Using DRLs for CT optimization: Sources and management of dose variability

Ehsan Samei

Overarching premise

Medicine: Discerning and intervening in the health state of the patient with sufficient accuracy, precision, and safety for definitive clinical outcome

Healthcare is about the patient, not the particularities of the techniques – techniques and quantities are valued to the extent they are relevant to the patient

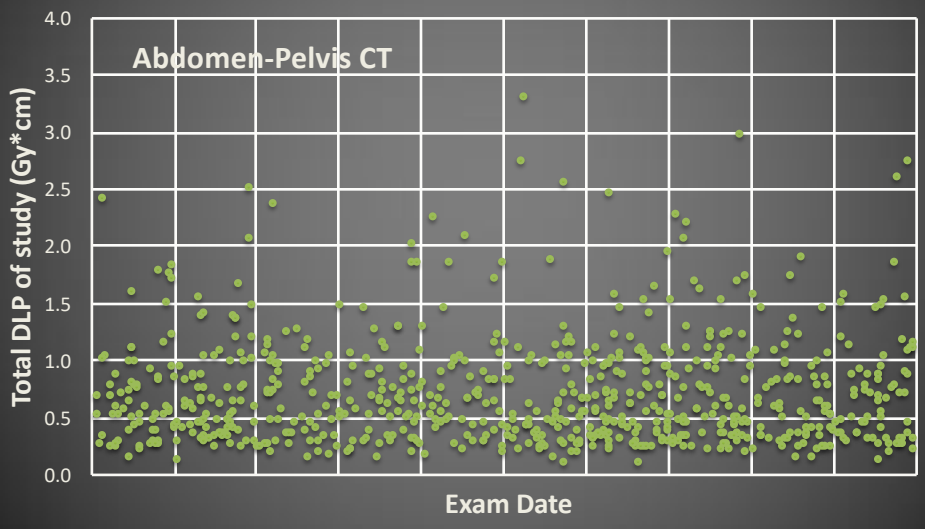
Reality check 1:
Clinical practice

Heterogeneous and Complex:

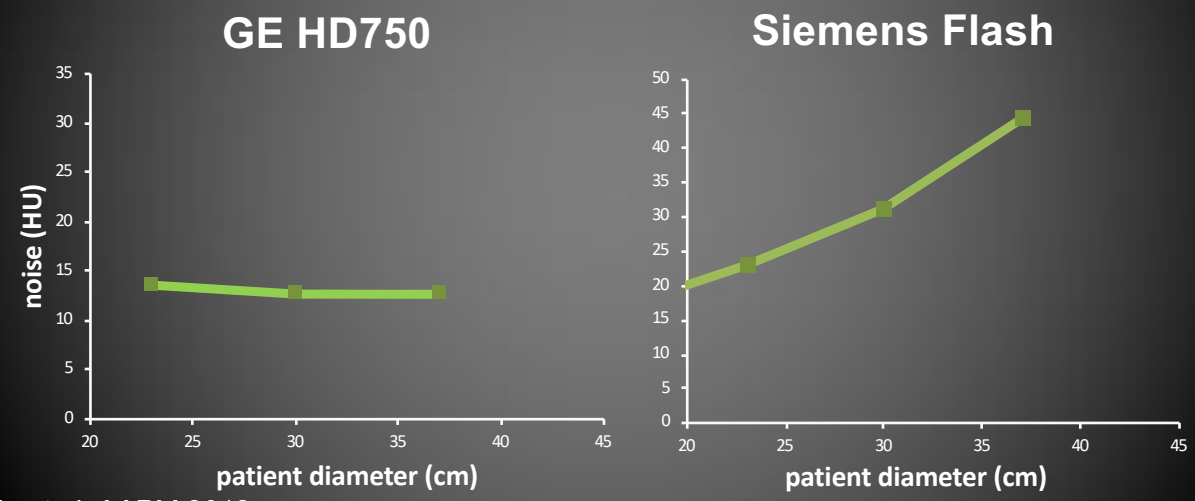
- Varying technologies
- Varying technical parameters
- Varying patients
- Varying human operators
- Competing interests

Variability in the quality of care

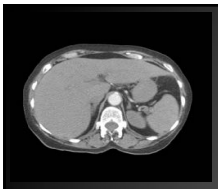
Variability across practice



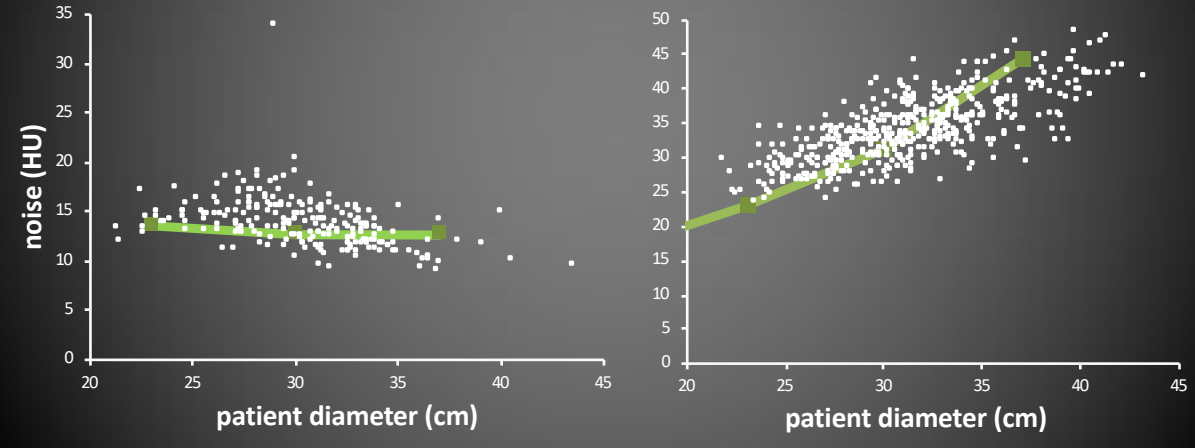
Noise versus patient size: Phantom



Ria et al, AAPM 2018



Noise versus patient size: Patients



Reality check 2:
There is a cost!

- **Most people will experience at least one diagnostic error in their lifetime**
  - 10% of patient deaths
  - 6-17% hospital adverse events
  - Leading type of paid medical malpractice
  - Claims twice as likely to result in death
  - Highest proportion of total payments.

Improving Diagnosis in Healthcare, NAM 2015

Drive towards high-quality, consistent, patient-centric, evidence-based, precise, and safe healthcare

Patient-oriented optimization of quality and safety

Driven towards high-quality, consistent, patient-centric, evidence-based, precise, and safe healthcare

Quality and safety optimization

A process to enable and ensure

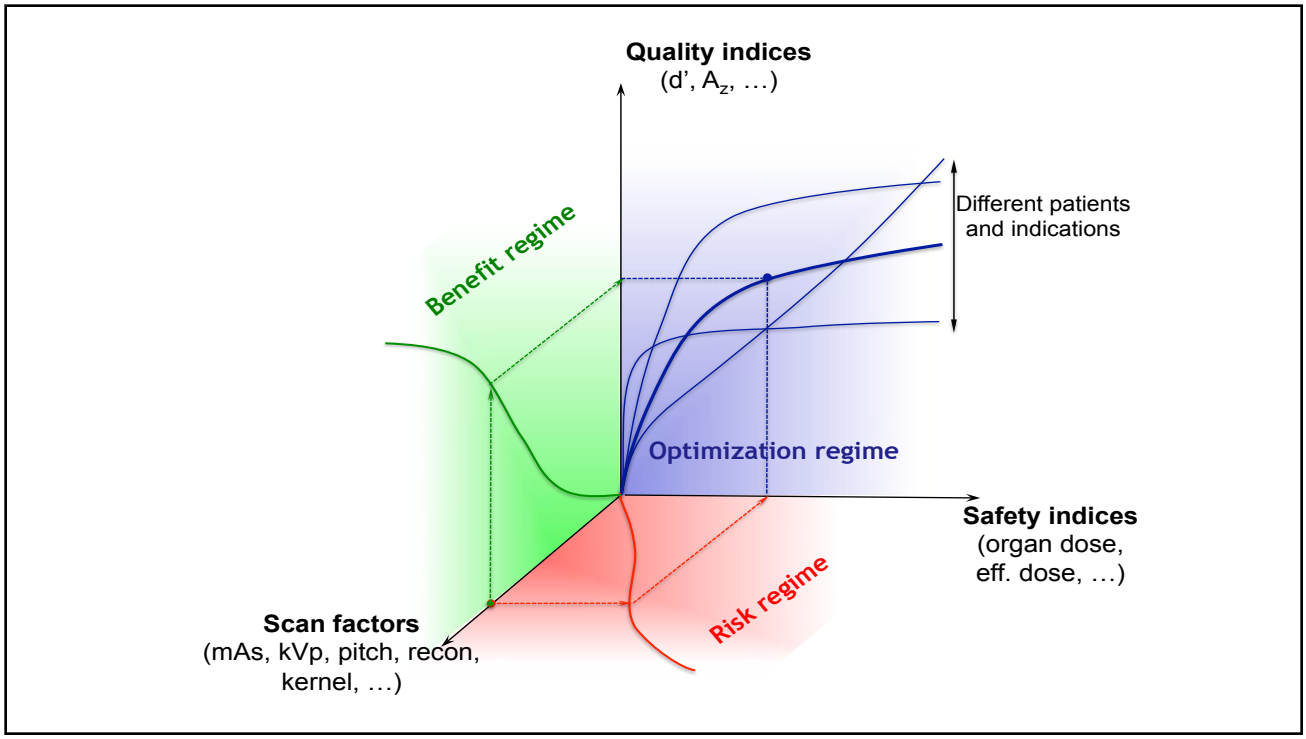
high-quality (accurate),

consistent (precise),

patient-centric, and

safe,

use of imaging in medicine

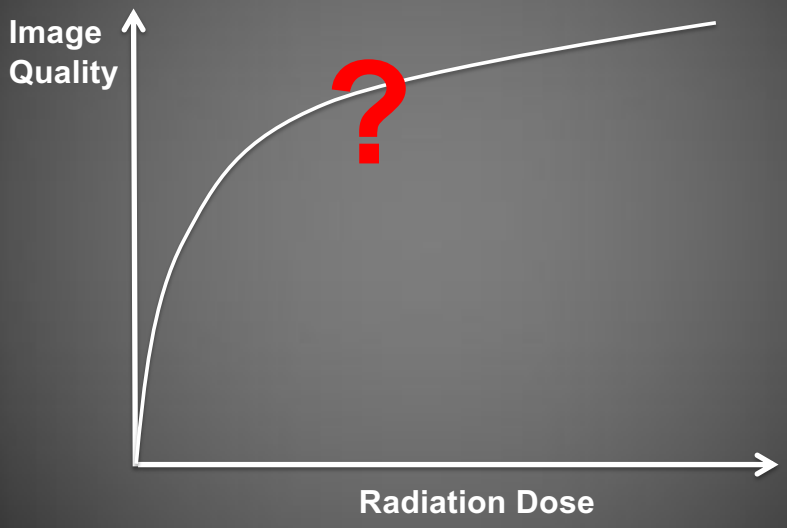


Optimization taxonomy

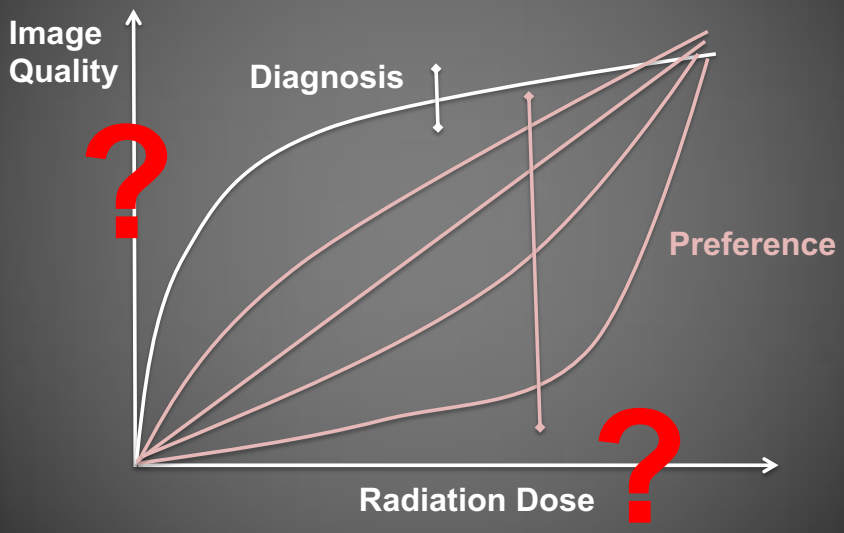
Independent variables (imaging parameters)

Dependent variables		
	Benefit	**Risk**
Physical	Quality indices (eg, MTF)	Output indices (eg, CTDI)
Clinical	Performance indices (eg, d', AUC)	Safety indices (eg, ED, RI)

Quality vs dose: the right balance?



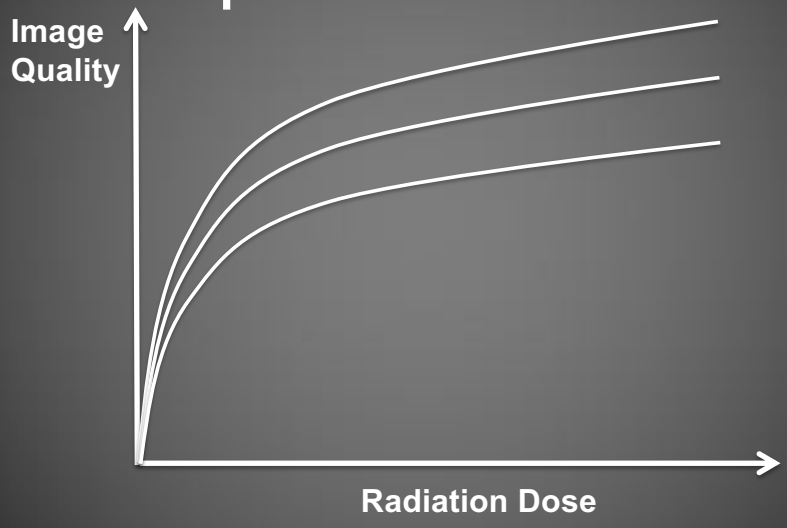
Metrology matters!

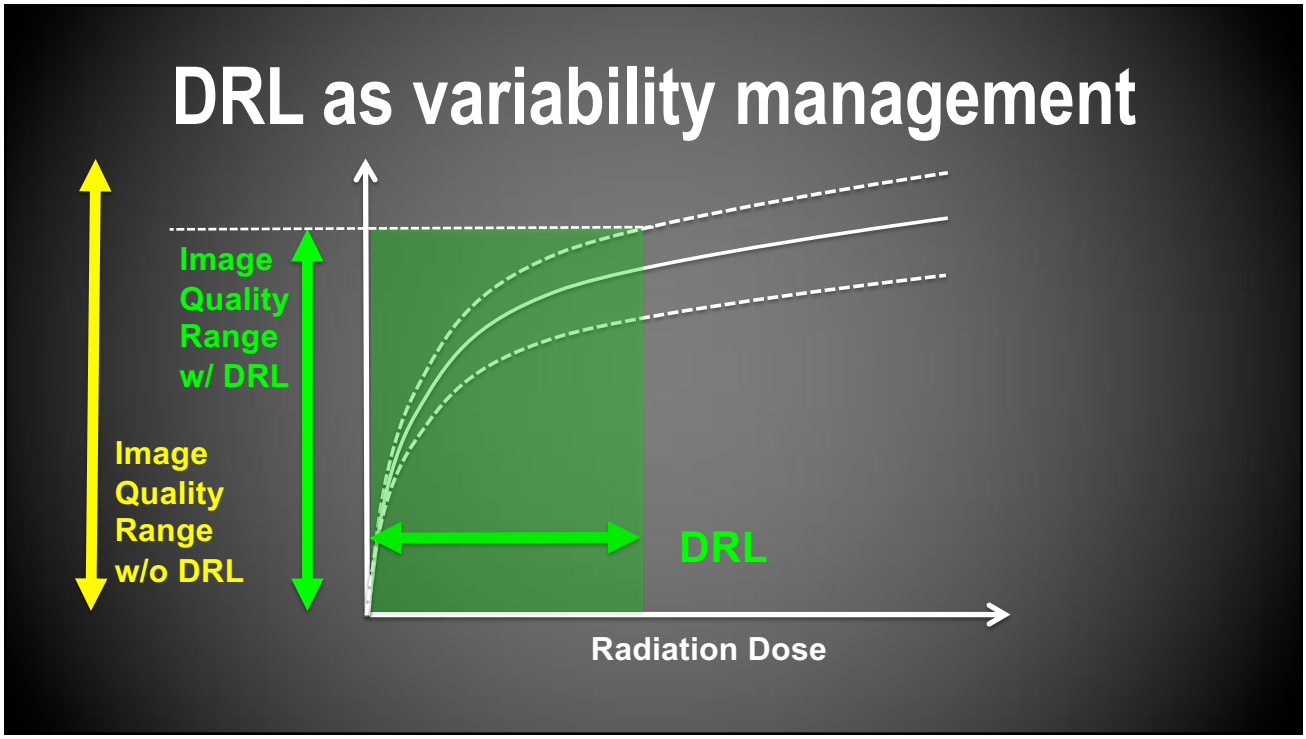


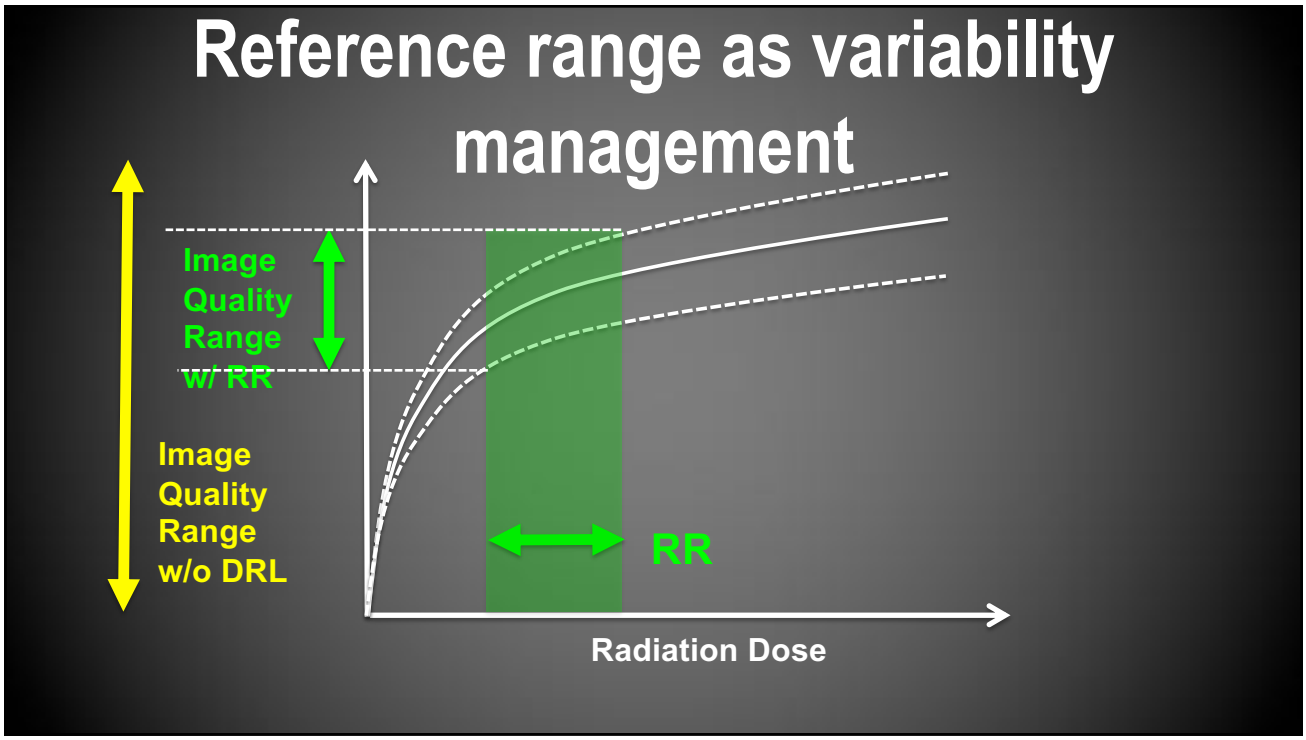
What are the right metrics?

1. Relevant: As much as possible, patient-/indication-centric (not modality or machine)
2. Robust: To ensure reliability and applicability (quantitative not subjective)
3. Smart: Maintained balance between robustness and relevance
4. Relatability: Surrogates relatable to clinical task/safety
5. Practical: Economic to measure

Variability from systematic (age, size) and operational effects

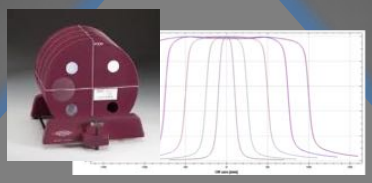






Precision by inference

Technology assessment

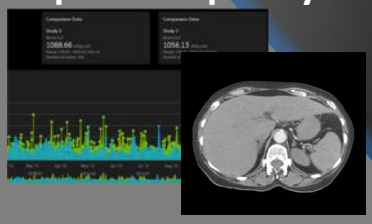


Precision by prescription

Prospective use definition

Precision by outcome

Retrospective quality audit



Precision by inference

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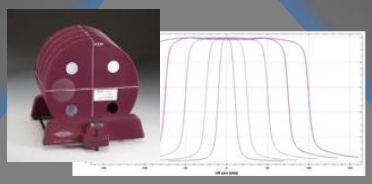


Apply constraints to
machine performance
in concordance with
self, peer, or mandates

Characterizing relevant intrinsic performance of CT system, TG233

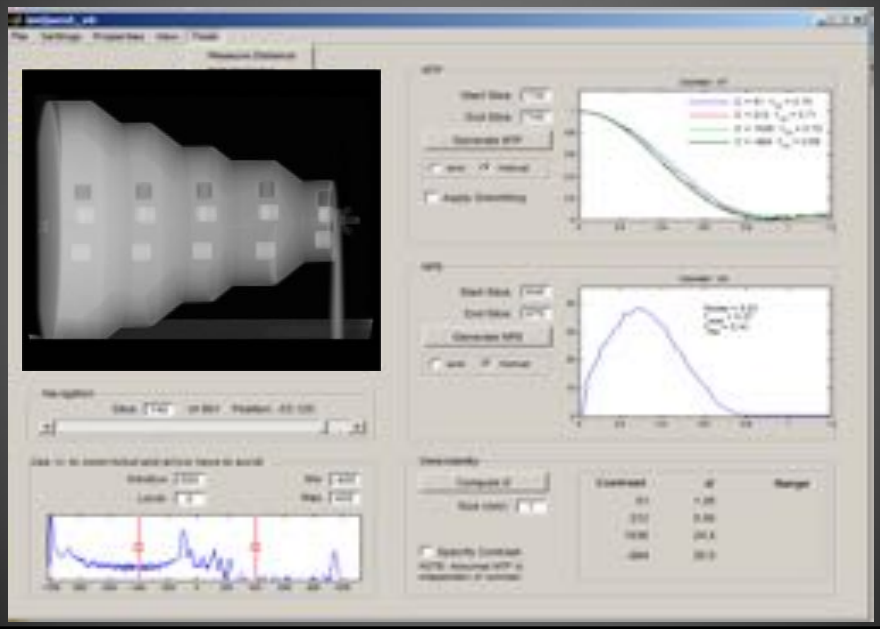
- Mercury Phantom 4.0
- Size matching population cohorts

Automated Characterization

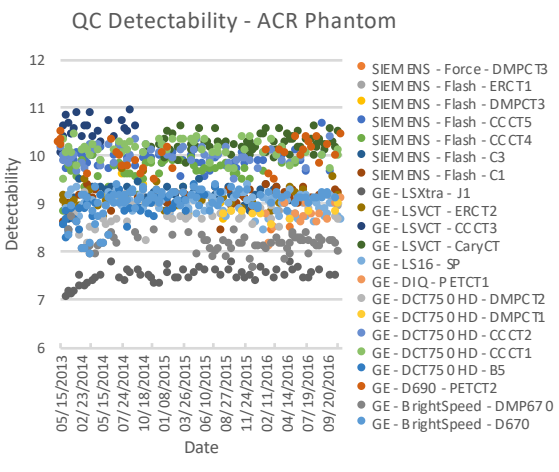
- **HU, Contrast, Noise, CNR, MTF, NPS**
- **TCM-dependency**
- **Detectability index**
- **Detectability indices for reference tasks**
  - **1, 5, 10 mm, 10 and 100 HU, designer, rect, Gaussian**

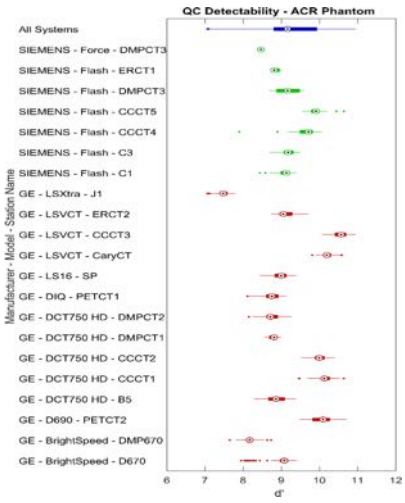
$$\left(d'_{NPWE}\right)^2 = \frac{\left[\iint MTF^2(u,v)W_{Task}^2(u,v)E^2(u,v)dudv\right]^2}{\iint MTF^2(u,v)W_{Task}^2(u,v)NPS(u,v)E^4(u,v) + MTF^2(u,v)W_{Task}^2(u,v)N_i\,dudv}$$

Automated Characterization



Detectability Indices Across Systems





Intersystem Variability	8.0%
Intrasystem Variability	
SIEMENS - Force - DMPCT3	0.1%
SIEMENS - Flash - ERCT1	1.0%
SIEMENS - Flash - DMPCT3	3.5%
SIEMENS - Flash - CCCT5	1.9%
SIEMENS - Flash - CCCT4	4.2%
SIEMENS - Flash - C3	2.1%
SIEMENS - Flash - C1	2.4%
GE - LSXtra - J1	2.4%
GE - LSVCT - ERCT2	3.1%
GE - LSVCT - CCCT3	2.0%
GE - LSVCT - CaryCT	1.7%
GE - LS16 - SP	2.1%
GE - DIQ - PETCT1	3.2%
GE - DCT750 HD - DMPCT2	2.8%
GE - DCT750 HD - DMPCT1	1.4%
GE - DCT750 HD - CCCT2	1.8%
GE - DCT750 HD - CCCT1	2.2%
GE - DCT750 HD - B5	3.0%
GE - D690 - PETCT2	3.0%
GE - BrightSpeed - DMP670	2.4%
GE - BrightSpeed - D670	3.8%

Intra-system variability: 1-4% Inter-system variability: 8%

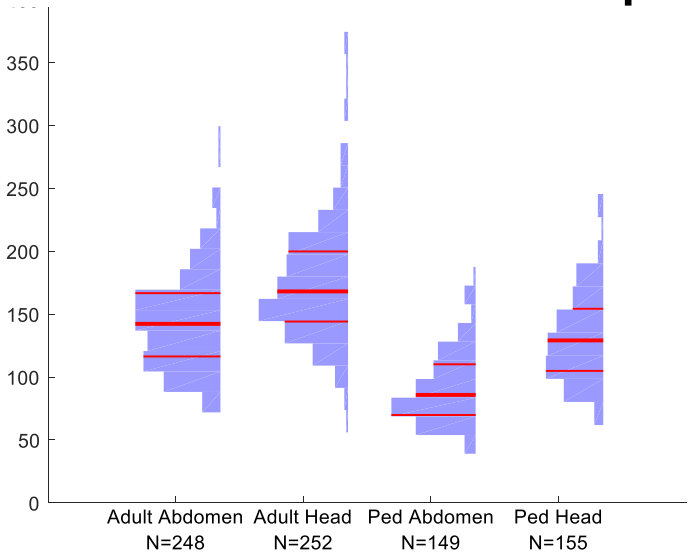
Apply constraints to protocol definitions in concordance with self, peer, or mandates

Precision by prescription

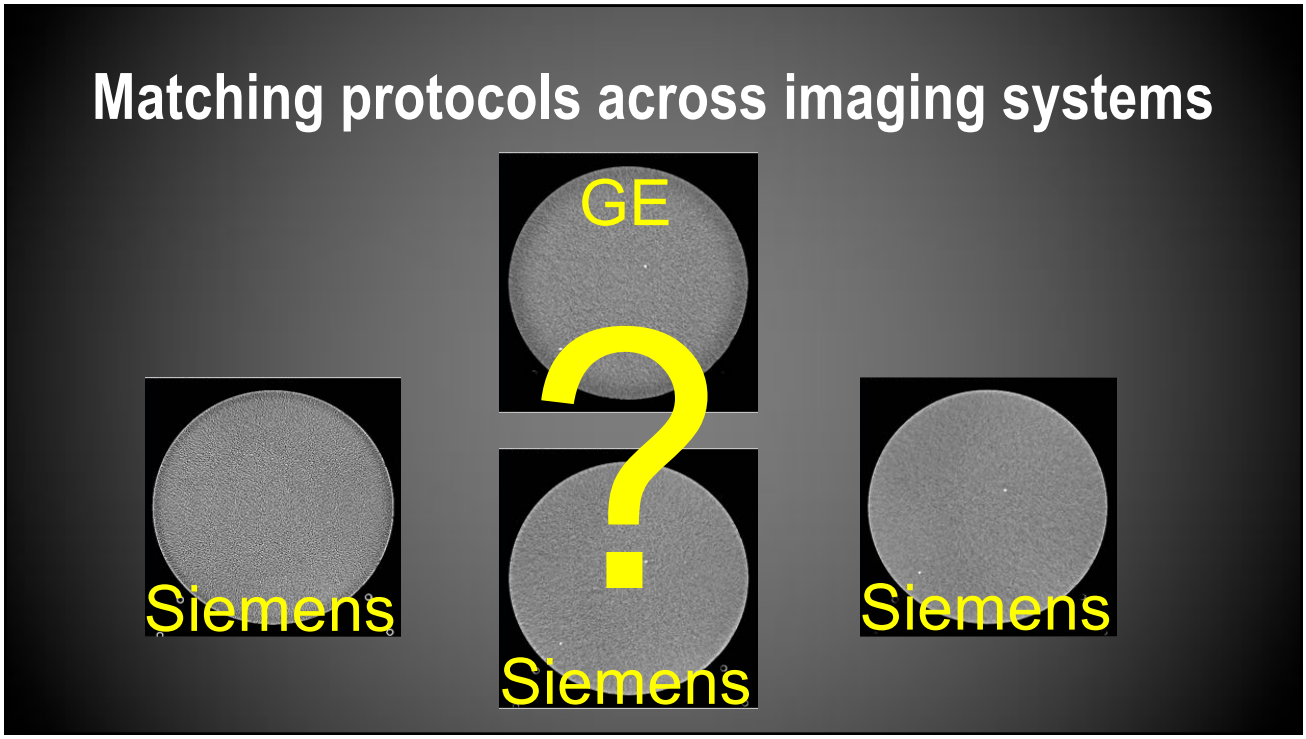
Prospective use definition

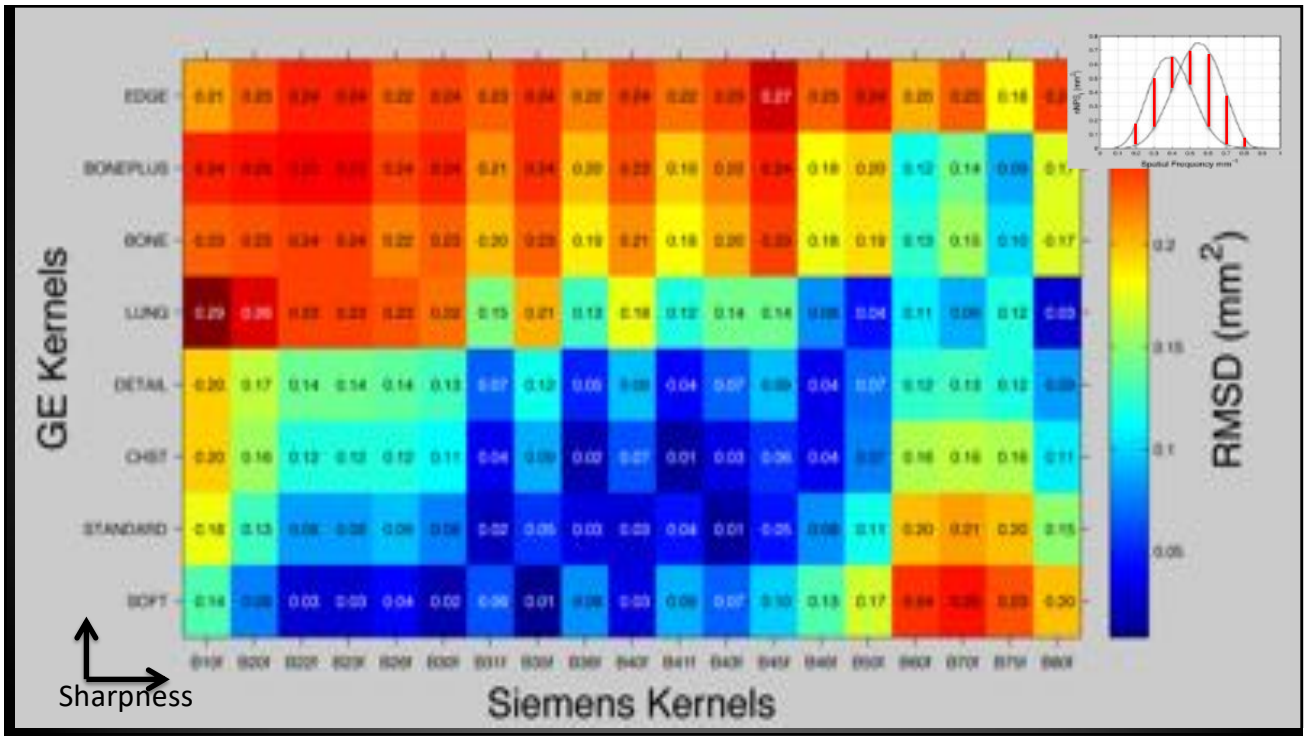
Detectability Indices Across the US

ACR-RSNA-Duke Collaborative project

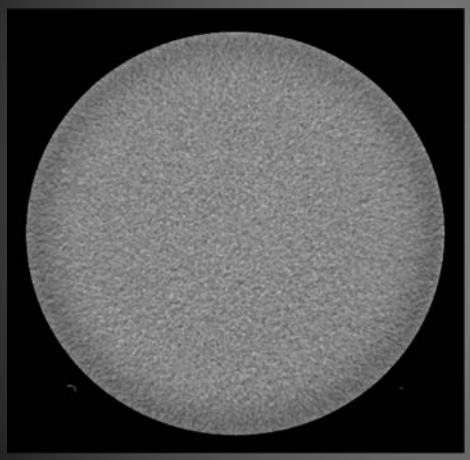


Zhang et al, RSNA, 2018

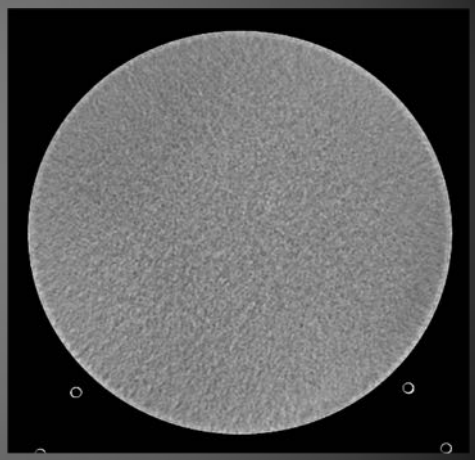




GE to Siemens "best match"

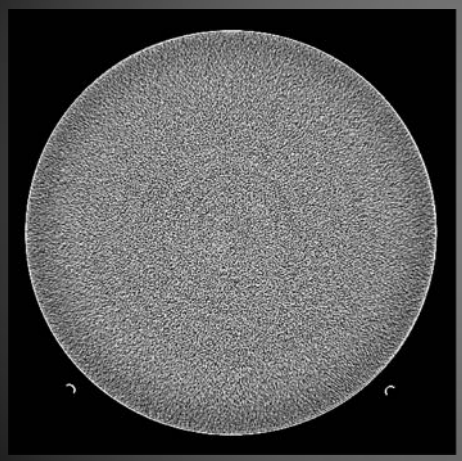


STD ASiR 40%

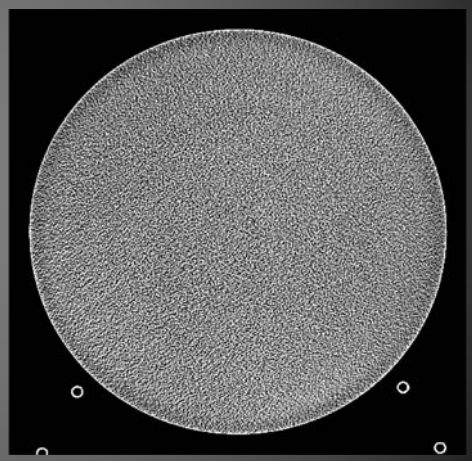


i40 SAFIRE 3

GE to Siemens "best match"

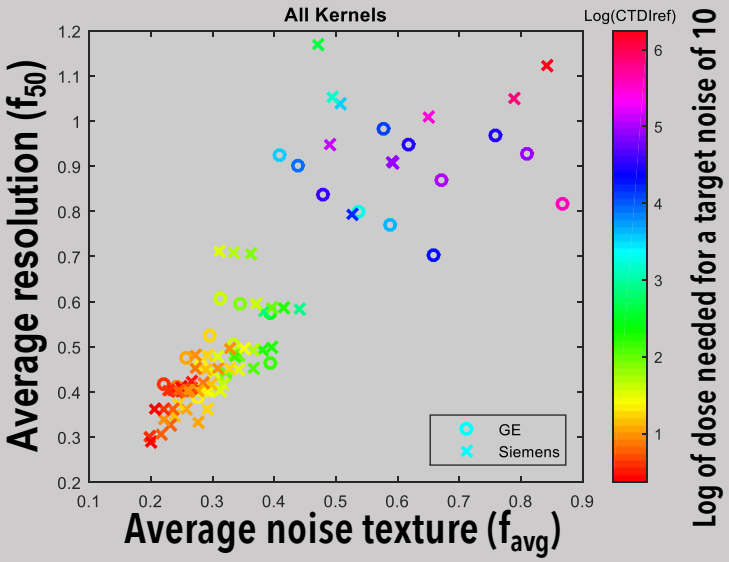


BONE PLUS ASiR 0%



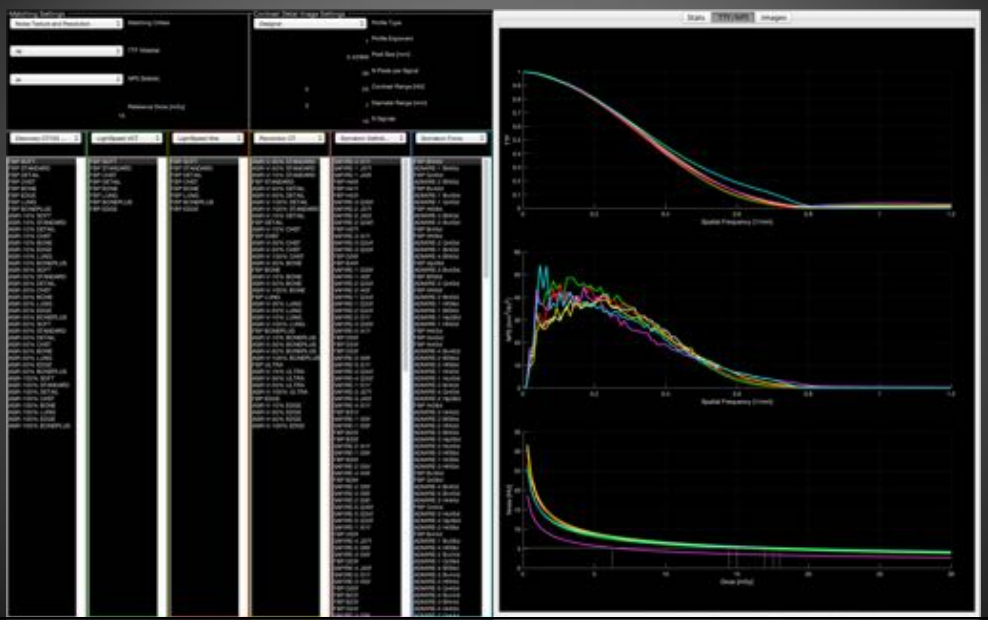
b70 SAFIRE 0

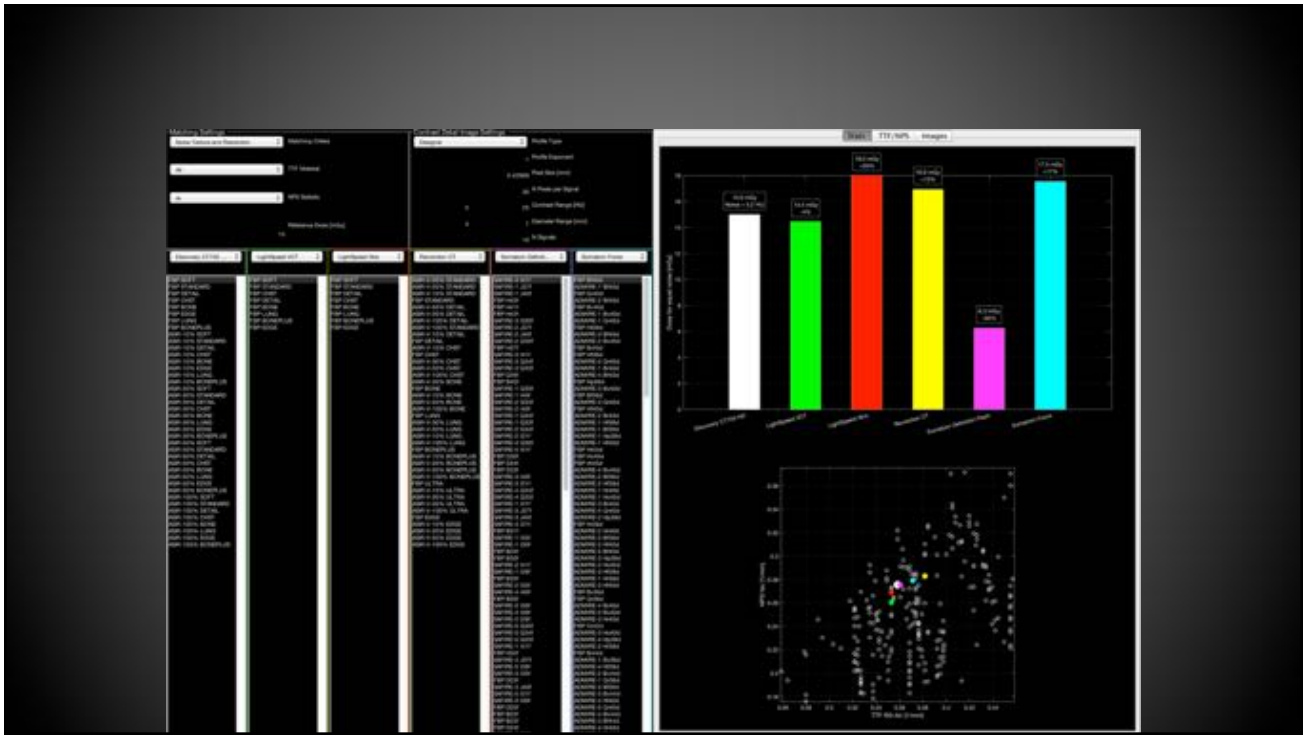
Matching Image Quality Across CTs

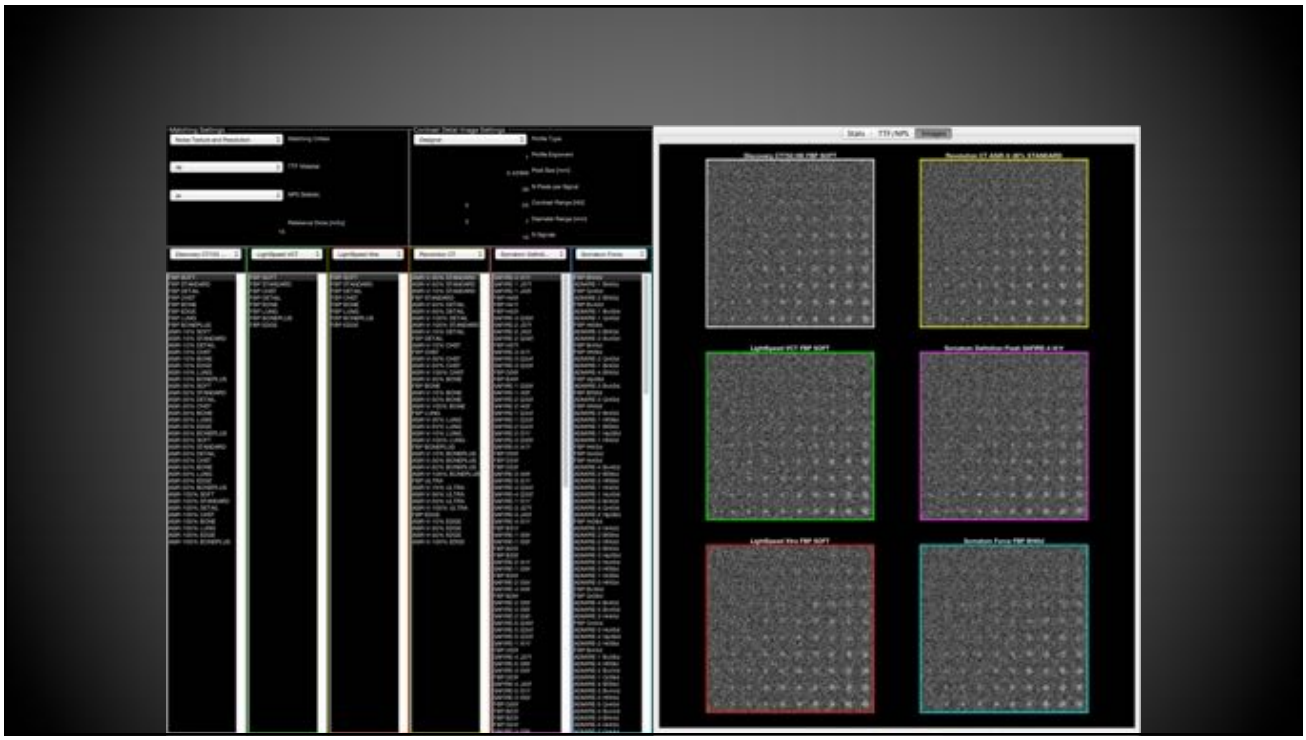


Winslow et al, Med Phys 2018

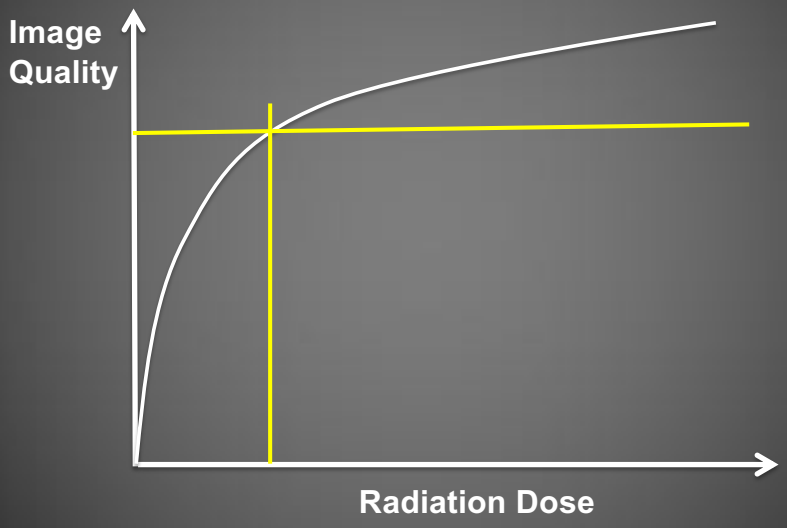
Protocol Matcher™



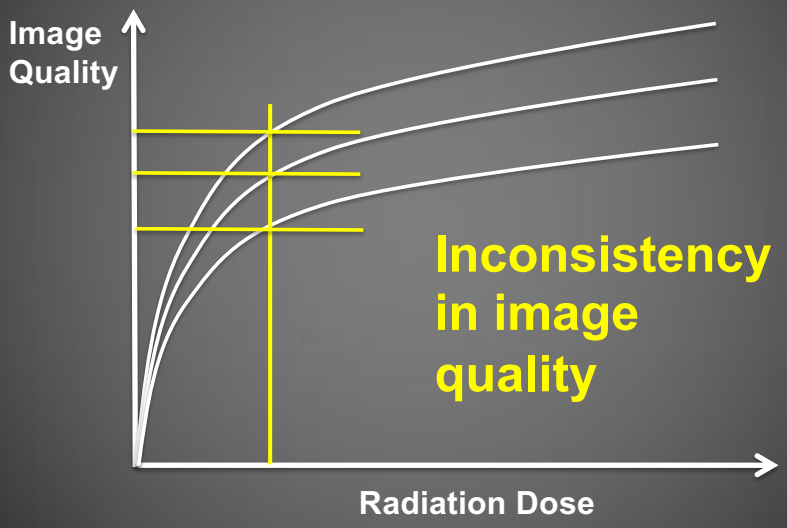


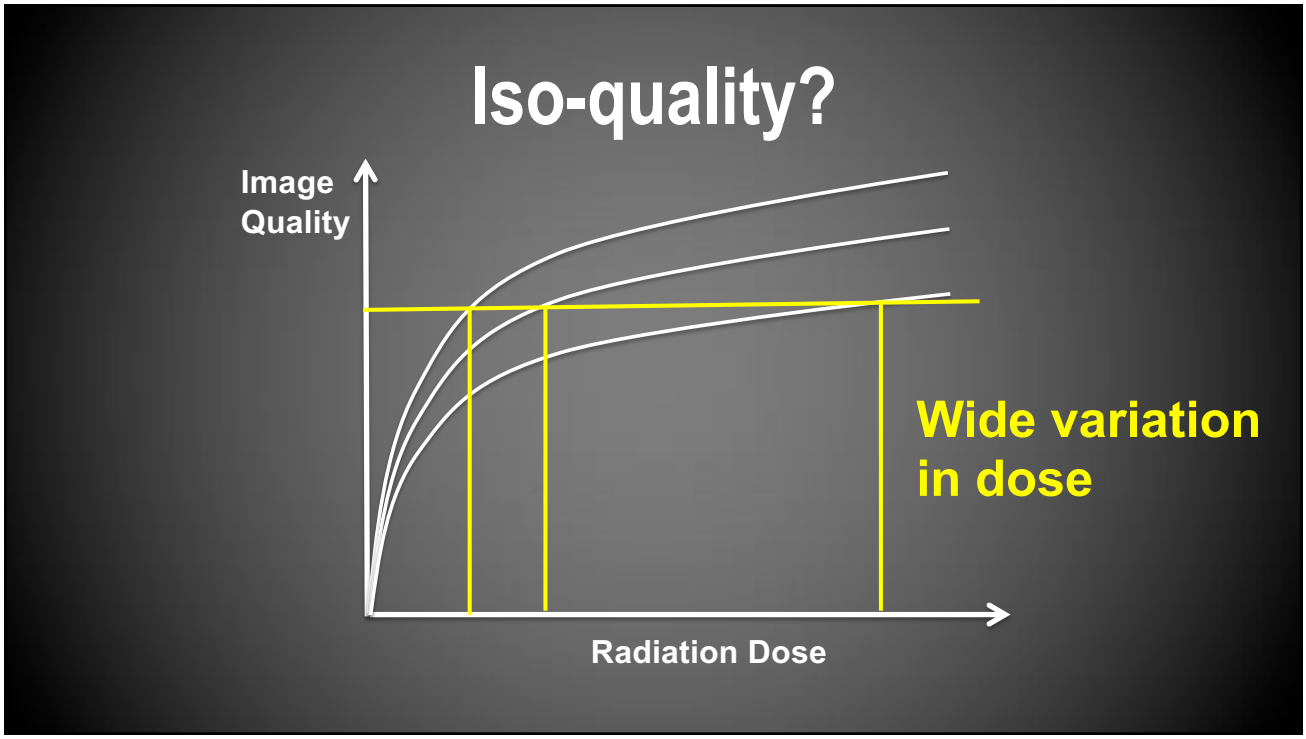


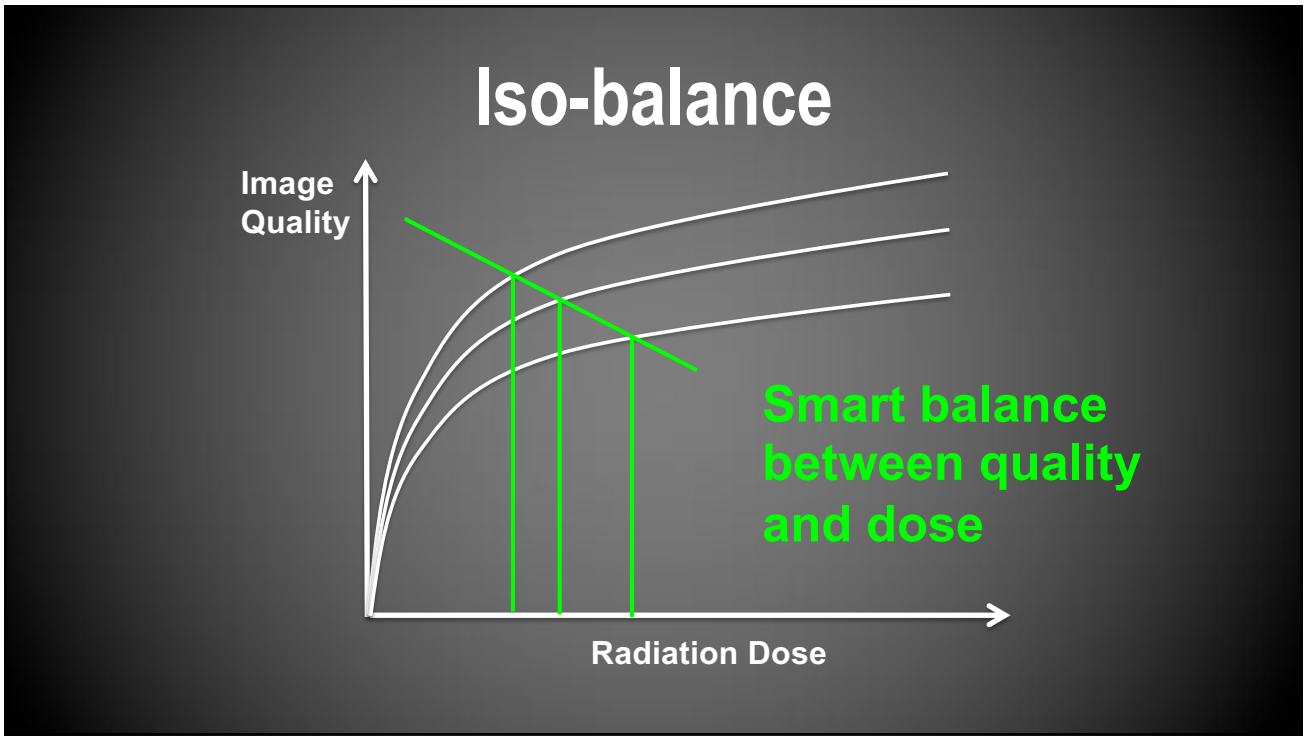
Quality vs dose: the right balance?



Iso-dose?







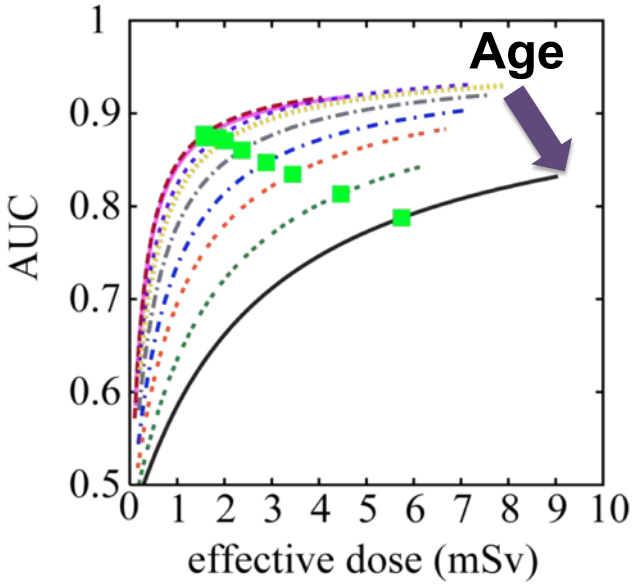
Optimization of dose for size

for-your-child.blogspot.com

http://www.pedrad.org

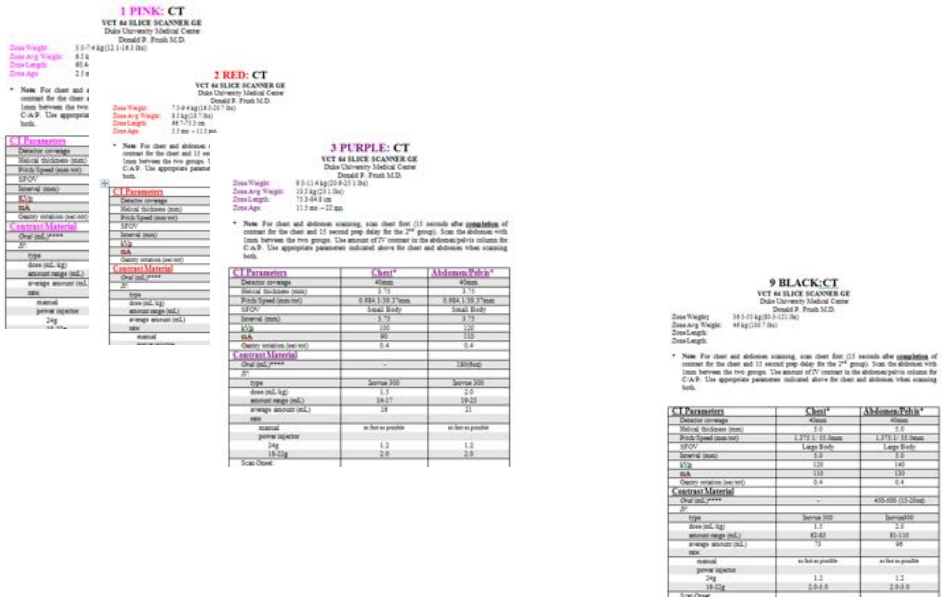
Iso-balance in practice

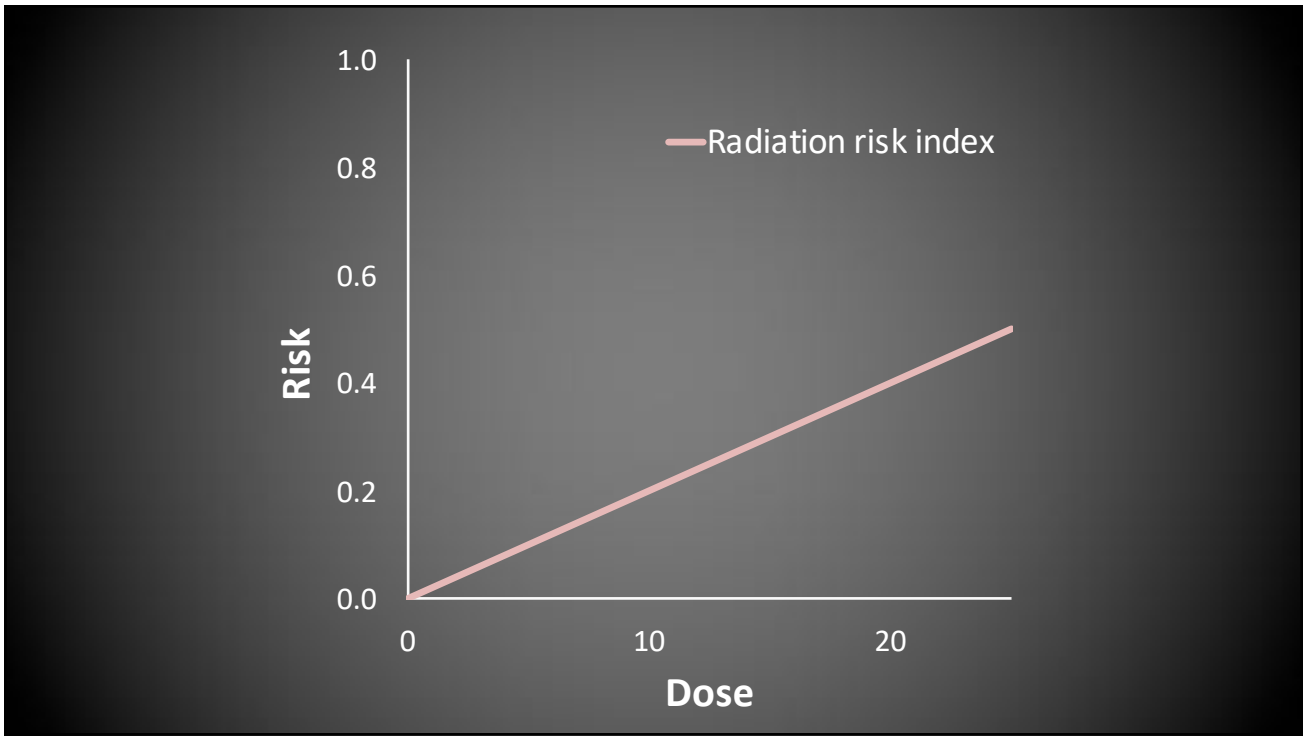
ALARA? ✓

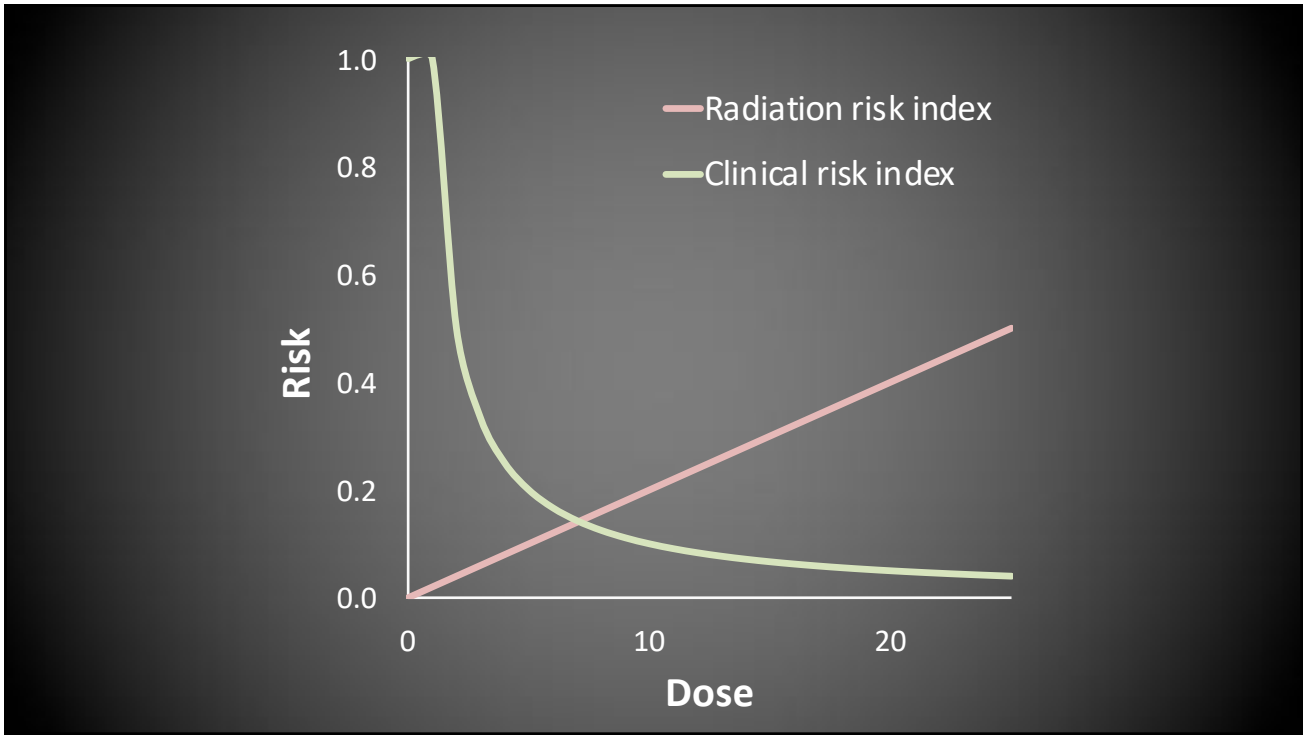


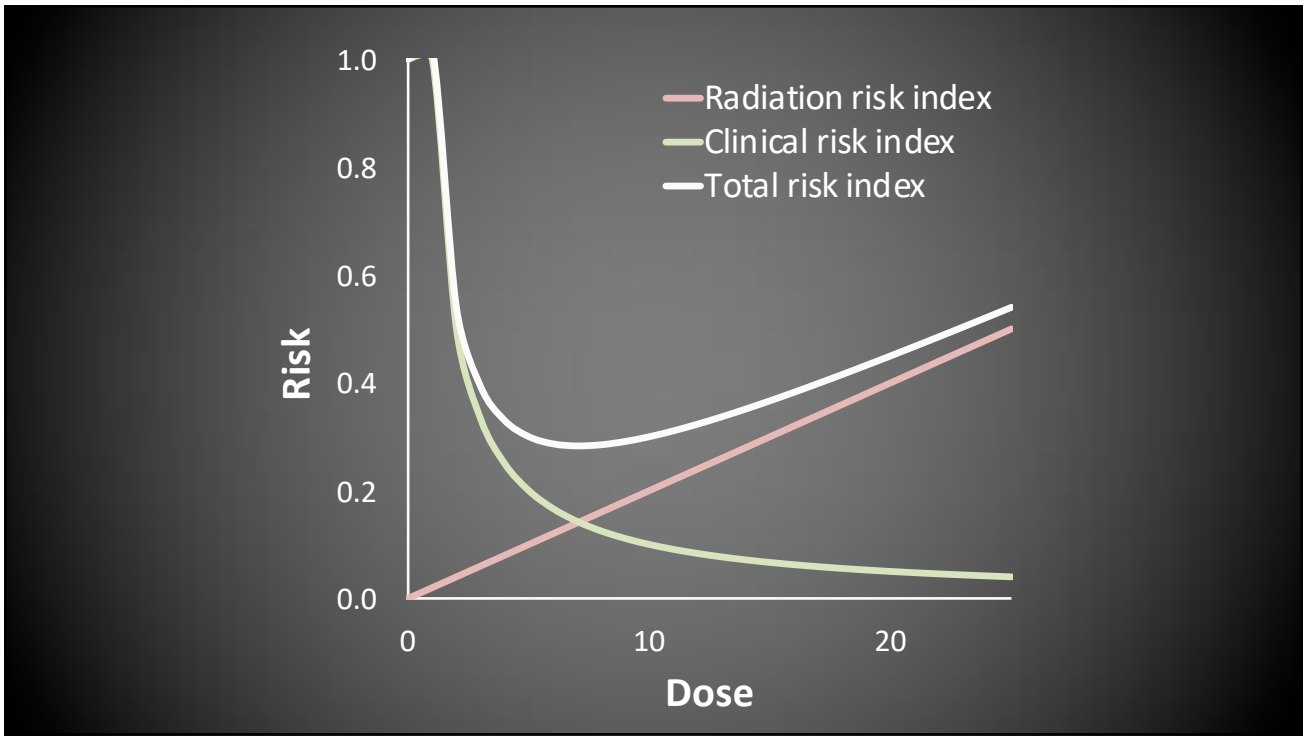
Samei et al, JMI, 2017
Samei et al, RPD, 2018

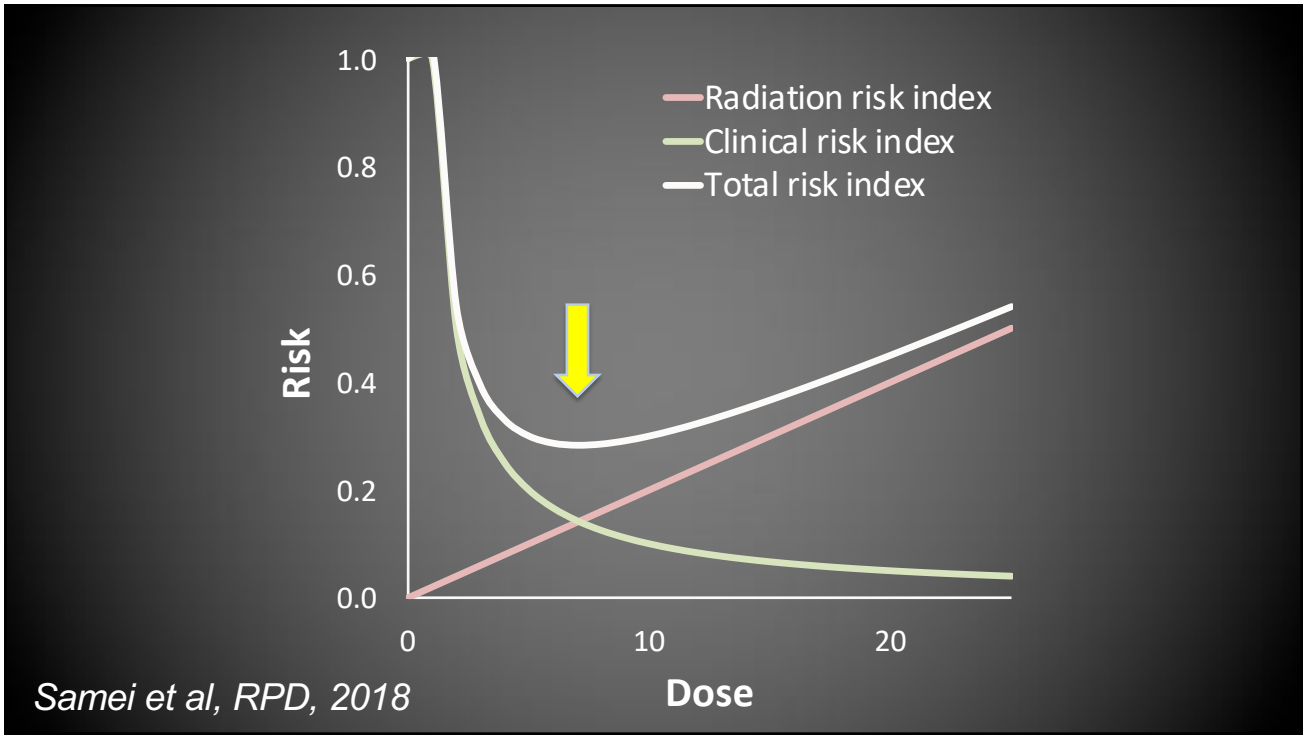
Duke Pediatric Protocols

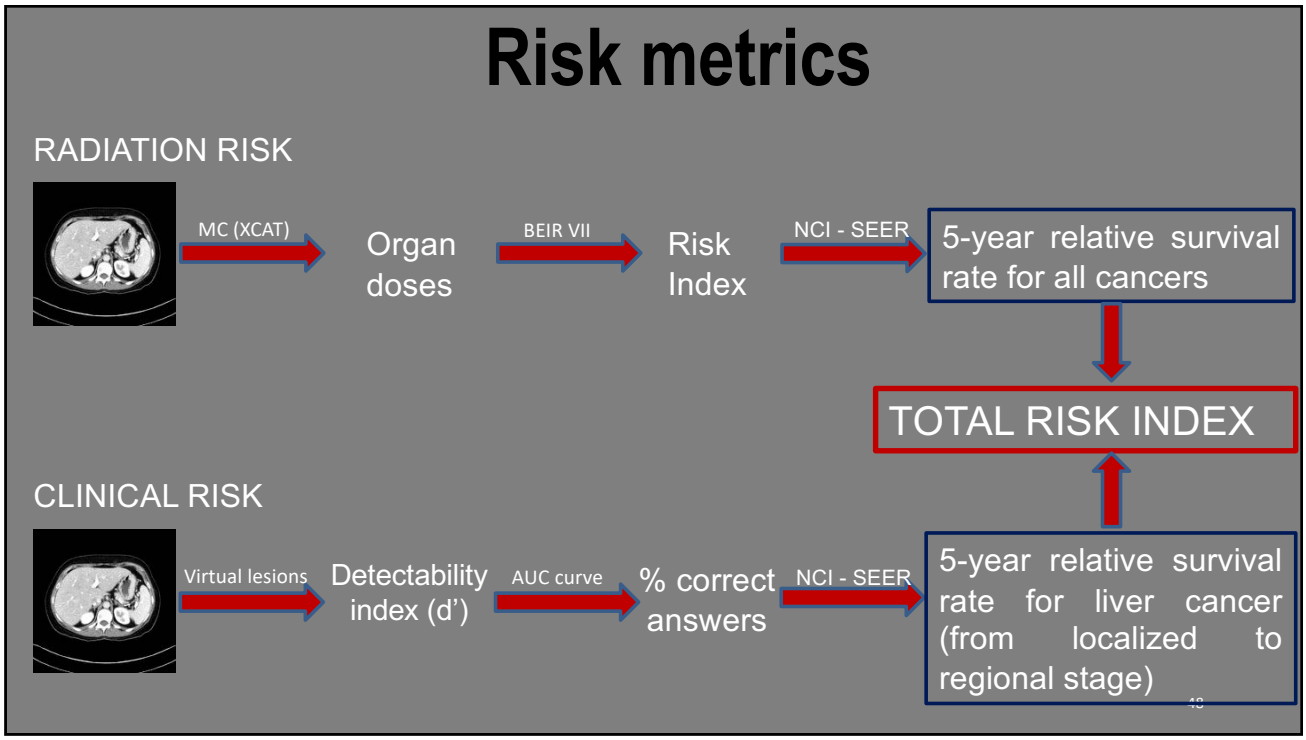




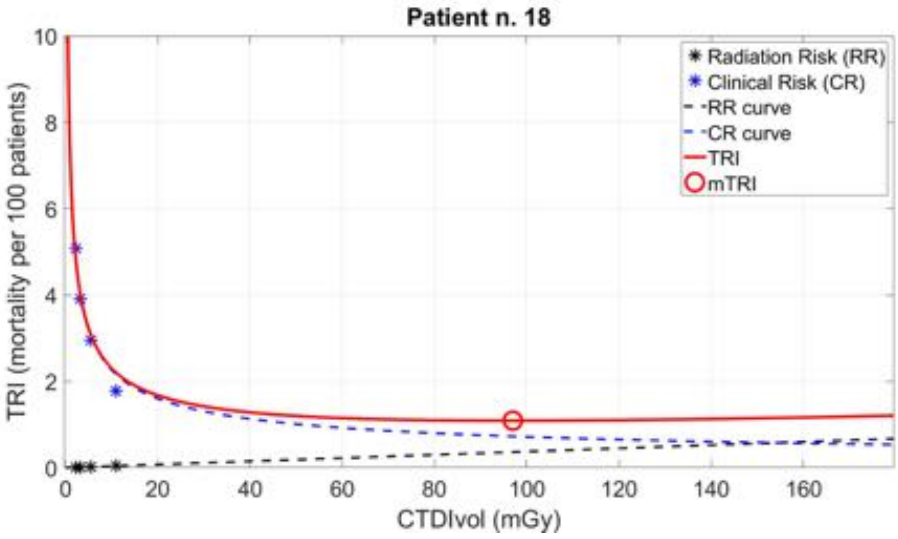




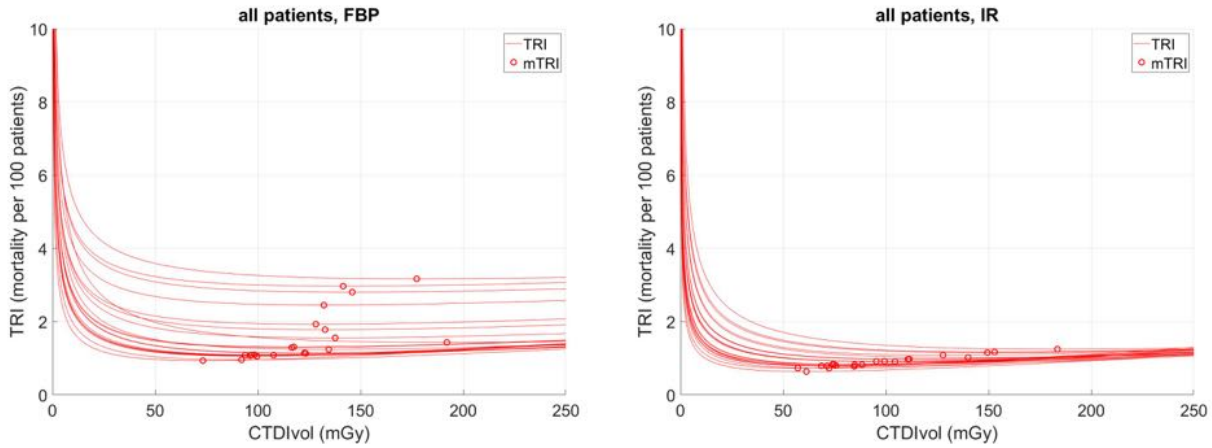


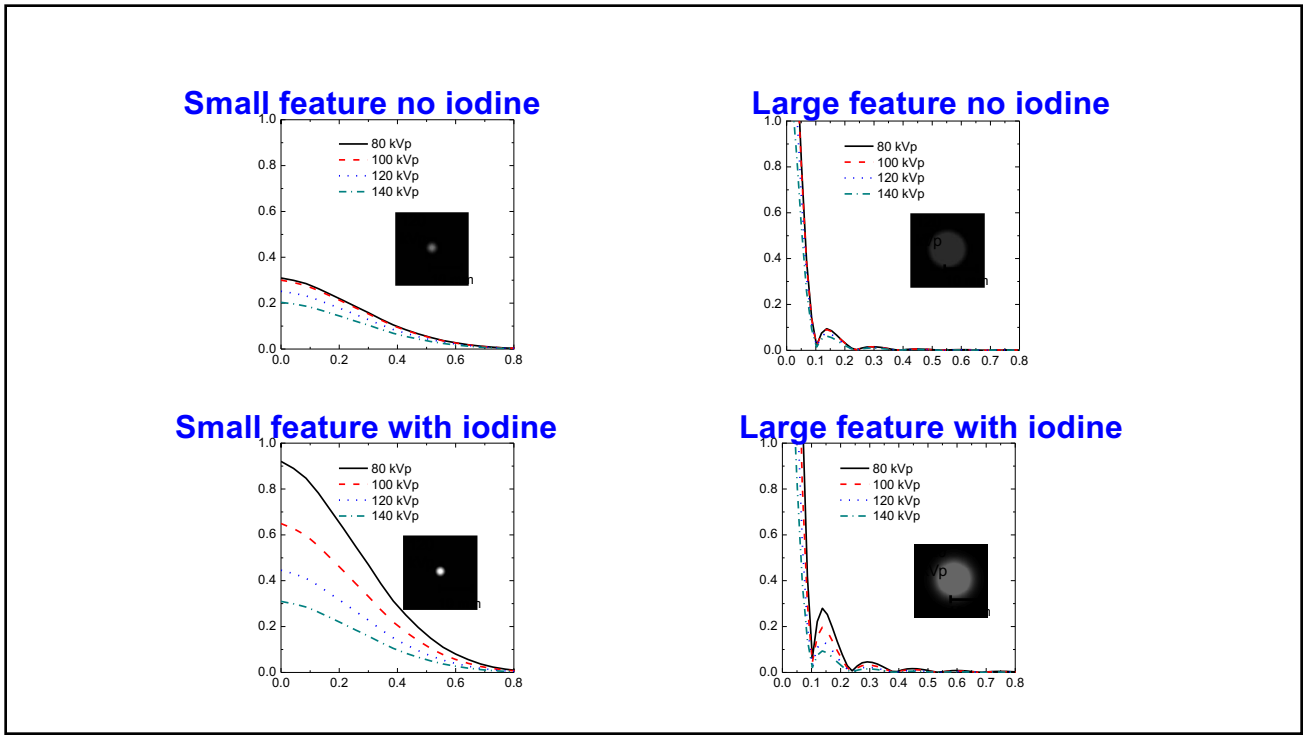


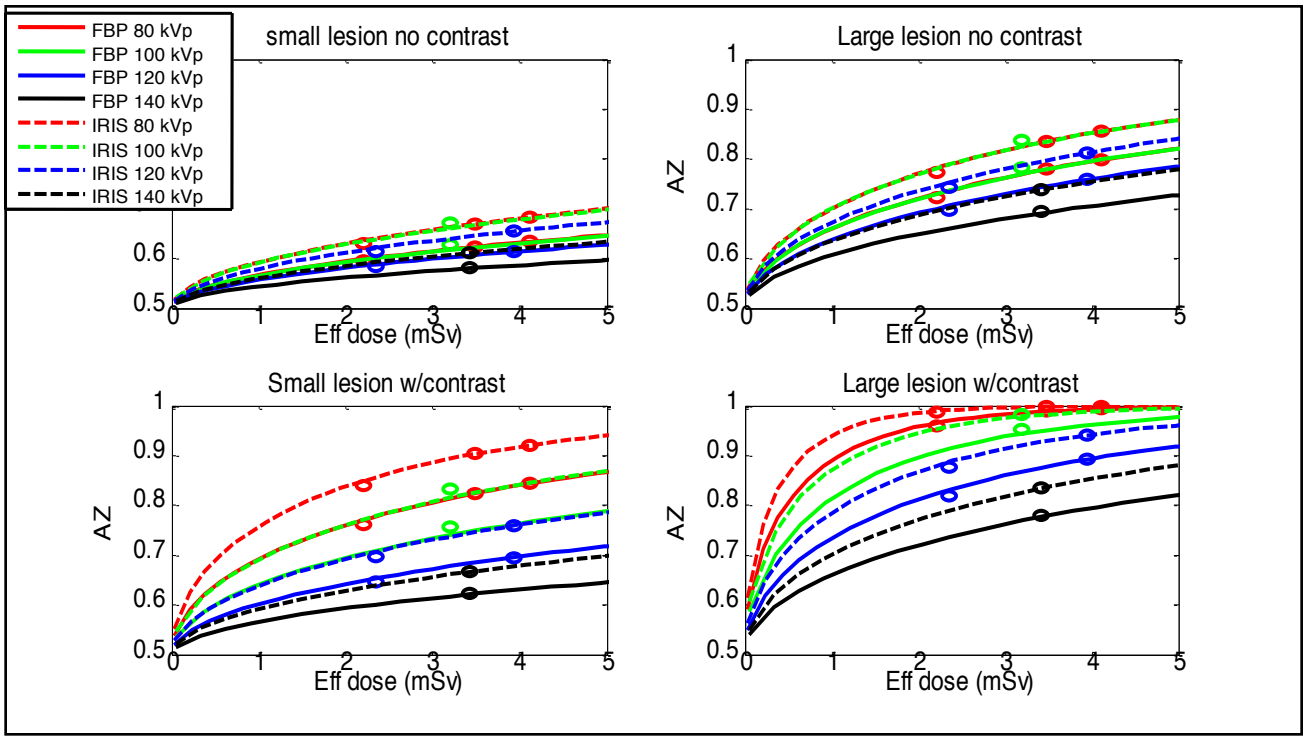
Risk curves

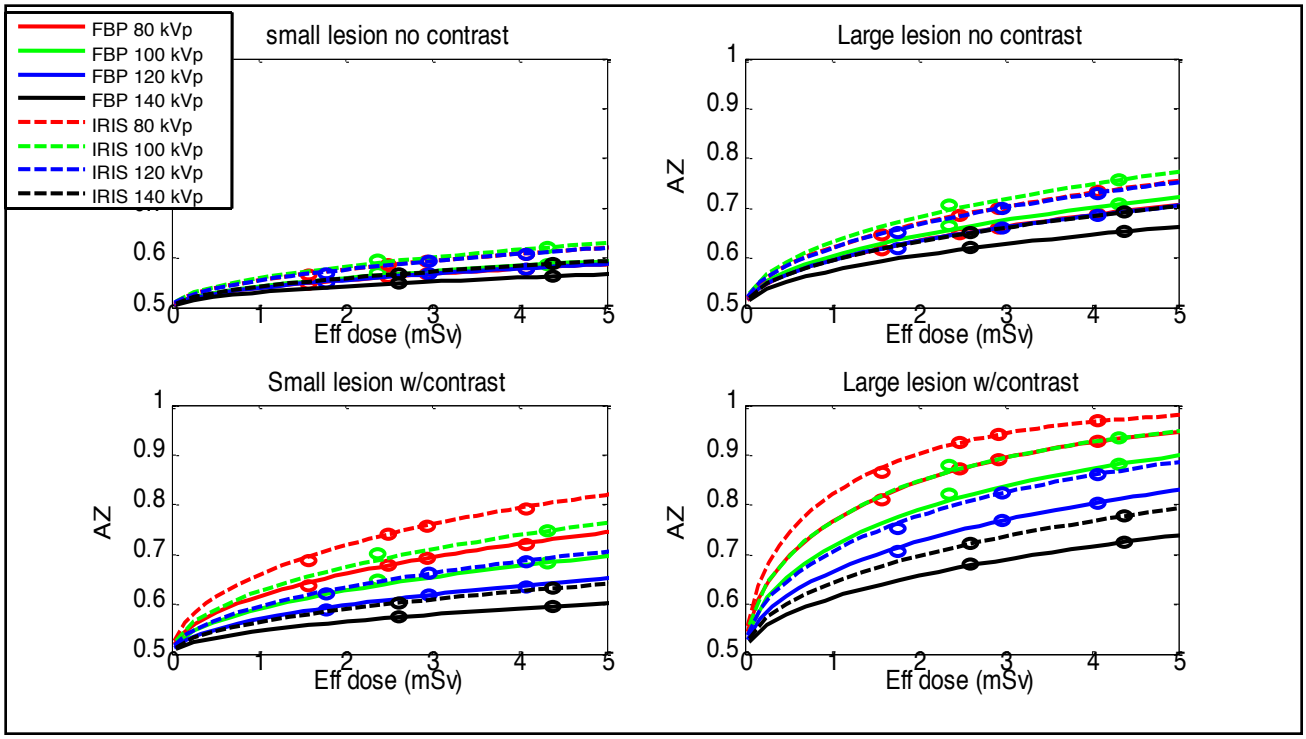


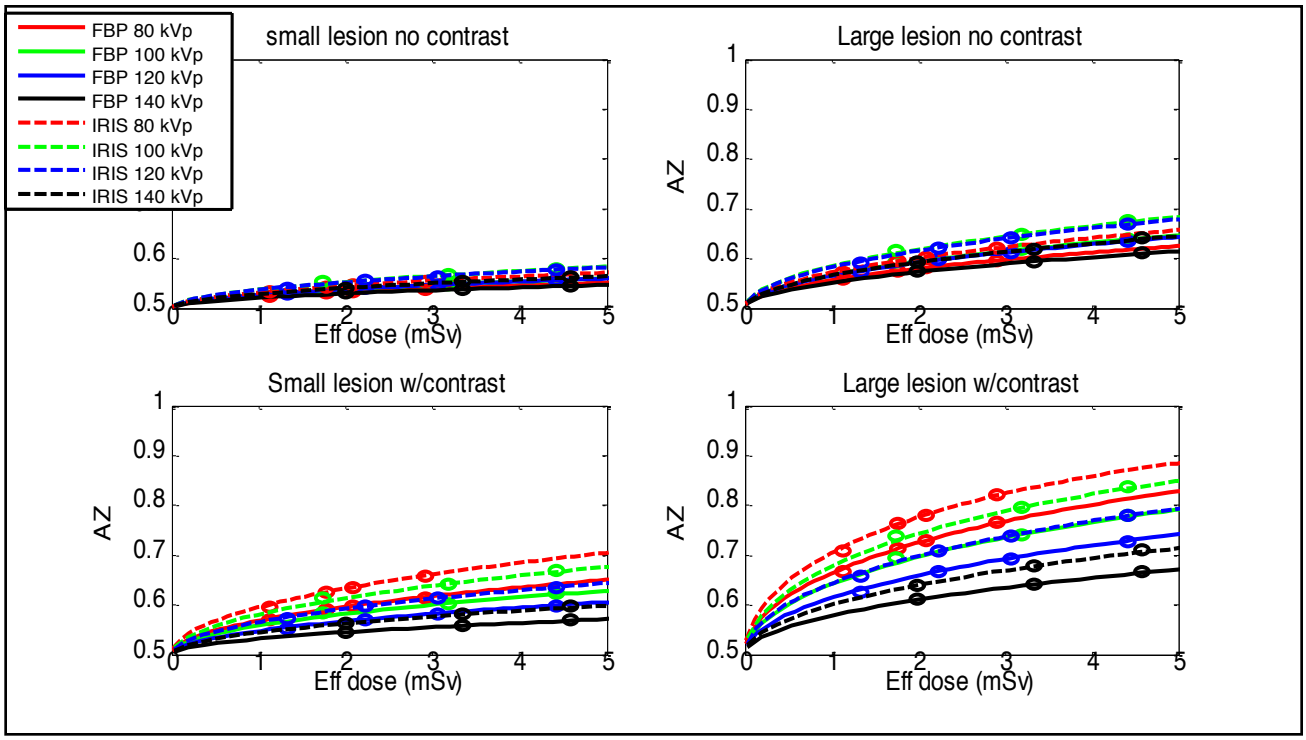
Risk curves (FBP – IR)



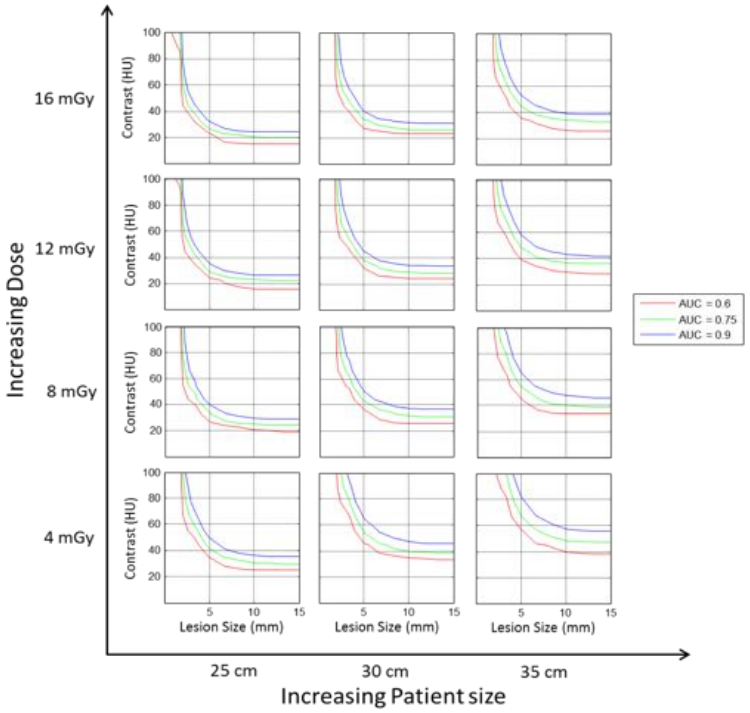


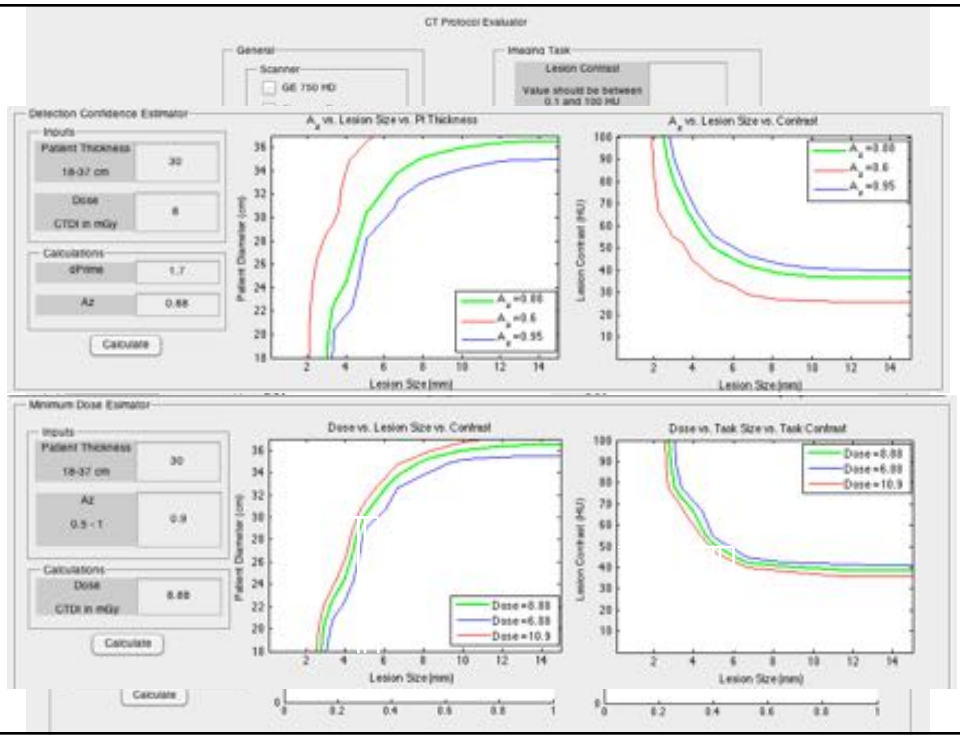


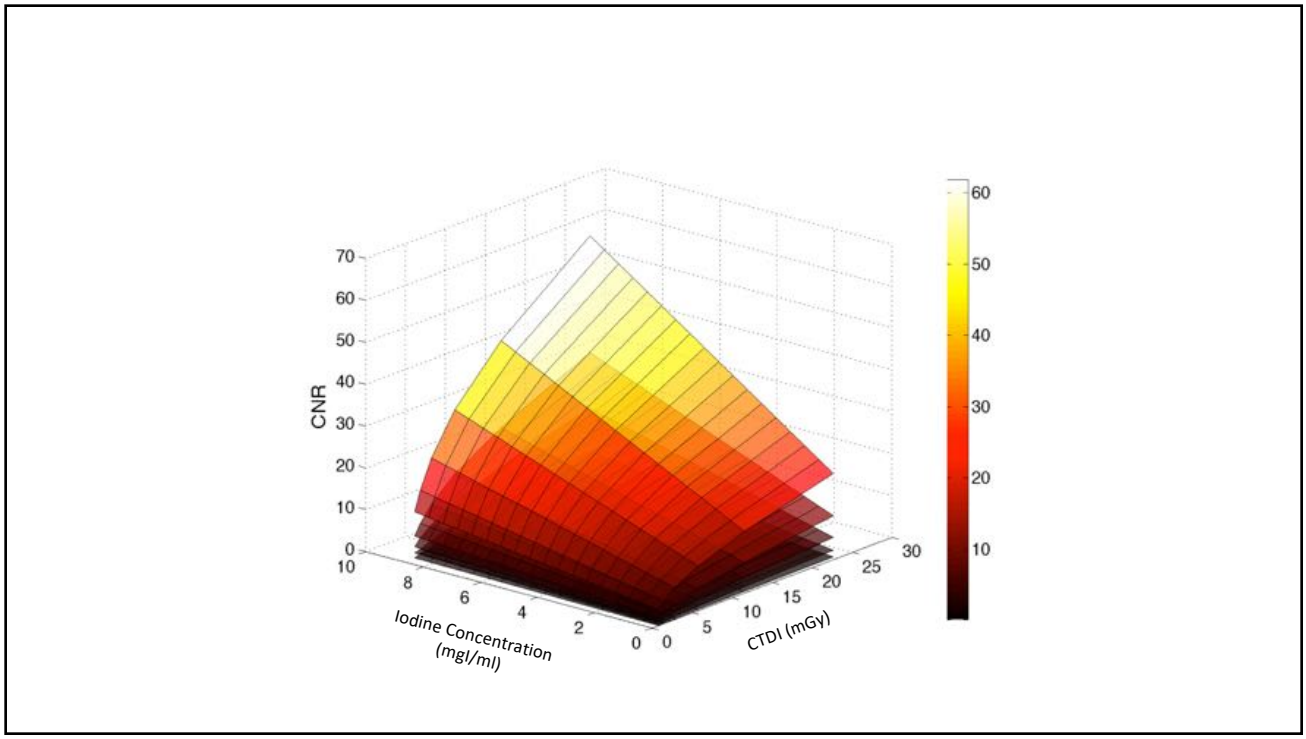




Detectability trends with dose/size







Apply constraints to
case performance
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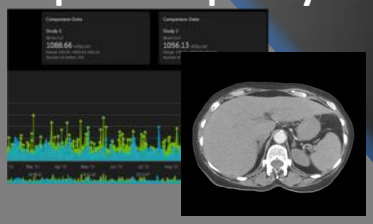
self, peer, or mandates

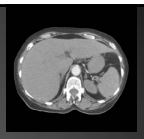
Precision by outcome

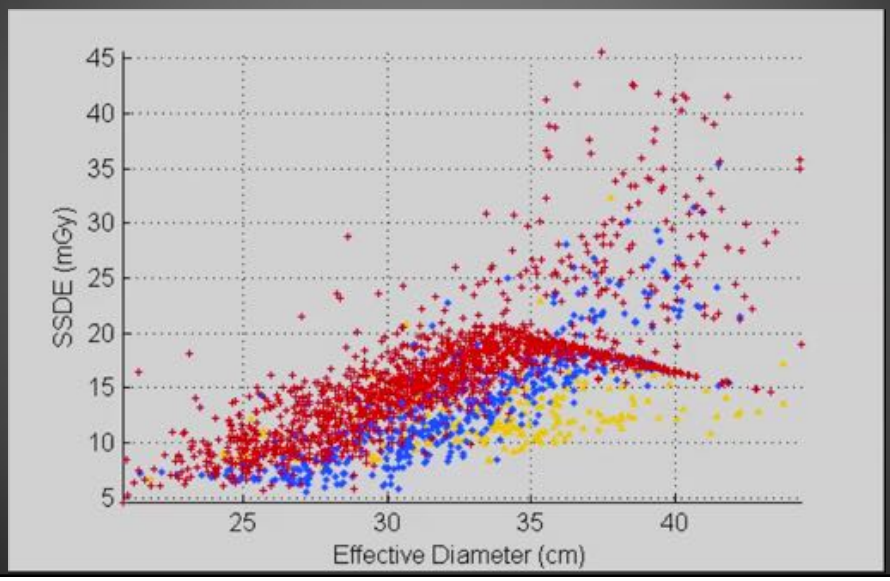
Retrospective quality audit

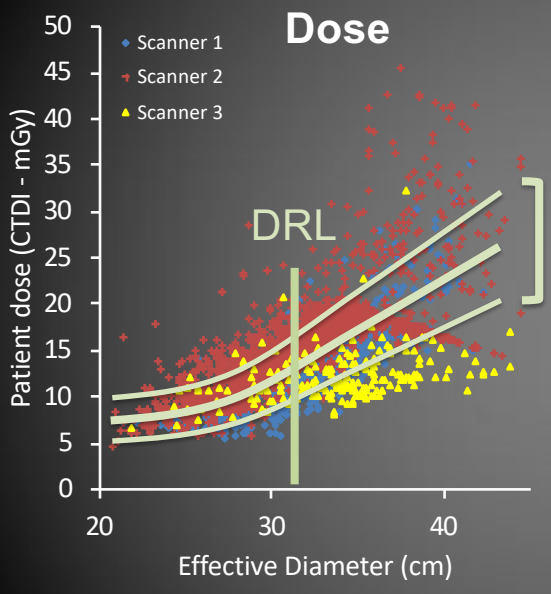


Retrospective audit

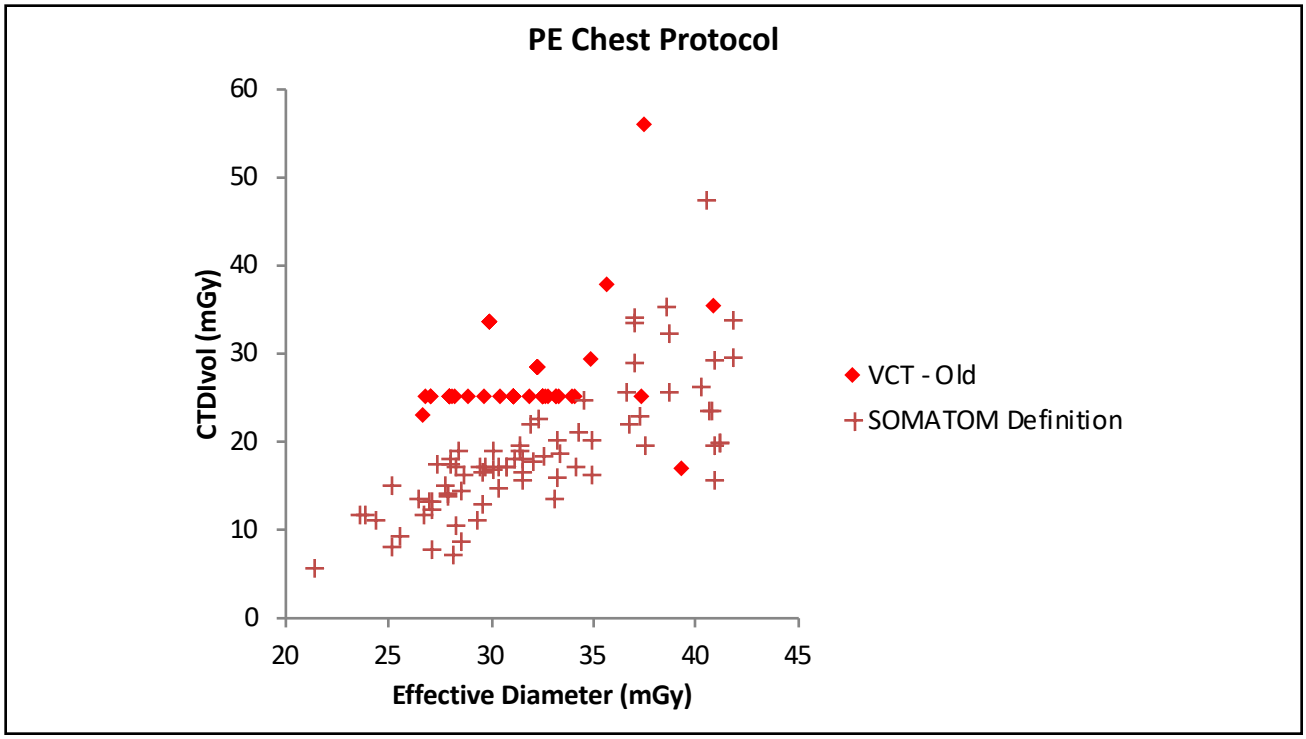
CT Dose Index + size + in vivo noise

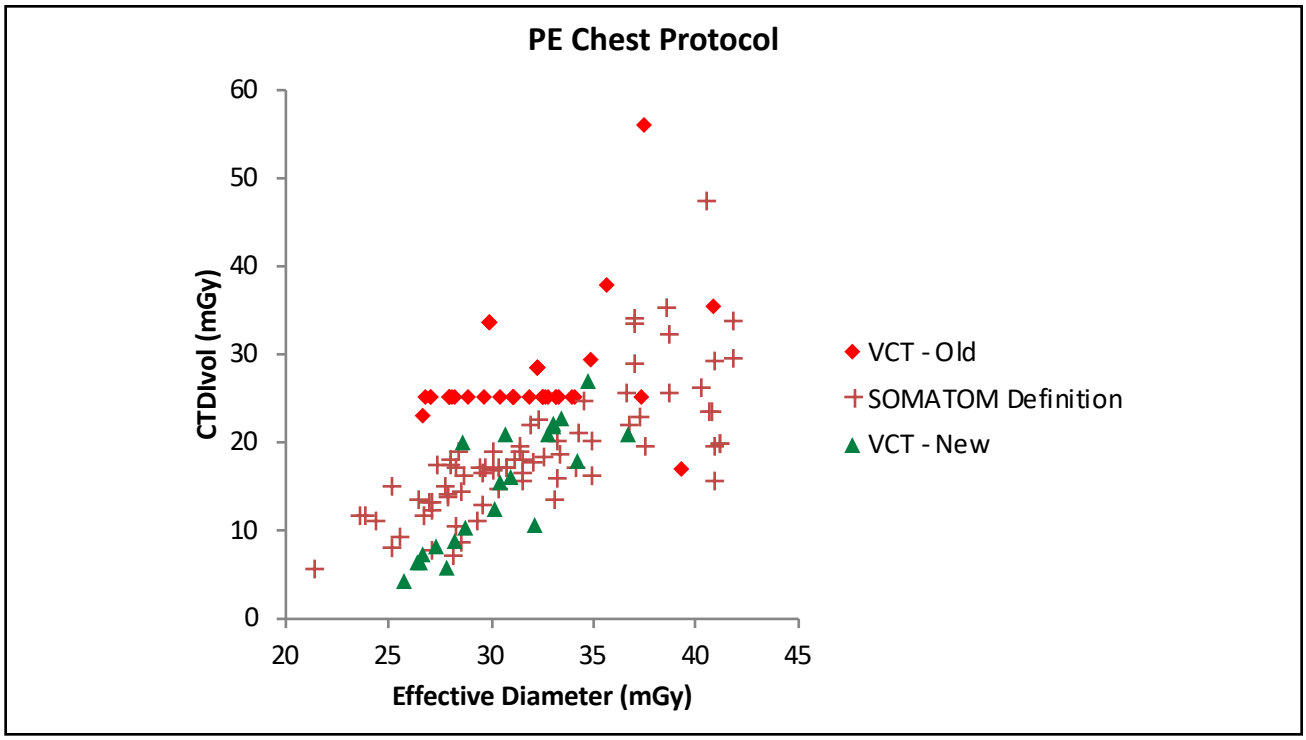


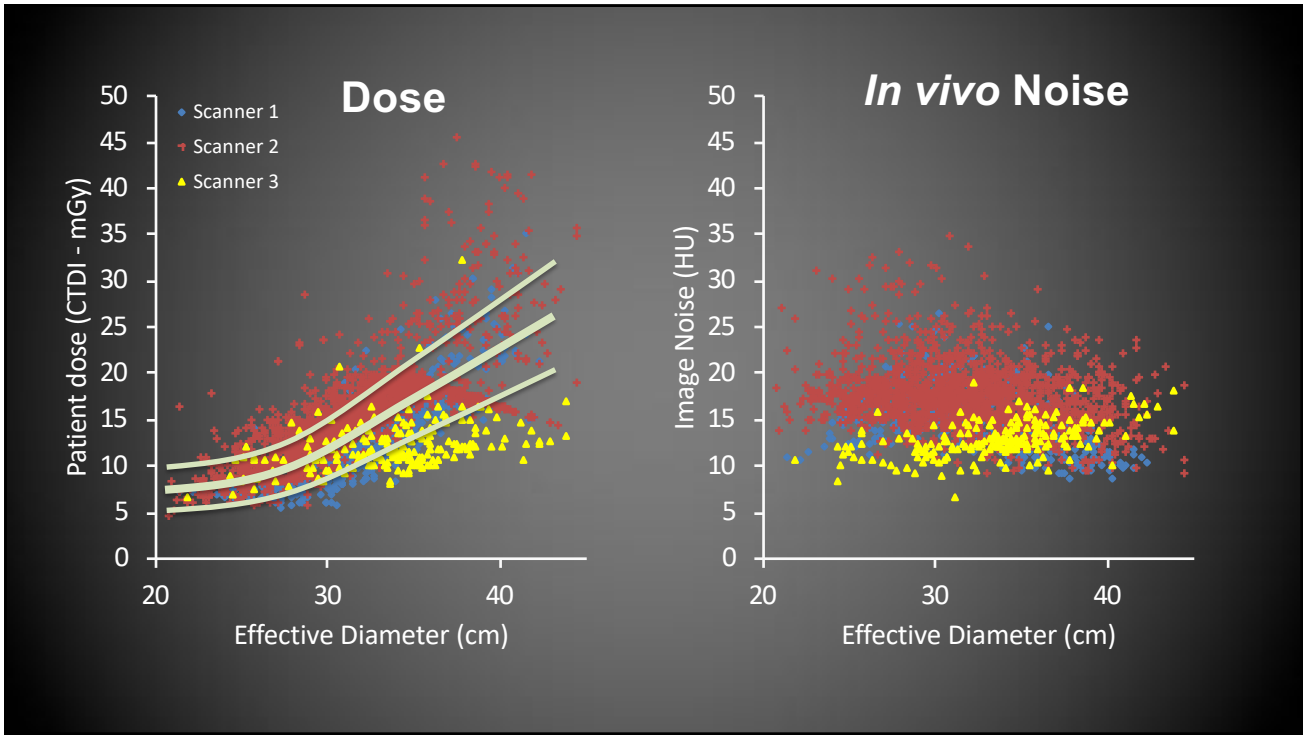


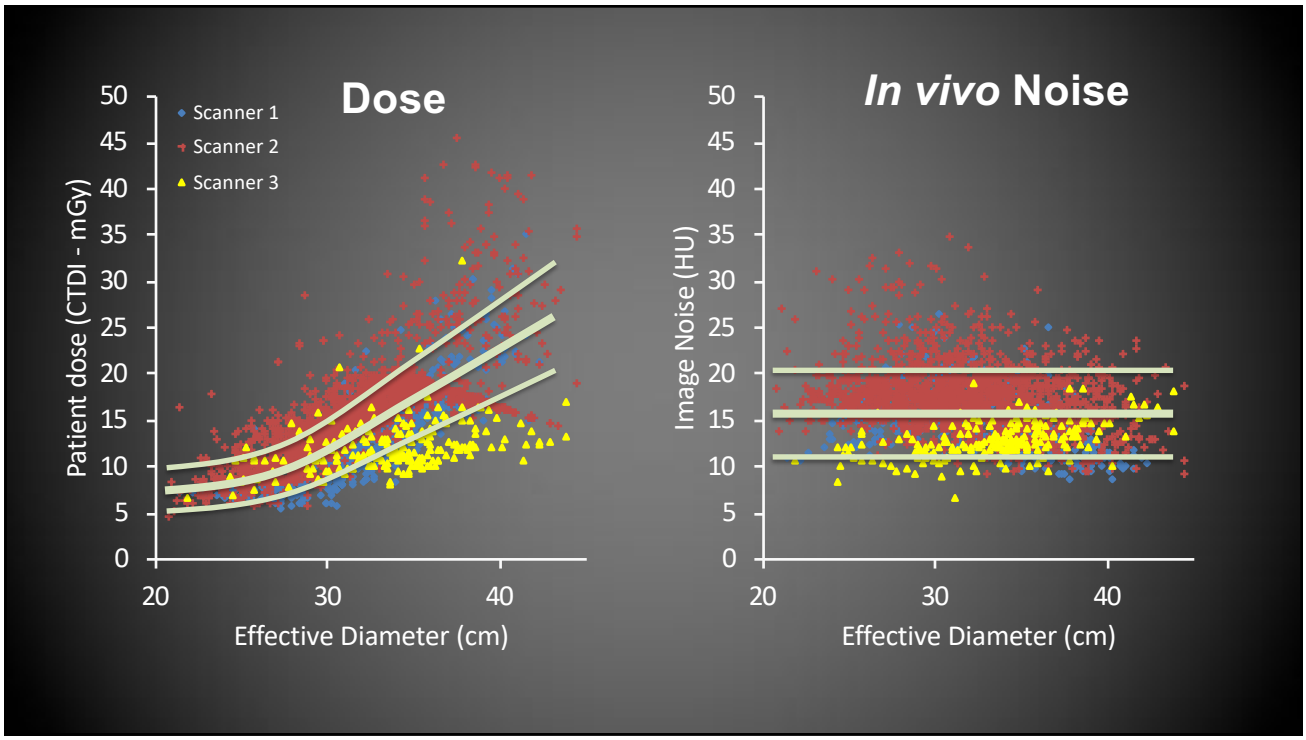


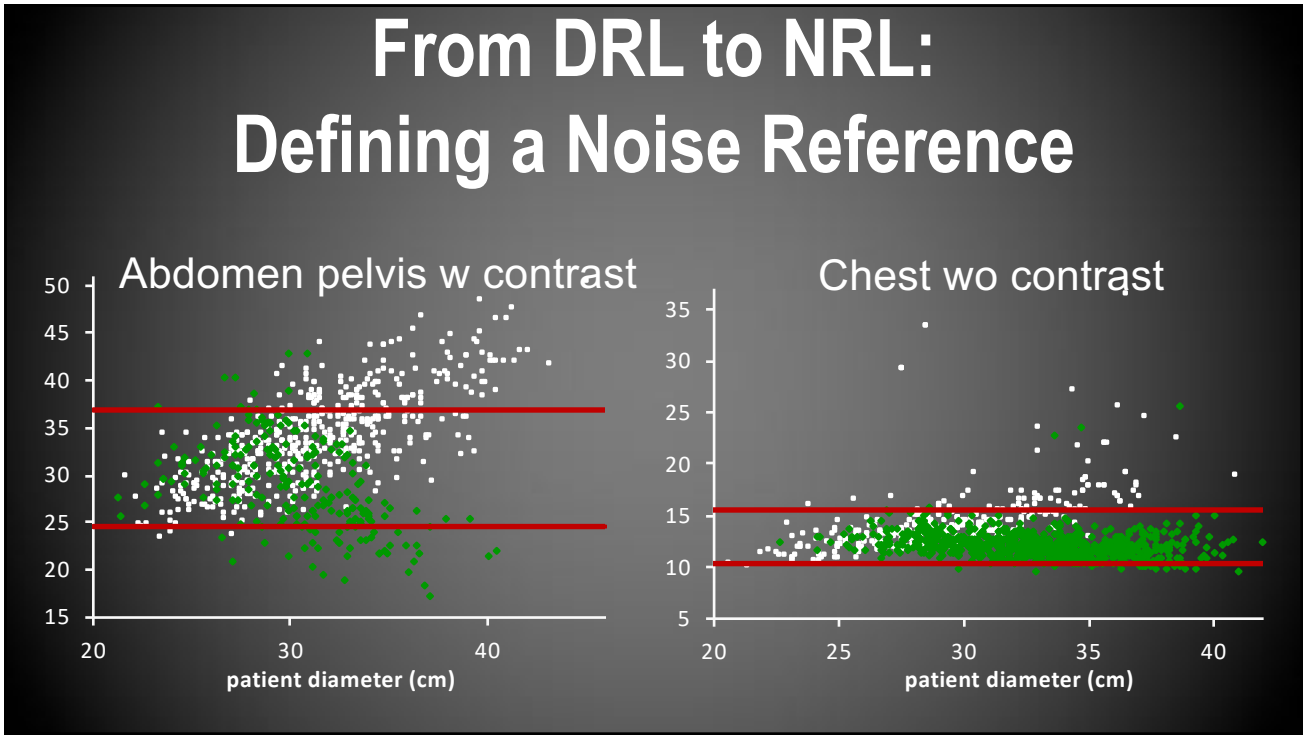
Quality range:
25-75% based on prior data

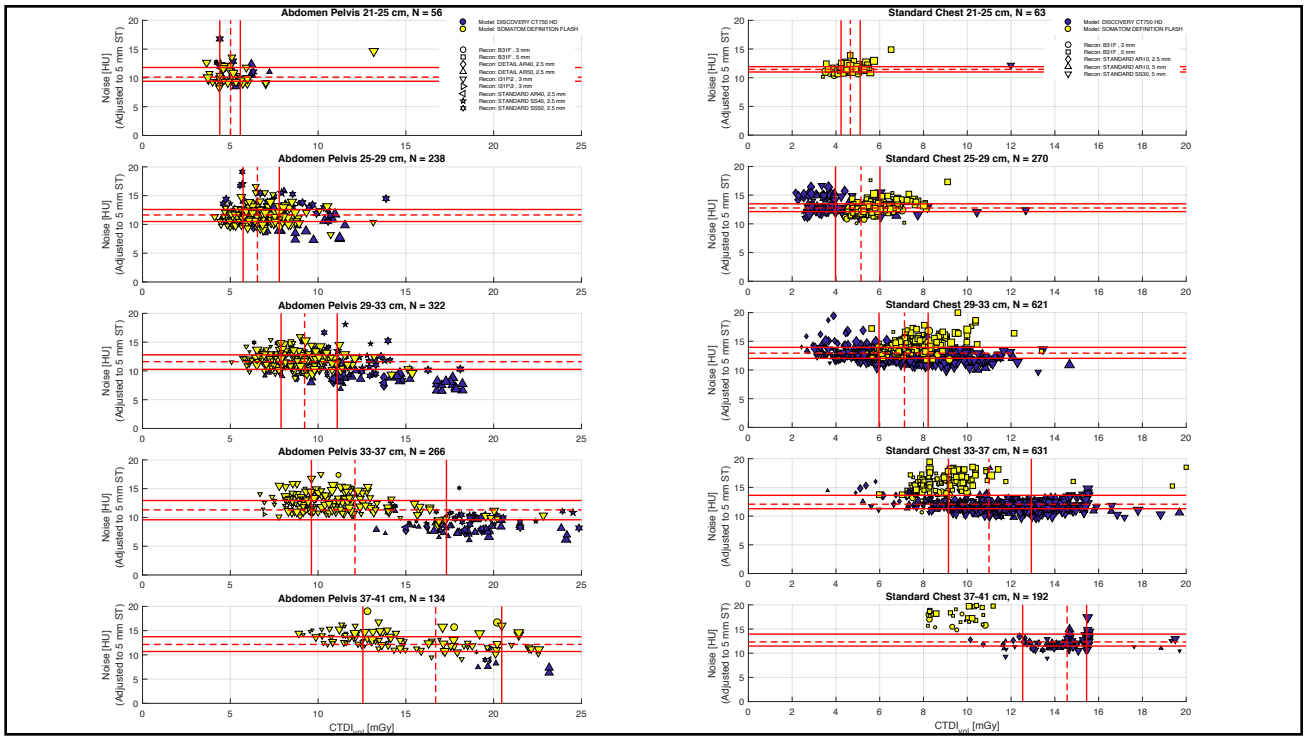






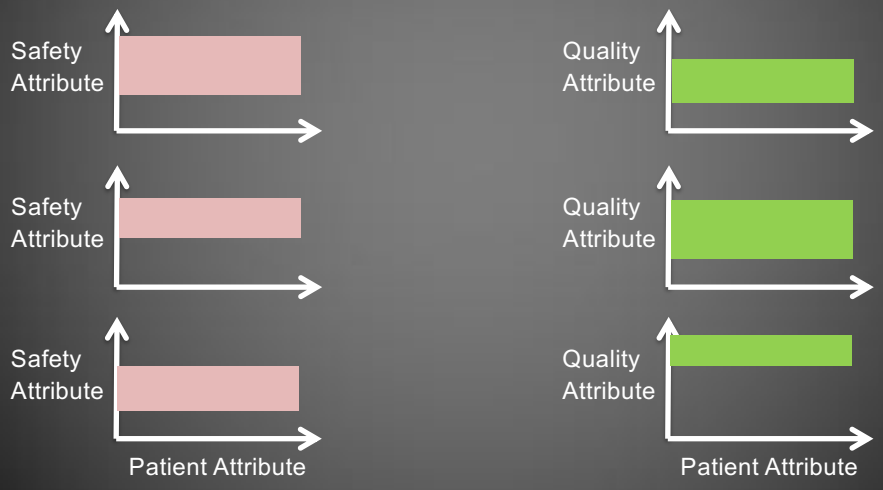






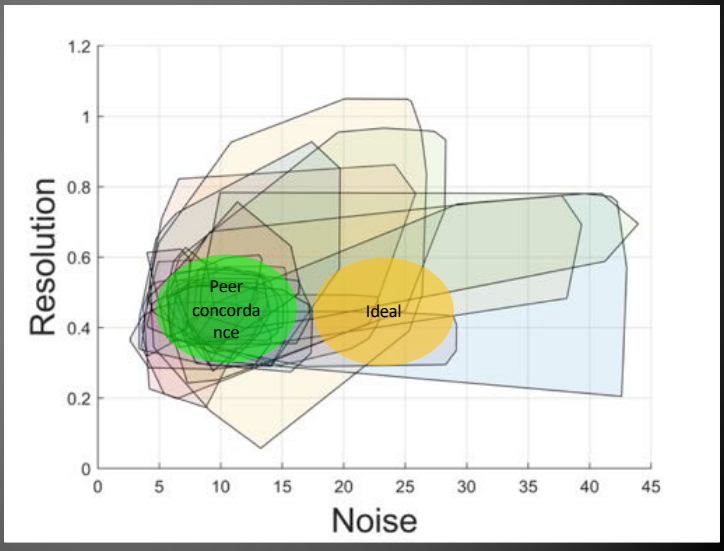
Multi-dimensional precision

Indication-specific safety & quality constraints



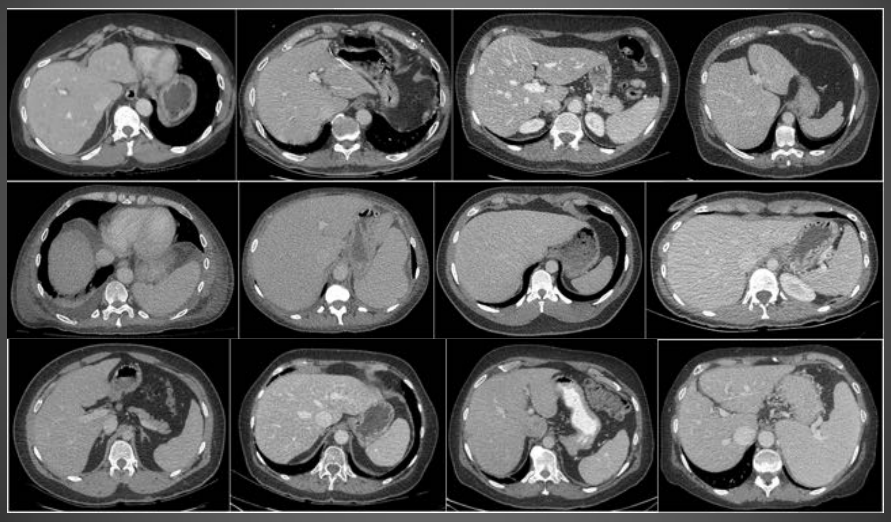
Multi-dimensional precision

- Noise, resolution, dose across
  - 103,547 total scans
  - 95 facilities
  - 3 manufacturers
  - 30 models
- The largest study of its kind in breadth and depth



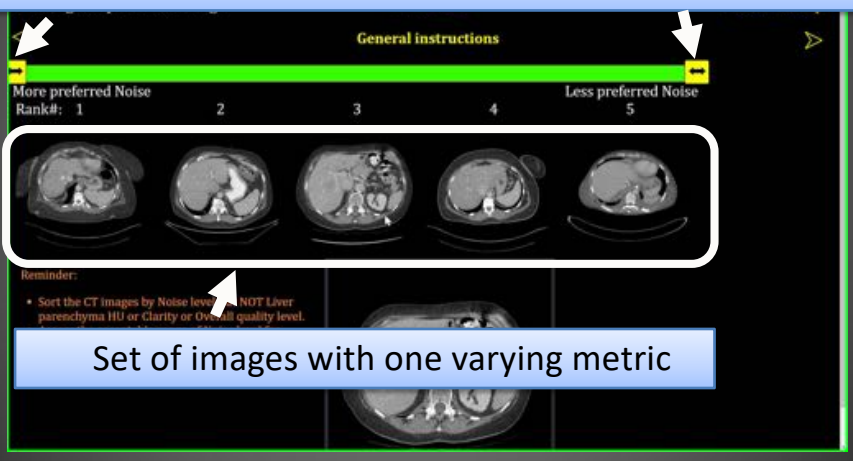
Smith et al, RSNA 2018

Observer preference studies



Observer preference studies

Acceptable range for detecting small hepatic lesions



Set of images with one varying metric

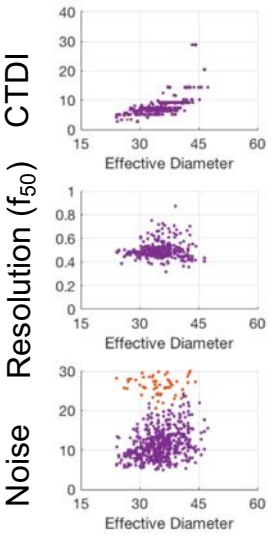
Radiologists preference

Metric	Overall rank order agreement		Clinically acceptable range of image quality metrics for abdominal CT examinations			
	Mean	Std error	Median	Mean	95% CI Lower bound	95% CI Upper bound
Noise (HU)	0.90	0.06	(17.8, 32.6)	(17.8, 32.5)	(17.8, 17.8)	(28.0, 37.1)
Liver parenchyma HU	0.98	0.19	(92.1, 131.9)	(97.2, 131.8)	(82.8, 111.5)	(131.6, 132.1)
Clarity	1.00	0.22	(0.45, 0.55)	(0.47, 0.55)	(0.43, 0.50)	(0.55, 0.55)

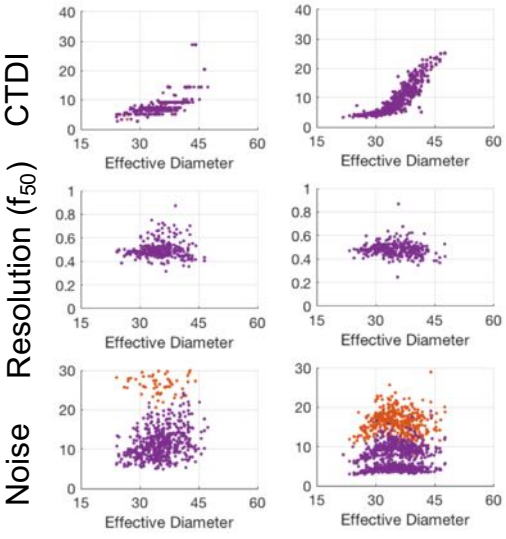
Chest						
Size Range	NRL	NRR	DoRL	DoRR	RRL	RRR
21.0-24.9	10.79	7.56	3.31	2.06	0.460	0.065
25.0-28.9	9.79	6.83	5.17	2.53	0.471	0.059
29.0-32.9	10.19	5.68	7.75	3.75	0.477	0.079
33.0-36.9	10.50	6.40	11.13	7.29	0.477	0.096
37.0-40.9	10.64	7.56	15.04	12.43	0.466	0.101
Abd-Pelvis						
Size Range	NRL	NRR	DoRL	DoRR	RRL	RRR
21.0-24.9	6.94	2.10	5.3	1.59	0.464	0.078
25.0-28.9	7.69	2.40	6.72	2.48	0.456	0.087
29.0-32.9	8.19	2.75	8.85	3.64	0.462	0.097
33.0-36.9	8.39	3.34	11.85	5.00	0.463	0.110
37.0-40.9	7.99	3.89	14.69	7.99	0.453	0.121

Smith et al, RSNA 2018

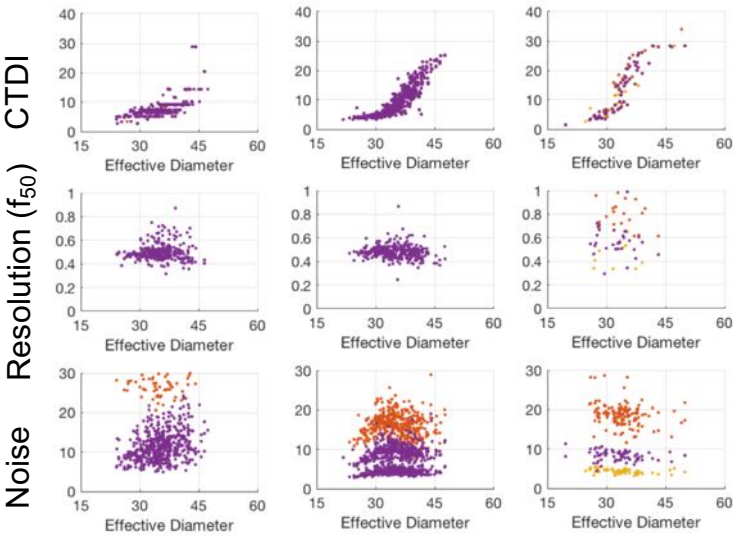
Intra-facility variability (Chest)



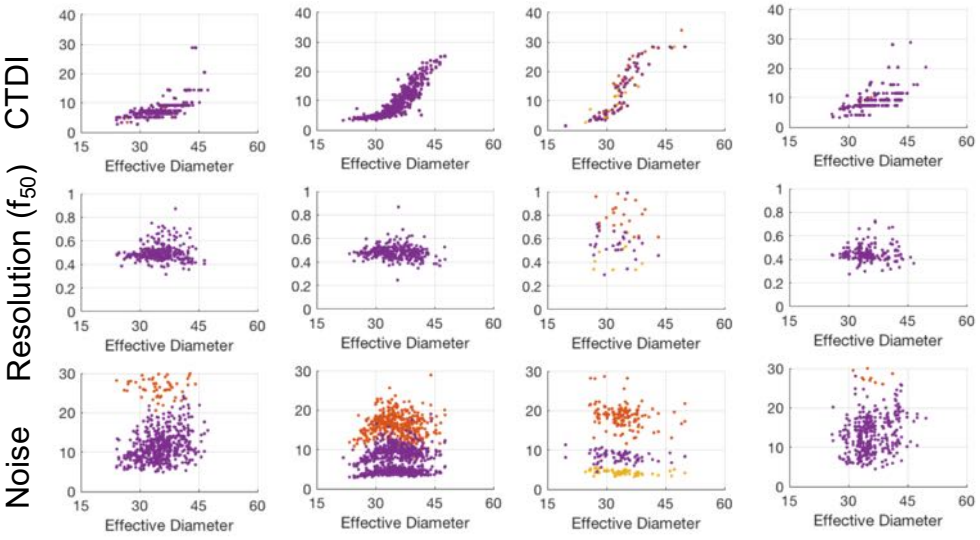
Intra-facility variability (Chest)



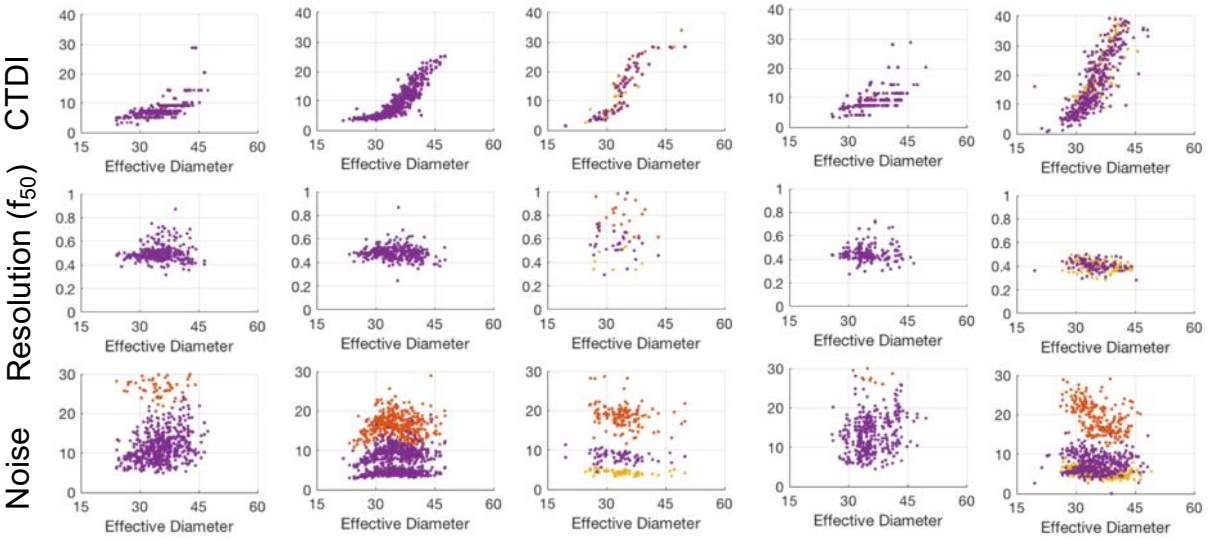
Intra-facility variability (Chest)



Intra-facility variability (Chest)

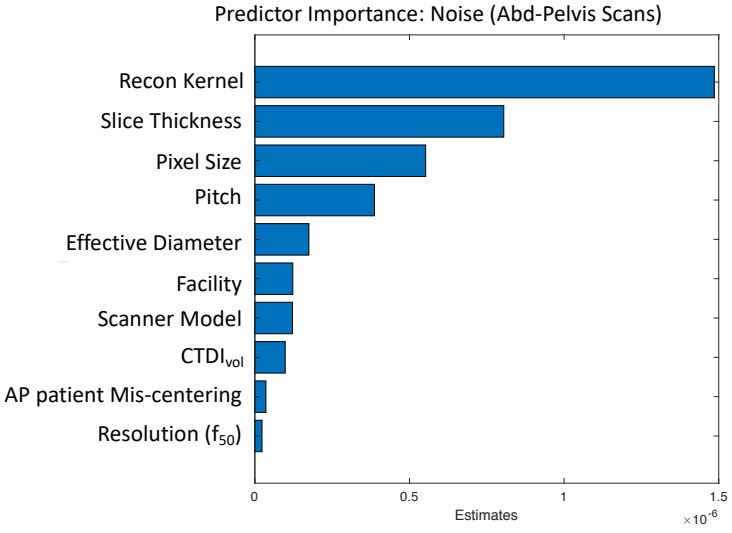


Intra-facility variability (Chest)



What are the sources of variability?

- Fit a regression tree to dataset and compare the effect size of tree nodes
- Compare rank ordering importance of parameters



Caveats

1. Streamlining metrology
2. Sorting out Incidental vs cumulative dose
3. Series based vs study-based analytics and constraints
4. Meaningful synthaxing the data – data fidelity
5. Meaningful analytics via smart AI
6. Retrospective analytics <=> prospective optimization
7. Resourcing the process

Take-home points

Take-home points

- Precision imaging requires patient-derived/relevant and pragmatic surrogates of Q and S
- Dose cannot be managed irrespective of image quality
- Quality and safety *together* form the basis of risk optimization for the patient, directly related to the very purpose of imaging

Take-home points

- There is a significant amount of intra-facility, and inter-facility variability
  - Inter-facility variability > Intra-facility variability
- DRL concept should be extended to Q&S analytics / constraints
- Q&S variability can be managed by applying constraints at 3 levels: machine performance, protocol design, and case performance

Take-home points

- Regions of agreement, reference levels, and reference ranges can be used as a peer-based guidance tool to increase consistency
- The biggest factors affecting Q&S factors
  - Convolution kernel, slice thickness, pixel size, pitch, size, facility, scanner model, patient centering