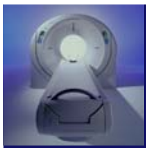

LUMC
Leids Universitair Medisch Centrum

Justification and optimisation of CT within a scientific framework

Koos Geleijns

Work in cooperation with
Raoul Joemai, Wouter Veldkamp, Wouter Teeuwisse, Ying-Lie O
LUMC, Leiden, The Netherlands

Marcal Salvado, Universitat Rovira i Virgili, Tarragona, Spain

Alfonso Calzado, Complutense University, Madrid, Spain

Justification and optimisation of CT within a scientific framework

Spatial resolution	Balancing dose and image quality
Radiation risk assessment	Justification of practices

Justification and optimisation of CT within a scientific framework

Spatial resolution Imaging of the cochlear implant	Balancing dose and image quality Selective shielding
Radiation risk Assessment Fatal tumor induction	Justification of practices Guideline development

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Justification and optimisation of CT within a scientific framework

Spatial resolution Imaging of the cochlear implant	Balancing dose and image quality Selective shielding
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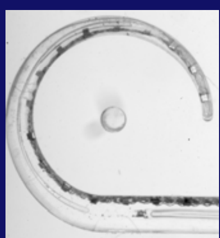
Spatial resolution: Imaging of the cochlear implant

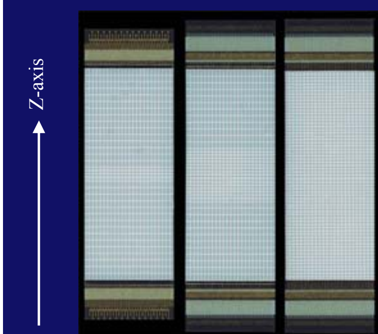


We want to <u>image</u> the cochlear implant and the surrounding bony structures

We want to <u>measure</u> the position of the electrodes relative to the bony structures

---

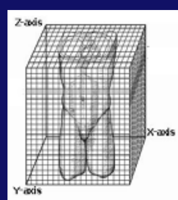
Spatial resolution: Imaging of the cochlear implant



4-slice	16-slice	64-slice
1998	2001	2004

Multislice CT (≥ 4 slice) since 1998

CT became a real 3D imaging modality



Submillimeter isotropic imaging

Spatial resolution: Imaging of the cochlear implant

64 slice scannners

	GE	Philips	Siemens	Toshiba
	Lightspeed	Brillance	Sensation	Aquilion
Smallest focal spot size (mm)				
	0.6 x 0.7	0.5 x 1.0	0.7 x 0.7	0.9 x 0.8
Acquisition configuration: active channels x detector size @ COR				
	64 x 0.625	64 x 0.625	2 x 32 x 0.6	64 x 0.5
In-plane spatial resolution (MTF0, lp/cm, mm/lp) sharpest algorithm				
	15.4 lp/cm	24 lp/cm	30 lp/cm	21.4 lp/cm
	0.65 mm/lp	0.42 mm/lp	0.33 mm/lp	0.47 mm/lp

Spatial resolution: Imaging of the cochlear implant

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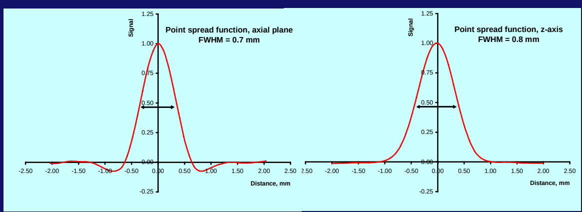
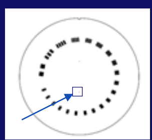
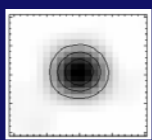
Can we trust this?

Spatial resolution: Imaging of the cochlear implant



If the object consists of two ideal points, just a distance FWHM apart, there is a fair chance that they will be separated in the image.





Spatial resolution: Imaging of the cochlear implant

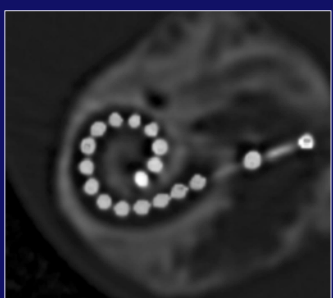
Measured point spread function (FWHM, mm)

	Scanner A	Scanner B	Scanner C	Scanner D
Axial (XY) plane	0.53 mm	0.68 mm	0.68 mm	0.48 mm
MTF0	0.42 mm/lp	0.65 mm/lp	0.47 mm/lp	0.33 mm/lp
Z-axis	0.84 mm	0.98 mm	0.81 mm	0.70 mm

Cochlear Implants
postoperative imaging: multi-slice CT (MSCT)

Cochlear implant:

Electrode size 0.4 mm!

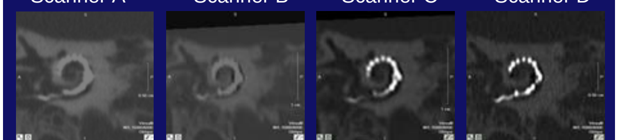


fresh temporal bone (ex-vivo)

Spatial resolution: Imaging of the cochlear implant

Cochlear implant in a perspex phantom

Scanner A　Scanner B　Scanner C　Scanner D



Cochlear implant in a human cochlea (ex vivo)

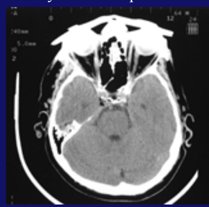
Justification and optimisation of CT within a scientific framework

Spatial resolution Imaging of the cochlear implant	Balancing dose and image quality Selective shielding
Radiation risk Assessment Fatal tumor induction	Justification of practices Guideline development

Balancing dose and image quality: Selective shielding

Eye shield in place.

Thyroid shield in position.



Hopper et al. **AJNR** 2001Clin

McLaughlin et al. **Clin. Radiol.** 2004

Balancing dose and image quality: Selective shielding

Absorbed dose to superficial organs and tissues was reported to be reduced by applying a sheet consisting of a compound of latex and bismuth on the skin close to superficial organs and tissues.

Papers 1997 – 2006:

- Fricke, B. L., Donnelly, L. F., Frush, D. P., Yoshizumi, T., Varchena, V., Poe, S. A., and Lucaya, J. In-Plane Bismuth Breast Shields for Pediatric CT: Effects on Radiation Dose and Image Quality Using Experimental and Clinical Data. Am.J.Roentgenol. 2003;180(2):407-11.
- Hein, E., Rogalla, P., Klingebiel, R., and Hamm, B. Low-Dose CT of the Paranasal Sinuses With Eye Lens Protection: Effect on Image Quality and Radiation Dose. **Eur Radiol.** 2002;12(7):1693-6.
- Hopper, K. D., King, S. H., Lobell, M. E., TenHave, T. R., and Weaver, J. S. The Breast: in-Plane X-Ray Protection During Diagnostic Thoracic CT--Shielding With Bismuth Radioprotective Garments. **Radiology** 1997;205(3):853-8.
- Hopper, K. D., Neuman, J. D., King, S. H., and Kunselman, A. R. Radioprotection to the Eye During CT Scanning. **Am.J.Neuroradiol.** 2001;22(6):1194-8.
- Hopper, K. D. Orbital, Thyroid, and Breast Superficial Radiation Shielding for Patients Undergoing Diagnostic CT. **Semin.Ultrasound CT MR** 2002;23(5):423-7.
- McLaughlin, D. J. and Mooney, R. B. Dose Reduction to Radiosensitive Tissues in CT. Do Commercially Available Shields Meet the Users' Needs? **Clin.Radiol.** 2004;59(5):446-50.
- Mukundan, S., Frush, D. P., Yoshizumi, T., Toncheva, G., Nguyen, G., and Marcus, J. The Use of a Bismuth Shield to Decrease Radiation Dose to the Eye in Children: An Anthropomorphic Phantom Study. **RSNA2004**; 2004. Report No.: SSC15-05
- Perisinakis K, Raissaki M, Theocharopoulos N, Damilakis J, Gourtsoyiannis N. Reduction of eye lens radiation dose by orbital bismuth shielding in pediatric patients undergoing CT of the head: a Monte Carlo study. **Med Phys.** 2005 Apr;32(4):1024-30.
- Colombo P, Pedroli G, Nicoloso M, Re S, Valvassori L, Vanzulli A. Evaluation of the efficacy of a bismuth shield during CT examinations. **Radiol Med (Torino).** 2004 Nov-Dec;108(5-6):560-8.
- Heaney DE, Norvill CA. A comparison of reduction in CT dose through the use of gantry angulations or bismuth shields. **Australas Phys Eng Sci Med.** 2006 Jun;29(2):172-8.

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Can we trust this?

Balancing dose and image quality: Selective shielding

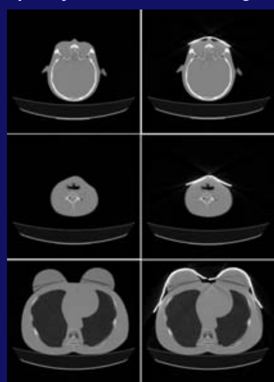
Shielding of the entrance beam

Shielding of the exit beam

Balancing dose and image quality: Selective shielding

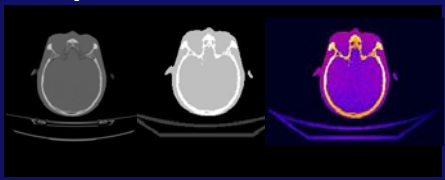
Images representing unshielded and shielded acquisitions from respectively a:

- CT brain,
- CT cervical spine, and
- CT chest scan.

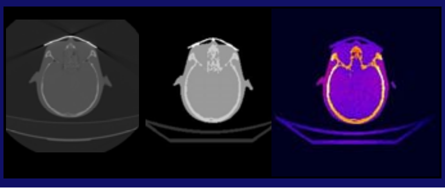


Original CT images | Voxel phantom 1.6 x1.6 x 4 mm^3 | Dose distribution by Monte Carlo simulation

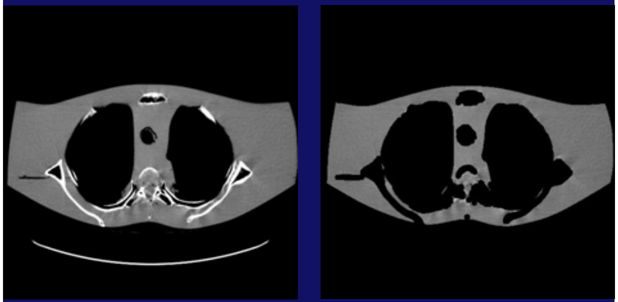
Without eye lens shieding



With eye lens shielding

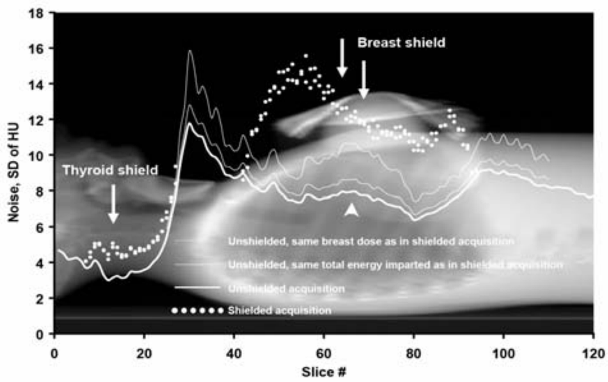


Balancing dose and image quality: Selective shielding



- Segmentation of soft tissue (WW100, WL20).
- Erosion of segmented soft tissue using a disk shaped structuring element.
- Noise (SD of HU) in ROI's (8x8 pixels) entirely located within segmented regions

Balancing dose and image quality: Selective shielding



Justification and optimisation of CT within a scientific framework

Spatial resolution Imaging of the cochlear implant	Balancing dose and image quality Selective shielding
Radiation risk Assessment Fatal tumor induction	Justification of practices Guideline development

Radiation risk assessment: Fatal tumor induction

frequency of radiological examinations

proportions of collective effective dose

Although CT examinations make up only a relatively small part of the total number of x-ray examinations, CT contributes a high proportion of the collective effective dose. The figures shown refer to Germany for the year 2003 [BMU, 2003], but can be taken as largely representative for most western countries.

Radiation risk assessment: Fatal tumor induction

Risk of cancer – The Lancet

Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries

The Lancet, 2004

International popular press

Radiation risk assessment: Fatal tumor induction

	Annual X-rays per 1000*	Total	
		Attributable risk (%)	Cases cancer per year
Country			
Australia	565	1·3	431
Canada	892	1·1	784
Croatia	903	1·8	169
Czech Republic	883	1·1	172
Finland	704	0·7	50
Germany	1254	1·5	2049
Japan†	1477	3·2	7587
Kuwait	896	0·7	40
Netherlands	600	0·7	208
Norway	708	1·2	77
Poland	641	0·6	291
Sweden	568	0·9	162
Switzerland	750	1·0	173
UK	489	0·6	700
USA	962	0·9	5695

The Lancet, 2004

Estimated number of radiation-induced cases of cancer per year in the UK by type of X-ray

	Cases of radiation-induced cancer per year*		
	Males	Females	Total
X-ray type			
Abdomen	16	15	31
Barium meal	5	6	11
Barium enema	27	28	55
Chest	1	3	4
Coronary angiography	13	28	41
CT scan	31	39	70
Cerebral angiography	1	1	2
Hip or pelvis	28	24	52
Lumbar spine	23	16	39
Screening mammography	··	8	8
Thoracic spine	2	4	6
Each other type	<10	<10	<20

CT scan: highest estimated number of radiation-induced cases of cancer

The Lancet, 2004

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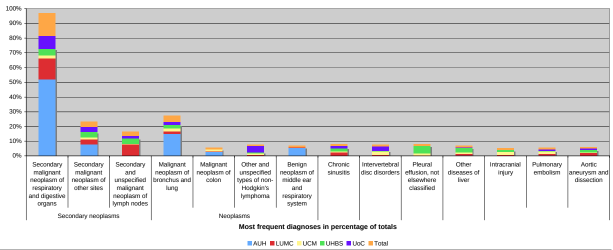
CT scan: highest estimated number of radiation-induced cases of cancer

Can we trust this?

Radiation risk assessment: Fatal tumor induction



Results of a multi center study: six centers (Ying Lie O – Leiden; K. Chlapoutakis & N. Theocharopoulos – Crete; Jolanta Hansen – Aarhus; Tilo Niemann – Basel; Laura Ruiz Lopez – Madrid)

Website: www.msct.eu

Radiation risk assessment: Fatal tumor induction

EVAR (endovascular aneurysm repair): a new technology designed to treat **AAA** (abdominal aortic aneurysm)

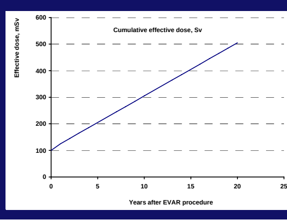
Hospital	Cumulative effective dose after 5 year follow-up
Hospital A	130 mSv
Hospital B	160 mSv
Hospital C	210 mSv

(pre-operative, per-operative and follow-up x-ray exposures (radiography, fluoroscopy and CT))

Radiation risk assessment: Fatal tumor induction

Effective dose accumulates rapidly: a common scenario

- First year: 100 mSv
- Second year: 25 mSv
- Next years: 20 mSv per year



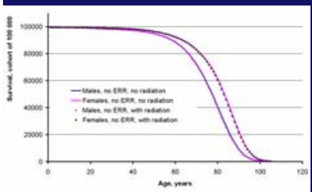
Disease related extra annual mortality

Three scenarios for the annual ERR:

0.00	no extra mortality
0.05	modest extra mortality
0.10	considerable extra mortality

Radiation risk model: BEIR VII

Radiation risk assessment: Fatal tumor induction

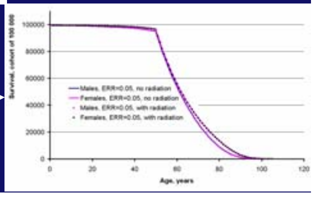


Survival curves
50 year old patient
EVAR for treatment of AAA
no ERR vs modest ERR

pre & per-oparative exposures
and follow up exposures

The Lancet, 2004

Realistic calculation



ERR = excess relative risk

Radiation risk assessment: Fatal tumor induction

Life expectancy (years)

Health status:	No ERR	Modest ERR (0.05)	Substantial ERR (0.1)
Radiation risk:	without / with	without / with	without / with
50 YOM	27.25 / 27.07	14.12 / 14.07	8.85 / 8.84
50 YOF	32.06 / 31.77	15.30 / 15.24	9.21 / 9.20
70 YOM	11.71 / 11.67	8.22 / 8.20	6.16 / 6.15
70 YOF	15.14 / 15.08	9.97 / 9.94	7.14 / 7.13

ERR: (annual) excess relative risk

Radiation risk calculated with the BEIR VII model

Radiation risk calculated for the following scenario: first year: 100 mSv; second year: 25 mSv; next years: 20 mSv per year

Justification and optimisation of CT within a scientific framework

Spatial resolution **Imaging of the cochlear implant**	**Balancing dose and image quality** **Selective shielding**
Radiation risk Assessment **Fatal tumor induction**	**Justification of practices** **Guideline development**

Justification of practices: Guideline development

Justification of medical radiation exposure is clearly of value where there is a need to balance the risk of adverse consequences from exposure to ionising radiation with the risk of adverse events if the procedure is not performed. Case by case justification might also have a legitimate role in some optimisation exercises (SRP International Committee Working Party Summary Report).

How? Just ask the medical doctors (radiologist)?

Justification of practices: Guideline development

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Can we trust this?

How? Just ask the medical doctors (radiologist)?

Justification of practices: Guideline development

When is it justified to use CT?

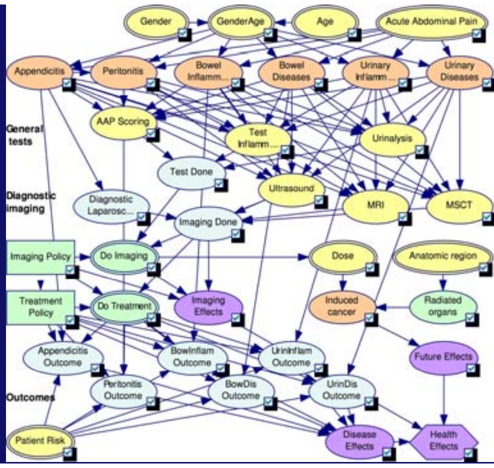
A mathematical model for guideline delevopment (Ying-Lie O; Leiden University Medical Center)

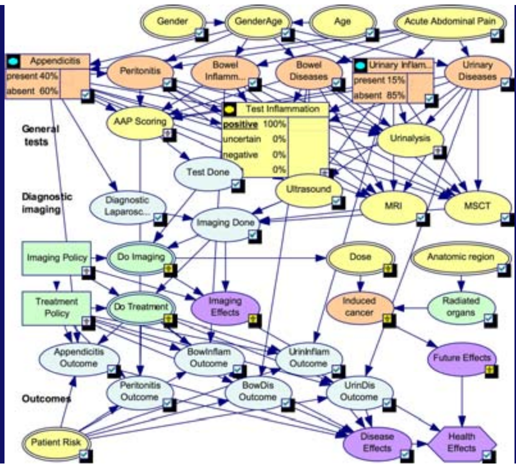
- Diagnostic imaging as an important technique for medical diagnosis
- Pros and cons of different scenarios (including radiation detriment)
- Complex interrelationships between disease and diagnostic techniques
- Evidence-based

Justification of practices: Guideline development

Acute abdominal pain: many differential diagnoses:

- Appendicitis
- Peritonitis
- Ureteral inflammation
- Other diseases of the ureter
- Intestinal inflammation
- Other intestinal diseases
- Pancreatitis
- Gynaecological diseases
- …





Justification of practices: Guideline development

Example: acute abdominal pain

Order of probabilities for different test results

Ranked Targets	Probability
Appendicitis:present	0.404
Urinary Inflammation:present	0.153
Bowel Inflammation:present	0.116
Bowel Diseases:present	0.044
Urinary Diseases:present	0.013
Peritonitis:present	0.005

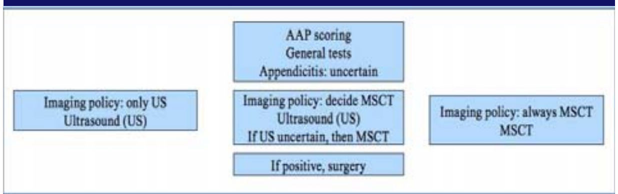
Ranked Targets	Probability
Urinary Inflammation:present	0.209
Urinary Diseases:present	0.183
Bowel Diseases:present	0.065
Appendicitis:present	0.055
Bowel Inflammation:present	0.015
Peritonitis:present	< 0.001

Ranked Targets	Probability
Bowel Diseases:present	0.079
Appendicitis:present	0.072
Urinary Inflammation:present	0.025
Urinary Diseases:present	0.022
Bowel Inflammation:present	0.020
Peritonitis:present	< 0.001

Justification of practices: Guideline development

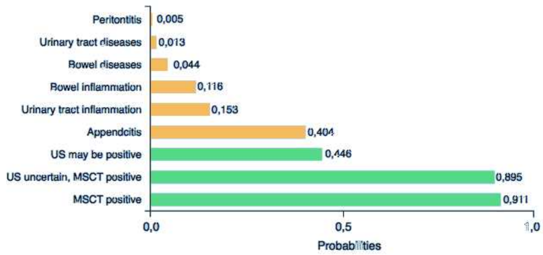
Acute abdominal pain, choice of imaging policy

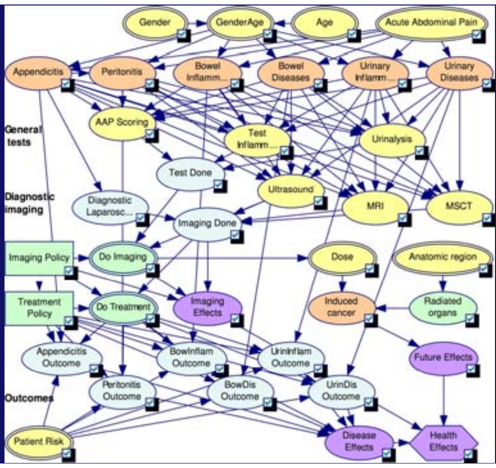
- Only ultrasound
- Always CT
- If ultrasound uncertain, then CT



Justification of practices: Guideline development

Probability of appendicitis





Justification of practices: Guideline development