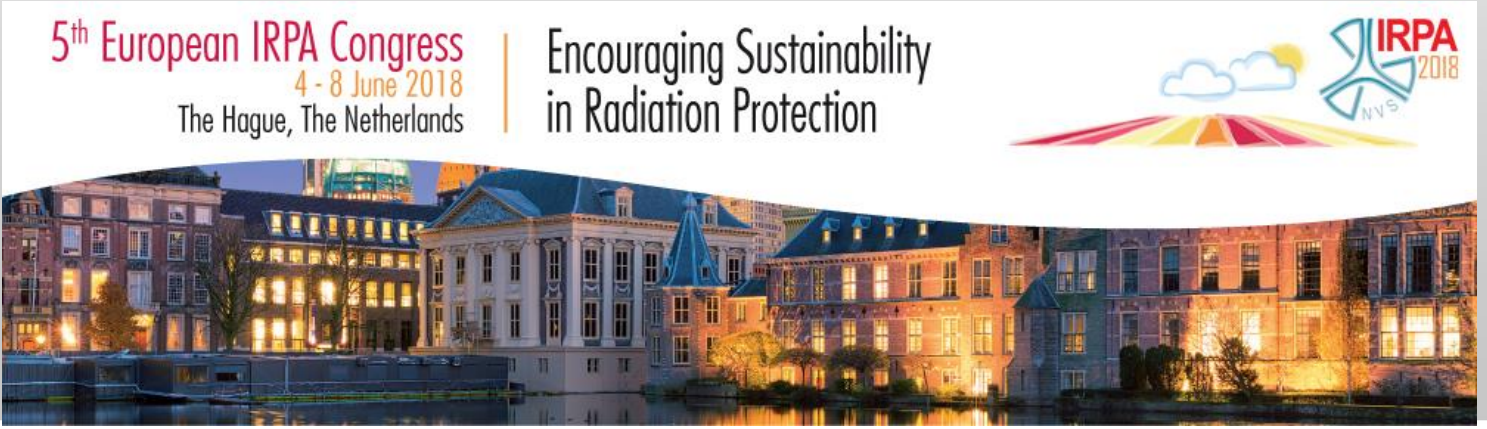
HERCA Heads of the European Radiological protection Competent Authorities

COCIR

Industry initiative on CT dose optimization in cooperation with HERCA

6th June 2018



Roy Irwan, Ph.D
Deputy-Chair COCIR-HERCA TF
Canon Medical Systems Europe

Disclaimer

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Historical background

HERCA Heads of the European Radiological protection Competent Authorities

February 2010 first meeting's agenda with CT manufacturers:

1. Increasing medical collective dose from CT scans
2. Risks associated with increasing dose and medical mistakes

Outcome of the meeting:

1. Dose efficiency of CT scanners
2. Transparency on dose reduction features
3. Quality assurance tools to prevent medical mistakes
4. A metric for patient dose
5. Improved training to users

HERCA Multi-Stakeholders' Meeting on the Optimised Use of CT Scanners

1st April 2015
Paris, France

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List of Participants

Organisation	Representative
HERCA	▪ Dr. Jürgen Griebel, HERCA WG Medical Applications (WG MA) chair ▪ Mr Steve Ebdon-Jackson HERCA WG MA co-chair, ▪ Ms Alexandra Schreiner, HERCA WG MA, WP CT manufacturers Chair ▪ Dr Lodewijk Van Bladel, WG MA/WP Justification Chair ▪ Ms Aurélie Isambert, WG MA Secretariat ▪ Mr Marc Valero, WG MA ▪ Ms Hanne Waltenburg, WG MA ▪ Mr Torsten Cederlund, WG MA ▪ Mr Alexander Schegerer, HERCA PoA ▪ Mr Verdun Francis, HERCA PoA ▪ Ms Sue Edyvean, HERCA PoA ▪ Ms. Olvido Guzmán, HERCA Secretariat
COCIR	▪ Mr Michael Chilbert, Philips Healthcare ▪ Mr Tony Roder, GE Healthcare ▪ Mr Roy Irwan , Toshiba Medical Systems ▪ Mr Lee Bush, GE Healthcare ▪ Mr Willem Overlaet , Toshiba Medical Systems ▪ Ms Nicole Denjoy, COCIR General Secretary (TBC)
EANM	▪ Dr Søren Holm, Chief Physicist
EC ENER	▪ Mr Georgi Simeonov, RP Unit ▪ Mr Ivo Alehno (TBC), RP Unit Head
EC SANCO	▪ Mr Aurelien Pérez, Healthcare systems Unit,
EFOMP	▪ Dr Penny Allisy-Roberts, EFOMP member
EFRS	▪ Mr Dean Pekarovič , EFRS advisory board member and CT expert.
ESR ESPR	▪ Prof. Guy Frija, ESR Past-President ▪ Prof. Claudio Granata, MD, Radiologist (ESPR) ▪ Ms Monika Hierath, ESR staff, head of EU/Int. Affairs dept.
ESTRO	▪ Prof. Tommy Knöös, Assoc. Prof. Radiation Physics,
FDA (USA)	▪ Dr Donald L. Miller, FDA, Chief Medical Officer for Radiological Health
IAEA	▪ Ms Jenia Vassileva, Radiation Protection of Patients Unit, RP Specialist
WHO	Apologies (cf welcoming message)

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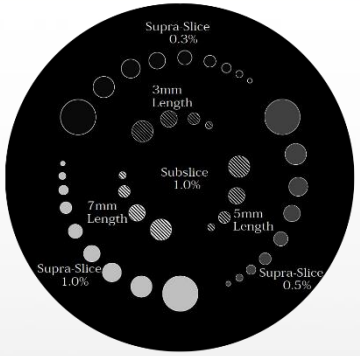
Commitment 1: *Characterization of CT Systems Standardized Benchmarking*

Aim: to provide transparency and easily understood values that attempt to characterize system performance through standardized test methods and conditions

Result: a white paper describing advanced analytical models for inclusion into product testing to measure image quality & associated dose more accurately than today

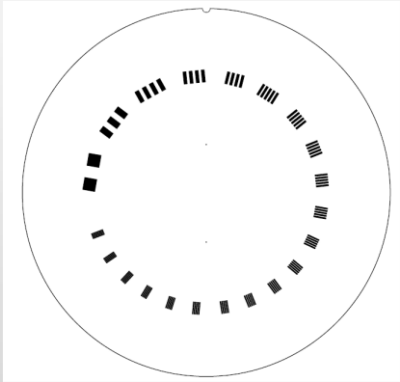
Commitment 1: Characterization of CT Systems Standardized Benchmarking

LCD @ 3mm @ 1% @ 10mm ST



Sample Results: Low Contrast Head

	GE	Philips	Siemens	Canon
10% MTF (lp/cm)	6.6	5.6	7.1	7.5
50% MTF (lp/cm)	3.9	3.0	3.3	4.1
Slice Width (mm)	5.6	5.8	4.5	5.0
Image Noise (HU)	3.7	2.4	3.8	4.2
Visual LCD at 1%*	2.3	2.3	3.0	2.2
Contrast (HU)	9.9	10.7	8.0	12.2
$CTDI_{vol\ (16\ cm)}$ (mGy)	50.3	51.7	59.6	49.9



* - Smallest pin visible (mm)

Results are averages from five scans, using factory default protocols

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Clinical Utility of Low Contrast

- Increased efficiency of manual contouring
  - Better visuals, easier edge detection
- Helps improving automated contouring
  - Edge detection algorithms more accurate with superb low contrast

The best image quality at the lowest dose

Commitment 2: *Implementation of Dose Reduction Measures in CT*

Aim: to foster the development and propagation of dose reduction/dose management measures across CT products.

Result: measures have been included in international standards.

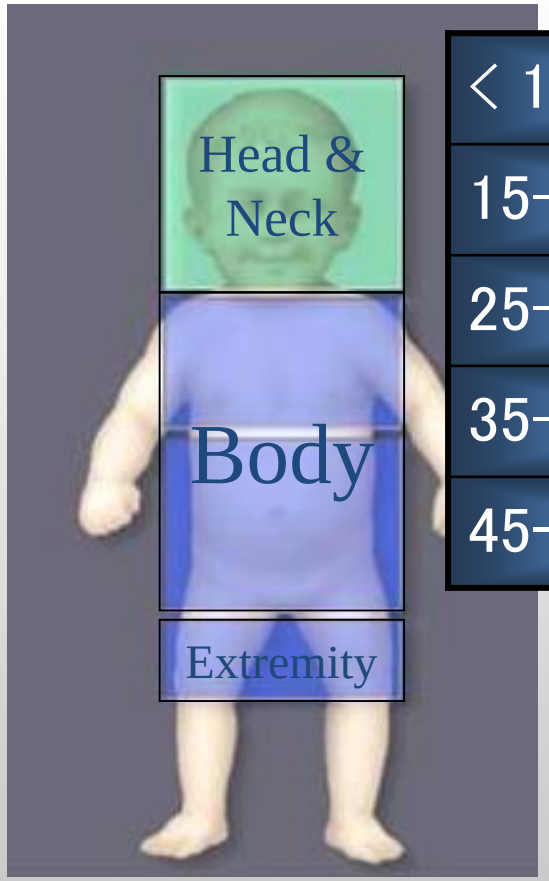
Commitment 2: Dose Reduction Measures – Periodic Assessment

http://www.cocir.org/site/fileadmin/5_Initiatives/COCIR_CT_MANUFACTURER_List_of_Dose_ManagementFeatures_05_July_2013.pdf

1. Pediatric protocol setting
2. Active / dynamic collimation
3. Iterative Reconstruction
4. Automatic Exposure Control
5. Dose display & reporting

Pediatric protocol

- *Be nice*
- *Do not lose temper or shout*
- *Beware of dirty nappies*
- *Do not drop on the floor*
- *Only pinch when nobody is looking*

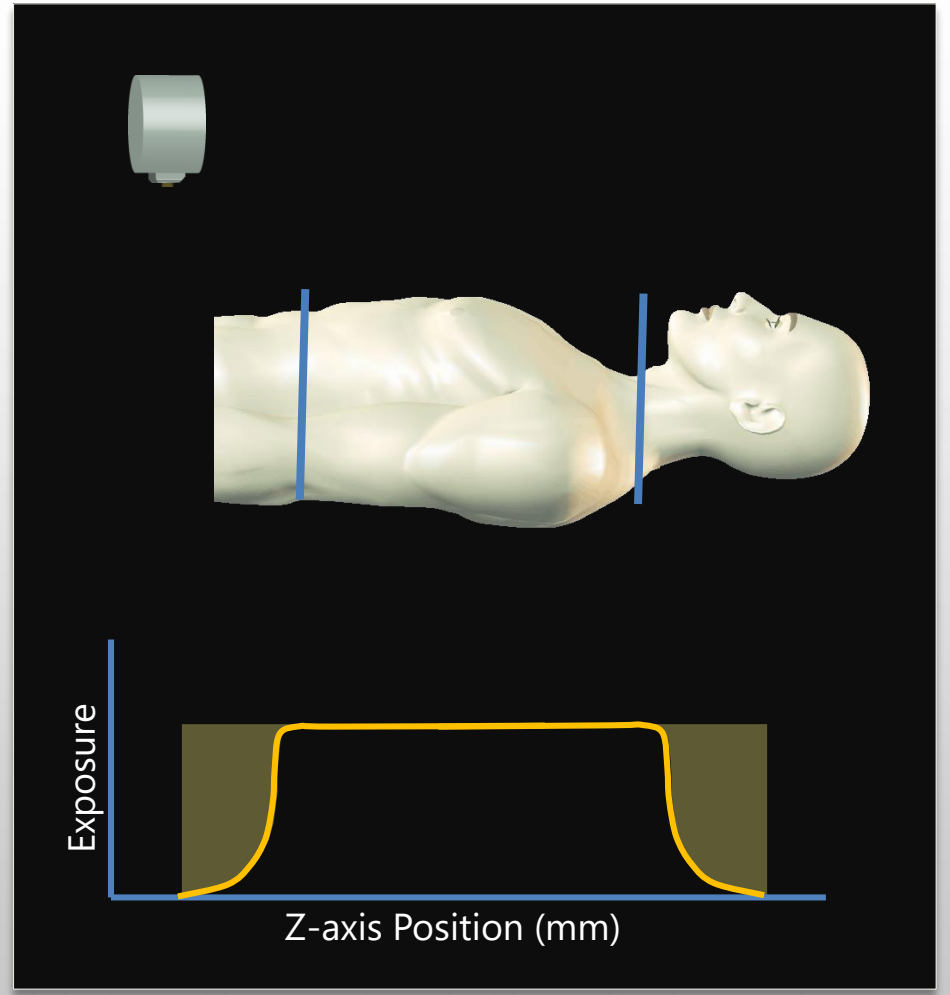


< 15 kg	70 mAs	80 kV
15–24 kg	80 mAs	80 kV
25–34 kg	100 mAs	80 kV
35–44 kg	120 mAs	80 kV
45–54 kg	180 mAs	80 kV

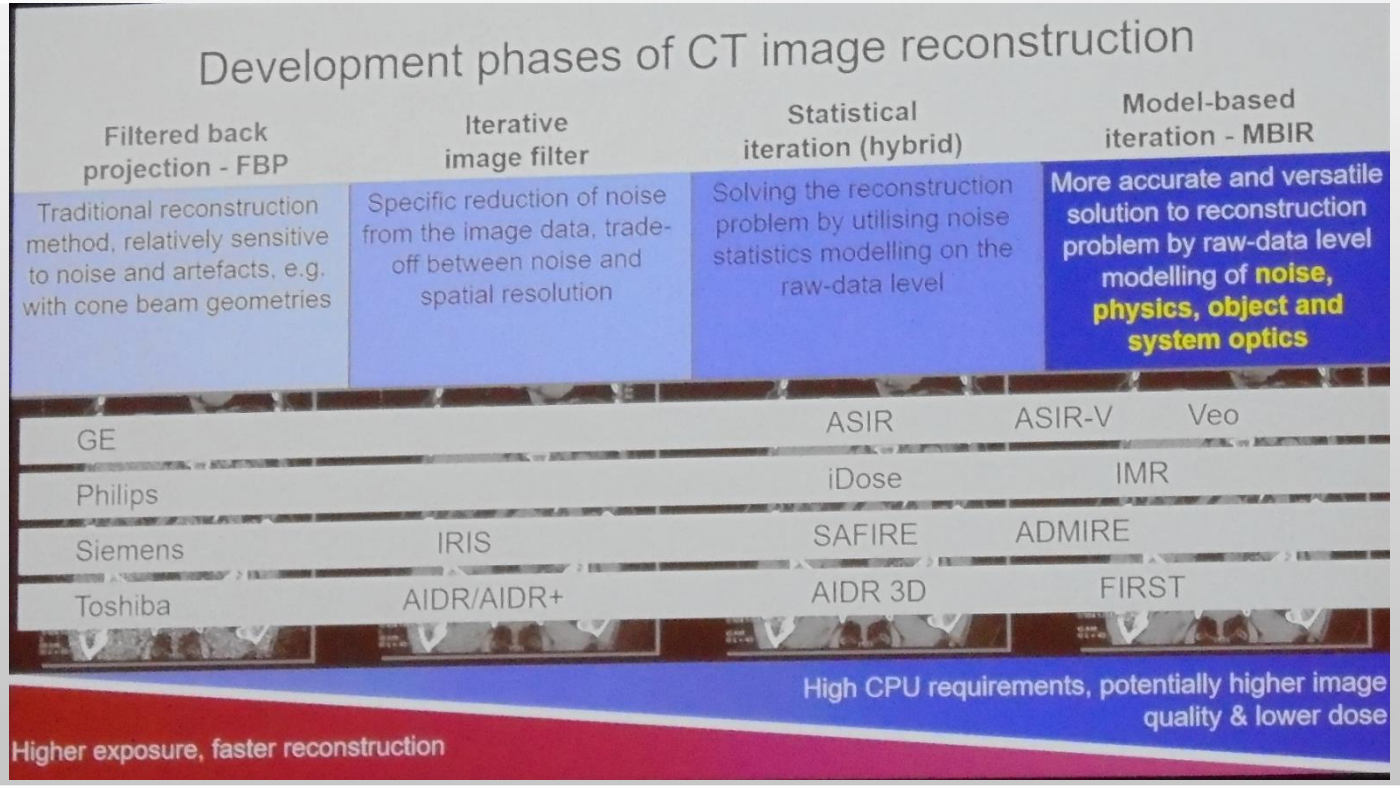
<6 months	150 mAs	80 kV
6 mo–3 years	300 mAs	80 kV
3 y – 6 years	220 mAs	120 kV

Active Collimation

Helical/Spiral over-ranging minimized for lower dose image acquisition

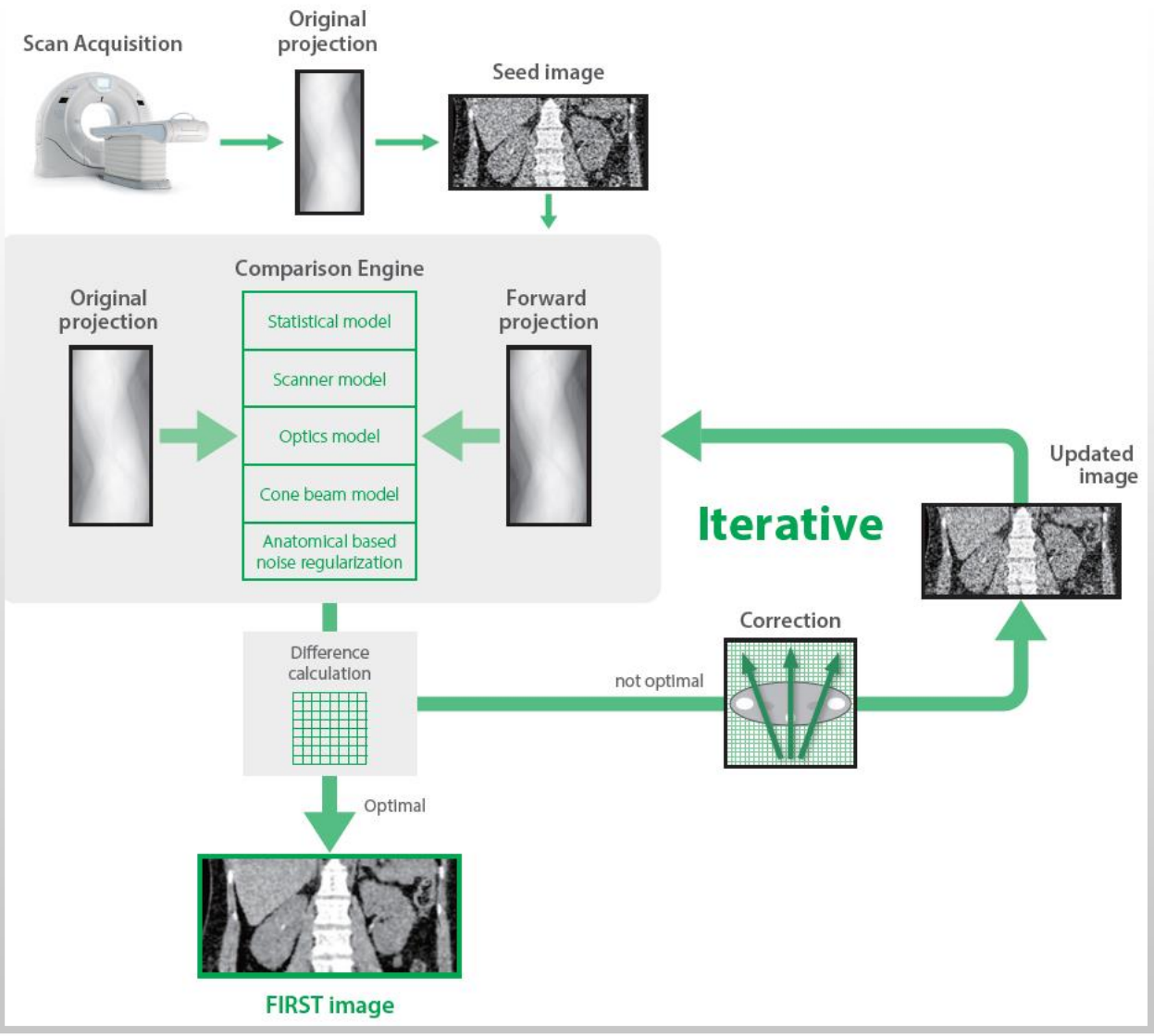


Iterative Reconstruction



Dr. M. Kortesnimie, ECR 2018

FIRST (Forward projected model-based Iterative Reconstruction SoluTion)

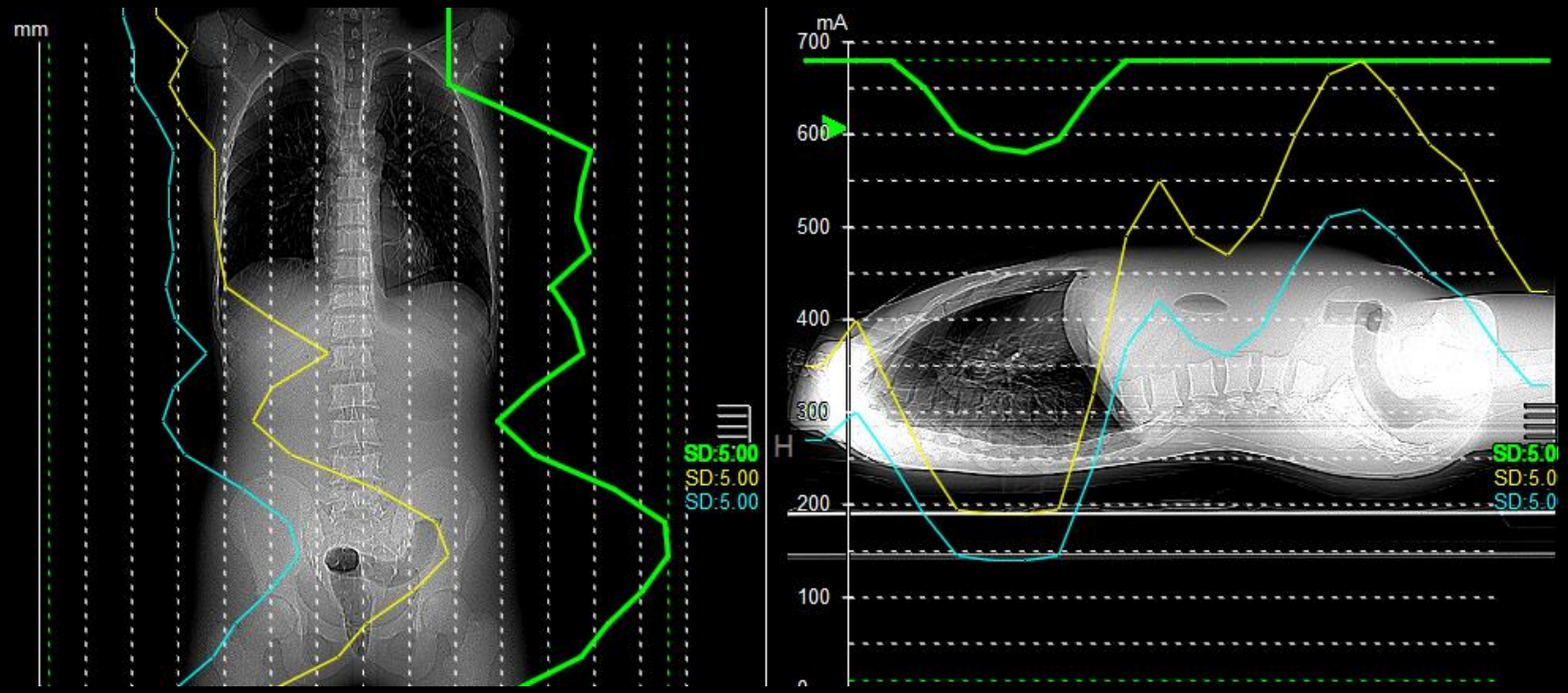


Iterative Reconstruction & Tube Current Modulation

FBP: 1517 mGy.cm

AIDR 3D: 866 mGy.cm

FIRST: 618 mGy.cm



PET/SPECT COMBINED WITH CT

In the last couple years, all major manufacturers of PET and PET/CT scanners have introduced technology that can lower the dose required to produce a quality exam.

CT SIDE

- In PET/CT imaging CT dose could be dramatically reduced compared to the diagnostic protocol. There is big room for CT dose reduction as long as the bias and noise in CT could be controlled in an acceptable range without introducing artifacts through CT-based PET attenuation correction.
- Automatic exposure control can reduce the dose by 20%
- Reduce CT radiation by reducing the time the patient is in the PET/CT scanner.
- Advanced CT dose reduction technology, noise reduction and extremely fast detection electronics
- Iterative reconstruction reduce your CT dose from a typical 7 to 8 mSv down to 0.3 mSv—that's about a 20 times reduction in the CT exposure when you don't need a diagnostic purpose CT,"

Commitment 3: *Dose Management & Reporting*

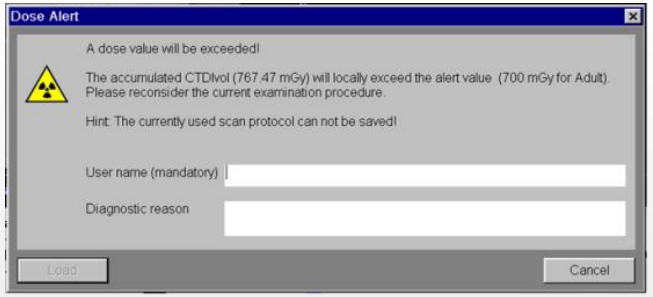
Aim: to support IHE-REM profile and enhance dose management and reporting capabilities.

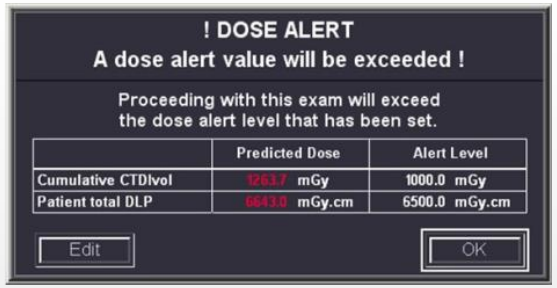
Result: Manufacturers have implemented Dose Check, DICOM SR, & Access Controls on systems.

Commitment 3: Dose Management & Reporting

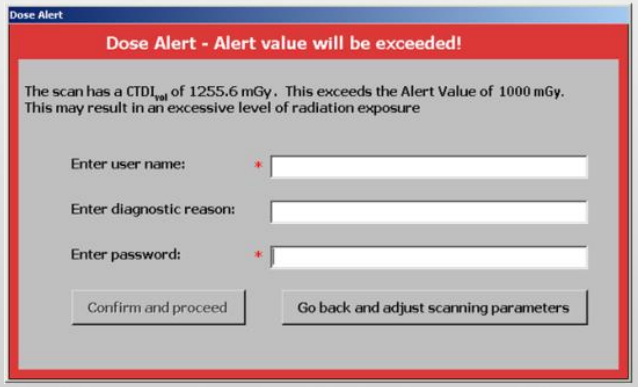
Dose Management

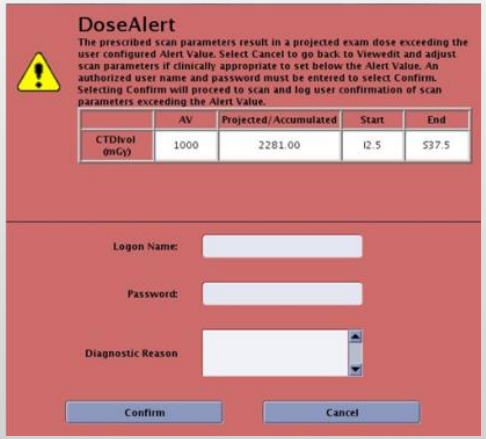
Phase 1: Dose Check
Complete – phased into CT systems





Phase 2: Security
Access Controls for CT





Standard released:

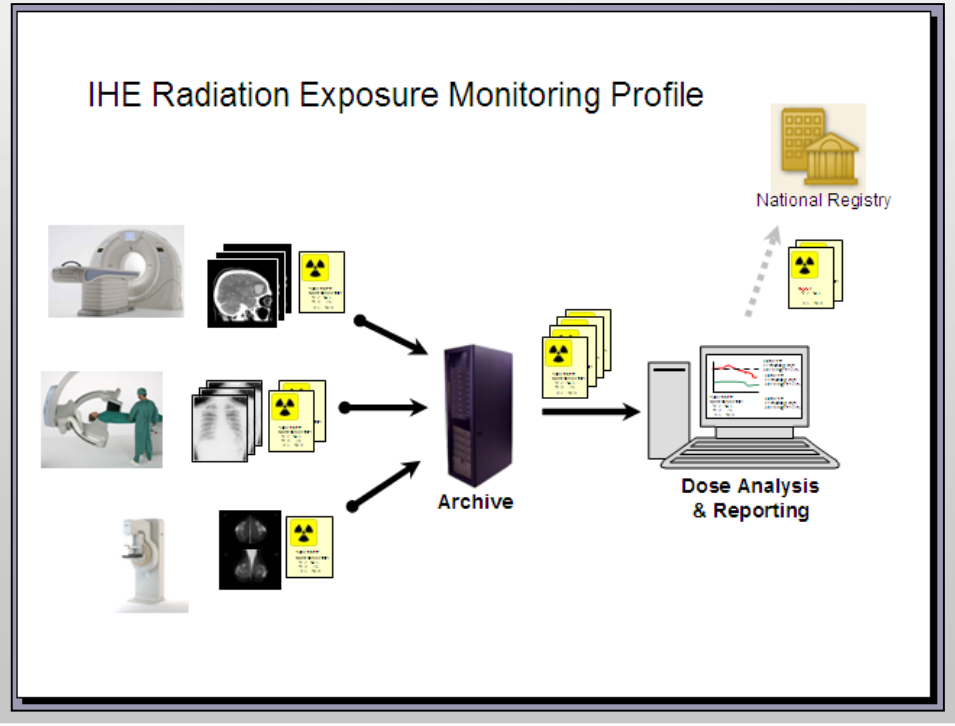
- Scanning & protocol privileges
- Patient ID, height, weight & gender
- Emergency Access
- Log File
- System Lock

Commitment 3: Dose Management & Reporting

Dose Reporting

Phase 1: $CTDI_{vol}$, DLP, & DICOM SR

CT systems display accepted dose metrics prior to scan initiation and record these metrics in a post exam DICOM Structured Report – enabling IHE-REM, quality assurance, and dose index registries



Source: Wikipedia

CT Scanner

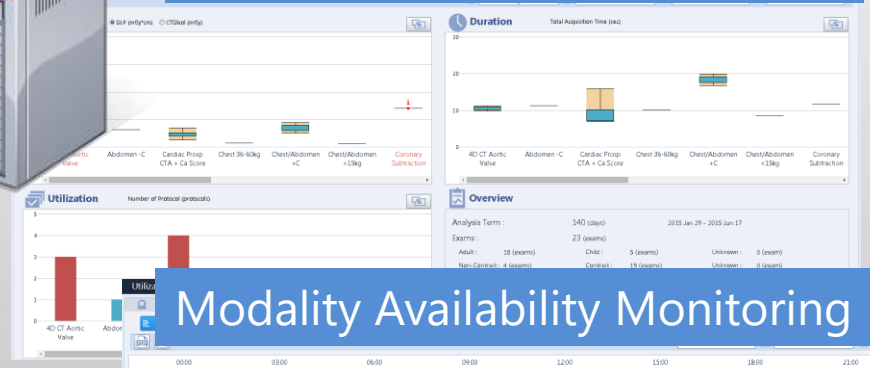
Administrator/Lead Tech/Physicist

Vitality XT Server

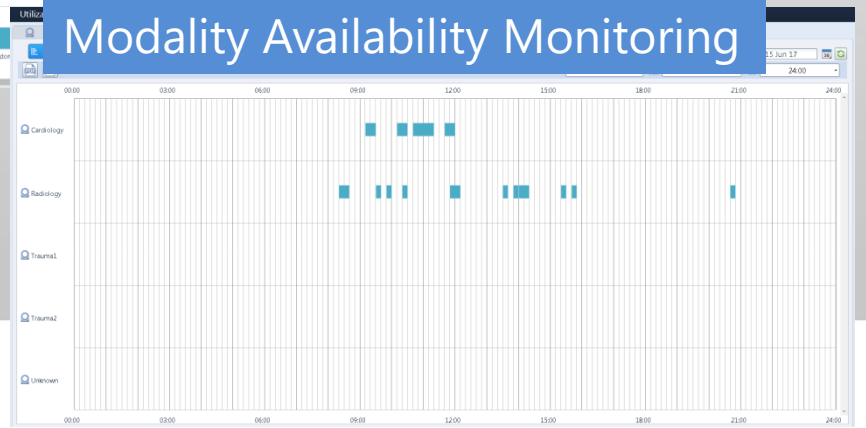
Send RDSR

X-Ray Angiography System

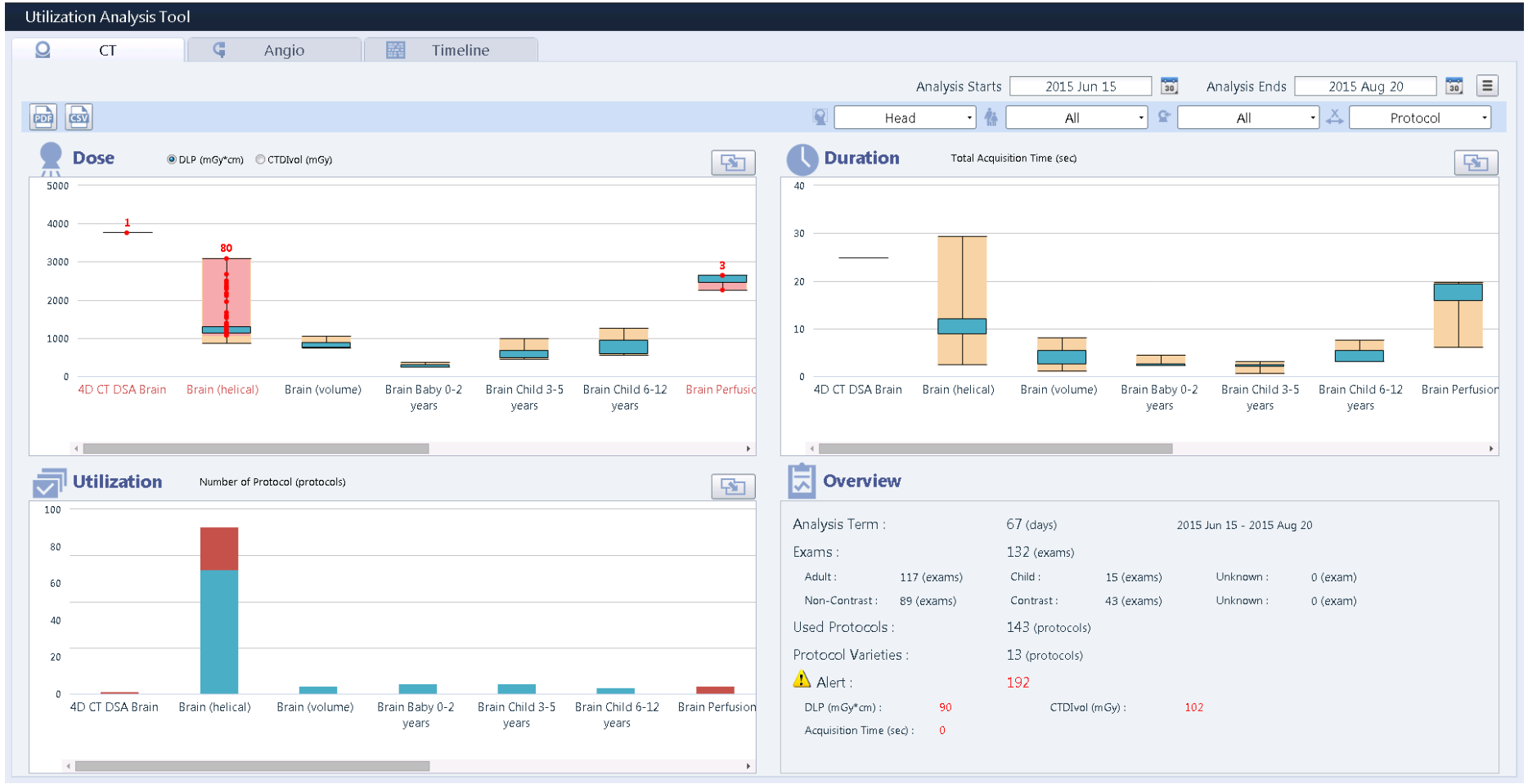
Dose Monitoring
Protocol Utilization Monitoring



Modality Availability Monitoring

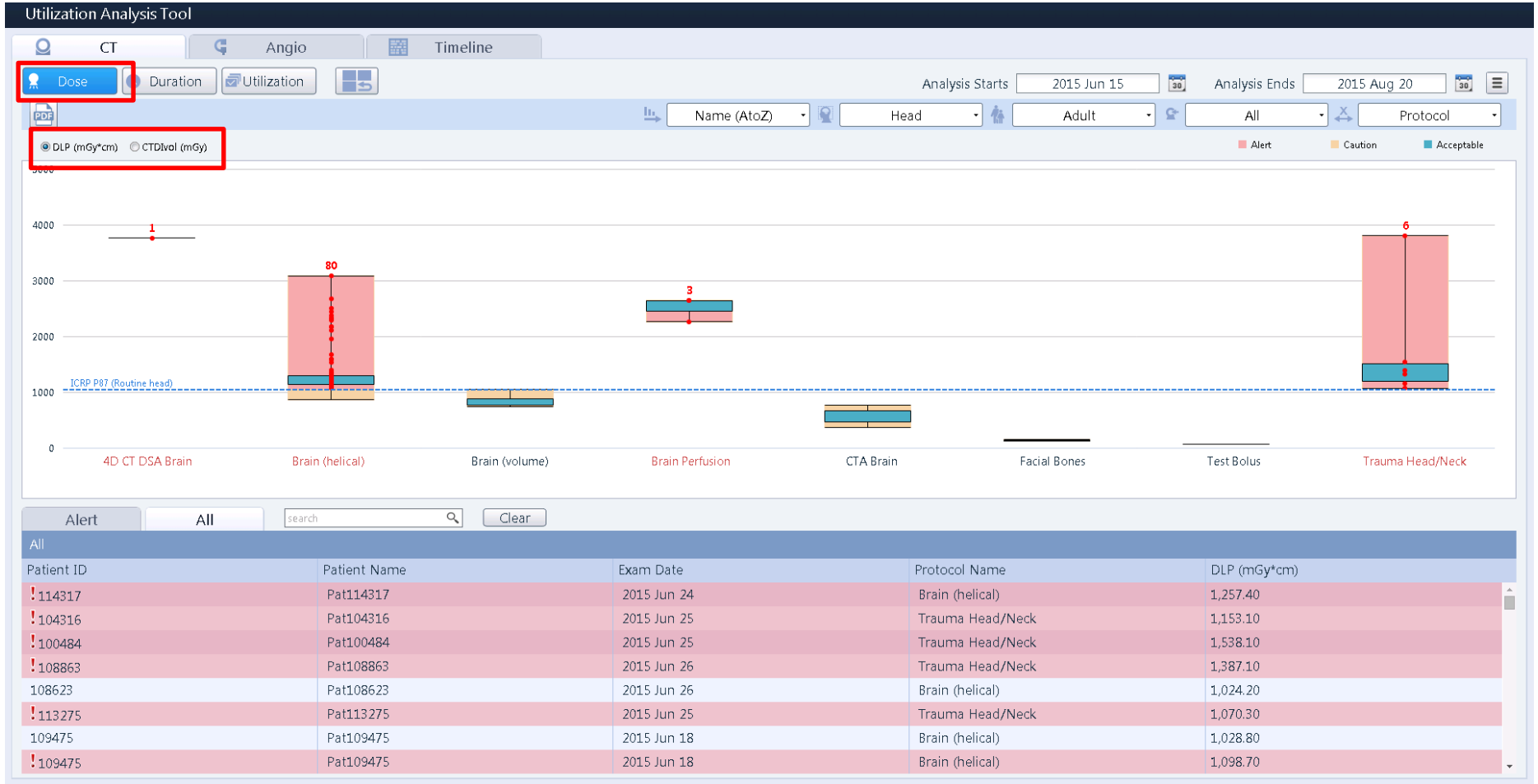


Overview


Utilization Analysis Tool
CT
Angio
Timeline
Analysis Starts
2015 Jun 15
Analysis Ends
2015 Aug 20
Head
All
All
Protocol
Dose
DLP (mGy*cm)
CTDIvol (mGy)
5000
4000
3000
2000
1000
0
1
80
3
4D CT DSA Brain
Brain (helical)
Brain (volume)
Brain Baby 0-2 years
Brain Child 3-5 years
Brain Child 6-12 years
Brain Perfusio
Duration
Total Acquisition Time (sec)
40
30
20
10
0
4D CT DSA Brain
Brain (helical)
Brain (volume)
Brain Baby 0-2 years
Brain Child 3-5 years
Brain Child 6-12 years
Brain Perfusion
Utilization
Number of Protocol (protocols)
100
80
60
40
20
0
4D CT DSA Brain
Brain (helical)
Brain (volume)
Brain Baby 0-2 years
Brain Child 3-5 years
Brain Child 6-12 years
Brain Perfusion
Overview
Analysis Term : 67 (days) 2015 Jun 15 - 2015 Aug 20
Exams : 132 (exams)
Adult : 117 (exams) Child : 15 (exams) Unknown : 0 (exam)
Non-Contrast : 89 (exams) Contrast : 43 (exams) Unknown : 0 (exam)
Used Protocols : 143 (protocols)
Protocol Varieties : 13 (protocols)
Alert : 192
DLP (mGy*cm) : 90 CTDIvol (mGy) : 102
Acquisition Time (sec) : 0

» Dose can be displayed as CTDI or DLP.

» CTDI or DLP are added up in a cumulative manner, regardless of overlap.



Commitment 3: Dose Management & Reporting

Dose Reporting

Phase 1: $CTDI_{vol}$, DLP, & DICOM SR

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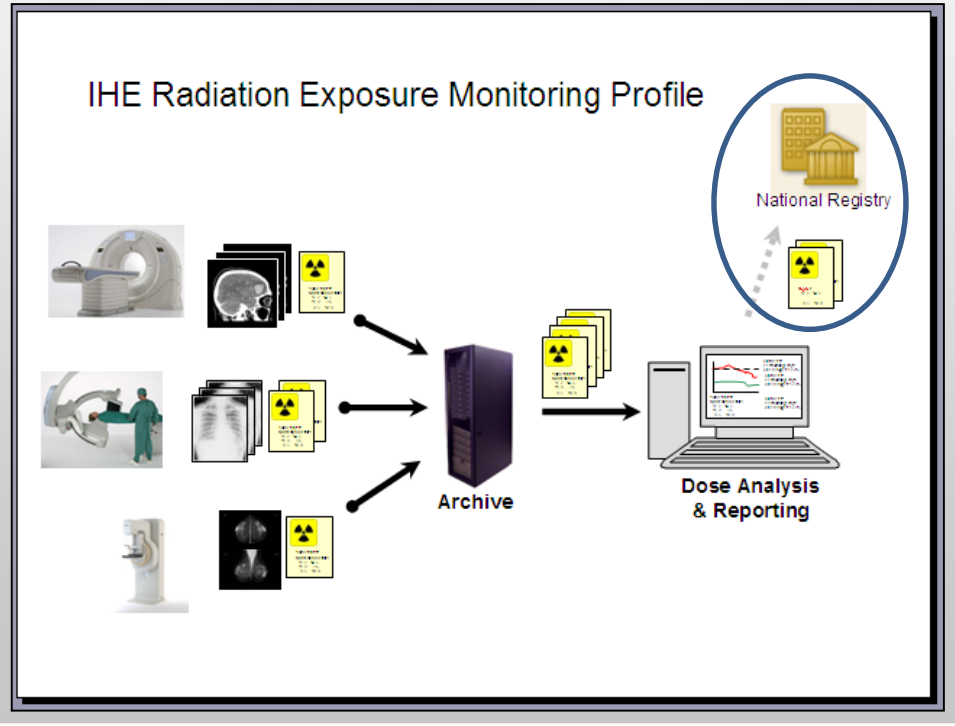
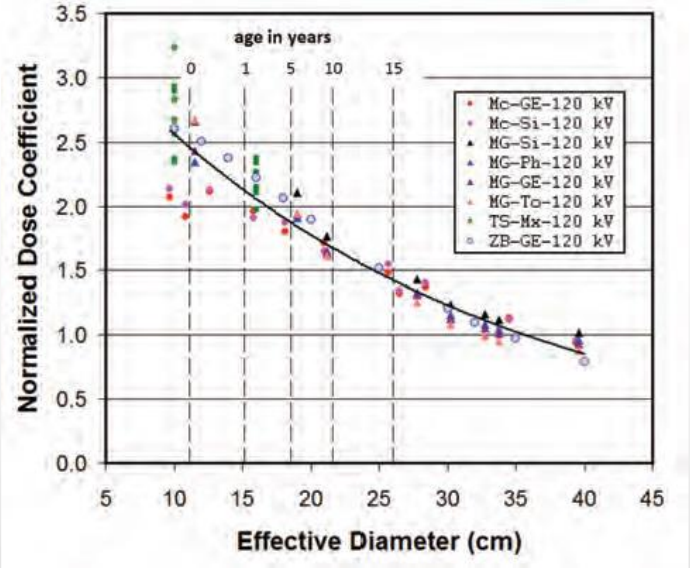


Phase 2 – Patient centric

1. Closer to "real patient dose"
2. Based on medical physicists (AAPM TG204 & TG220)
3. Manufacturers have suggested using scan projection radiograph for primary size estimation

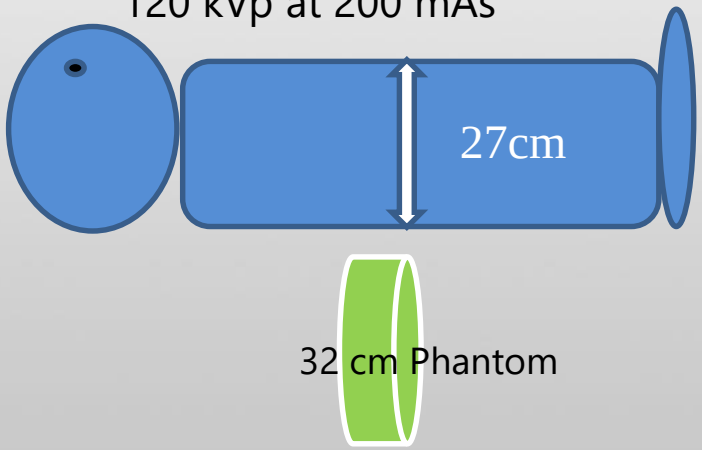
$$SSDE = CTDI_{vol} \times f_{size}$$



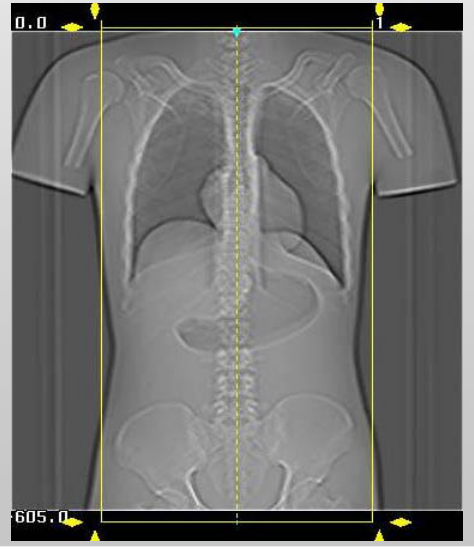
120 kVp at 100 mAs

$CTDI_{vol}$ = 10 mGy
SSDE = 13.2 mGy

120 kVp at 200 mAs



$CTDI_{vol}$ = 20 mGy
SSDE = 13.2 mGy



Commitment 4: *Provision of Specific Training Curricula*

Aim: to support appropriate, safe and effective use of imaging equipment by the clinical user

Currently: Specific training curricula on existing and new dose reduction techniques, how to use these features in daily practice, and how to enable users to continue to reduce patient dose

Commitment 4: Provision of Specific Training Curricula

1. Manufacturers' domain specific training curricula

Together with new developments in new CT products and radiation dose reduction techniques, scan protocols and CT user training is very important

» Manufacturers invest in the education of their customers (on site and via course programs)

2. Clinician/Physicist developed

Societies -such as ESR, EFOMP- and new projects -such as EuroSafe Imaging Campaign - develop public and member education programs on radiation dose education and awareness building

» Manufacturers contribute as a stakeholder to these programs

ESMPE
European School for Medical Physics Experts

COCIR

ESMPE European School for Medical Physics Experts

Computed Tomography. Technology, Dosimetry, Optimization.

January 25 – January 27, 2018, Prague, Czech Republic

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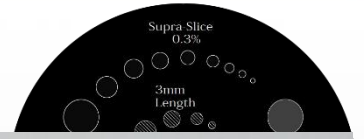
MANUFACTURERS' ROLE IN TRAINING AND EDUCATION

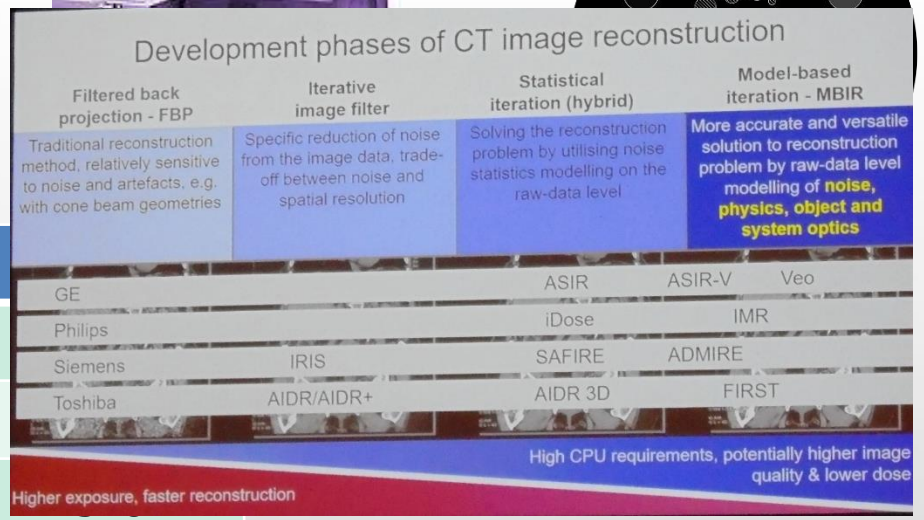
- The role of education and training is also an extremely important tool to ensure safety.
- Manufacturer's training is designed to support customer facilities in an effort to improve operating knowledge and increase the skill level of personnel. These programs consist of a variety of delivery mechanisms such as:
  - ✓ **Hands-on and didactic training** to reinforce skills needed to operate equipment
  - ✓ **Operator Manuals** to demonstrate information on dose optimization tools and dose reduction strategies
  - ✓ **Information on dose** related displays, indices, and where dose information is located
  - ✓ **Onsite training**, classroom instruction, remote instructor-led training and observation, online tutorial self-help, telephone support, publications, seminars, peer to peer physician training, and industry association educational material.

Commitment 1: Characterization of CT Systems Standardized Benchmarking

LCD @ 3mm @ 0.3% @ 10mm ST



Sample Results: Low Contrast Head



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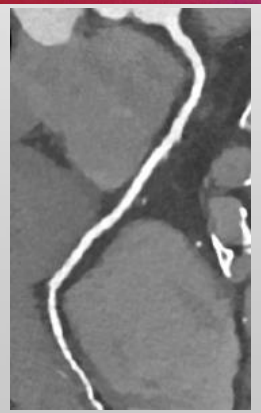

$$\cancel{D \propto \frac{1}{SD^2}}$$

* - Smallest pin visible (mm)

Results are averages from five scans, using factory default protocols

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ICRU report 54*

Image quality (IQ): the effectiveness by which an image can be used for its intended task

Golden standard of IQ: how well radiologists can perform a clinical task on a set of images.

* ICRU, ICRU report 54, *Medical imaging – the assessment of IQ*, ICRU, Bethesda, Maryland (1995)

Human observer studies

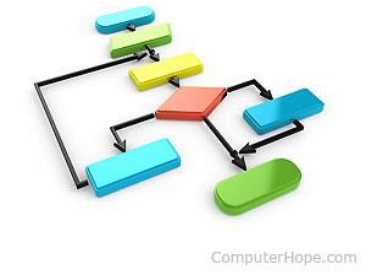
Human observer performance can be difficult to reproduce

- Intra-observer variability
- Inter-observer variability

Drawbacks:

- Complex
- Expensive
- Time consuming
- Possible bias

Model observer studies



The most popular model observers used in CT image quality assessment are:

Non Pre-Whitening matched filter with an Eye filter (NPWE)

Channelized Hotelling model observer (CHO)

- They have been successfully applied to simple detection and discrimination tasks in CT phantom images with uniform backgrounds.
- There exist different implementations in the literature.
- They are starting to be used to analyze the influence in the detectability of lesions in textured backgrounds mimicking the patients' anatomy (example: lung, liver…) and in real patient images.

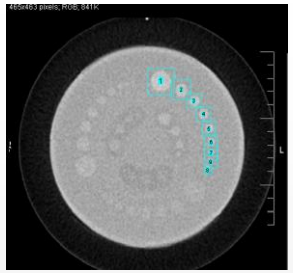
Model observer studies (NPWE)

Each model observer applies a "template" to the sets of images.

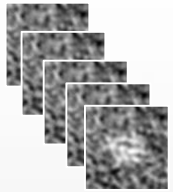
The template represents the strategy followed by the model to mimic human eyes.

Decision variables are calculated for each transformed set, e.g. 2 AFC

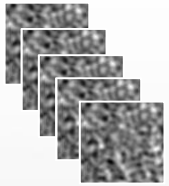
Detectability index (*d'*)

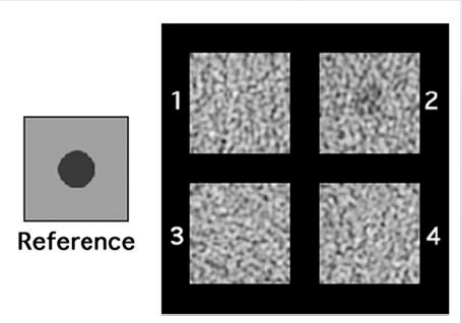


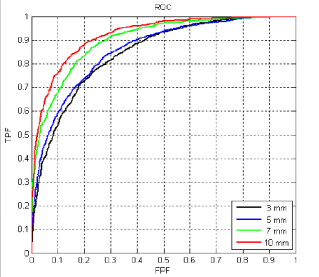
Signal present set



Signal absent set







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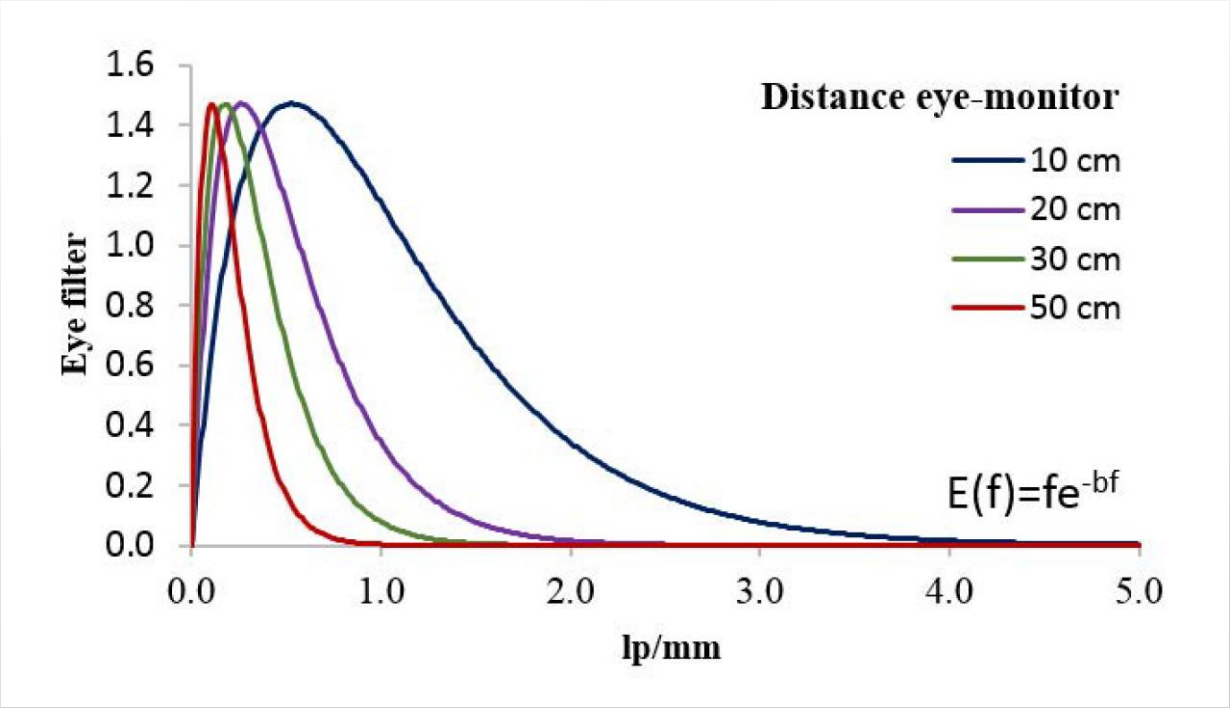
R. F. Wagner et al, "Application of information theory to the assessment of CT," Med. Phys. **6**, 83–94,1979.

Model observer studies (NPWE)

Eye filter (**E**): Represents the human contrast sensitivity function (CSF).

CSF: Measured contrast detectability threshold for a range of spatial frequencies.

Eye filter proposed by Burgess*



$$E(f) = f e^{-bf}$$

f = the spatial frequency
b = maximum at 4 cycles/degree

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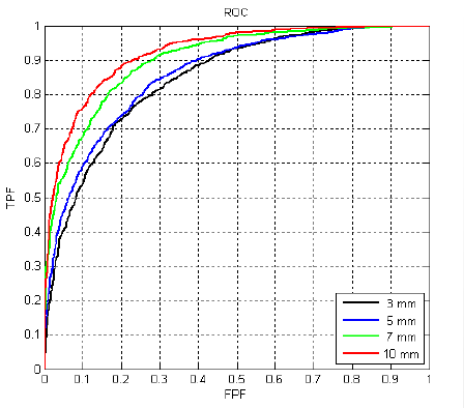
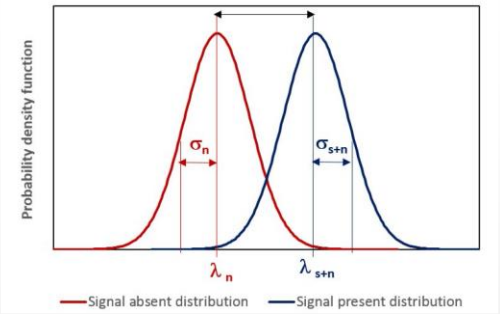
*Burgess E, et al, "*Human observer detection experiments with mammograms and power-law noise*," Med. Phys. 28, 419–437 (2001).

Model observer studies (NPWE)



$$d' = \frac{\langle T \rangle_1 - \langle T \rangle_2}{\sqrt{\frac{1}{2}\sigma_1^{\,2} + \frac{1}{2}\sigma_2^{\,2}}}$$

Detectability index



$$PC = 0.5 + 0.5\,erf\left(\frac{d'}{2}\right)$$

Proportion Correct

If PC ≥ 75% → The object is visible (Visibility threshold)
Other visibility thresholds appear in the literature

Canon

*Reiser I, Nishikawa RM, "*Identification of simulated micro calcifications in white noise and mammographic backgrounds*". Med Phys 2006;33:2905-2911

Model observer studies (NPWE)

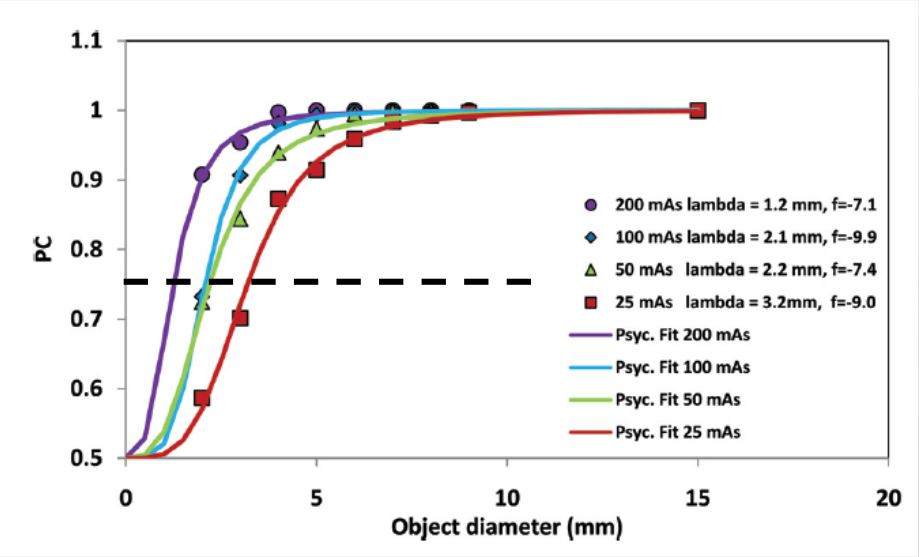
Automated assessment of low contrast sensitivity for CT systems using a model observer

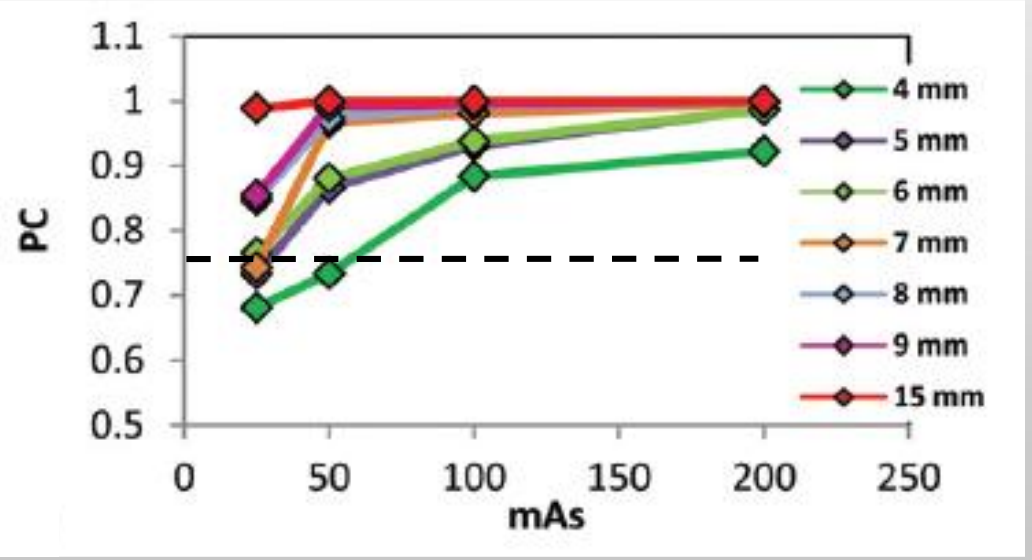
I. Hernandez-Giron[a)]
Física Mèdica, Facultat de Medicina i Ciències de la Salut, Universitat Rovira i Virgili, 43201 Reus, Spain and Departamento de Radiología, Universidad Complutense de Madrid, 28040 Madrid, Spain

J. Geleijns
Radiology Department, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands

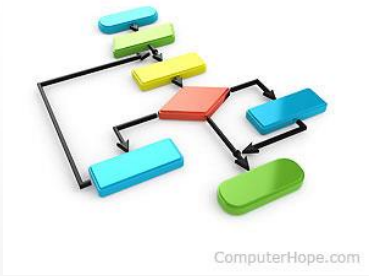
A. Calzado
Departamento de Radiología, Universidad Complutense de Madrid, 28040 Madrid, Spain

W. J. H. Veldkamp
Radiology Department, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands





Model observer studies



The most popular model observers used in CT image quality assessment are:

Non Pre-Whitening matched filter with an Eye filter (NPWE)

Channelized Hotelling model observer (CHO)

- They have been successfully applied to simple detection and discrimination tasks in CT phantom images with uniform backgrounds.
- There exist different implementations in the literature.
- They are starting to be used to analyze the influence in the detectability of lesions in textured backgrounds mimicking the patients' anatomy (e.g. lung, liver) and in real patient images.

Model observer studies (CHO)

Each model observer applies a "template" to the sets of images.

↓

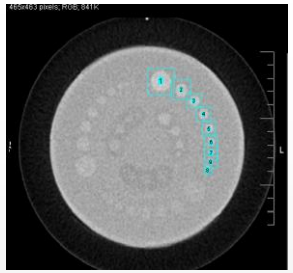
The template represents the strategy followed by the model to channelize images.

↓

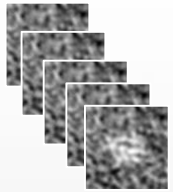
Decision variables are calculated for each transformed set, e.g. 2 AFC

↓

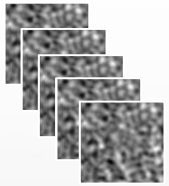
Detectability index (*d'*)



Signal present set

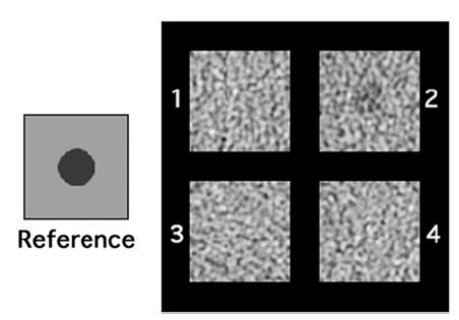


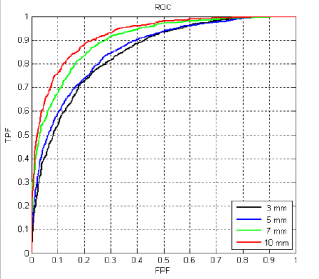
Signal absent set



Types of channels:

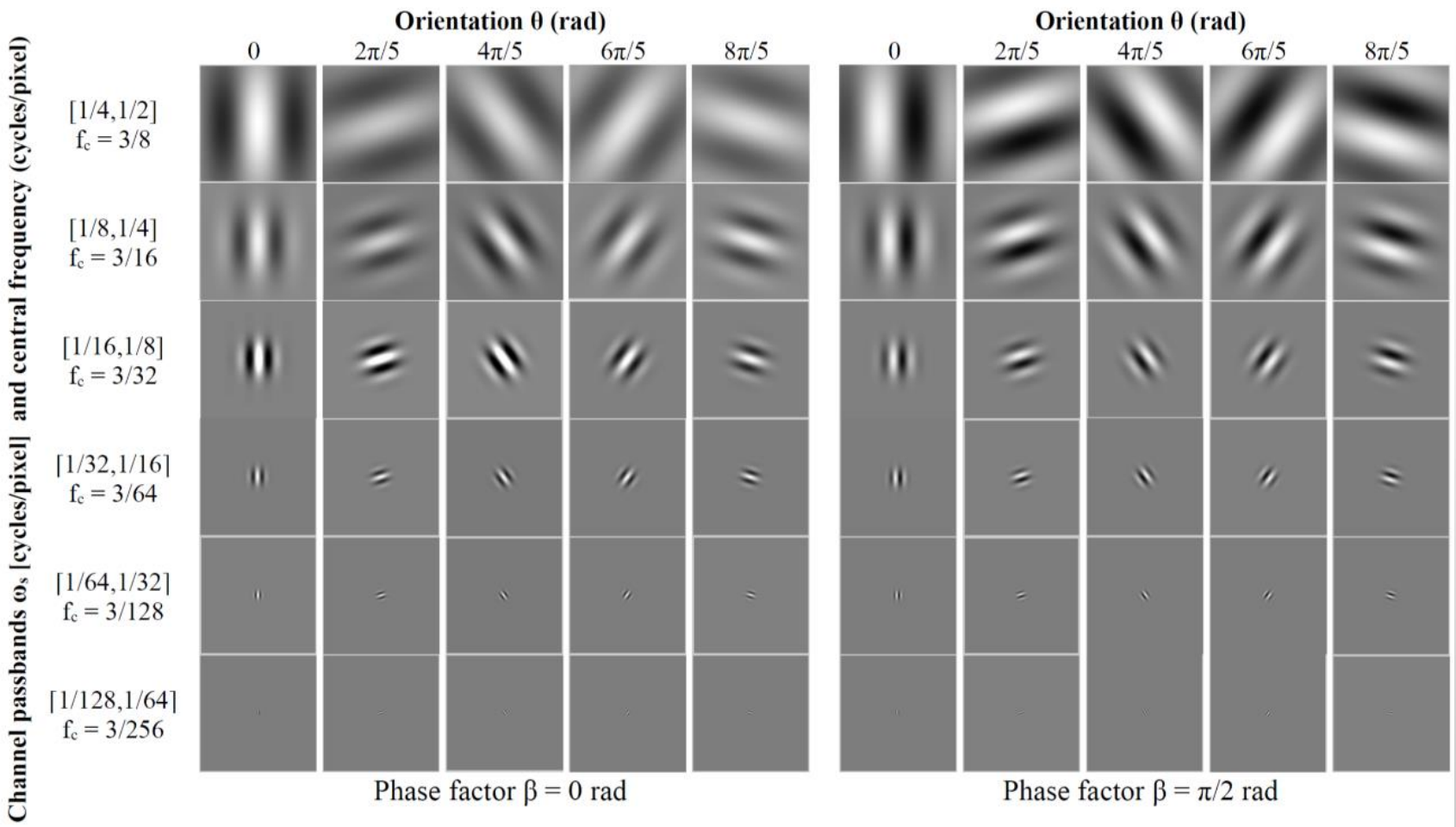
- Laguerre-Gauss
- Gabor
- Difference of Gaussians (DOG)





Canon Abbey et al.,"Modelling visual detection tasks in correlated image noise with linear model observers", Handbook of Medical Imaging, (2000)

CHO model: Gabor channels



Implementation of Gabor channels proposed by Wunderlich et al* and by Yu et al.**

This particular CHO with 60 Gabor channels has been successfully applied in detection and discrimination tasks in CT phantom images for a range of dose levels.

*Wunderlich A, Noo F, *Image covariance and lesion detectability in direct fan-beam X-ray computed tomography*, Phys Med Biol 2008;53:2471-93.

**Yu L et al, *Prediction of human observer performance in a 2-alternative forced choice low-contrast detection task using channelized Hotelling observer: impact of radiation dose and reconstruction algorithms*, Med Phys 2013.

Brief comparison NPWE and CHO

Each model observer applies a "template" to the sets of images.

The template represents the strategy followed by the model to mimic human eyes.

Decision variables are calculated for each transformed set, e.g. 2 AFC

Detectability index

NPWE	CHO
Model : Eye filter	Channels (Gabor, LG, DOG)
Domain : Frequency	Spatial
Computational: Less	More

Each model observer applies a "template" to the sets of images.

The template represents the strategy followed by the model to channelize images.

Decision variables are calculated for each transformed set, e.g. 2 AFC

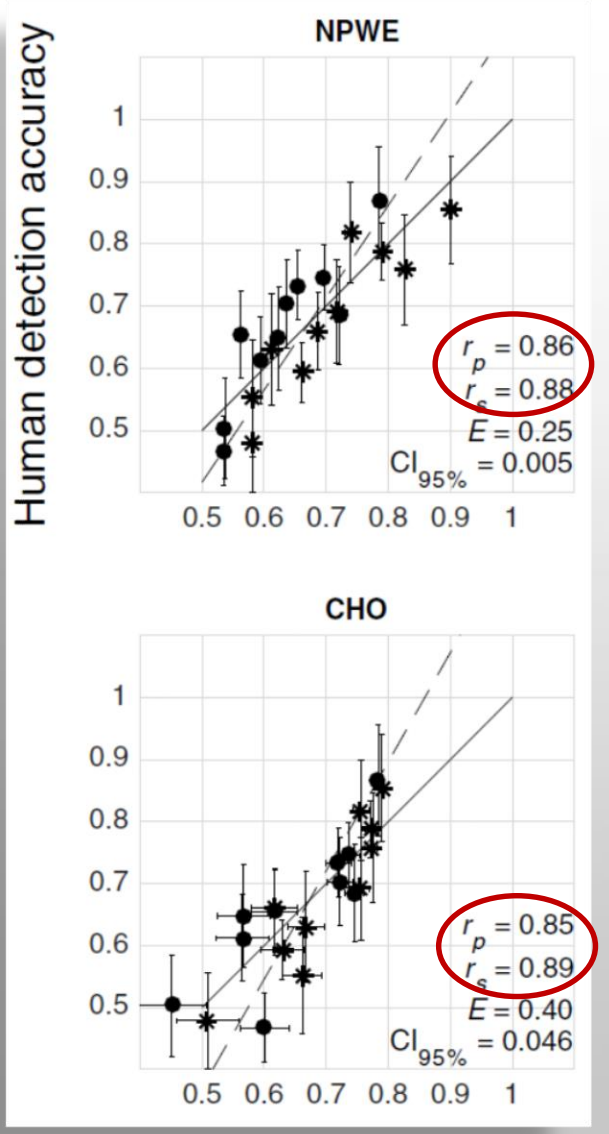
Detectability index

Brief comparison NPWE and CHO

Journal of Medical Imaging 3(3), 035506 (Jul–Sep 2016)

Correlation between human detection accuracy and observer model-based image quality metrics in computed tomography

Justin Solomon[a,*] **and Ehsan Samei**[a,b,c]
[a]Duke University Health System, Department of Radiology, Carl E. Ravin Advanced Imaging Laboratories, 2424 Erwin Road, Suite 302, Durham, North Carolina 27705, United States
[b]Duke University Medical Center, Department of Radiology, Clinical Imaging Physics Group, 2424 Erwin Road, Suite 302, Durham, North Carolina 27705, United States
[c]Duke University, Pratt School of Engineering, Departments of Biomedical Engineering and Electrical and Computer Engineering, 2424 Erwin Road, Suite 302, Durham, North Carolina 27705, United States



Canon

Solomon J, Samei E, *Correlation between human detection accuracy and observer model-based image quality metrics in computed tomography*," J. Med. Imag. 3(3), (2016)

Brief comparison NPWE and CHO

Each model observer applies a “template” to the sets of images.

The template represents the strategy followed by the model to mimic human eyes.

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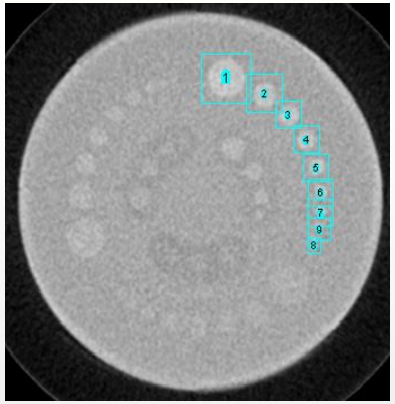
Detectability index



NPWE	CHO
Model : Eye filter	Channels (Gabor, LG, DOG)
Domain : Frequency	Spatial
Computational: Less	More

Each model observer applies a “template” to the sets of images.

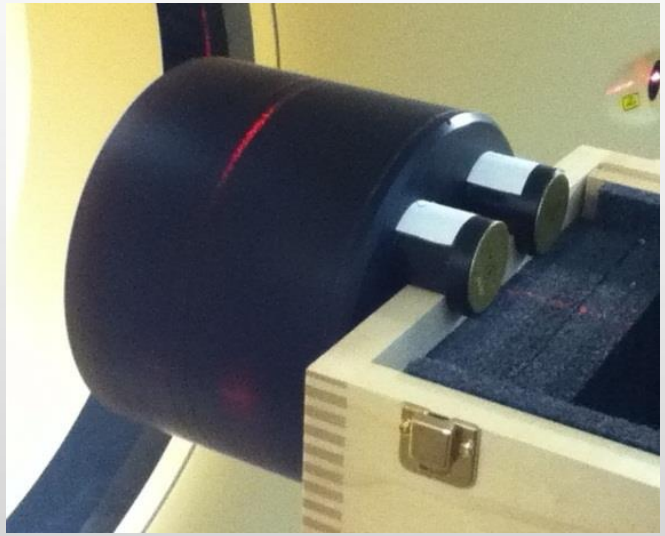
The template represents the strategy followed by the model to channelize images.

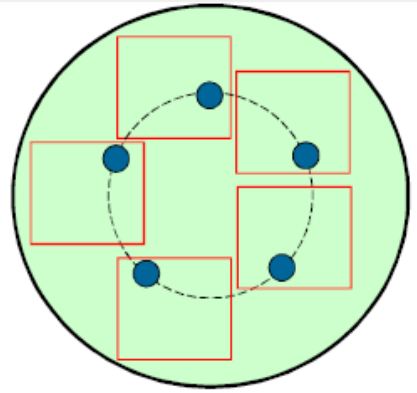
Decision variables are calculated for each transformed set, e.g. 2 AFC

Detectability index

Status Update: Commitment 1
Test Conditions, Dose & Image Quality

Catphan is not suitable for the analytical model. Therefore, new phantom design in order to quantify IQ/Dose efficiency.



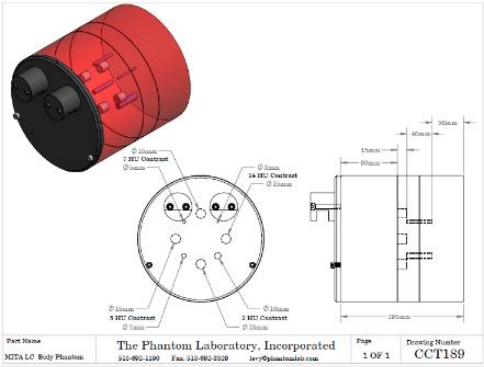


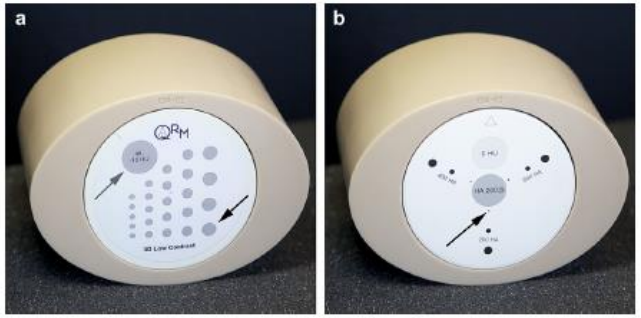
Objects with same radial location with randomly placed ROIs

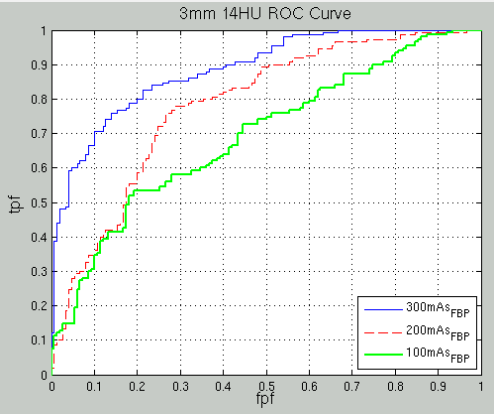
New Phantom Design

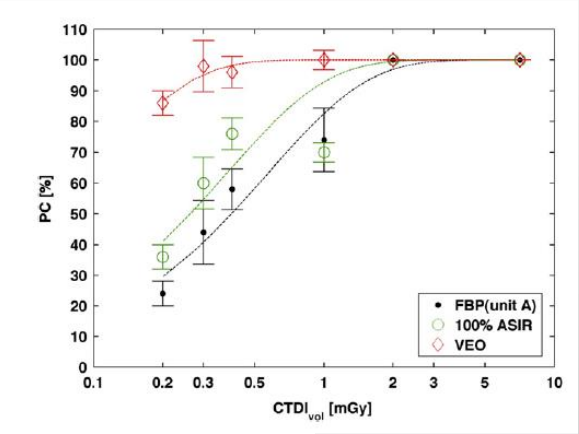
1. Two phantoms, each 20cm in outer diameter.
2. Each has one section of low contrast rods, 4*cm* in z axis w/ varied contrast & diameter.
3. One uniform section 4*cm* in *z*, and two buffer regions at the end of the phantom to avoid end effects.
4. Reference objects added for quality control, 1.5*cm* in length
5. Agreed to use elliptical body ring for body studies. No ring for head phantom.

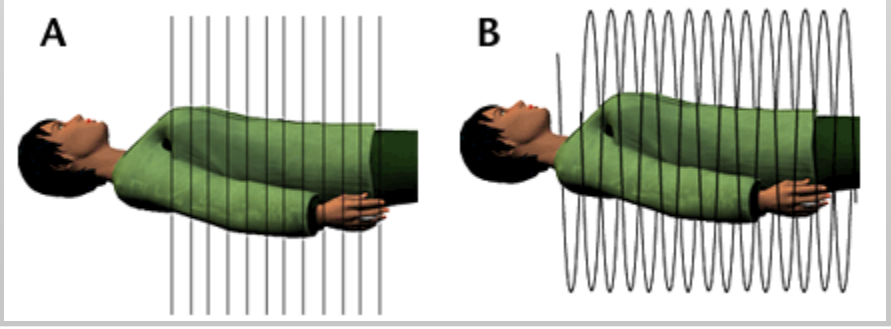
Brief comparison Industry and Academic community











Summary

HERCA Heads of the European Radiological protection Competent Authorities

COCIR

Industry initiative on CT dose optimization in cooperation with HERCA

Commitment 1: *Characterization of CT Systems Standardized Benchmarking*

Commitment 2: *Implementation of Dose Reduction Measures in CT*

Commitment 3: *Dose Management & Reporting*

Commitment 4: *Provision of Specific Training Curricula*

With thanks to:

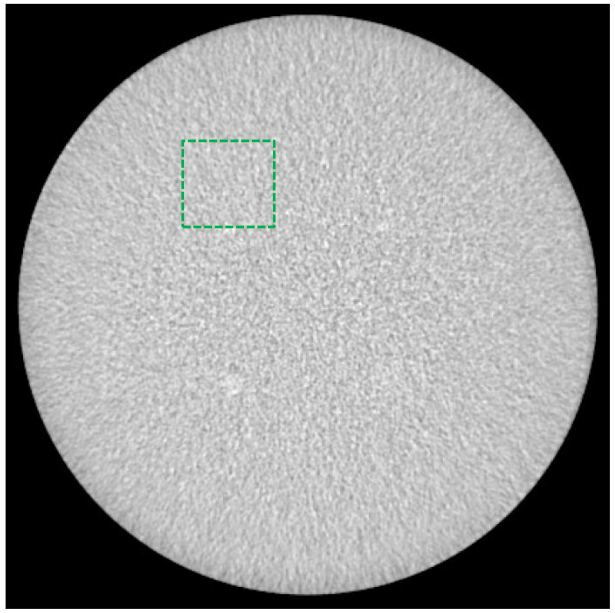
LEIDEN UNIVERSITY MEDICAL CENTER

Irene Hernández Girón, PhD
Radiology Department. Leiden University Medical Center (LUMC), The Netherlands

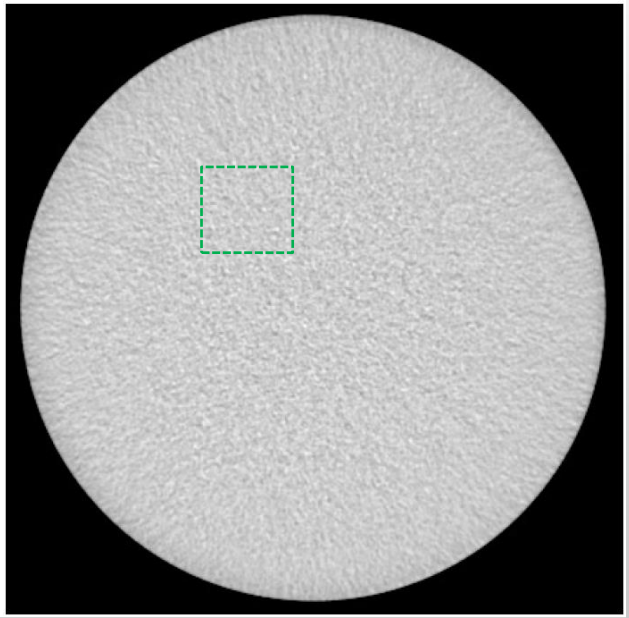
Thank you for your attention!

Receiver Operating Characteristic (ROC)

signal module

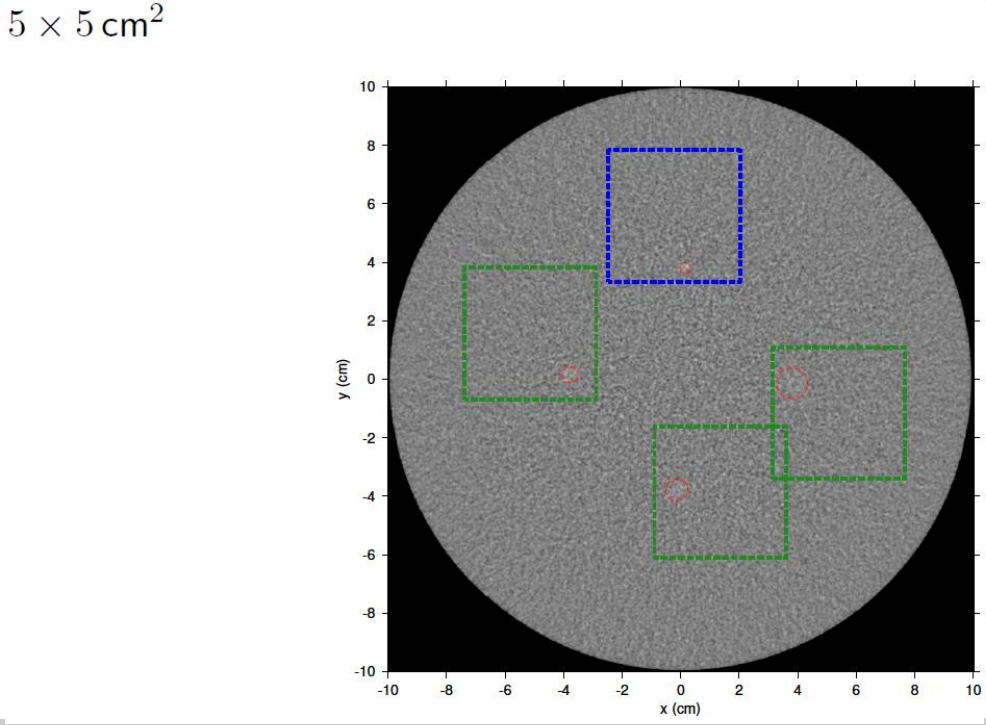


blank module



Ref: MITA-FDA Webinar, June 2014

Localization ROC



Ref: MITA-FDA Webinar, June 2014

FROC

Nonparametric signal detectability evaluation using an exponential transformation of the FROC curve

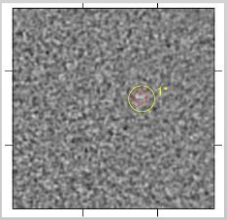
Lucretiu M. Popescu[a)]
Food and Drug Administration Center for Devices and Radiological Health 10903 New Hampshire Avenue, Silver Spring, Maryland 20993

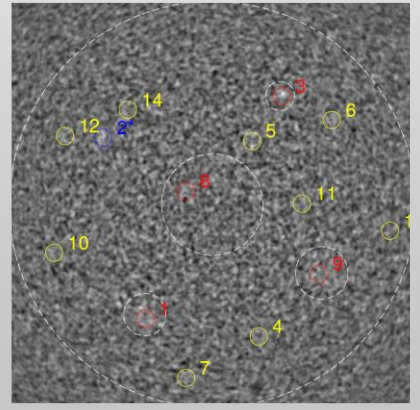
(Received 17 May 2011; revised 15 August 2011; accepted for publication 15 August 2011; published 26 September 2011)

Purpose: To develop an efficient nonparametric method for evaluation the detectability of signals at unknown locations in images, as a mean for image quality assessment.
Methods: We use the free-response methodology that allows the image observer to mark and score all locations found as suspicious in an image, summarizing these results in a free-response operating characteristic (FROC) curve. However, unlike the relative (or receiver) operating characteristic (ROC), or the localization ROC (LROC), the FROC curve has an undefined, theoretically infinite, right side limit. Therefore area under the FROC curves cannot be directly used as an overall performance index, as the area under the curve is for ROC or LROC. We circumvent this drawback by using a transformation of the abscissa that leads to a finite integration range. By applying an exponential transformation we derive a nonparametric estimator for such a metric, and we study its properties by deriving analytical expressions for the mean and standard deviation in conditions of scores independence.
Results: A comparative study with other related nonparametric estimators for ROC, LROC, and alternative FROC (AFROC) method is presented.
Conclusions: The new nonparametric estimator has sensitivity and scalability properties that make it particularly advantageous for signal detectability evaluation in phantom experiments using model observers. © *2011 American Association of Physicists in Medicine*. [DOI: 10.1118/1.3633938]

Summary and conclusions

- The MITA phantom can be used for image quality evaluation using unknown-location signal detection
  - Use randomly placed ROIs for human reader experiments with LROC or simple signal localization setups
  - Free-response reading can be used with automatic signal searching and EFROC data analysis
- EFROC method is the most efficient (and can operate well without a blank-module)
- Our emulation of LROC and signal localization studies using ROIs indicate that they are less efficient but still feasible





Ref: MITA-FDA Webinar, June 2014

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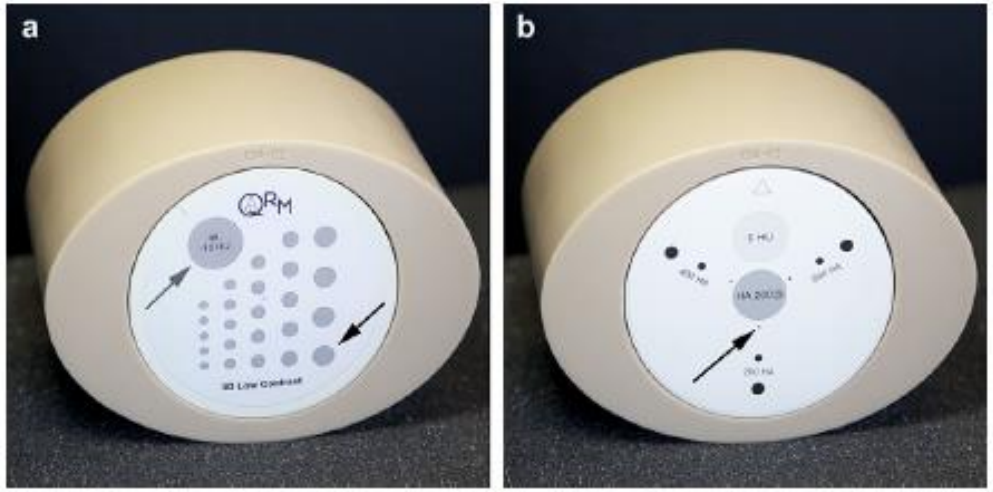
ORIGINAL PAPER

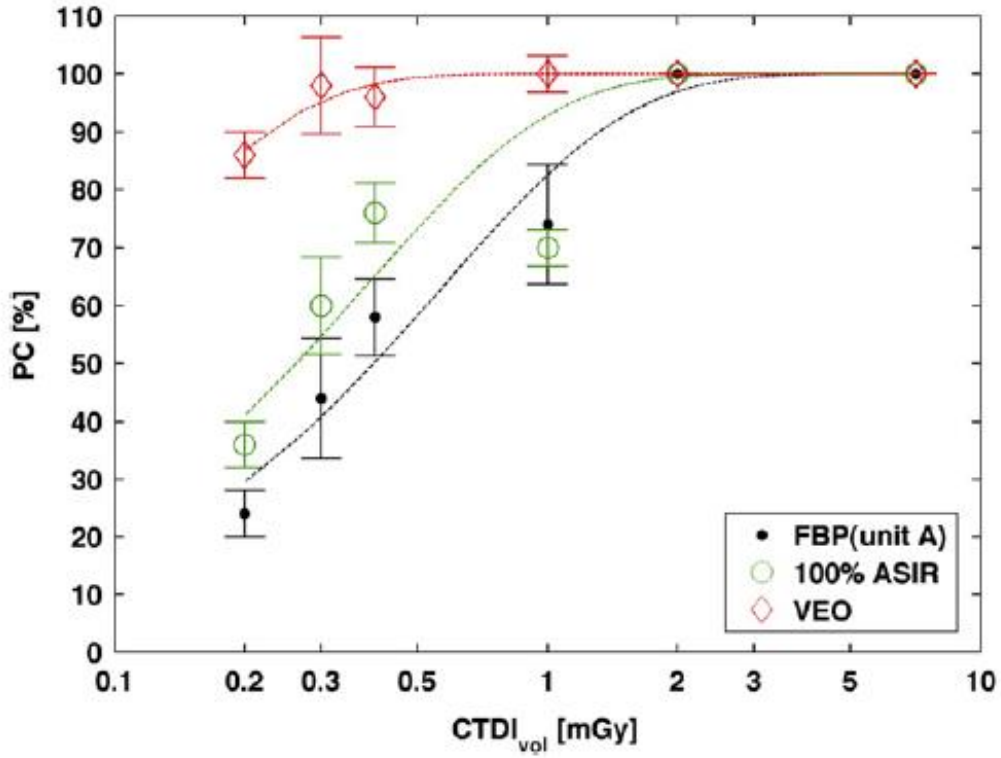
Iterative reconstruction methods in two different MDCT scanners: Physical metrics and 4-alternative forced-choice detectability experiments – A phantom approach

Frédéric A. Miéville [a,*], Françoi
François O. Bochud [a], Francis R

[a] Institute of Radiation Physics, University Hospita
1007 Lausanne, Switzerland
[b] Department of Radiology, University Hospital Ce
1011 Lausanne, Switzerland
[c] Department of Radiology, Necker Children's Hosp
75743 Paris, France

Received 25 August 2011; received in revised form
Available online 2 January 2012





Update on the non-prewhitening model observer in computed tomography for the assessment of the adaptive statistical and model-based iterative reconstruction algorithms

Julien G Ott[1], Fabio Becce[2], Pascal Monnin[1], Sabine Schmidt[2], François O Bochud[1] and Francis R Verdun[1]

[1] Institute of Radiation Physics, Lausanne University Hospital, Rue du Grand-Pré, 1-1007 Lausanne, Switzerland
[2] Department of Diagnostic and Interventional Radiology, Lausanne University Hospital, Rue du Bugnon, 46-1011 Lausanne, Switzerland

Canon