Medical Physics 2.0

Emerging Practice of Medical Physics in CT

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CARL E. RAVIN ADVANCED IMAGING LABORATORIES

Duke CIPG
Clinical Imaging Physics Group

Medical Physics 1.0

- We have done a GREAT job using engineering and physics concepts to
  - Design systems with superior performance
  - Ensure minimum intrinsic performance
  - Claim compliance
- But…

Why 1.0 is not enough

- Clinical performance?
- Optimization of use?
- Consistency of quality?
- Changing technology?
- Value-based healthcare?

1.0 to 2.0

- Clinical imaging physics extending from
  - intrinsic to extrinsic
  - Specs to performance
  - compliance to excellence
  - Quality to consistency
  - Equipment to operation

Outline

A. Physics implications of new technologies
B. New metrics and metrology
C. Operationalizing medical physics 2.0

A. Physics implications of new technologies

Physics and new technologies

1. Hardware
   - New detectors
   - Operation is extra low dose
   - Photon-counting

Physics and new technologies

2. Acquisitions
   - Innovative helical scans
   - Wide-beam acquisitions
   - AEC and its variants

Physics and new technologies

3. Image processing
   - Iterative reconstructions
   - Kernels
   - Quantitative CT
   - Higher order data analysis
     - 3D rendering
     - CAD
     - Functional analysis (eg, perfusion)

Physics and new technologies

4. New designs and applications
   - Dual-energy
   - Inverse geometry
   - Application specific devices
     - Dental
     - MSK
     - Breast
     - RT

B.
New Metrics and Metrologies

Metrics and metrology

1. Radiometrics
   - From CTDI to SSDE and beyond
2. Qualimetrics
   - From CNR to d' and beyond
   - Size, contrast, and texture effects

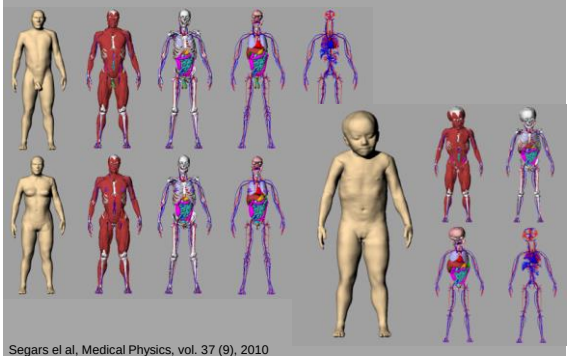
Radiometrics

Metric	Definition
CTDI	Radiation output of a CT system in a standard sized phantom
SSDE	Radiation output of a CT system adjusted for the average patient size (for chest, abdomen/pelvis scans)
Organ dose	Dose to individual organs; estimated by simulation or experimental measurement
Effective Dose	Weighted sum of organ/tissue equivalent dose for radiation sensitive organs ignoring patient specific factors
Risk index	Weighted sum of organ/tissue equivalent risk for radiation sensitive organs, accounting for age, gender, anatomy

Samei, Ped Rad, in press, 2014

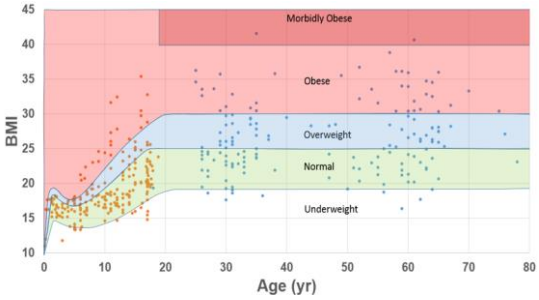
Metric	Measure-able	Scanner model and factors	Patient Size	Patient anatomy	Patient age	Patients Gender	Modality generic	Patient avg total burden
CTDI								
SSDE								
Organ dose								
Effective Dose								
Risk index								

Virtual human models for organ dosimetry



Segars el al, Medical Physics, vol. 37 (9), 2010

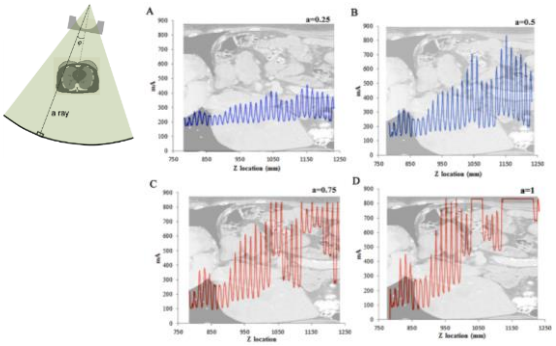
Population Representation



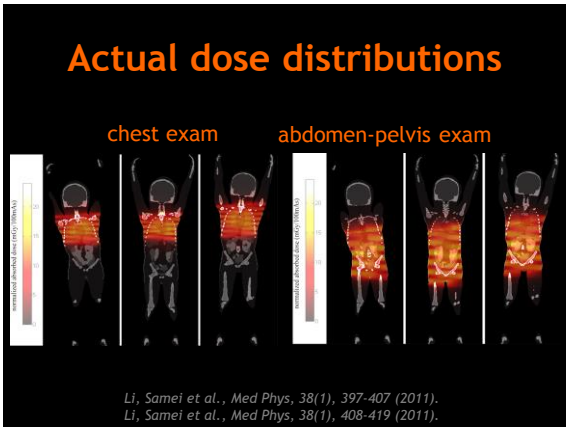
Building towards 400 patient models

Imaging Simulation

Tube Current (mA) Modulation

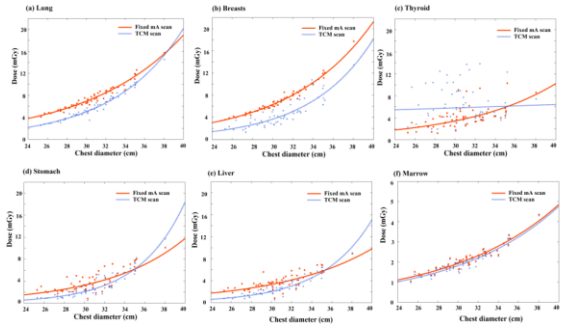


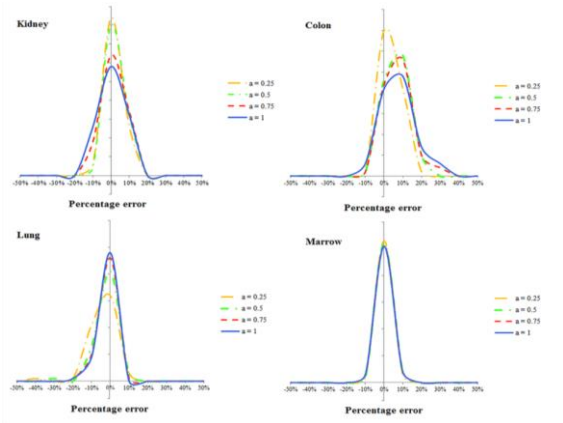
Actual dose distributions



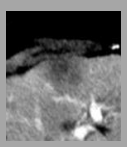
Li, Samei et al., Med Phys, 38(1), 397-407 (2011).
Li, Samei et al., Med Phys, 38(1), 408-419 (2011).

Typical organ dose values (chest CT)





Qualimetrics

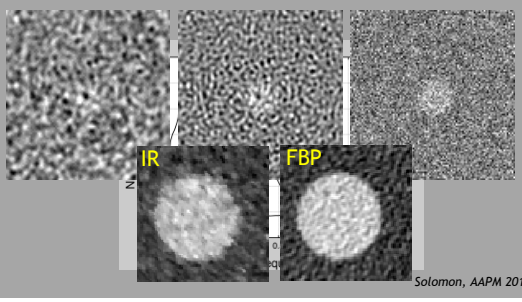


1. Contrast 2. Lesion size 3. Lesion shape 4. Edge profile	Feature of interest
5. Resolution 6. Viewing distance 7. Display	Image details
8. Noise magnitude 9. Noise texture 10. Operator noise	Distractors

Parameters that are measured by CNR

1. Contrast 2. Lesion size 3. Lesion shape 4. Edge profile	Feature of interest	1. Contrast
5. Resolution 6. Viewing distance 7. Display	Image details	?
8. Noise magnitude 9. Noise texture 10. Operator noise	Distractors	8. Noise magnitude

Why CNR is not enough: Noise texture

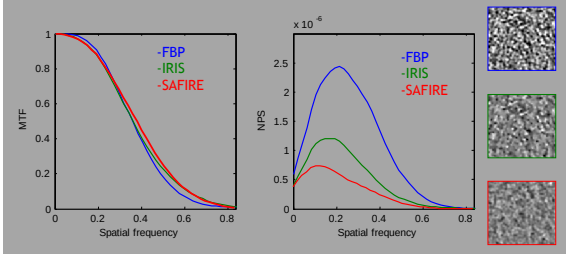


Solomon, AAPM 2012

Resolution and noise, eg 1

Comparable resolution

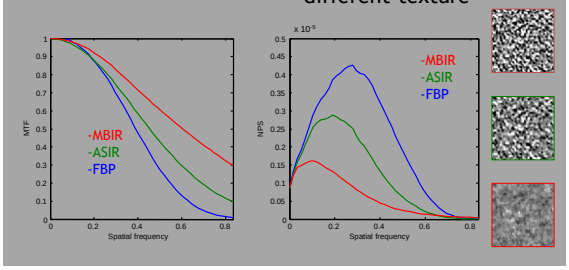
Lower noise but different texture



Resolution and noise, eg 2

Higher resolution

Lower noise but different texture



Detectability index

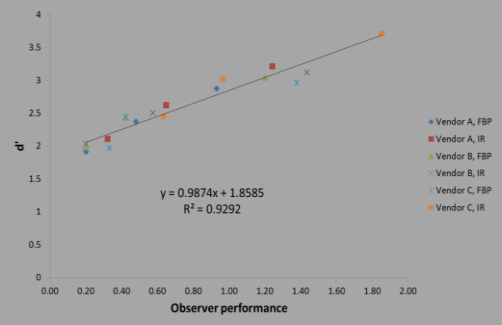
Resolution and contrast transfer × Attributes of image feature of interest

Image noise magnitude and texture

$$\left(d'_{NPWE}\right)^2 = \frac{\left[\iint MTF^2(u,v)W_{Task}^2(u,v)E^2(u,v)dudv\right]^2}{\iint MTF^2(u,v)W_{Task}^2(u,v)NPS(u,v)E^4(u,v) + MTF^2(u,v)W_{Task}^2(u,v)N_i\,dudv}$$

Richard, and E. Samei, Quantitative breast tomosynthesis: from detectability to estimability. Med Phys, 37(12), 6157-65 (2010).
Chen et al., Relevance of MTF and NPS in quantitative CT: towards developing a predictable model of quantitative... SPIE2012

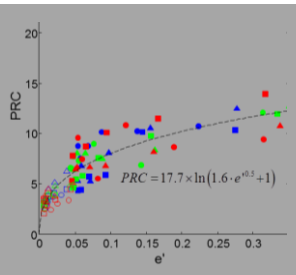
d' vs observer performance



Christianson et al, Radiology, in print 2014

Predicted precision matches empirical precision!

$$PRC_j = 1.96\sqrt{2\sigma^2_{ijj}} \,/\, V_{true}$$
$$\approx 2.77\hat{\sigma}_{ijj} \,/\, V_{true}$$
$$= 2.77\sqrt{\sum_{i=1}^{n}\sum_{k=1}^{K}\frac{(V_{ijk}-\bar{V}_{ij})^2}{n(K-1)}} \,/\, V_{true}$$



- FBP, 0.625 mm, small nodule
- FBP, 1.25 mm, small nodule
- FBP, 2.5 mm, small nodule
- ASiR, 0.625 mm, small nodule
- ASiR, 1.25 mm, small nodule
- ASiR, 2.5 mm, small nodule
- MBIR, 0.625 mm, small nodule
- MBIR, 1.25 mm, small nodule
- MBIR, 2.5 mm, small nodule
- FBP, 0.625 mm, large nodule
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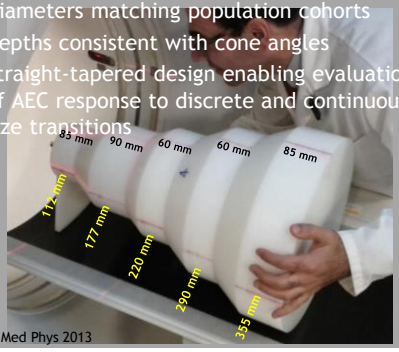
- MBIR, 1.25 mm, large nodule
- MBIR, 2.5 mm, large nodule

Task-based assessment metrology Mercury Phantom 3.0

- Diameters matching population cohorts
- Depths consistent with cone angles
- Straight-tapered design enabling evaluation of AEC response to discrete and continuous size transitions



Wilson et al, Med Phys 2013

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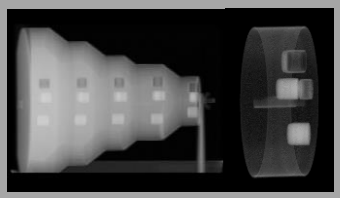
Design: Resolution, HU, noise



- **Representation of abnormality-relevant HUs**
- **Iso-radius resolution properties**
- **Matching uniform section for noise assessment**

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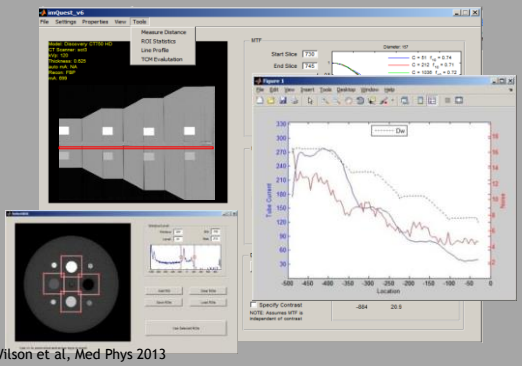
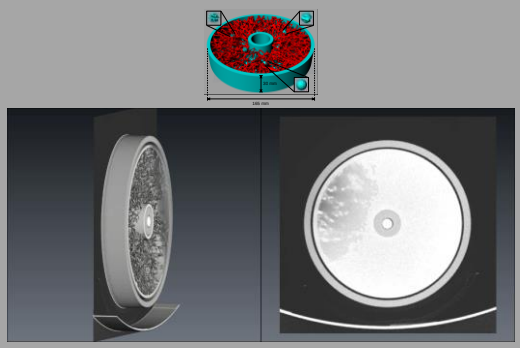
imQuest: image quality evaluation software

HU, Contrast, Noise, CNR, MTF, NPS, and d' per patient size, mA modulation profile



Wilson et al, Med Phys 2013

Lung texture representation



Solomon et al, Med Phys, accepted 2014

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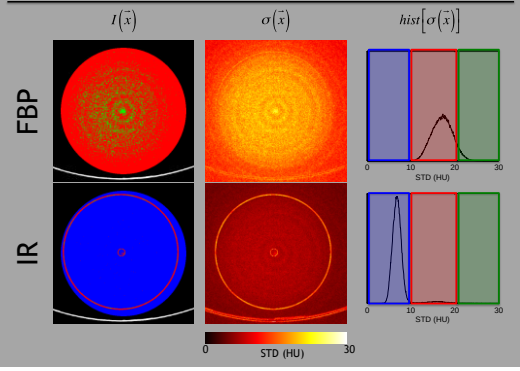
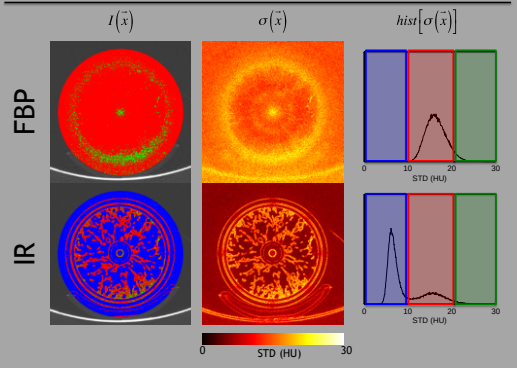
Noise in the uniform phantom



Noise in the lung phantom



C. Operationalizing Medical Physics 2.0

Operational medical physics 2.0

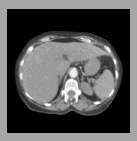
1. Quality by prescription
2. Quality by outcome
3. Training and communication
4. Pragmatism QC

Components of quality assurance

System performance assessment
Quality by inference

Prospective protocol definition
Quality by prescription

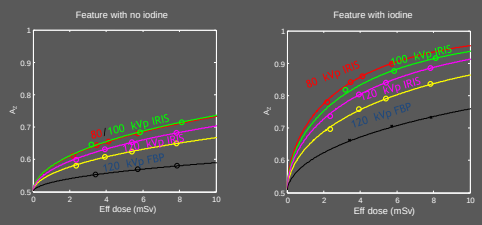
Retrospective performance assessment
Quality by outcome



kV IR optimization

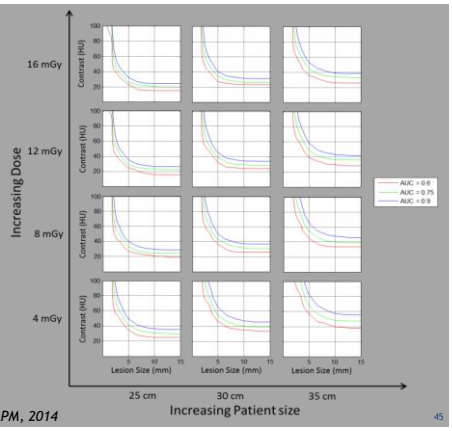
ACR phantom

Task	Optimal technique	% dose reduction (wrt 120 kVp FBP)
No Iodine	80/100 kVp with IRIS	36%
With Iodine	80 kVp with IRIS	40%



Samei, Richard, Med Phys, in press, 2014

Detectability trends with dose/size



Smitherman, AAPM, 2014

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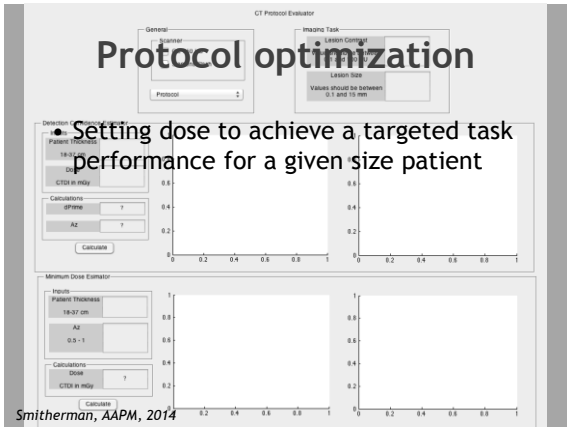
Protocol optimization

- Setting dose to achieve a targeted task performance for a given size patient



Smitherman, AAPM, 2014

Protocol optimization

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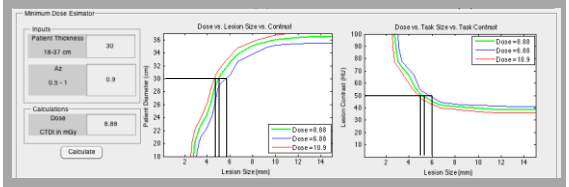
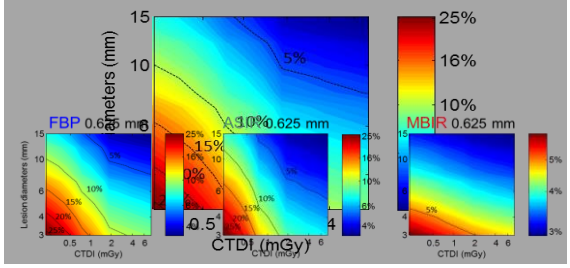


Smitherman, AAPM, 2014

Quality-dose dependency

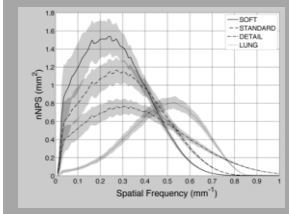
Quantitative volumetry via CT

PRC: Relative difference between any two repeated quantifications of a nodule with 95% confidence

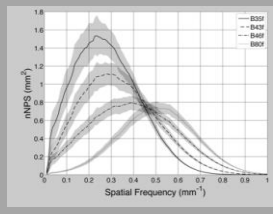


Noise texture vs kernel

GE

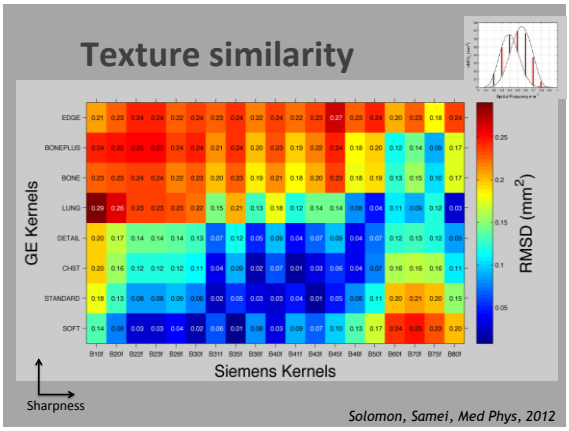


Siemens



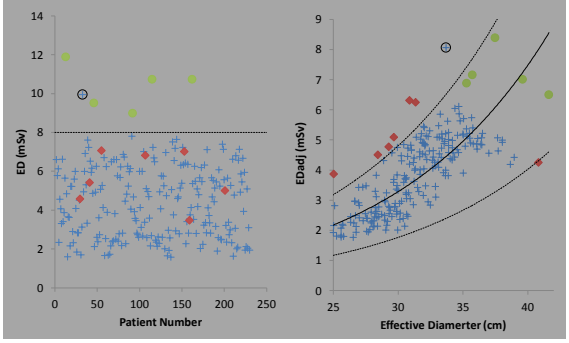
Solomon, Samei, Med Phys, 2012

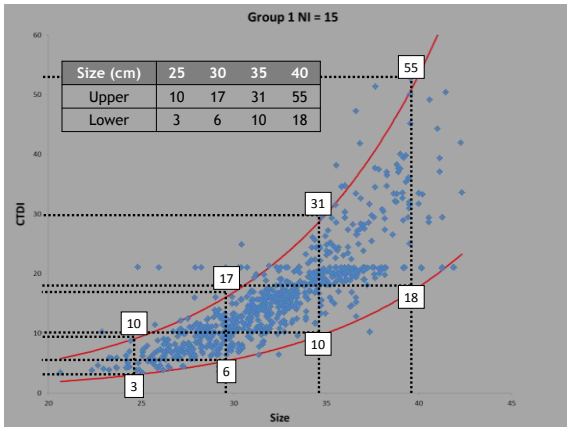
Texture similarity

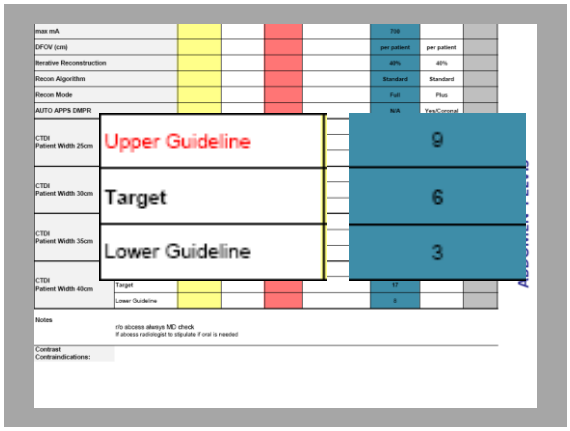


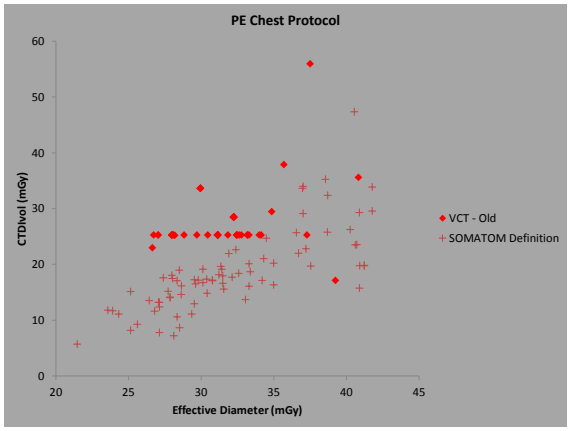
Solomon, Samei, Med Phys, 2012

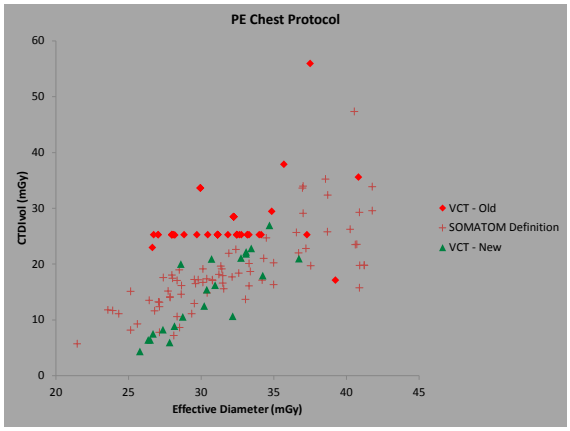
Proper dose tracking – with size




Group 1 NI = 15
Size (cm) 25 30 35 40
Upper 10 17 31 55
Lower 3 6 10 18
55
31
17
18
10
10
6
3
CTDI
Size


Upper Guideline
9
Target
6
Lower Guideline
3

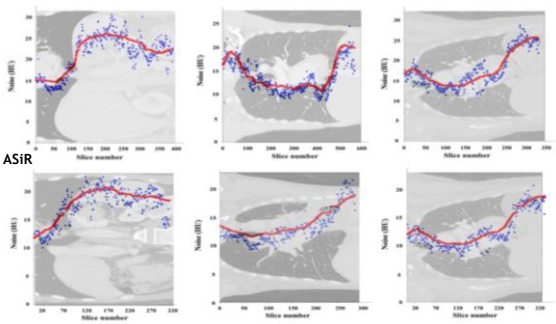

PE Chest Protocol
CTDIvol (mGy)
Effective Diameter (mGy)
VCT - Old
SOMATOM Definition



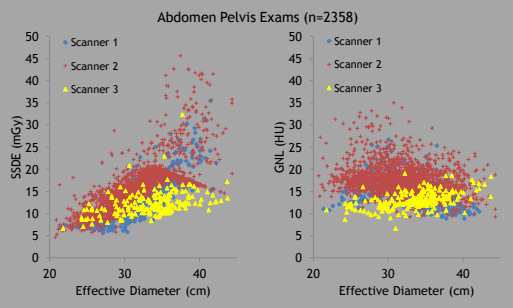
Noise per slice

FBP

ASiR

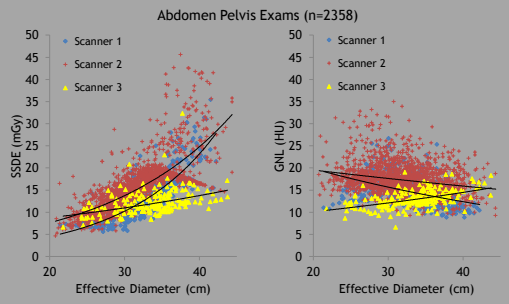


Trends in dose and noise



Christianson, AAPM, 2014

Trends in dose and noise



Christianson, AAPM, 2014

Communication

- Insular days of medical physics are over
- We are as good as we can communicate

Pragmatic medical physics

- We need to be smarter with our 1.0 activities to clear space for 2.0 stuff
- Action for the sake of action is not value-based

Conclusions: Clinical imaging physics at the cross-road

- New technologies necessitates an upgrade to physics metrology
- Clinical needs requires to become more operationally minded
- New healthcare realities provides us an opportunity to become more value-conscious