CT Users Group Meeting

15th December 2015, Public Health England

Mathematical observers for image quality optimisation:

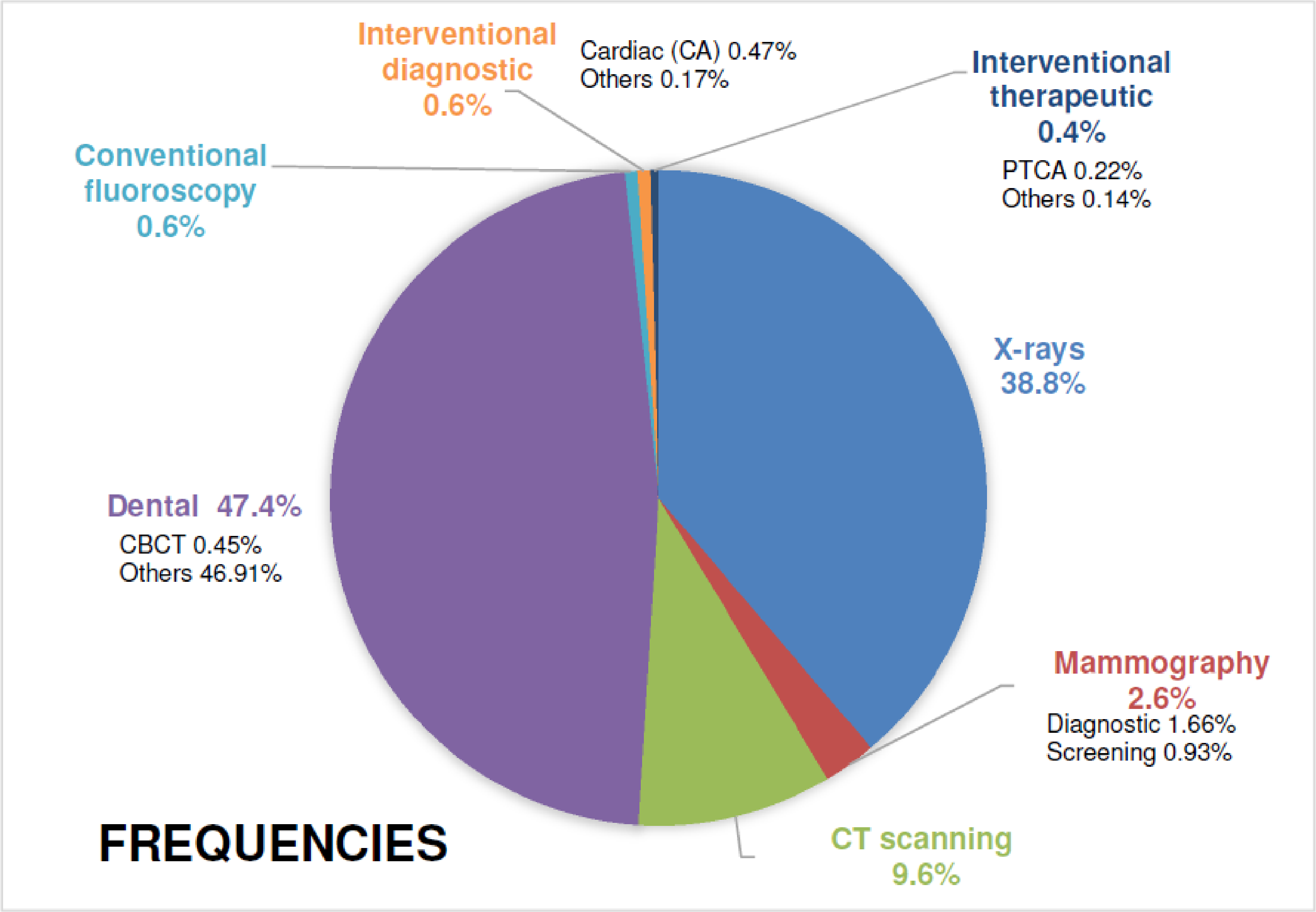
Results of a benchmark protocol with a Channelized Hotelling Observer

N. Ryckx, D. Racine, A. Ba, J. Ott,
F. Bochud, F. R. Verdun

Introduction

- Computed tomography
  - Valuable diagnostic information
    - Morphologic features
    - Functional/dynamic processes
    - Interventional
    - Standalone or hybrid (nuclear medicine)
  - Increased use → Increased exposure
    - Individual patients
    - Population

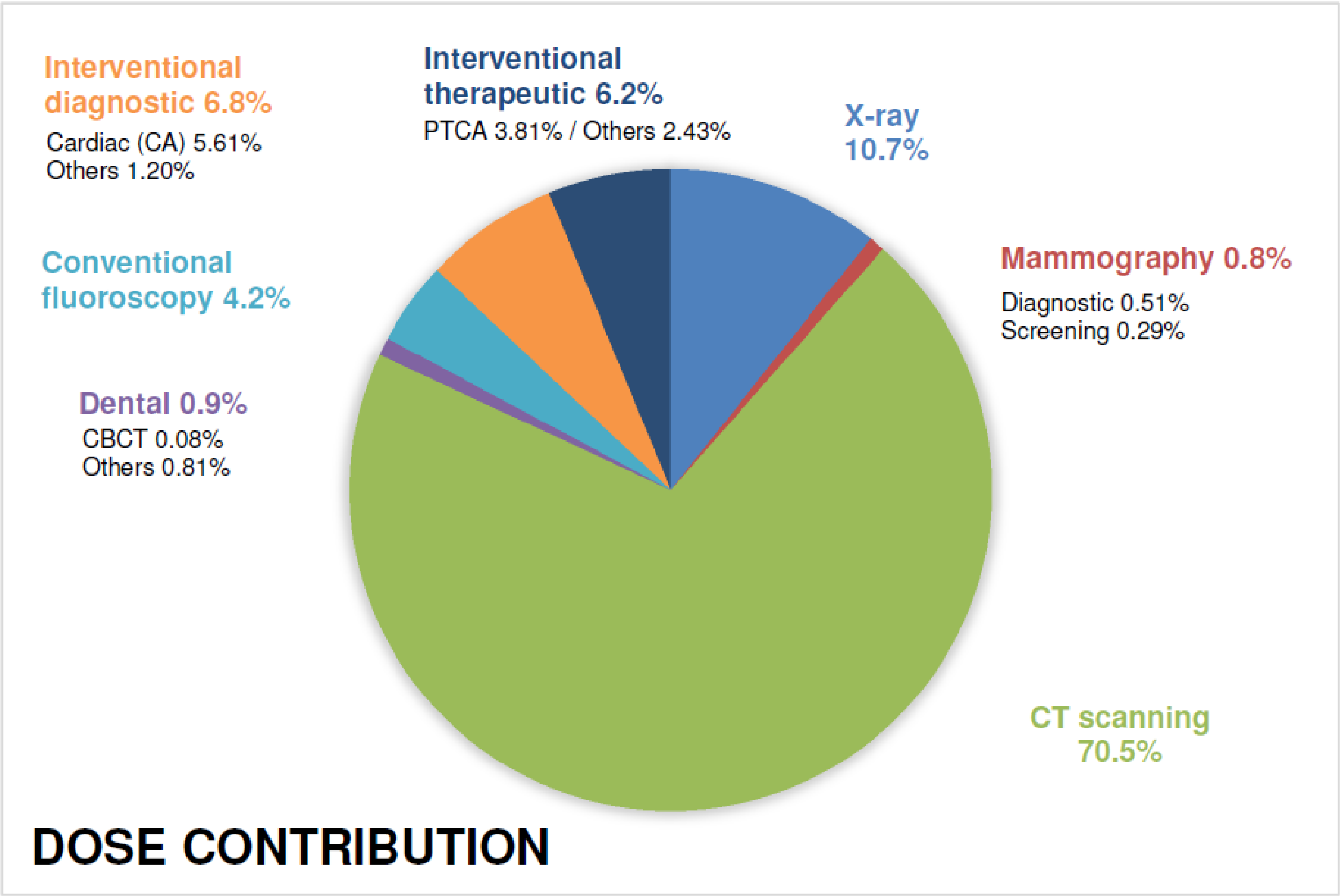
Introduction



Exposure of the Swiss population by radiodiagnostics: 2013 review
R. Le Coultre et al., Radiat Prot Dosim (2015), doi: 10.1093/rpd/ncv462

Introduction

Figure 5: Contribution of each radiological modality to collective dose



Exposure of the Swiss population by radiodiagnostics: 2013 review
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From medical physics 1.0 …

Phantom measurements
-CNR
-MTF
-NPS

Proposal from E. Samei, RSNA 2015

… to medical physics 2.0

Phantom measurements
-CNR
-MTF
-NPS

Clinical use of the device
-Patient dose
-Protocol per demand

Image quality
-Task-based
-Clinically relevant

Proposal from E. Samei, RSNA 2015

Why model observers?

- Dose is easily quantifiable ($CTDI_{vol}$)
- Image quality: Compromise
  - Image dose
  - Physical parameters
- Information in the image
  - Physical metrics (NPS, MTF, CNR, SNR)
  - Observer (VGA, ROC studies)
- Iterative reconstruction
  - Dose reduction w/o affecting image quality

➡ Does this work?

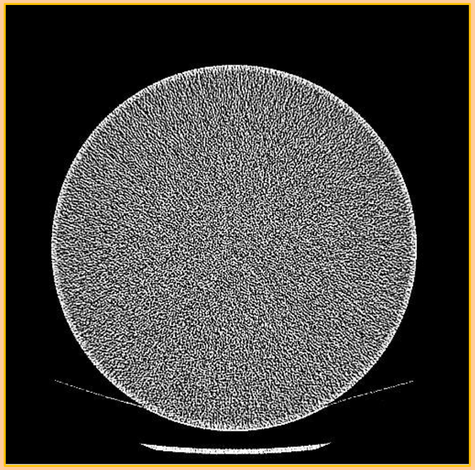
Image quality evaluation with FBP

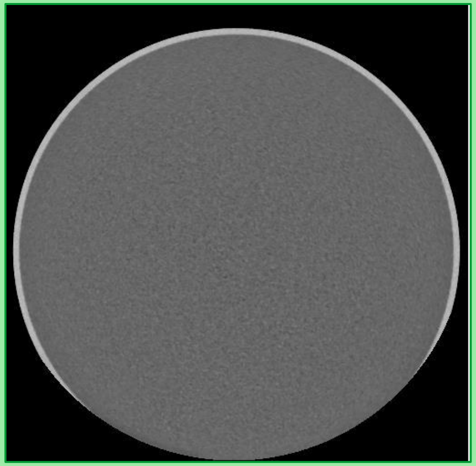
- FBP: Linear algorithm
  ➔ "All" conditions required for classical metrics

- Typical QA phantom: Catphan® 600

Image quality evaluation with FBP

- Noise





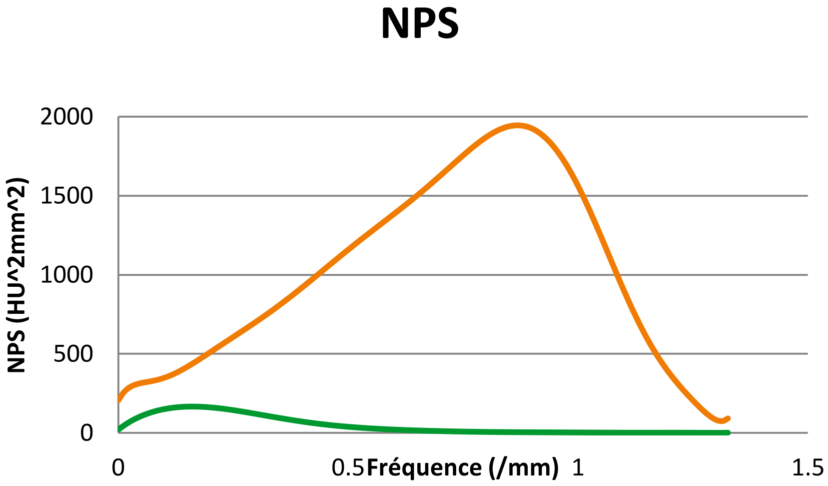
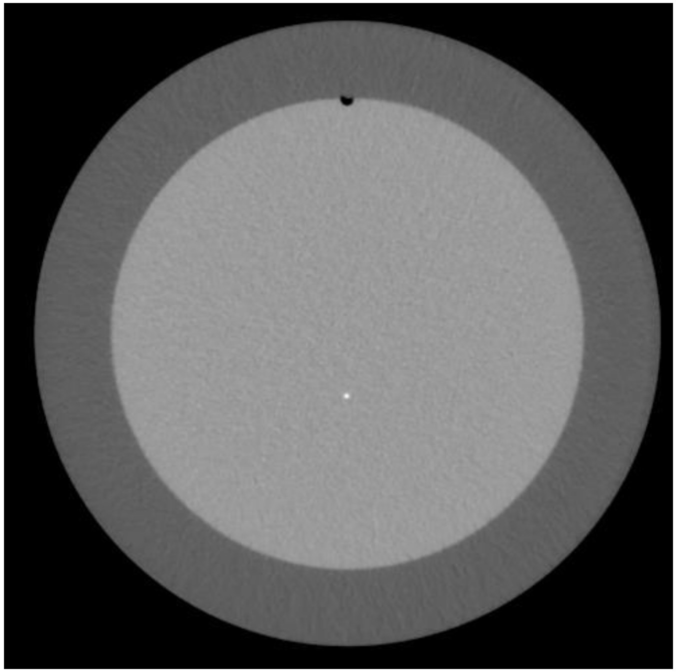


Image quality evaluation with FBP

- Spatial resolution (MTF)



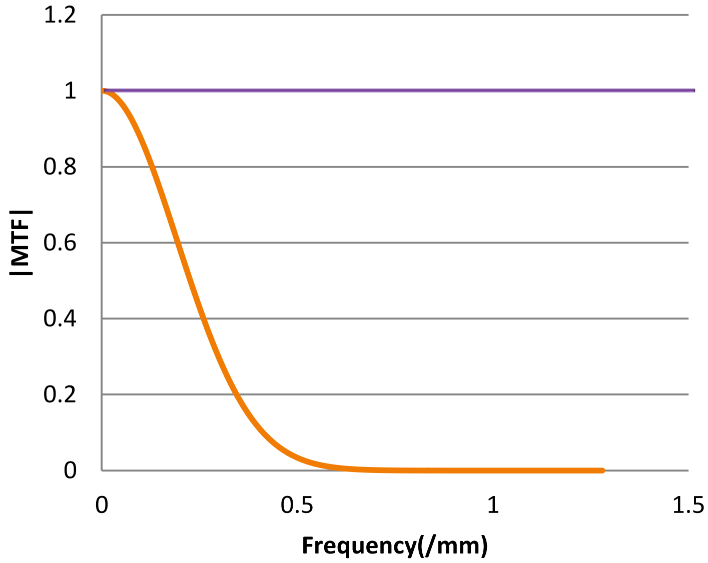
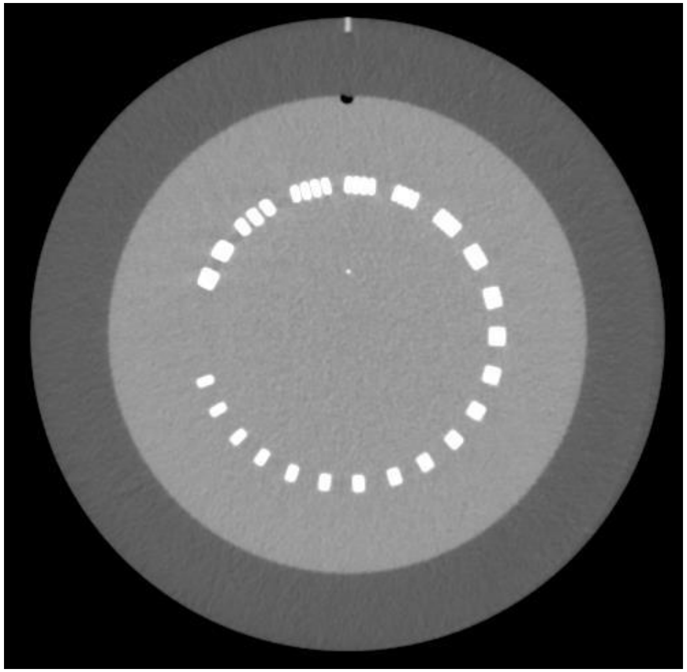


Image quality evaluation with FBP

- High/low contrast detectability



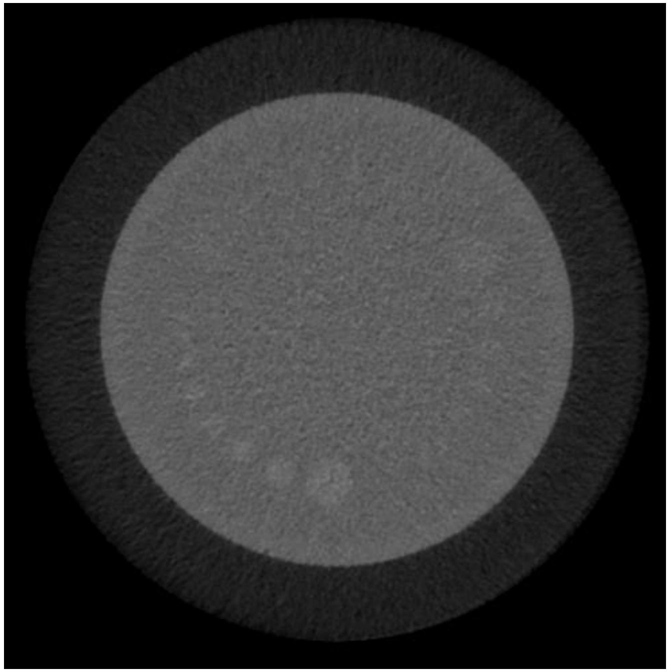
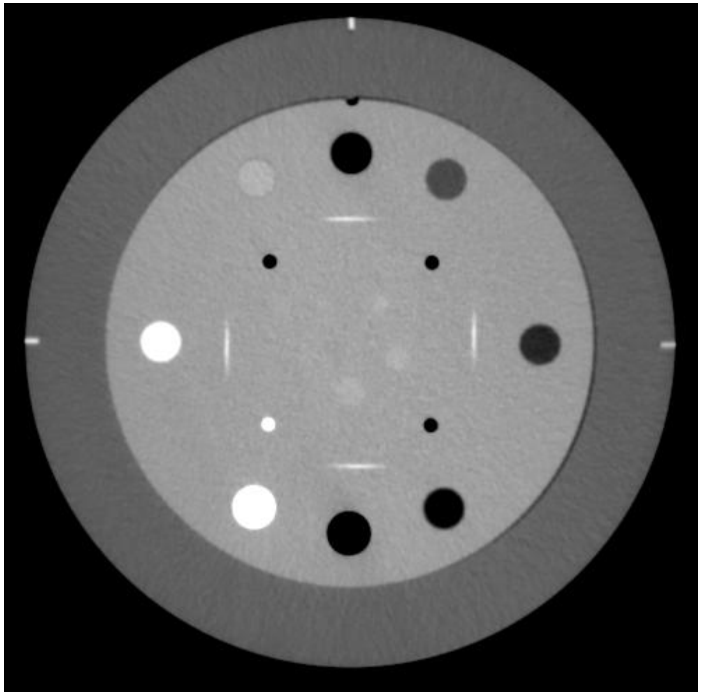


Image quality evaluation with FBP

- Contrast-to-noise ration (CNR)



Iterative reconstruction

- All previous physical metrics
  - Excellent for machine QA (stability)
  - Not relevant anymore for IR

- Why?
  - Non linear algorithms
  - Definitely no noise stationarity

- How to assess image quality then?

Model observer

- Mathematical model yielding a figure of merit
- Objective characterization
  - Detectability of low contrast structures
- Figure of merit: Percentage of correct responses for low contrast detection
  - Or d' or AUC

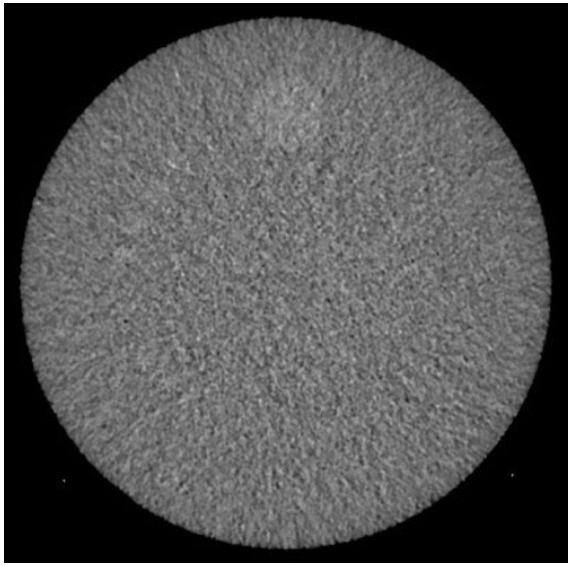
➔Objective response

➔Clinically relevant (<u>task-based</u>)

Model observer

- *An Improved Index of Image Quality for Task-based Performance of CT Iterative Reconstruction across Three Commercial Implementations,* O. Christianson, J. J. S. Chen, Z. Yang, G. Saiprasad, A. Dima, J. J. Filliben, A. Peskin, C. Trimble, E. L. Siegel, E. Samei, Radiology (2015)
- NPWE model observer + ACR phantom

$$d'^2 = \frac{[\iint W(r)^2 \cdot TTF(r)^2 \cdot V(r)^2 \, r dr]^2}{\iint W(r)^2 \cdot TTF(r)^2 \cdot V^4 \cdot NPS(r) \, r dr + \iint n_i \cdot W(r)^2 \cdot TTF(r)^2 \cdot NPS(r) \, r dr}, \quad (2)$$

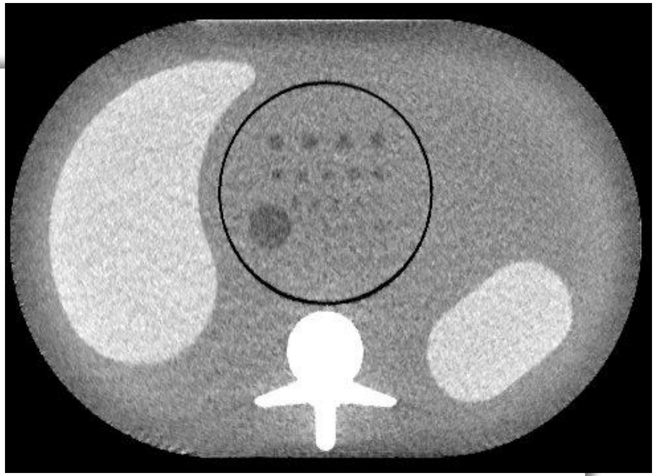


Model observer

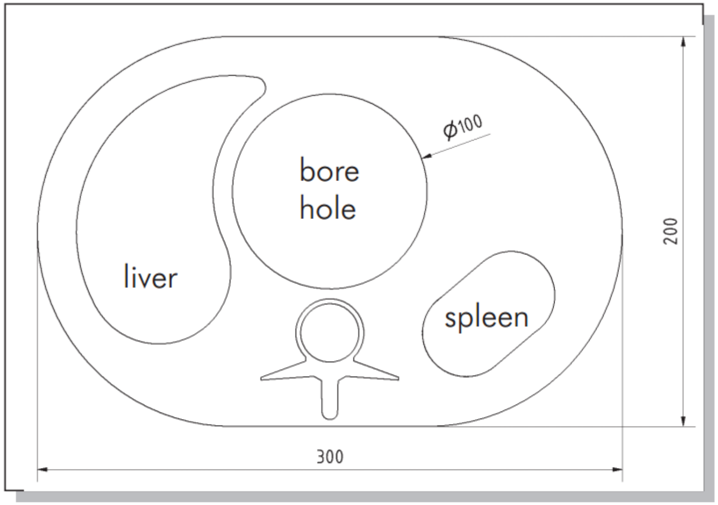
NPWE model
-Fourier space
-Quite robust
    -Easy to point critical parameter
-Not very flexible
    -Not many input parameters

CHO model
-Image space
    -Easier to apprehend
-Adaptable to human behaviour

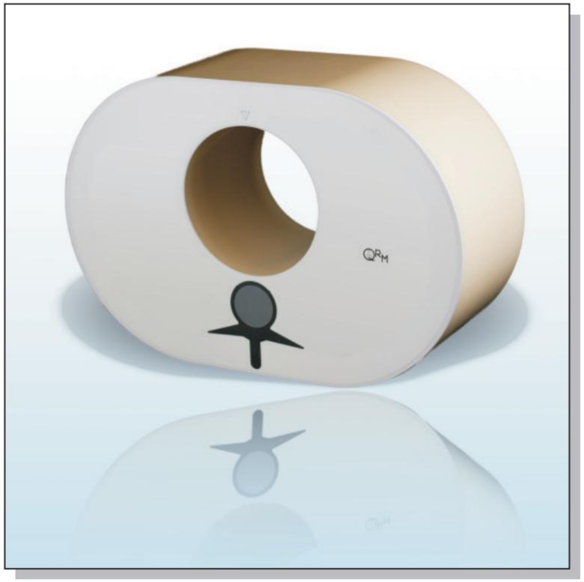
Model observer



- Anthropomorphic phantom
  - Low-contrast spheres
  - Acquisition/reconstruction in known conditions



Sketch of the complete anthropomorphic QRM-Abdomen (height 100 mm).



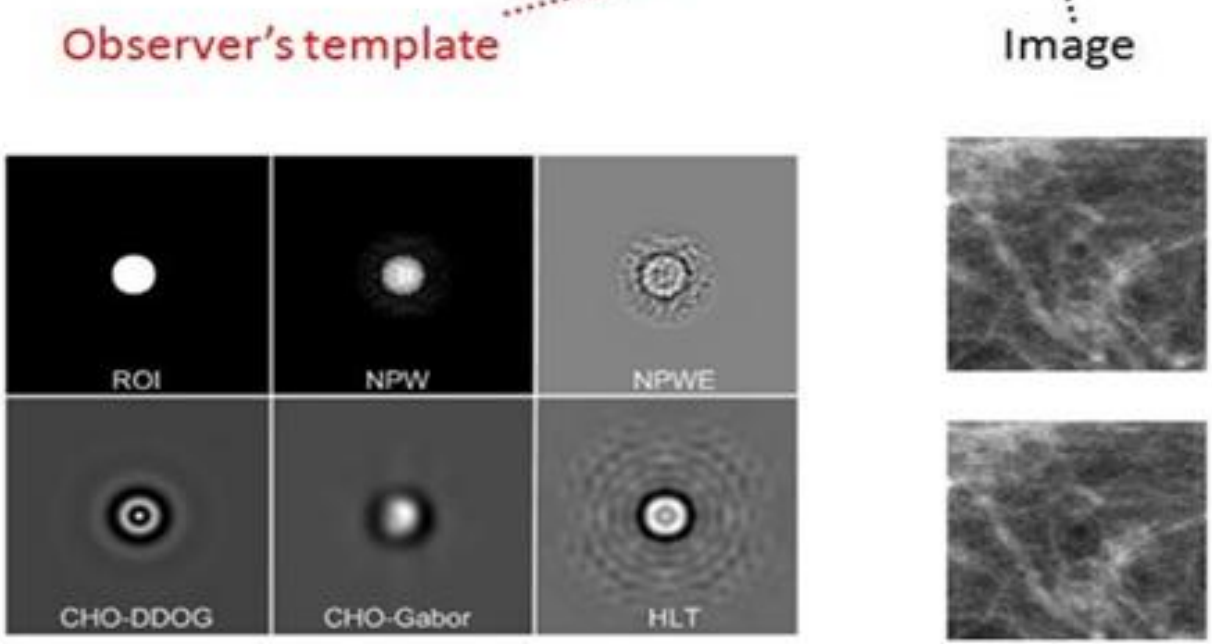
QRM-Abdomen

Source: http://www.qrm.de/content/pdf/QRM-Abdomen.pdf

Model observer

- Calculation of a decision variable λ

$$\lambda = \mathbf{w}^T \mathbf{g} + \varepsilon$$

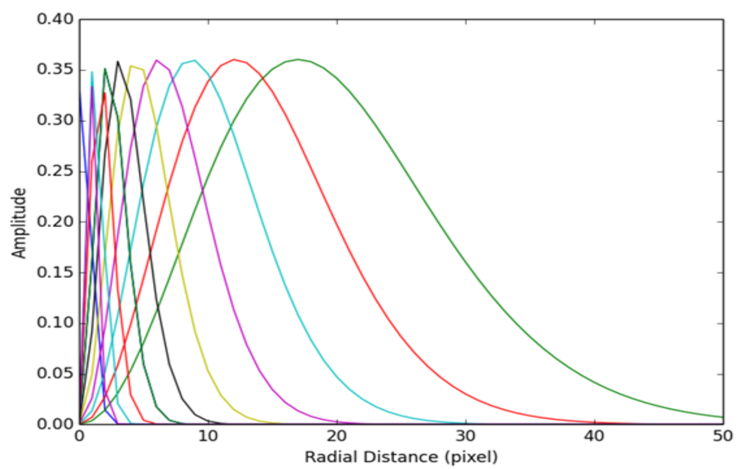


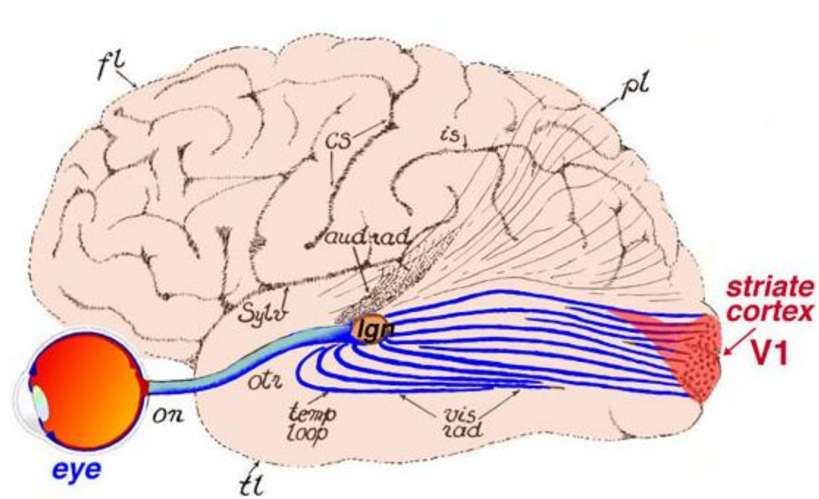
Model observer: Template

- Template derived from inverse of background covariance matrix
- To reduce the matrix dimensionality
  - Use of channels (DDoG: Dense Difference of Gaussians)

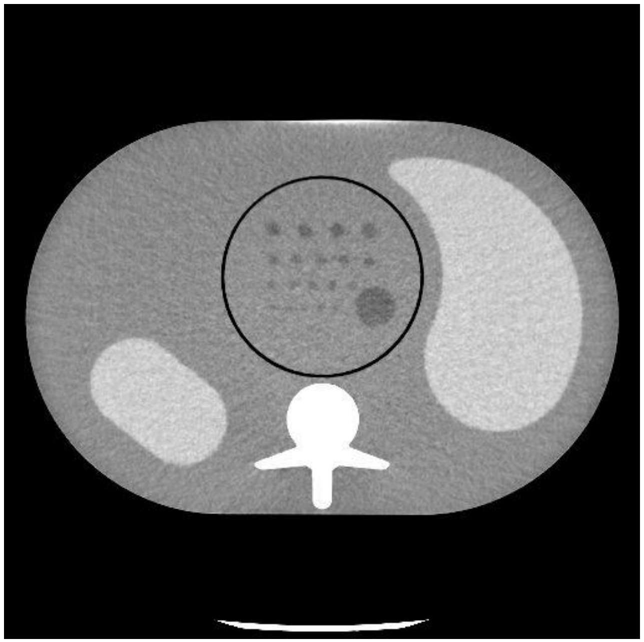
$$w_{CHO} = K_{n,c}^{-1} \times s_c$$

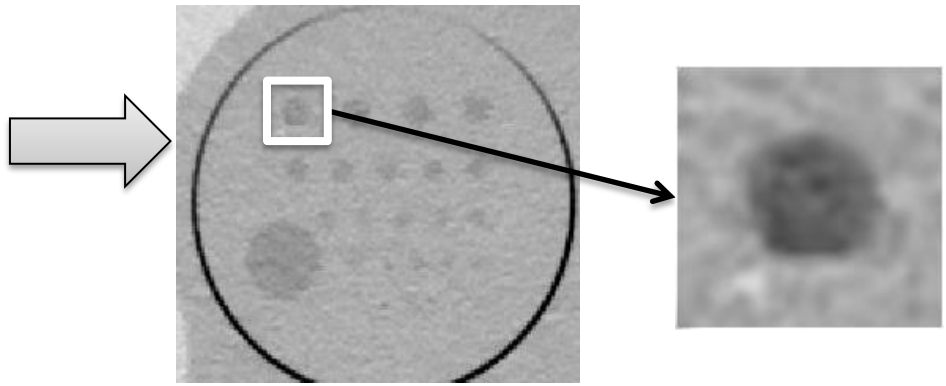
- Channels: Mimic the signal analysis by the visual cortex (V1)





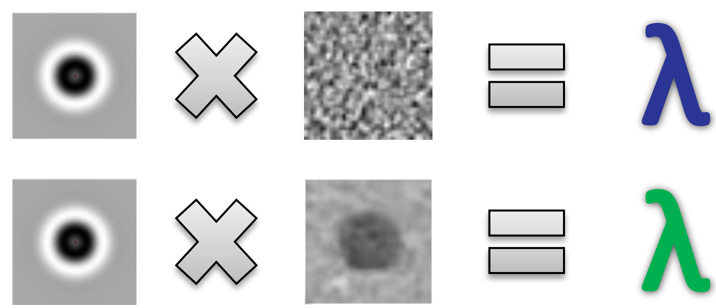
Model observer: Calculus

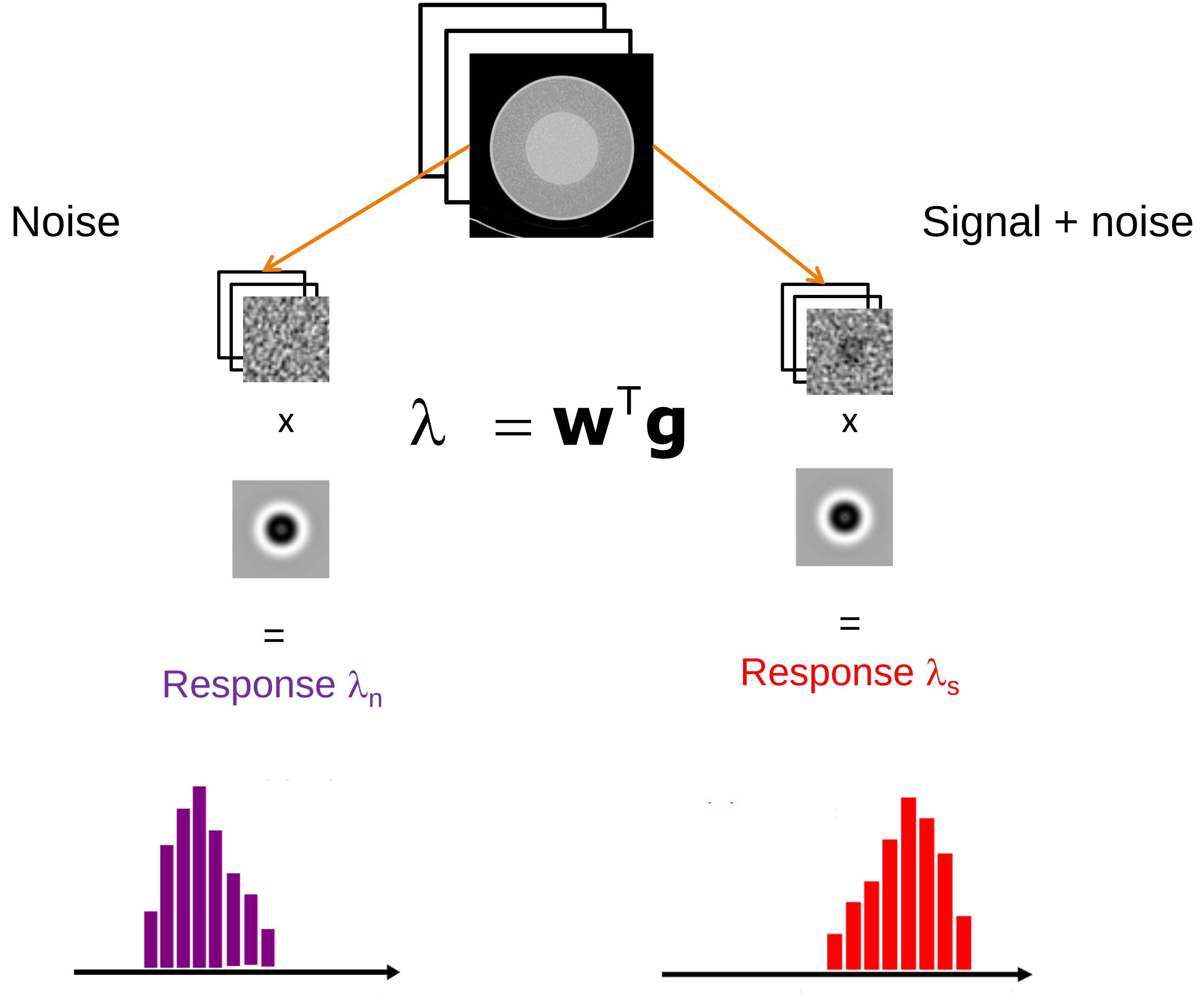




g_i

$$w_{CHO}^{T} \times g_i = \lambda$$



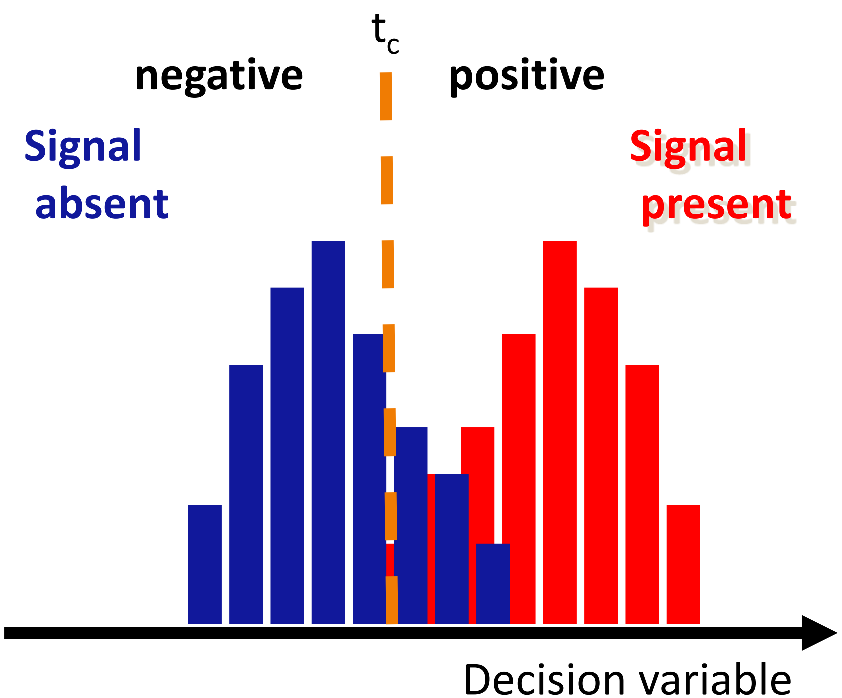

Noise
Signal + noise
x
x
$\lambda = \mathbf{w}^T\mathbf{g}$
=
=
Response λ_n
Response λ_s

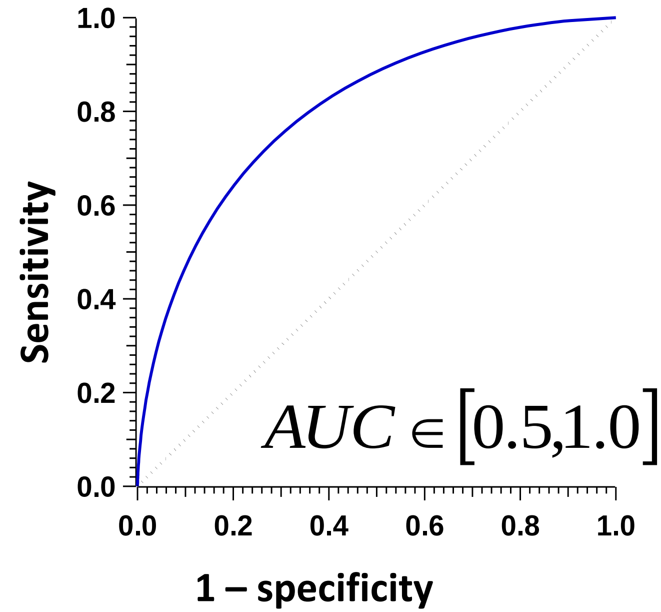
Model observer: Calculus

- ROC (receiver operating characteristic)
  - 100 points

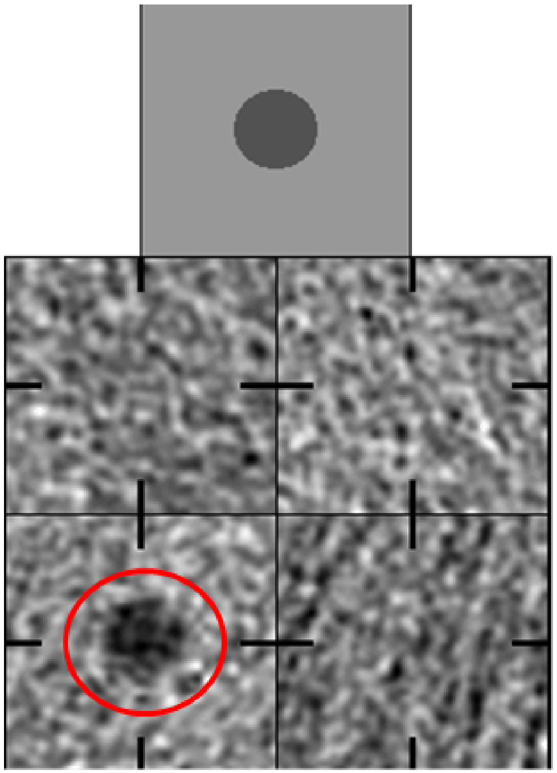
d' = detectability index

$$d' = \frac{\langle \lambda_s \rangle - \langle \lambda_n \rangle}{\sigma_\lambda}$$

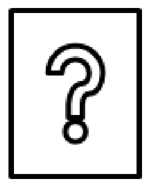




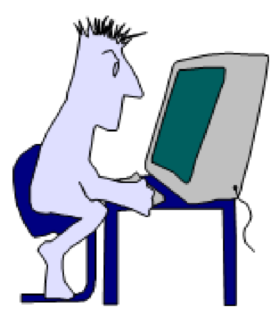
Verification: 4-AFC humans



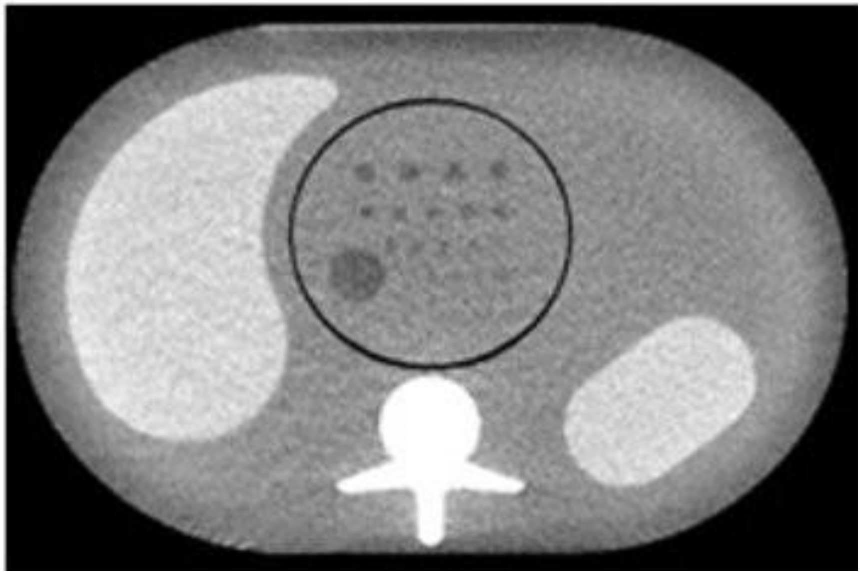
$\lambda_{4\text{-AFC}}$: Distribution of response variables shows if the results match human perception.



Percent correct : PC



Results



- CT units (2014)
  - 54 were visited (20% of all CT units in the country)
  - All manufacturers were represented
  - Large heterogeneity

canton de vaud

CHUV

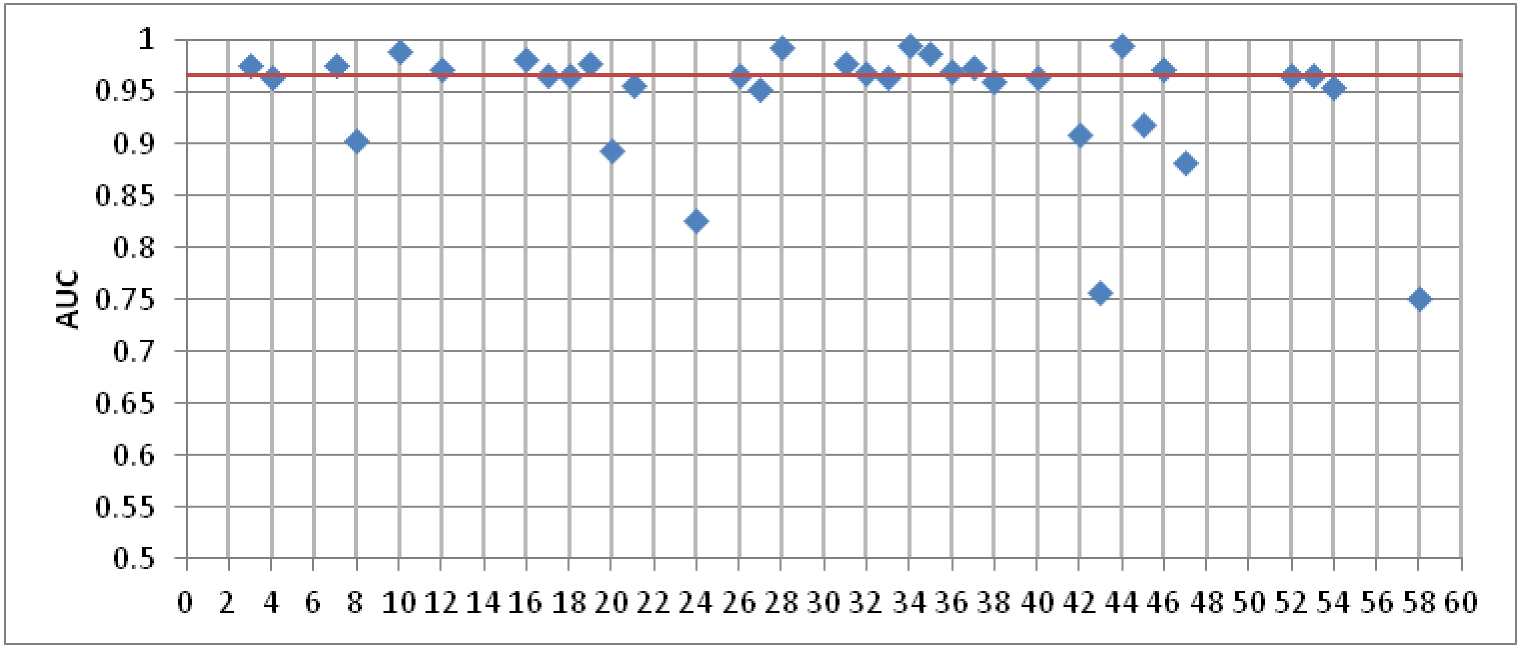
Results: Acquisition protocols

- Benchmark protocol
  - Tube voltage: 120kVp
  - $CTDI_{vol}$: 15mGy (2015: add 5mGy and 10mGy)
  - Pitch: 1 (or as close as possible)
  - Slice thickness: 2.5mm or 2mm
  - Reconstruction algorithm : Filtered Back Projection

- Local protocol
  - Local parameters
  - Reconstruction algorithm: FBP or IR (depending on model)

Results

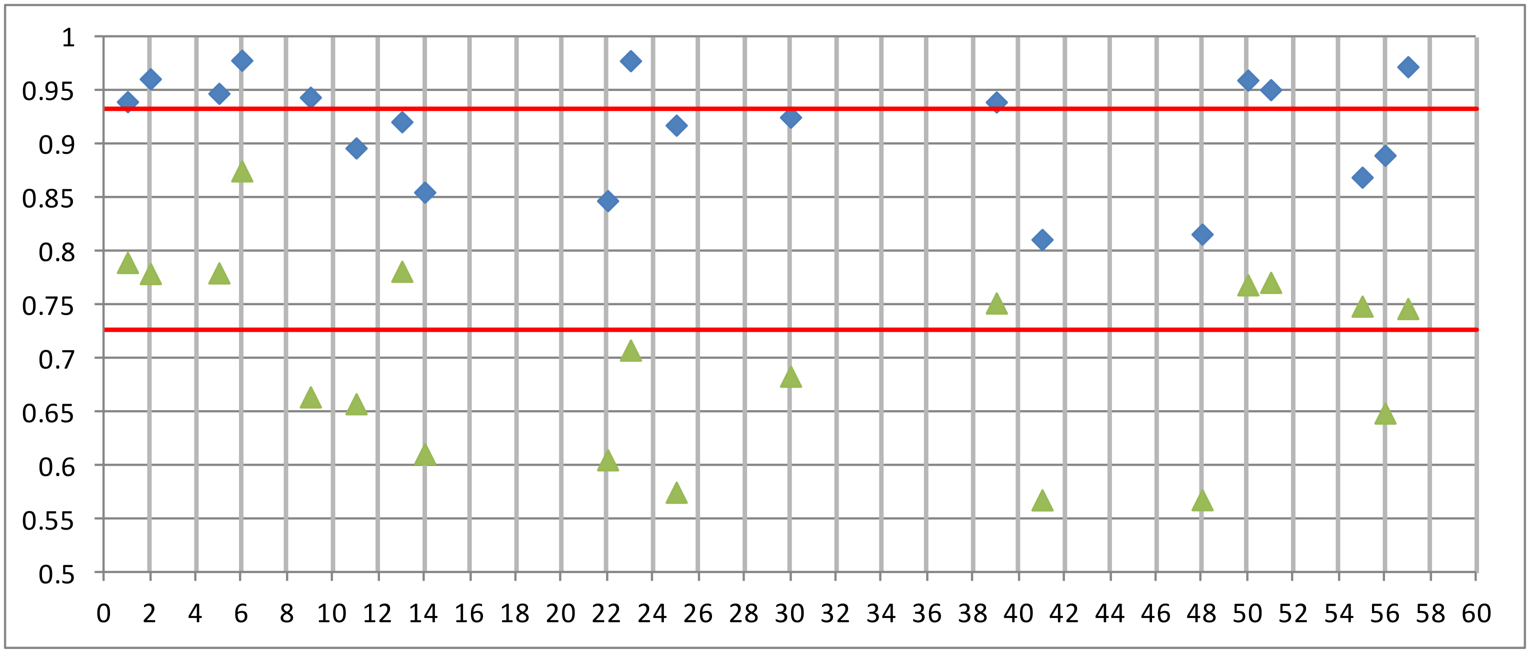
- Benchmark protocol – 5mm / 20 HU



  - Small disparity
  - Some points outside

Results

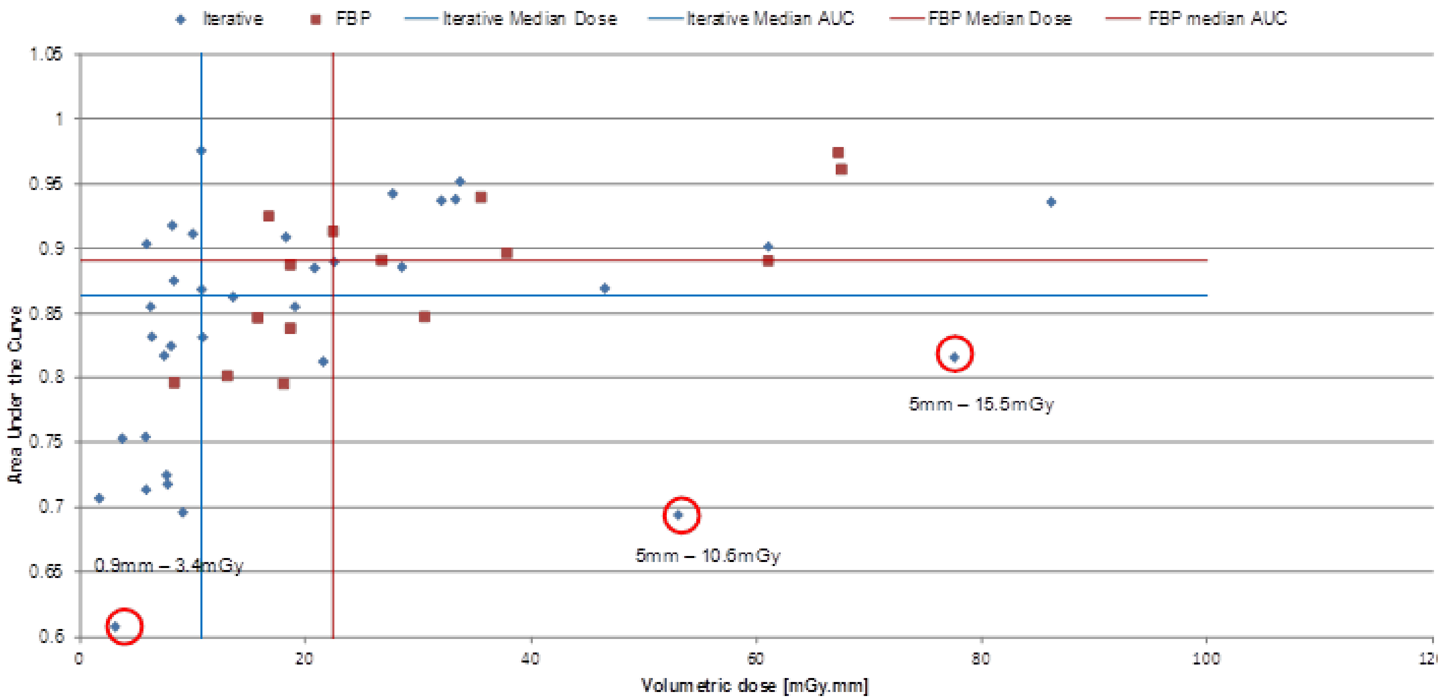
- Benchmark protocol – 5mm (▲) vs. 8mm (◆)



  - Size increases the performance
  - Contrast increases the performance

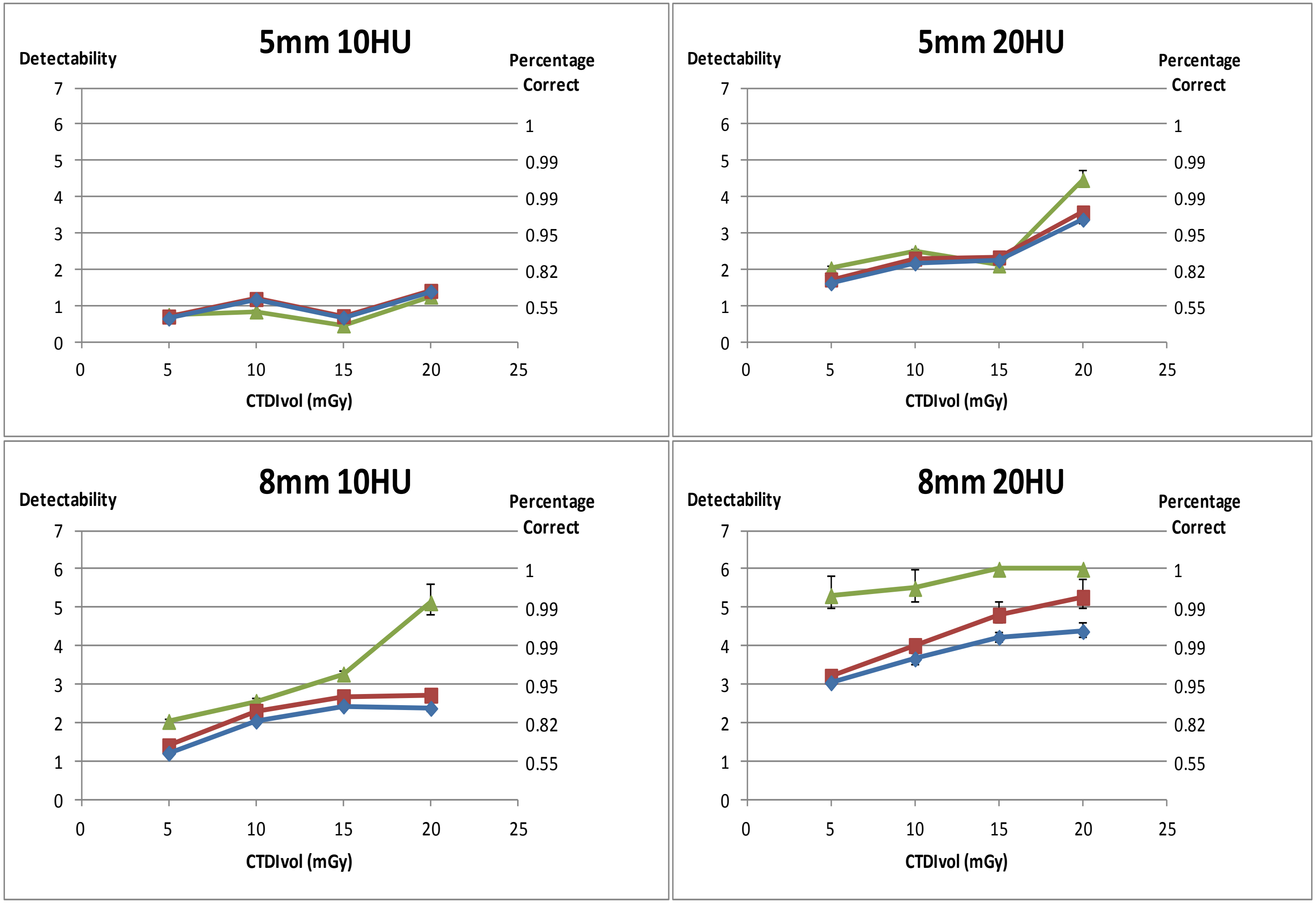
Results

- Local protocol – 5mm / 20HU



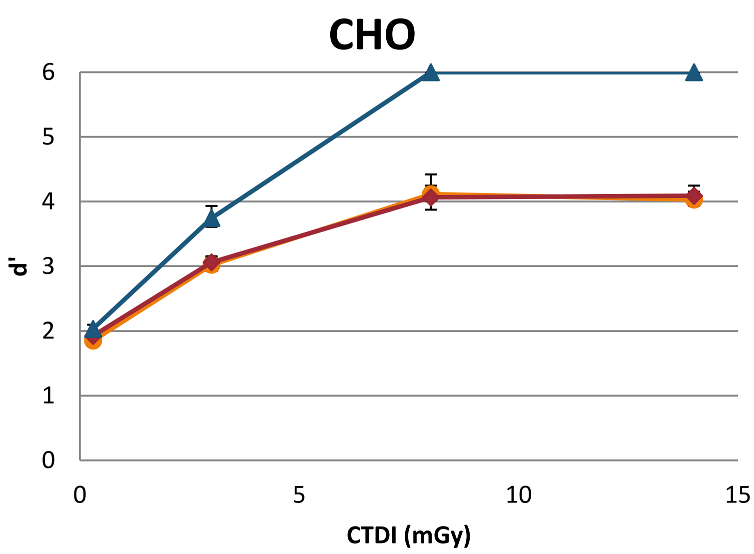
  - Unexpected parameters deteriorate image quality
  - Dose decrease with IR

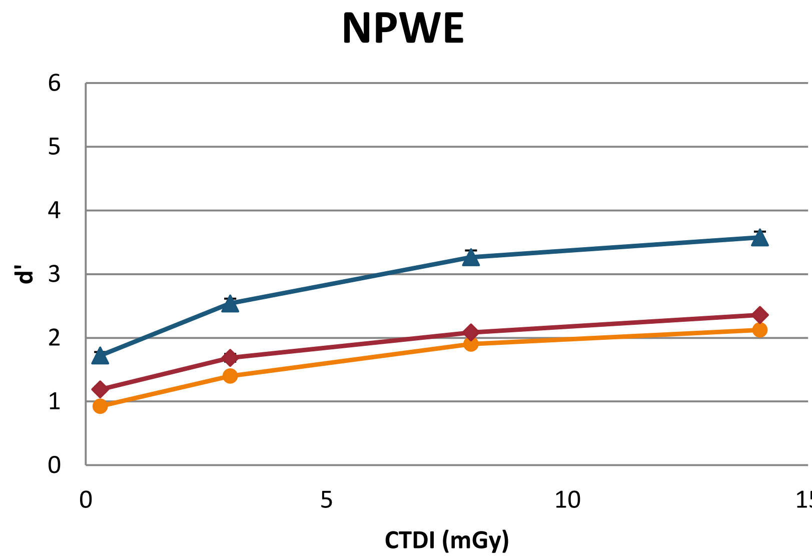
Results: Effect of dose (2015)



Response of the CHO model for 4 dose levels. ◆: FBP, ■: 1st generation IR, ▲: 2nd generation IR.

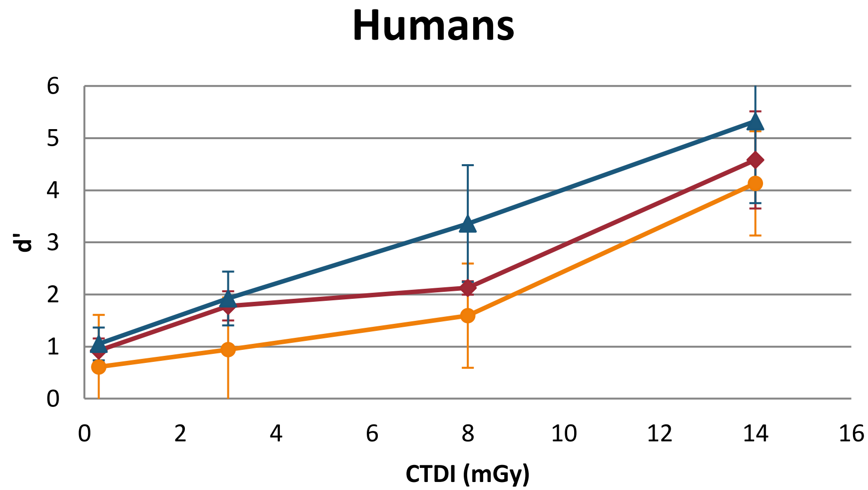
Results: MO vs. humans





8mm/10HU targets

Response of the CHO (top left) and NPWE (top right) model, compared to human observers (bottom right) for 4 dose levels. ●: FBP, ◆: 1st generation IR, ▲: 2nd generation IR.



Limitations

- Dose reduction potential based on homogenous phantoms
  - Noise attenuation less for transition zones
    - Edges noisier
    - Structure detection linked to noise structure
    - IR changes noise structure

  → Potential overestimation of reduction potential

Conclusion

- IR: Classic metrics no longer valid
- Objective task-based image quality
  - Benchmarking of CT
  - Image quality at high dose level: Homogenous
  - Link with clinical practice
- Limitations
  - Localisation of lesion known a priori
  - Homogenous phantom
  - Tube current modulation: Some lack of knowledge

Outlook

- Medical physics 3.0 (E. Samei)
  →As close as possible to clinical relevance
  - CTDIvol → SSDE
  - CNR → d’
  - Uniform phantoms → Textured phantoms
  - Fixed mA → TCM
- More complicated tasks
  - Localisation of a lesion
  - E. Samei: “ e’ ”: Change in lesion size

Thank you for your attention