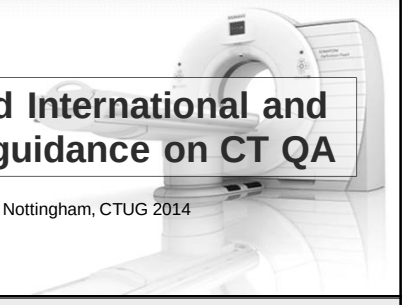

# Updated International and Nordic guidance on CT QA

Nottingham, CTUG 2014

HELSINKI UNIVERSITY
DEPARTMENT OF PHYSICS

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## WHO definition

A QA programme in diagnostic radiology is an **organized effort** by the staff operating a facility to ensure that

- the diagnostic images produced are of a sufficiently high quality, that they consistently provide **adequate diagnostic information**
- at the lowest possible cost
- and with the **least possible exposure** of the patient to radiation.



## EU RP 162

**Practical Consequences of the MED Directive**

1. Acceptance testing must be carried out before the first use of the equipment for clinical purposes (MED 8.2).
2. Necessary measures must be taken by the holder of the radiological installation to improve inadequate or defective features of equipment (MED 8.3). Competent authorities must ensure the holders of equipment adopt and apply specific criteria of acceptability for equipment in order to indicate when intervention is necessary, including taking the equipment out of service (MED 8.3).
3. Quality assurance programmes including quality control measure must be implemented by the holder (MED 8.2).

One of the principal responsibilities and functions of a medical physicist is the establishment, implementation, and supervision of quality assurance (QA) programs. This includes the acceptance and commissioning of new equipment and the technical supervision of maintenance.



## International references

1. AAPM Report No. 1, (1977) – phantoms for CT QA
2. WHO Quality Assurance in Diagnostic Radiology (1982)
3. AAPM Report 39 (1993) – acceptance of CT
4. EUR 16262 - EC (2000) – EU quality criteria for CT
5. ImPACT CT Scanner Acceptance Testing (2001)
6. AAPM Report 74 (2002) – quality control in digital radiology
7. IEC-60601-2-44 (2002) – particular requirements of safety for CT
8. NAGEL, H.D. (Ed.), Radiation Exposure in Computed Tomography, 4th edition (2002)
9. AAPM TG-66 Report 83 (2003) – CT simulators
10. **IPEM Report 32 Part III (2003) - measurements of performance characteristics in CT**
11. **IEC 61223-3-5 (2004) & 2-6 (2006) – acceptance + constancy / imaging performance in CT**
12. **IPEM Report 91 (2005) – performance testing in CT**
13. ICRU Report 74 (2006) – patient dosimetry
14. IAEA Report No. 39 (2006) – applying radiation safety standards
15. IAEA Technical Reports Series No. 457 (2007) – international CoP in dosimetry
16. DICOM Supplement 127 (Dose SR) (2007)
17. AAPM Report 96 (2008) – radiation dose in CT
18. AAPM Report 111 (2010) – future of CT dosimetry
19. **IEC-60601-2-44 (2009+A1:2012) – safety and performance of CT**
20. IAEA Human Health Reports No. 5 (2011) – CT dosimetry for wide cone-beams
21. KALENDER, W.A., Computed Tomography: Fundamentals, System Technology, Image Quality, Applications, 3rd edition (2011)
22. ACR CT QC manual (2012)
23. EU RP 162 (2012) – criteria for acceptability of medical radiological equipment
24. **NACP publication in Acta Rad (2012)**
25. **IAEA Report 19 (2012) – CT QA programme**
26. Manufacturer's manuals



## Nordic references

1. Radiation and Nuclear Safety Authority Finland (STUK). Acceptability requirements for x-ray equipment used in health care. Radiography and fluoroscopy equipment and computed tomography appliances. Helsinki: STUK, 2006:1–9.
2. Swedish Radiation Safety Authority (SSM). Strasakerhetsmyndighetens forfattningssamling. Stralsakerhetsmyndighetens foreskrifter om rontgendiagnostik. Stockholm: SSM, 2009:1–10.
3. National Board of Health Denmark. Bekendtgørelse om medicinske røntgenanlæg til undersøgelse af patienter. Bekendtgørelse nr. 975 af 16. Copenhagen: National Board of Health Denmark, 1998:1–27.
4. The Norwegian Radiation Protection Authority (NRPA). Forskrift om stralevern og bruk av straling (stralevernforskriften). Østeras: NRPA, 2010:1–12.
5. Radiation and Nuclear Safety Authority Finland (STUK). Quality assurance guidelines for x-ray equipment in healthcare. STUK report 2/2008. Helsinki: STUK, 2008:1–17.
6. Swedish Radiation Safety Authority (SSM). Stralsakerhetsmyndighetens forfattningssamling. Stralsakerhetsmyndighetens allmanna rad om prestandaspecifikationer vid upphandling av utrustning for rontgendiagnostik. Stockholm: SSM, 2009:1–9.
7. National Institute of Radiation Hygiene. Report on Nordic radiation protection co-operation. A Quality Control Programme for Radiodiagnostic Equipment: Acceptance tests. Herlev: National Institute of Radiation Hygiene, 1999:1–66.



## Main categories and types of QA tests

Categories:
- **Safety** (electrical, mechanical, laser, radiation)
- **Mechanical** (alignment lights, alignment of table and gantry, table and gantry positioning, slice localization from scout images)
- **Imaging performance** (noise & uniformity, CT number linearity, low contrast, spatial res, display performance)
- **Dosimetry** (CTDI head/body, patient dosimetry)

Types:
- **Acceptance**
- **Commisioning**
- **Constancy** (annual/technical and more frequent user performed tests)
- **Accreditation**

**Table 1-2 Definitions and Actions associated with Satisfactory Performance, Remedial and Suspension Levels**

| State | Definition and / or Action |
|---|---|
| Satisfactory Performance | Operation of the equipment with all performance and safety criteria within the holder's prescribed values. |
| Remedial Level Contravened | Poor performance sufficiently close to satisfactory performance that it will not reduce the clinical effectiveness or equipment safety, but requiring remedial action to restore satisfactory performance as soon as the service availability permits it. Remedial levels are set by the holder or his/her agent, e.g. an MPE, and take account of the clinical use of the equipment. |
| Suspension Level Contravened | Failure to comply with one or more suspension levels. This requires immediate suspension of the equipment from clinical use and investigation of the cause of the unsatisfactory performance. Remedial action to restore satisfactory performance may be possible. Alternatively, following a documented risk assessment, prepared by the MPE and the practitioner, the suspended equipment maybe considered for use in limited circumstances. The holder and the operators must be advised in writing of the suspension and the related limitation(s) in use. If neither of these actions is possible, the equipment must be suspended from use. |

EU 2012

mika.kort

## QA in CT

*Nordic recommendations (2012)*

Recommended tests:

MECHANICAL
1. Patient table movement
2. Zero degree gantry tilt*
3. Gantry tilt indicator
4. Visual inspection of positioning lasers*

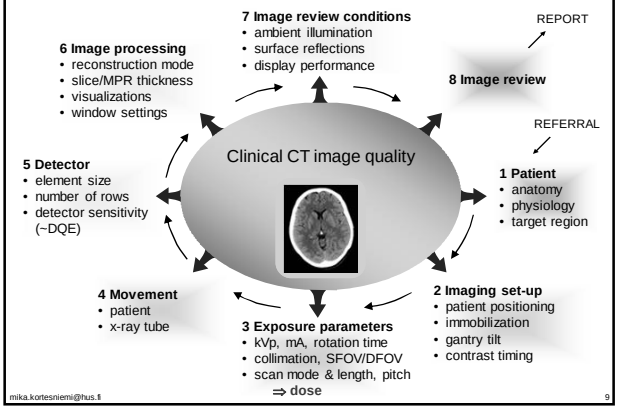
DOSE / BEAM QUALITY
5. Positioning lasers
6. Coach position and slice location
7. Dose display and specifications
8. Dose free in air
9. Dose-mAs linearity
10. Tube potential
11. Half-value layer (HVL)
12. Dose profile in z-direction
13. Geometric efficiency

IMAGING PERFORMANCE
14. CT number of water
15. CT number of various materials
16. CT number linearity*
17. Tomographic section thickness
18. Noise
19. Uniformity
20. Interslice noise
21. Geometric accuracy*
22. Spatial resolution
23. Low-contrast detectability*

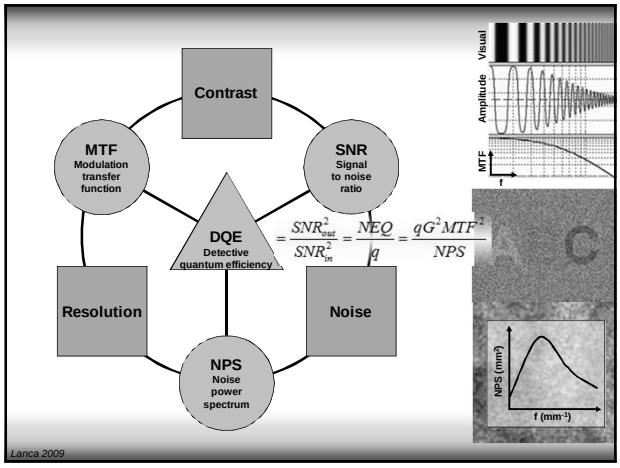
Not included:
- Artefacts
- Display & ambient conditions
- Site evaluation

Optional tests:
1. Total filtration
2. Dose profile in x/y direction
3. Helical image quality
4. AEC test (mA-modulation)
5. Scattered radiation
6. Radiographer tests
7. Figure of merit calculations

## Factors affecting image quality



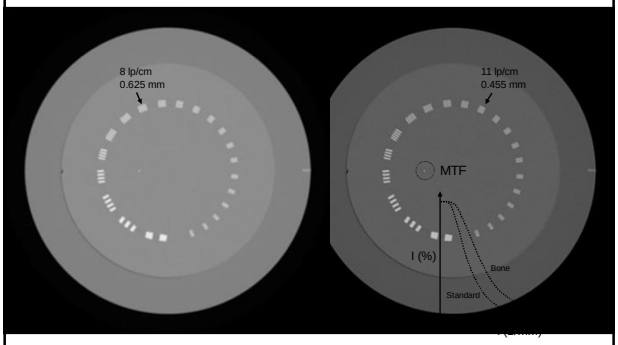

mika.kortesniemi@hus.fi 9




*Lanca 2009*

## Spatial resolution

*High contrast resolution with two filters (GE VCT 64)*




Standard Bone

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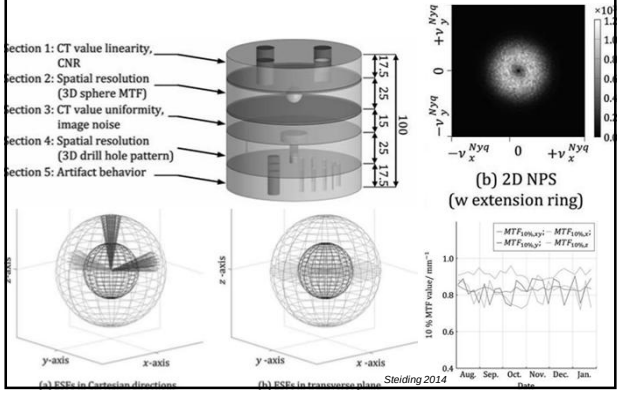
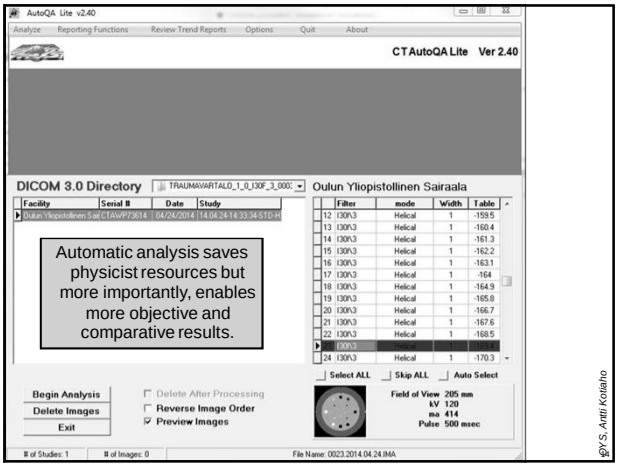
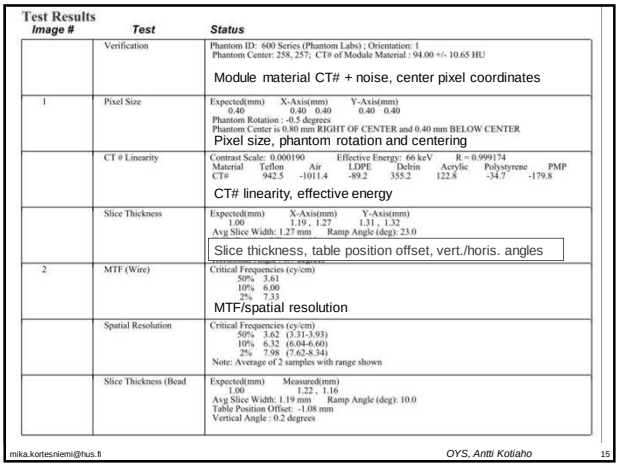
## Spatial resolution

*Cone-beam technology may require more extensive resolution evaluation*




*Steiding 2014*


AutoQA Lite v2.40
CT AutoQA Lite Ver 2.40
DICOM 3.0 Directory
Oulun Yliopistollinen Sairaala
Automatic analysis saves physicist resources but more importantly, enables more objective and comparative results.
Begin Analysis
Delete Images
Exit
Delete After Processing
Reverse Image Order
Preview Images
Select ALL
Skip ALL
Auto Select
Field of View 205 mm
kV 120
ma 414
Pulse 500 msec
©Y.S. Antti Kotiaho


Test Results
Image #
Test
Status
Verification
Module material CT# + noise, center pixel coordinates
Pixel Size
Pixel size, phantom rotation and centering
CT # Linearity
CT# linearity, effective energy
Slice Thickness
Slice thickness, table position offset, vert./horis. angles
MTF (Wire)
MTF/spatial resolution
Spatial Resolution
Slice Thickness (Bead
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OYS, Antti Kotiaho
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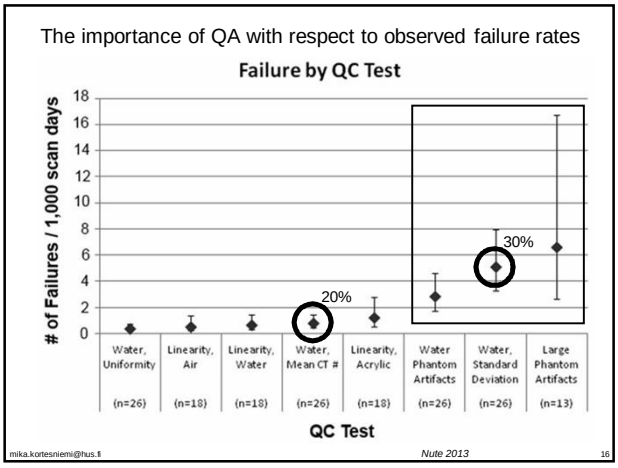
The importance of QA with respect to observed failure rates
Failure by QC Test
# of Failures / 1,000 scan days
20%
30%
Water, Uniformity (n=26)
Linearity, Air (n=18)
Linearity, Water (n=18)
Water, Mean CT # (n=26)
Linearity, Acrylic (n=18)
Water Phantom Artifacts (n=26)
Water, Standard Deviation (n=26)
Large Phantom Artifacts (n=13)
QC Test
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Nute 2013
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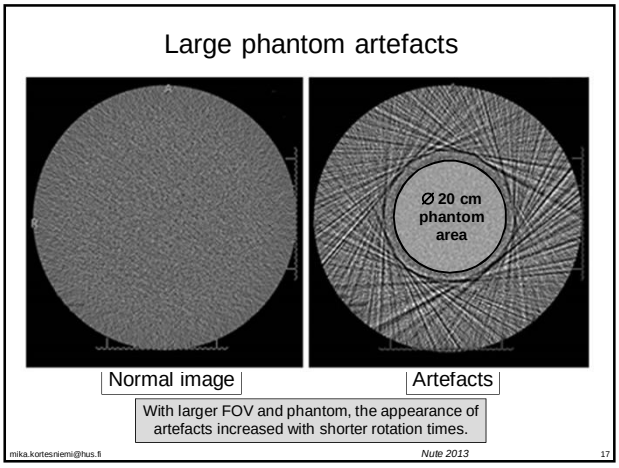
Large phantom artefacts
Ø 20 cm phantom area
Normal image
Artefacts
With larger FOV and phantom, the appearance of artefacts increased with shorter rotation times.
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Nute 2013
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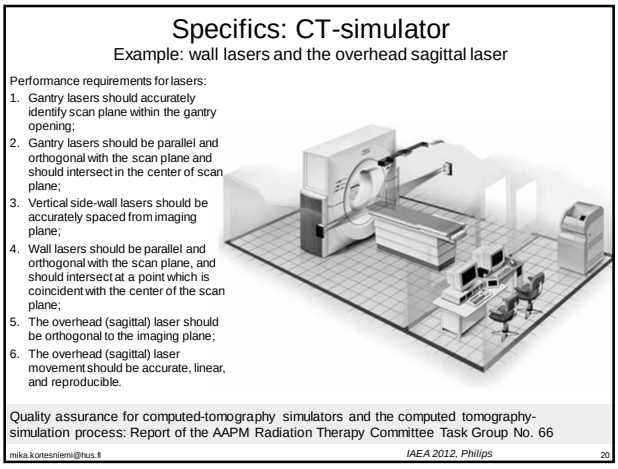
Specifics: CT-simulator
Example: wall lasers and the overhead sagittal laser
Performance requirements for lasers:
1. Gantry lasers should accurately identify scan plane within the gantry opening;
2. Gantry lasers should be parallel and orthogonal with the scan plane and should intersect in the center of scan plane;
3. Vertical side-wall lasers should be accurately spaced from imaging plane;
4. Wall lasers should be parallel and orthogonal with the scan plane, and should intersect at a point which is coincident with the center of the scan plane;
5. The overhead (sagittal) laser should be orthogonal to the imaging plane;
6. The overhead (sagittal) laser movement should be accurate, linear, and reproducible.
Quality assurance for computed-tomography simulators and the computed tomography-simulation process: Report of the AAPM Radiation Therapy Committee Task Group No. 66
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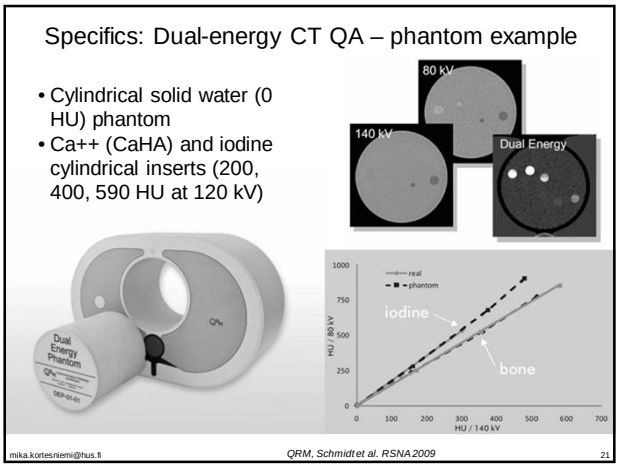
IAEA 2012, Philips
20


Specifics: Dual-energy CT QA – phantom example
• Cylindrical solid water (0 HU) phantom
• Ca++ (CaHA) and iodine cylindrical inserts (200, 400, 590 HU at 120 kV)
80 kV
140 kV
Dual Energy
Dual Energy Phantom
real
phantom
iodine
bone
HU / 80 kV
HU / 140 kV
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QRM, Schmidt et al. RSNA 2009
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## CTDI for wider beam collimations

The current use of cone beam scanner technology clearly demonstrates the deficiencies of the standard CT dosimetry methodology.

The IEC/IAEA interim solution with two interpretations of the definition of $CTDI_w$ ($C_w$) depending on the beam width:

- For beams of less than 40 mm, the conventional definition is given.
- For a beam width greater than 40 mm, $C_w$ can be written as:

$$C_{w,NT} = C_{w,Ref} \times \left( \frac{C_{a,100,NT}}{C_{a,100,Ref}} \right)$$


where $C_{w,NT}$ is the weighted CT air kerma index for a beam width of NT mm (if NT > 40 mm), $C_{w,Ref}$ is the weighted CT air kerma index for a reference beam width of 20 mm (or closest possible below 20 mm), and similarly, $C_{a,100,NT}$ is the CT air kerma index measured free-in-air with a 100 mm integration length chamber for a beam width of NT mm and $C_{a,100,Ref}$ is a similar quantity at the reference beam width.

*… vs long chambers or point dosimeters.*



## QA in CT

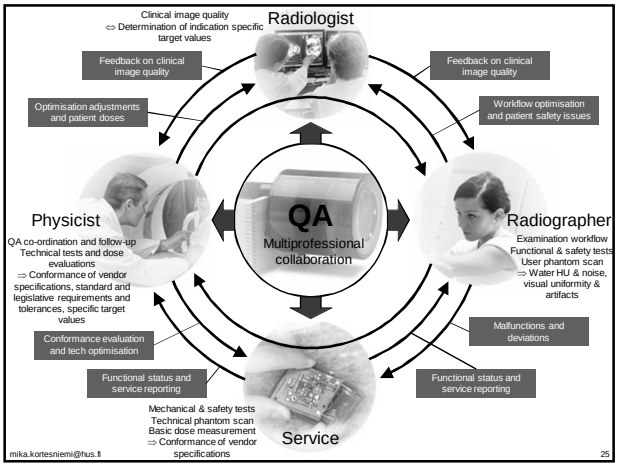
*National recommendations (Finland)*

| User tests | | |
|---|---|---|
| 4.5.1 | Tube warm-up & air calibration | daily |
| 4.5.2 | CT-numbers | weekly |
| 4.5.3 | Noise and artefacts | weekly |

*and other recommended tests of the manufacturer*

| Technical tests | | |
|---|---|---|
| 4.5.4 | Slice position accuracy | 6 months |
| 4.5.5 | CT-numbers | 6 months |
| 4.5.6 | Uniformity | 6 months |
| 4.5.7 | Geometric accuracy | 6 months |
| 4.5.8 | Slice thickness | 6 months |
| 4.5.9 | Table movement accuracy | 6 months |
| 4.5.10 | Spatial resolution | 6 months |
| 4.5.11 | Low contrast resolution | Acceptance |
| 4.5.12 | Dose sensitivity profile | Acceptance |
| 4.5.13 | Dose display | 1 year |

*and other recommended tests of the manufacturer*

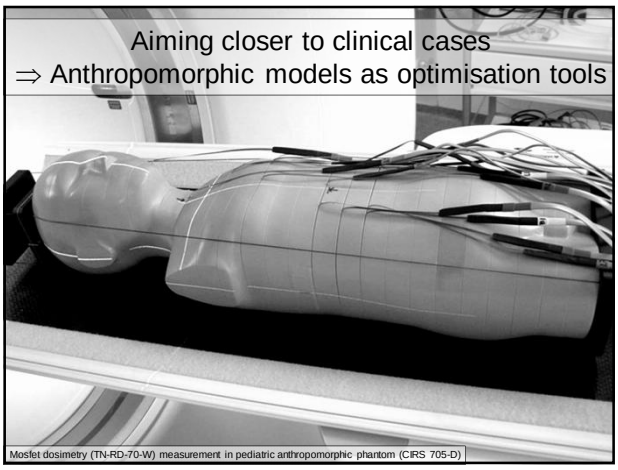





# Need for optimisation



## Aiming closer to clinical cases
## ⇒ Anthropomorphic models as optimisation tools



Mosfet dosimetry (TN-RD-70-W) measurement in pediatric anthropomorphic phantom (CIRS 705-D)

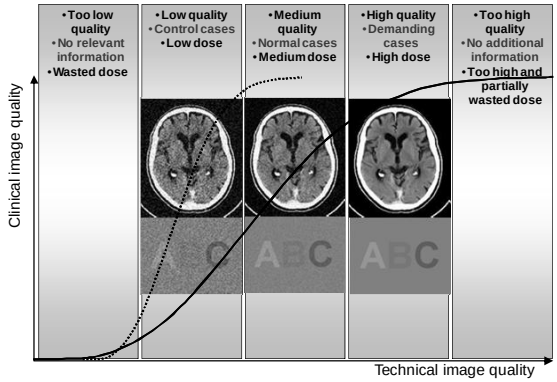
## Aiming closer to clinical cases
## ⇒ Indication based Diagnostic Reference Levels

DRL

| Examination type or indication | $CTDI_{vol}$ mGy | DLP mGy·cm |
|---|---|---|
| Head/brain | 55 | 800 |
| Sinuses | 13 | 190 |
| Chest | 9 | 290 |
| Abdomen | 12 | 560 |
| Body | 12 | 770 |
| Aorta (neck to groin) | 10 | 630 |
| Indication - HRCT | 5 | 140 |
| Indication - lung tumour | 11 | 430 |
| Indication - renal stones | 7 | 330 |
| Indication - lymphoma | 11 | 970 |
| Indication - trauma body | 17 | 1300 |
| Indication - colonoscopy (prone) | 6.5 | total from both positions: 930 |
| Indication - colonoscopy (supine) | 12 | |

*STUK 2013, Finland*

## Clinical image quality – finding the right level

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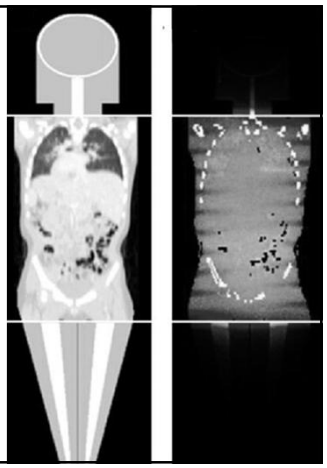
## QA trends

- Phantoms may become more simple, but analysis methods may become more complicated
- Subjective visual evaluation of image quality ⇒ automatic, objective, quantitative analysis
- Larger amount of collected data; from small samples to continuous follow-up of the entire production data volume
- Higher utilization of clinical & diagnostic metadata for optimization and process streamlining
- Patient specific dose estimates and organ dose data



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# Handling the big data

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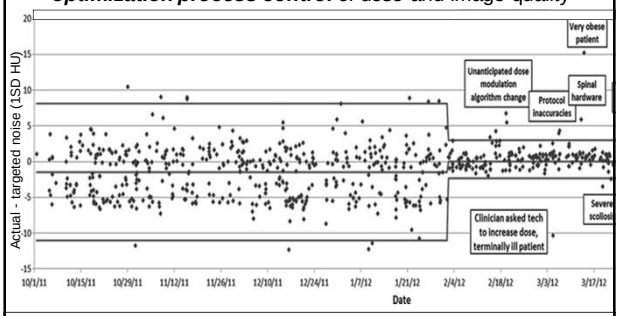
## PACS data collection and follow-up – towards ***optimization process control*** of dose and image quality




- The process control helps to decrease variation in CT image quality, target image quality can be achieved more consistently and accurately, also the size-specific dose estimates decreased.
- Large scale process control provides on-line description of the whole production image data status and helps to recognize deviations (~patient safety) and guide optimization improvements.

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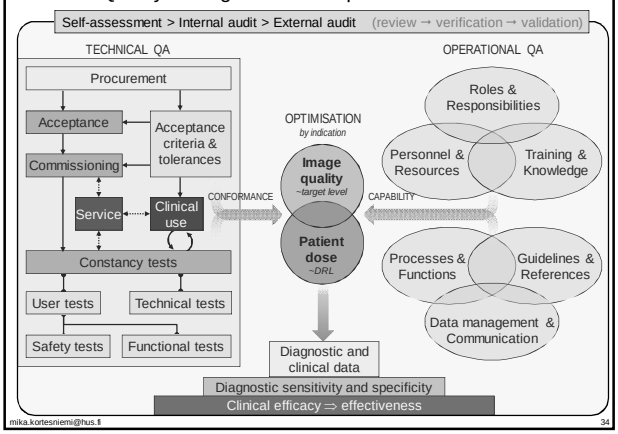
## Quality management and optimisation scheme

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