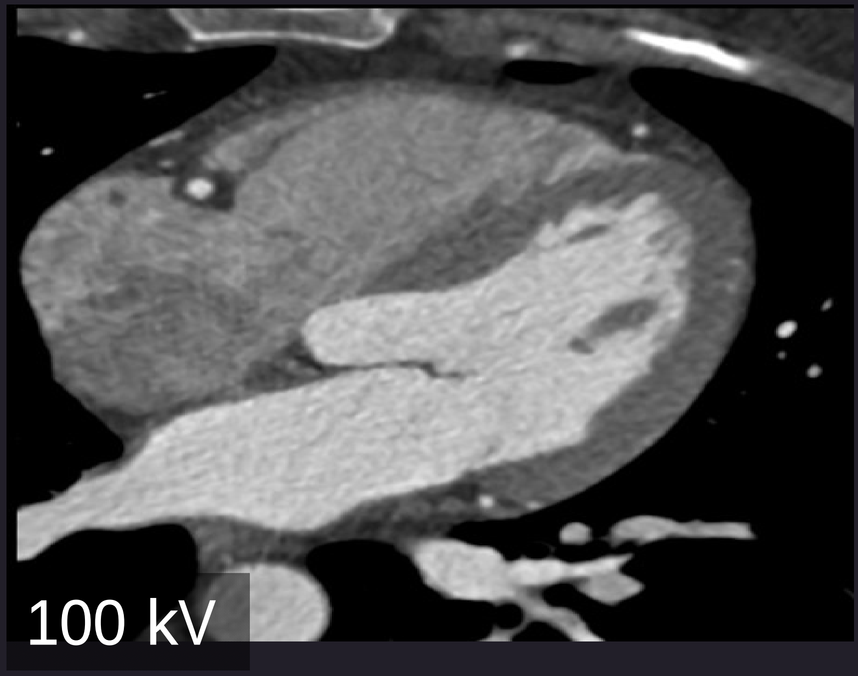
< 90 kg or BMI < 30 kg/m² (Hausleiter et al, JACC Img 2010)

< 100 kg (+ tech eyeball)

Dose by protocol

	120kV	100 kV
Spiral, No pulsing	~ 25 mSv	~ 18 mSv
Spiral, Pulsing	~13 mSv	~ 9 mSv
Spiral, Aggresisve Pulsing	~ 5 mSv	~ 3 mSv
Prospective Trigger	~3 mSv	~ 2 mSv
High Pitch Spiral (“Flash“)	~ 1.4 mSv	~ 0.9 mSv

Tube Voltage



100 kV vs. 120 kV: 31% reduction of dose

20% increase in noise

Iterative Reconstruction

“Iterative Reconstruction“

“IRIS“ - “ASIR“ - “ADIR“ - “iDose“

Standard

Iterative Reconstruction

“Sub mSv“

N = 50

Dose = 0.76 mSv

Sensitivity 100%

Specificity 82%

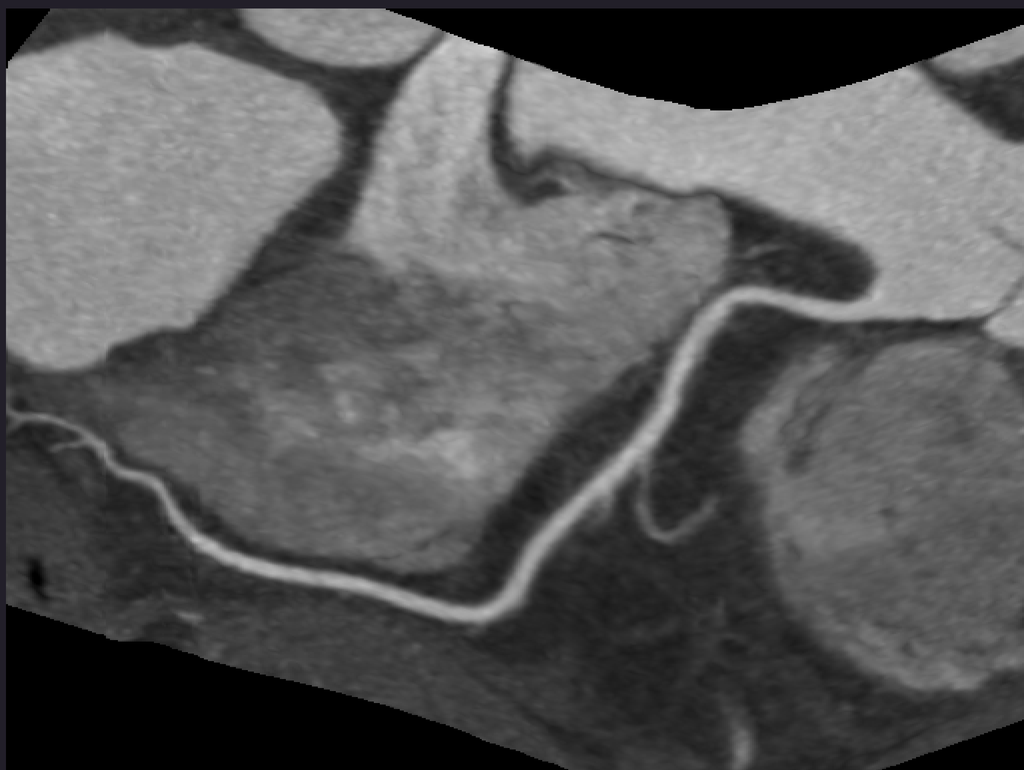
Detection of Coronary Artery Stenoses by Low-Dose, Prospectively ECG-Triggered, High-Pitch Spiral Coronary CT Angiography

Stephan Achenbach, MD,* Tobias Goroll,* Martin Seltmann, MD,* Tobias Pflederer, MD,* Katharina Anders, MD,† Dieter Ropers, MD,* Werner G. Daniel, MD,* Michael Uder, MD,† Michael Lell, MD,† Mohamed Marwan, MD*

J Am Coll Cardiol Img 2011;4:328–37

“Sub mSv“

80 kV



57 kg

Prospective trigger

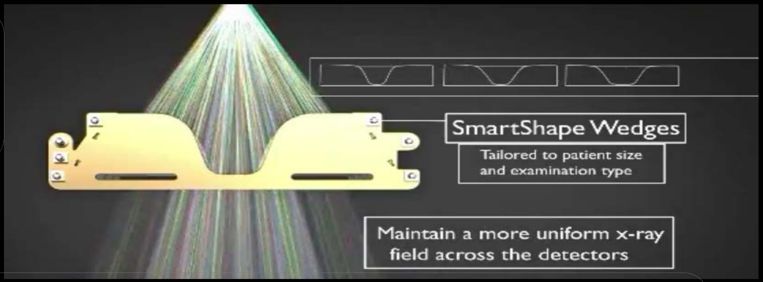
0.58 mSv

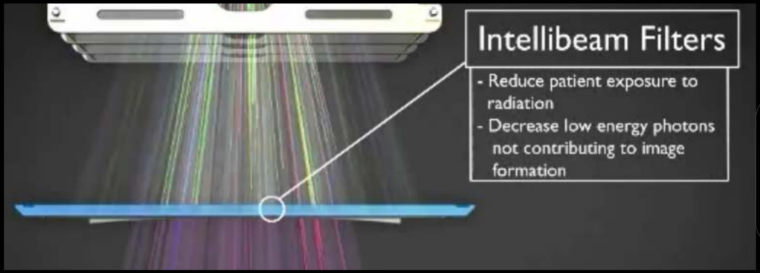
PHILIPS

Reducing Dose Throughout the Imaging Chain

Quality, Quantity and Where Needed: At the point of ***creating*** *x-rays*

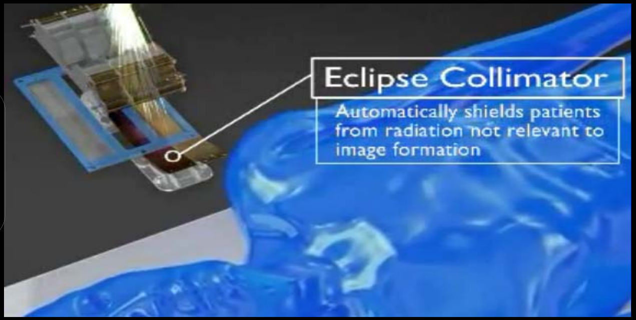
SmartShape: Increase beam hardness and reduce soft radiation when possible





IntelliBeam Filters: Shapes the beam intensity based on object size

Eclipse DoseRight Collimator: Blocks unnecessary "over-ranging" at the start and end of all helical scans

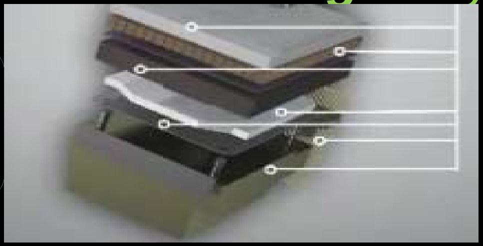


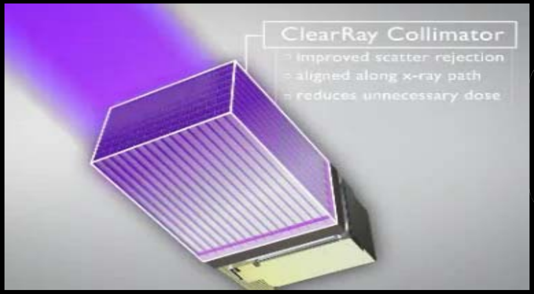
PHILIPS

Reducing Dose Throughout the Imaging Chain

*Quality, Quantity and Where Needed: At the point of **detecting** x-rays*

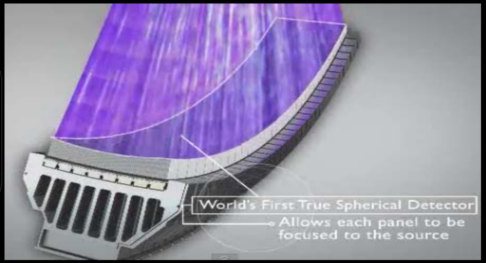
NanoPanel Detector: Reduced electronic noise. 86% improvement over conventional electronics





ClearRay Collimator: Reduces scatter artifact and nonuniformity. 3x improved scatter to primary ratio (SPR)

Spherical Detector: Geometry for true cone-beam focus.

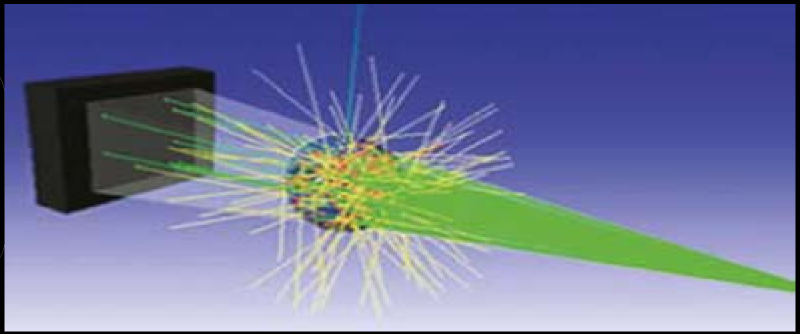


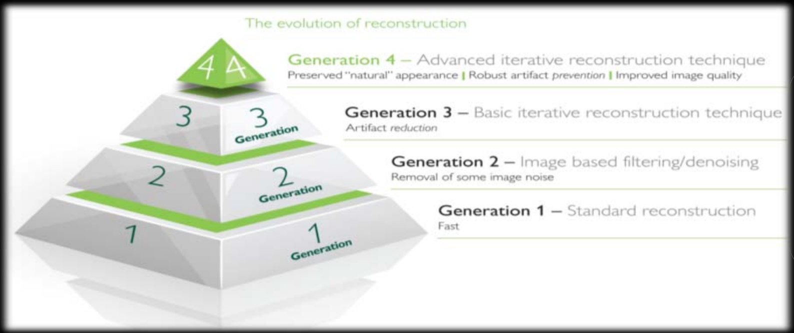
PHILIPS

Optimizing Image Quality Throughout the Chain

*Quality, Quantity and Where Needed: At the point of **creating images***

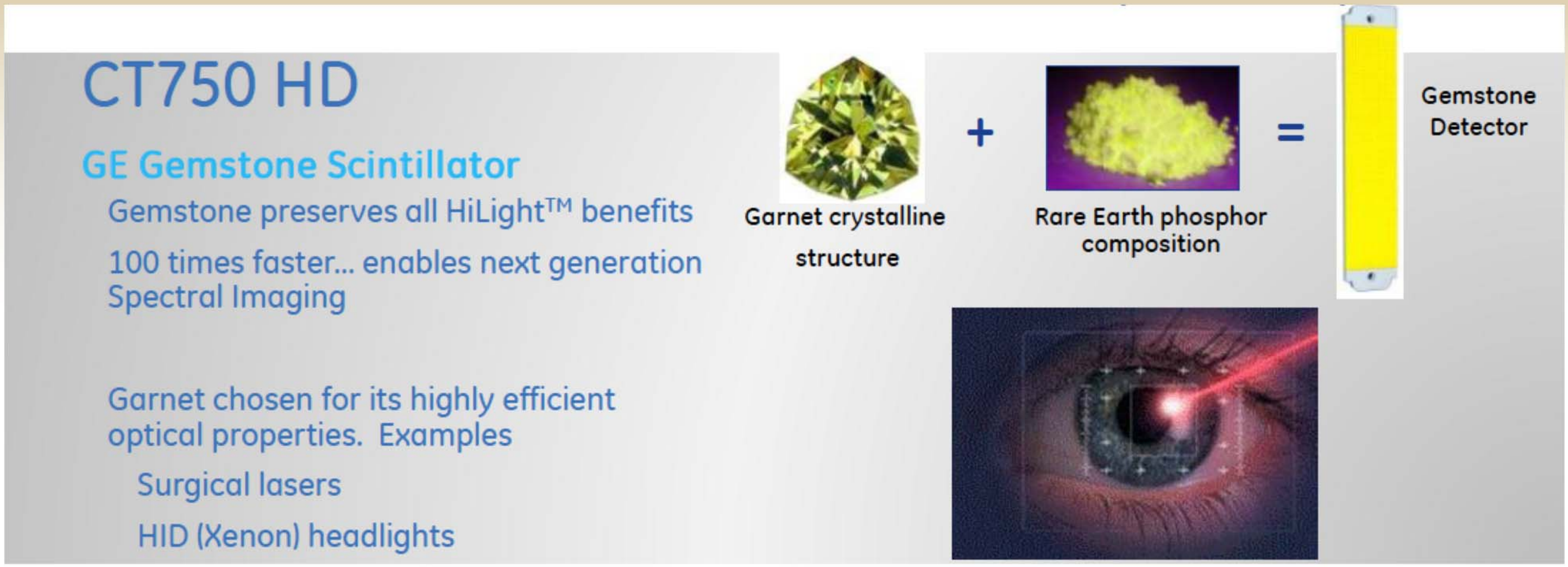
ClearRay Reconstruction: Reduces beam hardening and scatter artifacts. Improved homogeneity of HU and sharpness of organs.





iDose^4 Iterative Reconstruction Technique: Improve image quality, Preserve "natural" appearance, Robust artifact prevention, and Fast reconstruction speed.

Novel detector technology

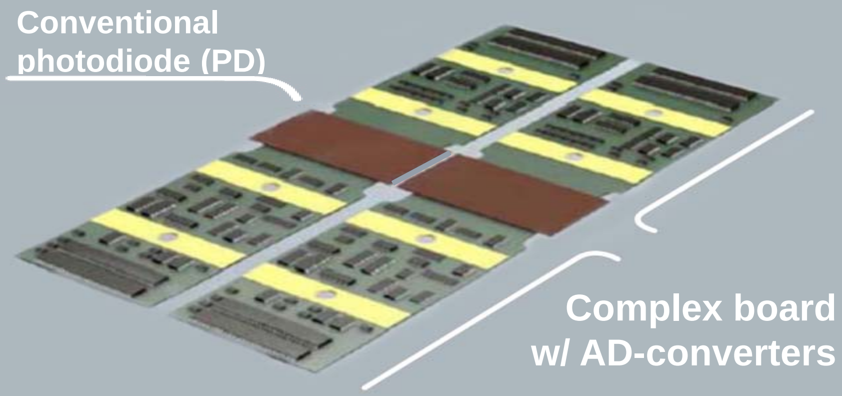


Stellar Detector

Highly integrated design with full electronic integration

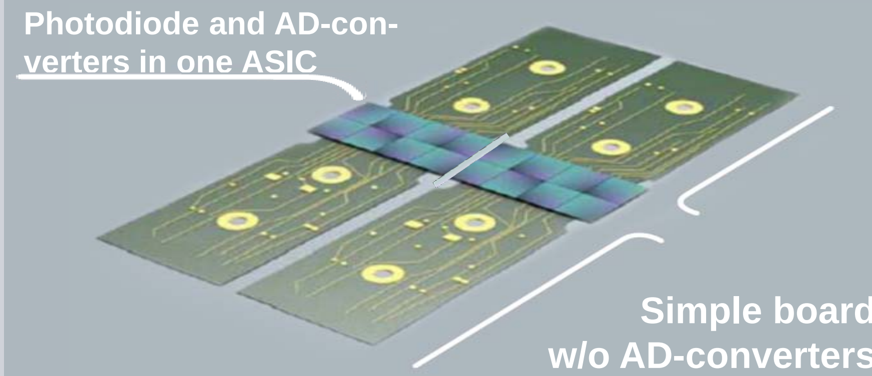
SIEMENS

Conventional Detector



- Discrete PD and AD-converters
  → high number of electronic parts
- Long elec. connection distance
- Typical elec. noise contribution

Fully Integrated Stellar Detector

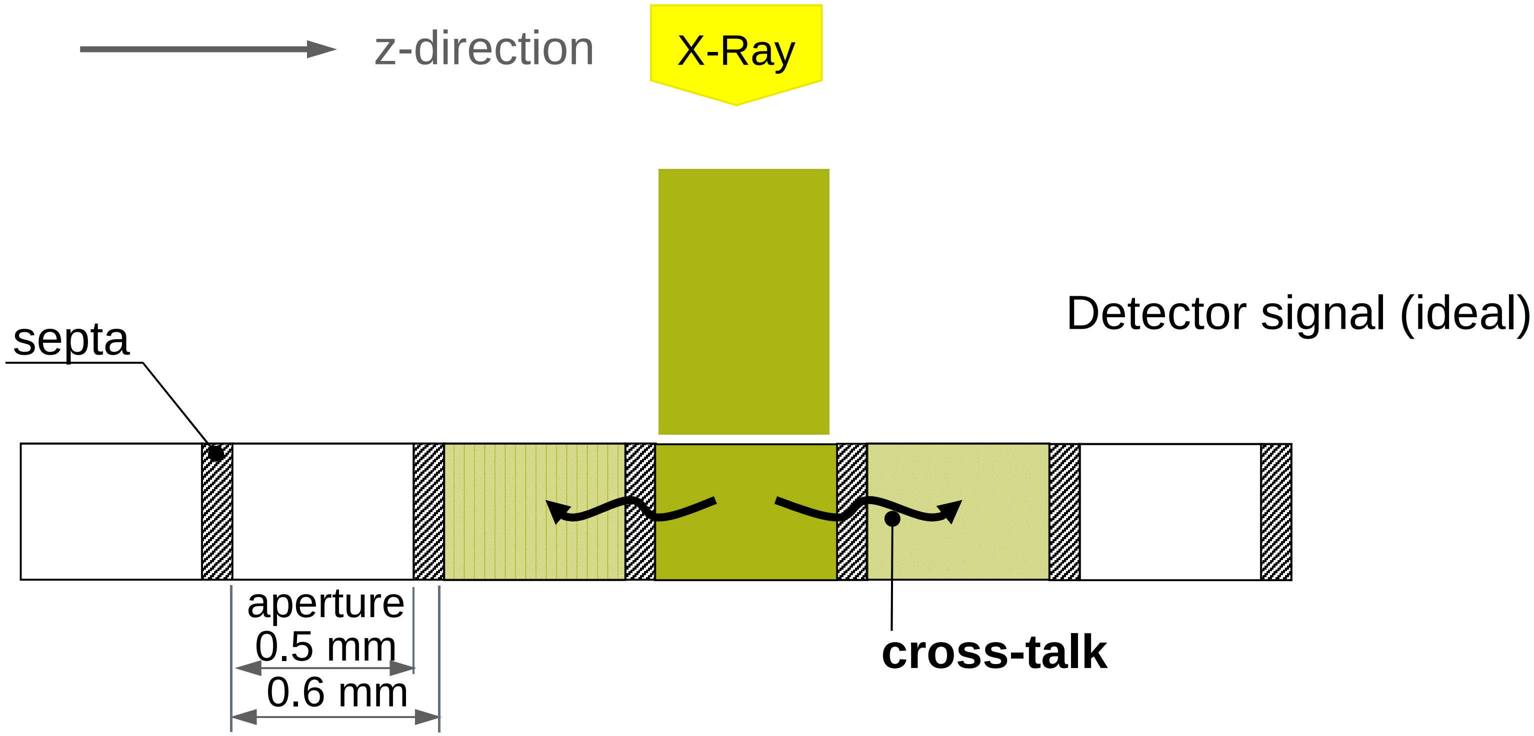


- Integrated PD and AD-converters in one ASIC
- Virtually no connection distance
- Significantly reduced elec. noise

AD: Analog-to-Digital-Converter // ASIC: Application Specific Integrated Circuit

Stellar Detector

Minimizing cross-talk is key



Stellar Detector with Edge Technology

Physical proof of high resolution cross-plane imaging

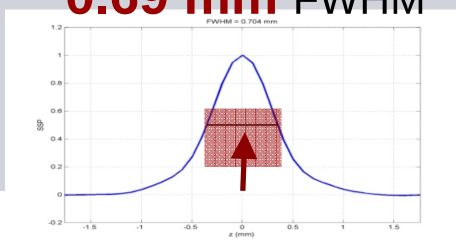
SIEMENS

Standard Detector

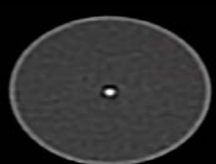
0.6 mm slice

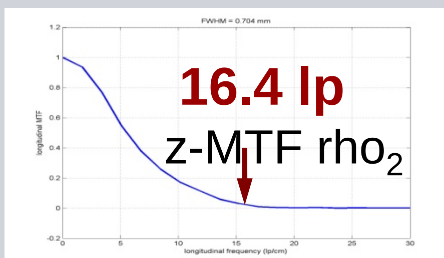
B70

0.69 mm FWHM



Disc Phantom





16.4 lp

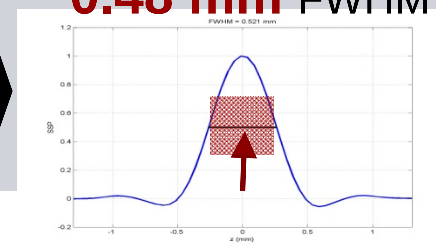
z-MTF rho_2

New Stellar Detector

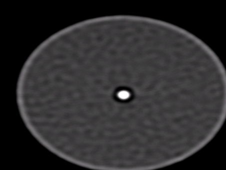
0.6 mm slice

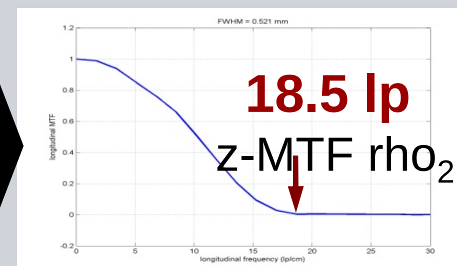
B70

0.48 mm FWHM



Disc Phantom





18.5 lp

z-MTF rho_2

MTF: Modulation Transfer Function // FWHM: Full width at Half Maximum

Stellar Detector
Minimized electronic noise

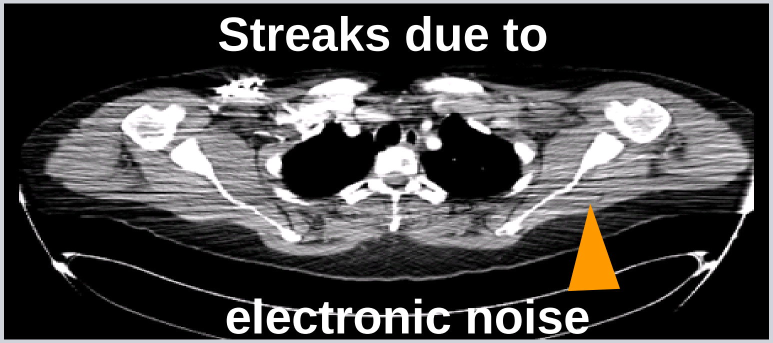
Conventional detector

Signal

el. noise

High signal:
small patient
high dose

Conventional detector



Signal

el. noise

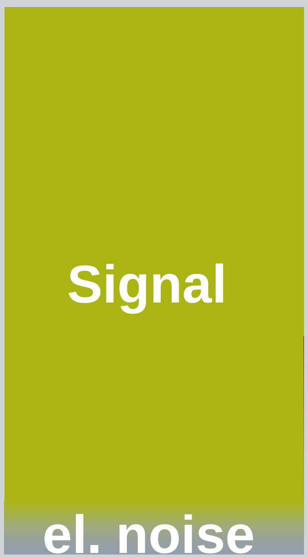
Low signal:
large patient
low dose

Courtesy of Dr. J. Hausleiter, MD, Cardiologist, German heart center, Munich, Germany

Stellar Detector

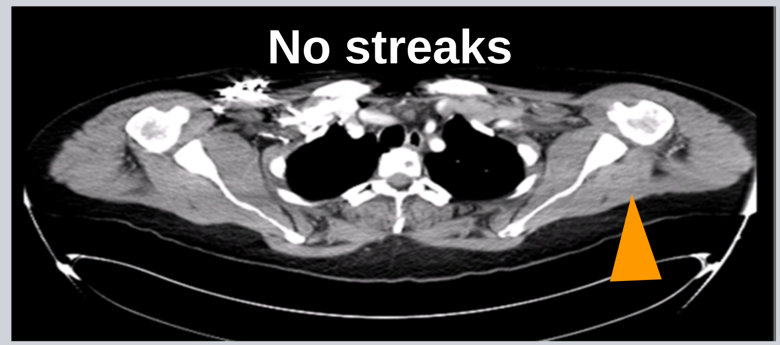
Minimized electronic noise

Conventional detector



High signal:
small patient
high dose

Stellar Detector



Low signal:
large patient
low dose

Courtesy of Dr. J. Hausleiter, MD, Cardiologist, German heart center, Munich, Germany

Stellar Detector

Analogy for HiDynamics with TrueSignal Technology

SIEMENS

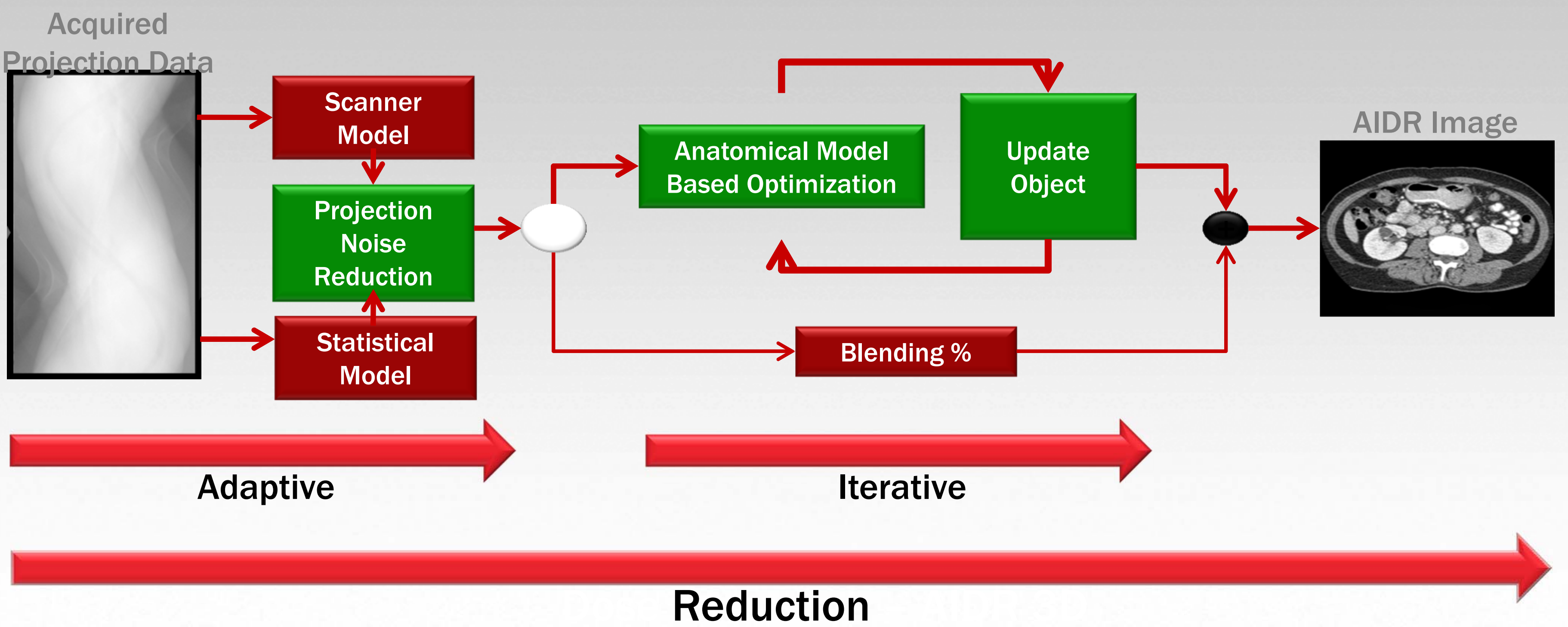
Conventional Detector

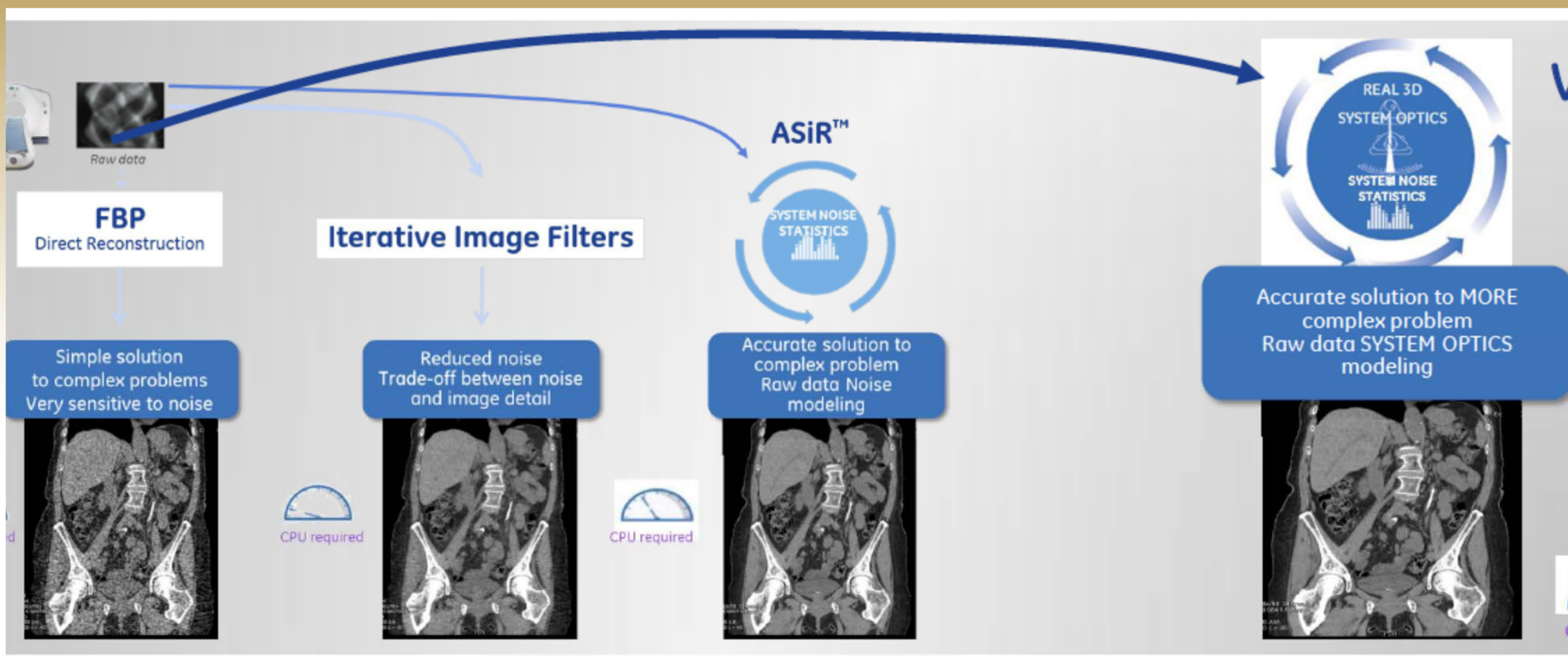
- Limited dynamic range
- Potential detail loss

New Stellar Detector

- Full dynamic range
- Higher image detail

AIDR 3D Algorithm



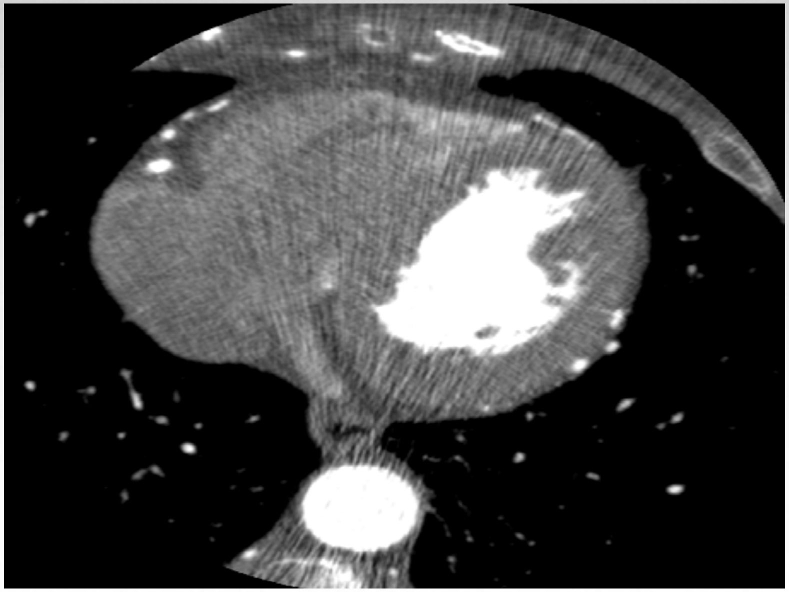


GE “VEO” and Siemens “SAFIRE”: raw data IR technology

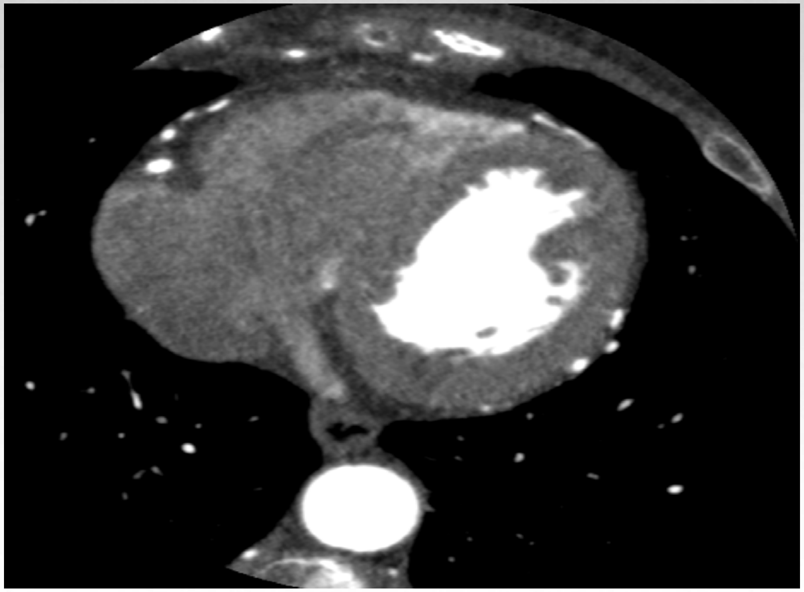
OU WB

Cardiac: Effective Dose 0.4 mSv

Without AIDR 3D

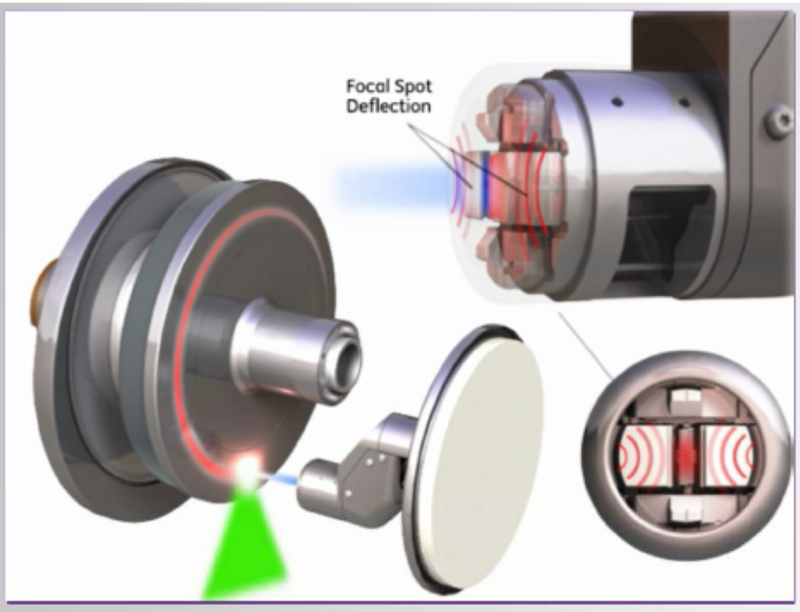


With AIDR 3D



Courtesy Monash Medical Center, Melbourne, Australia

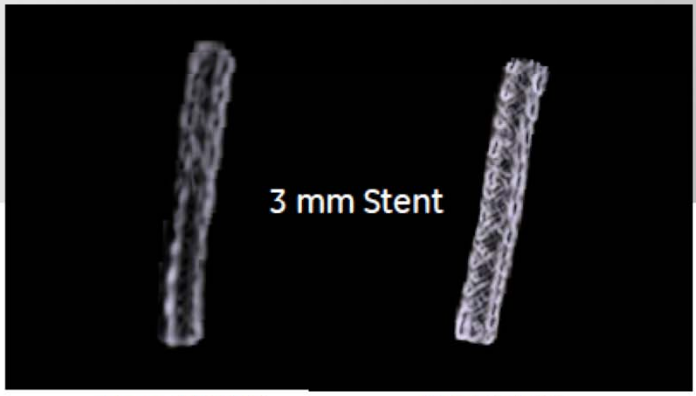
Performix™ HD Tube
Increased spatial resolution and spectral imaging



Dynamic Focal Spot Control
- Increased data sampling

Ultra-Fast kVp Switching

Power on Demand
- Maximum Power: 835mA
- Up to 570mA on smallest spot
- Heat storage capacity: 8 MHU



Non-HDCT CT750 HD

HD Fast Switching Generator

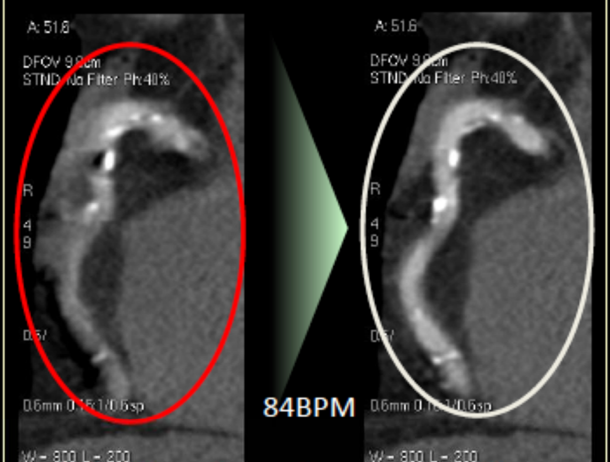
Powerful and Ultra Fast

- 100KW
- 10mA to 835mA for imaging patients of all sizes
- Sub msec kVp switching dual energy imaging with a single tube.
  - As fast as a blink of an eye

Discovery CT750 HD FREEdom Edition

World's first cardiac spectral CT

Motion FREEdom



Intelligent motion correction

SnapShot Freeze

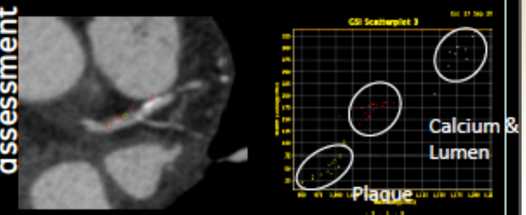
Calcium FREEdom

Iodine (HAP)*

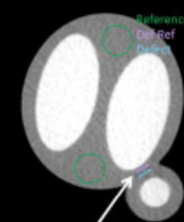
Enhanced coronary visualization **GSI Cardiac**

Horizon FREE

Plaque material composition assessment



Accurate perfusion calculations



Preparing you for the future

*GSI is delivered with a base set of materials from the NIST database and is engineered for the capability to add other material from this database. Currently, HAP is not included on the scanner/viewer as one of the materials, but can be loaded by the user following instructions in the GSI Viewer User Manual.

Why don't we achieve <1 mSv scans in practice?

- Most sites do not have new scanners incorporating all new technology
- Even in sites that do, it is very difficult to achieve stable HR <50 bpm in a large volume of typical patients
- The RCA lies on the right atrium, which moves during diastole. This frequently leads to motion artifacts; MDs are reluctant to use single beat acquisition for that reason
- Patients in these studies were imaged with 80 kVp. Our pts are not suitable due to high BMI. Noise levels are too high even with IR.

OU
WB

What is in the future for low dose cardiac CT?

- Key #1 to achieving lower doses: faster temporal resolution.
- This would permit use of single heartbeat protocols in more pts.
- Increasing detector sensitivity could reduce # of photons needed.
- With further reconstruction improvements expect better image quality/photon energy.
- Expect routine doses of <70 mGy-cm (<1 mSv) median within 5 yrs. That would be an 80% reduction from today.

OU WB

The Last Word

We need an automated dose monitoring and reporting registry.

An imaging center cannot improve
if they don’t know there is a problem.

Thank you for your attention!

OUWB