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Joint ICTP/IAEA Advanced School on Dosimetry in Diagnostic Radiology and its Clinical Implementation

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Optimization

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Joint ICTP-IAEA Advanced school on Dosimetry in Diagnostic Radiology:
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Optimization in clinical practice

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Definition of optimization

- This is a general word used in language and also specific words used in clinical practice and radiation protection.
- Optimization (mathematics), trying to find maxima and minima of a function
- Process optimization, in business and engineering, methodologies for improving the efficiency of a production process

Protection Definition

- **optimization of protection (and safety)**
  - The *process* of determining what level of *protection and safety* makes *exposures*, and the probability and magnitude of *potential exposures*, “as low as reasonably achievable, economic and social factors being taken into account” (***ALARA***), as required by the International Commission on Radiological Protection *System of Radiological Protection (ICRP 103)*.
  - This is not the same as optimization of the *process* or *practice* concerned. An explicit term such as *optimization of protection (and safety)* should be used.

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Optimization in clinical practice

- the process of determining how to obtain the required diagnostic outcome for a patient from a procedure while minimising factors that cause patient detriment, with economic and societal factors being taken into account[1]
- Optimisation involves input from the radiologist, radiographer and medical physicist.

[1]optimization of clinical practice should also be applied to non radiation diagnostic modalities such as those with the use of ultrasound and magnetic resonance imaging

Optimization

Also includes the concept of maximizing the benefit of the use of radiation while minimizing the risk of detriment.

Therefore a knowledge of risk estimation may be important in optimization in clinical practice.

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Factors in risk estimation

- The concept of risks versus benefit.
- Relative and absolute risk
- The concept of justification
- Stochastic Risk
- Risk from Deterministic Effects
- Special considerations for patients who are or who might be pregnant
- Special considerations for paediatric patients
- Special considerations for research exposures

Factors in plain radiography

- Controllable factors affecting **image quality** in plain radiography
  - Radiographic protocol (kVp, mAs, projection etc.)
  - Scatter rejection
  - Collimation
  - Image receptor quantum statistics, receptor speed
  - Image resolution
  - Optimal display and reading conditions
- Controllable factors affecting **patient dose** in plain radiography
  - Radiographic protocol (kVp, mAs, projection etc.)
  - Patient size variation usually requires changes in examination protocol
  - Added filtration including effect of high z filtration
  - Collimation
  - Absorption of the beam after the patient, including the grid
  - Image receptor sensitivity
  - Geometric Factors
  - Automatic exposure set up

Factors in fluoroscopy

- Controllable factors affecting **image quality** in fluoroscopy
  - Automatic exposure control set up
  - Radiographic protocol (kVp, mA for manual operation, projection, field size or image magnification etc.)
  - Collimation, including virtual collimation
  - Geometric Factors
  - Scatter rejection
  - Image receptor quantum statistics, receptor sensitivity, aperture, TV chain
  - Image resolution
  - Optimal display and reading conditions
- Controllable factors affecting **patient dose** in fluoroscopy
  - Beam on, including pulsed fluoroscopy
  - Automatic exposure control set up
  - Radiographic protocol (kVp, mA for manual operation, projection, field size or image magnification etc.)
  - Patient size variation usually requires changes in examination protocol
  - Added filtration including effect of high z filtration
  - Collimation, including virtual collimation
  - Absorption of the beam after the patient, including the grid
  - Image receptor sensitivity
  - Geometric Factors
  - Last image hold

Factors in CT

- Controllable factors affecting **image quality** in CT
  - Radiographic protocol
    - kVp, mAs for manual operation
    - Pitch
    - Reconstruction filter
    - Scan Length and number of scan series
  - Automatic exposure control (correct dose modulation techniques)
  - Collimation selection including MDCT considerations
  - Scan mode (axial, spiral or MDCT)
  - Image receptor quantum statistics, image processing algorithms
  - Image resolution
  - Optimal display and reading conditions

- Controllable factors affecting **patient dose** in CT
  - Radiographic protocol
    - kVp, mAs for manual operation
    - Pitch
    - Reconstruction filter
    - Scan Length and number of scan series
  - Patient size variation usually requires changes in examination protocol
  - Automatic exposure control (correct dose modulation techniques)
  - Collimation selection including MDCT considerations including overscaning and over beaming
  - Scan mode (axial, spiral or MDCT)

Steps in Optimization of clinical practice

1. Initial preparation
2. Image Quality & Dose Assessment
3. Review of current status of procedure
4. Intervention
5. Verify effect of optimization process
6. Monitor

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Step 1: Initial preparation
Step 2: Image Quality & Dose Assessment

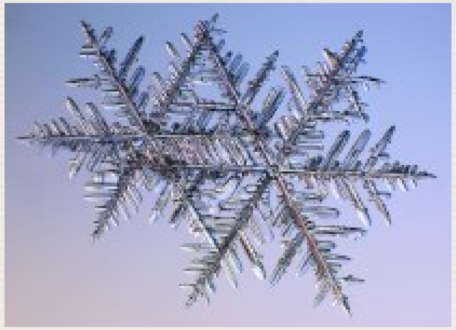
- **Initial preparation**
  - Establish agreement for an optimisation process with the radiology department, including a schedule of achievable targets.
  - Determine the priority for examinations to be optimised for a particular modality in conjunction with clinicians and radiographers, considering such factors as examination risk and frequency
  - Check QA status of equipment used for procedure
  - Establish clinically appropriate image quality requirements in collaboration with clinicians
- **Dose & Image Quality Assessment**
  - Determine Image Quality
  - Determine patient doses (preferably from a patient audit or may be phantom based)

Step 3: Review of current status of procedure
Step 4: Intervention

- **Review of current status of procedure**
  - Compare examination dose with appropriate benchmarks if available.
  - Compare examination image quality with appropriate benchmarks if available
  - In conjunction with the radiologist and radiographer review examination related data including
    - Radiographic protocol
    - Equipment configuration
    - Image reading conditions
  - Investigate the effect on image quality and dose of varying the parameters for the above list.
- **Intervention**
  - Recommend changes to the radiographic protocol, equipment configuration and or viewing conditions, based on the review of the procedure (above)

Step 5: Verify effect of optimization process
Step 6: Monitor procedure

- **Verify effect of optimization process**
  - After an agreed period of clinical introduction repeat the dose and image quality analysis to determine the effectiveness of the optimization intervention
  - Record the results of the optimisation procedure in a way that is accessible to all interested parties, particularly the radiographers and clinicians
- **Monitor procedure**



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Worked example in CT: Multi phase Liver Procedure

- Initial preparation:
  - A review of the frequency and dose estimates for CT was made.
  - The results were discussed with radiologists and senior radiographer in CT.
  - A new algorithm to suppress noise was available so it was decided to optimize the multi phase liver procedure using this algorithm
  - This procedure was also selected because the multi phase nature allowed the possibility of comparing phases with and without the use of the new algorithm

CT exam frequency

Count of Exam Description from 01/01/04 to 26/4/04

Exam description	Number	%	cum %
CTB Brain	1103	33.53	33.53
CTA Abdo & Pelvis +/- IVC	285	8.66	42.19
CTA Abdo & Pelvis	251	7.63	49.82
CTC Chest Abdo & Pelvis	202	6.14	55.96
CTC Chest	194	5.90	61.85
CTS Spine Cervical	172	5.23	67.08
CTC Chest PE Study	108	3.28	70.36
CTC High Res Chest	96	2.92	73.28
CTA KUB	88	2.67	75.96
CTA Liver Multiphase	78	2.37	78.33
CTI Interventional Procedure	73	2.22	80.55

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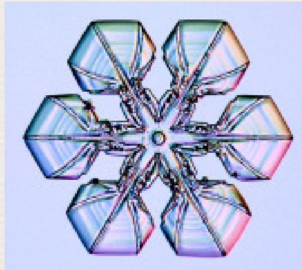
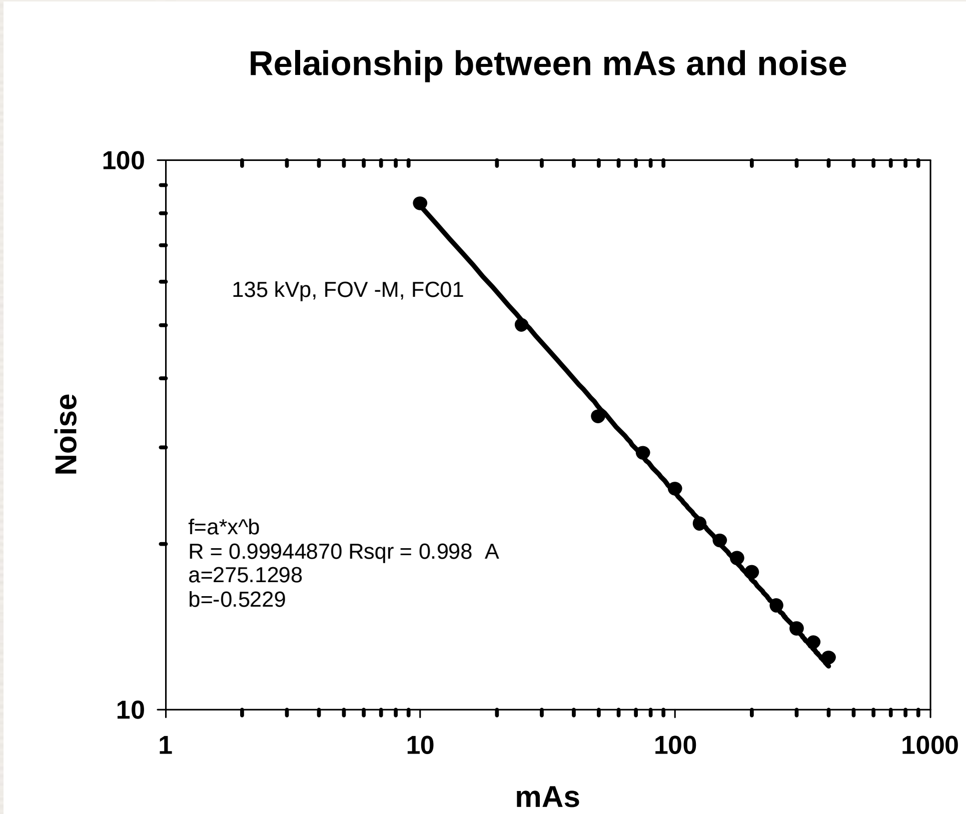
Comparison calculated doses with benchmarks

CTExpo - V1.2.1						Impact	DRL - NRPB 1999		McLean - Moss survey - Australia - 2004		
Exam description	CTDIw, eff	DLPw*	E*male	E*female	Duterus*	Duterus*	CTDIw,eff	DLPw*	E*male	E*female	DLPw*
CTB Brain		**1023.21**	2.33	2.35	0.00	0.00	60	**1050**	2.48	2.53	970
CTA Abdo & Pelvis +/- IVC	19.41	853.88	13.00	18.24	37.54	29.00					
CTA Abdo & Pelvis	19.41	853.88	13.00	18.24	37.54	29.00			10.44	14.7	700
CTC Chest Abdo & Pelvis		1280.64	20.10	26.58	38.29	29.50					
CTC Chest	10.4	427.00	7.10	8.3	0.8	0.00	30	650	6.11	7.41	430
CTS Spine Cervical	59.94	599.42	3.28	3.51	0.00	0.00					
CTC Chest PE Study	23.3	559.00	8.30	6.20	0.00	0.00					
CTC High Res Chest		141.80	1.94	2.35	0.01	0.00			1.20	1.45	84
High res CT (3 series)		242.45	3.94	4.93	0.02				1.20	1.45	84
CTA KUB	19.41	853.88	13.00	18.24	37.54	29.00					
CTA Liver Multiphase		989.73	**19.18**	**21.60**	4.15	3.60					

Dose & Image Quality Assessment with phantom

- Noise measurements were made as a function of dose
- Use of new algorithm showed there was a 30% reduction in dose with no change in noise.
- It was recognised that resolution might be compromised, however it was not possible to measure this accurately
- It was agreed that a clinical intervention take place with the new algorithm (ethics approval granted)





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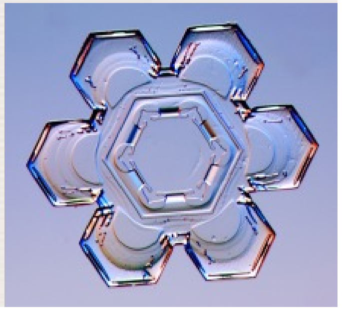
Review of current status of procedure

- 25 patients were trialed with the new algorithm applied for one phase at lower dose
- The resultant series was scored by 2 radiologists and 2 registrars in a blind trial using EC quality criteria
- It was shown statistically that the normal and low dose images were not distinguishable by the observers
- Concluding that the dose reduction was acceptable



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"… lifetime cancer mortality risk attributable to the radiation exposure from a single abdominal CT examination in a 1-year-old child is approximately 1 in 550 …"

"Endangered Species"
Szikora

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Brenner *et al.* AJR, 2001; 176: 289-296

How well do we examine children in CT

Effective dose for paediatric male patients				
	8 week Abdomen & pelvis - routine	7 year Abdomen & pelvis - routine	8 week Chest routine	7 year Chest routine
Average	**6.82**	**10.65**	**4.59**	**6.57**
Std dev	6.07	6.81	5.11	5.15
Max	26.65	28.07	19.25	21.72
Min	0.73	1.25	0.24	0.44
Count	25	38	26	35

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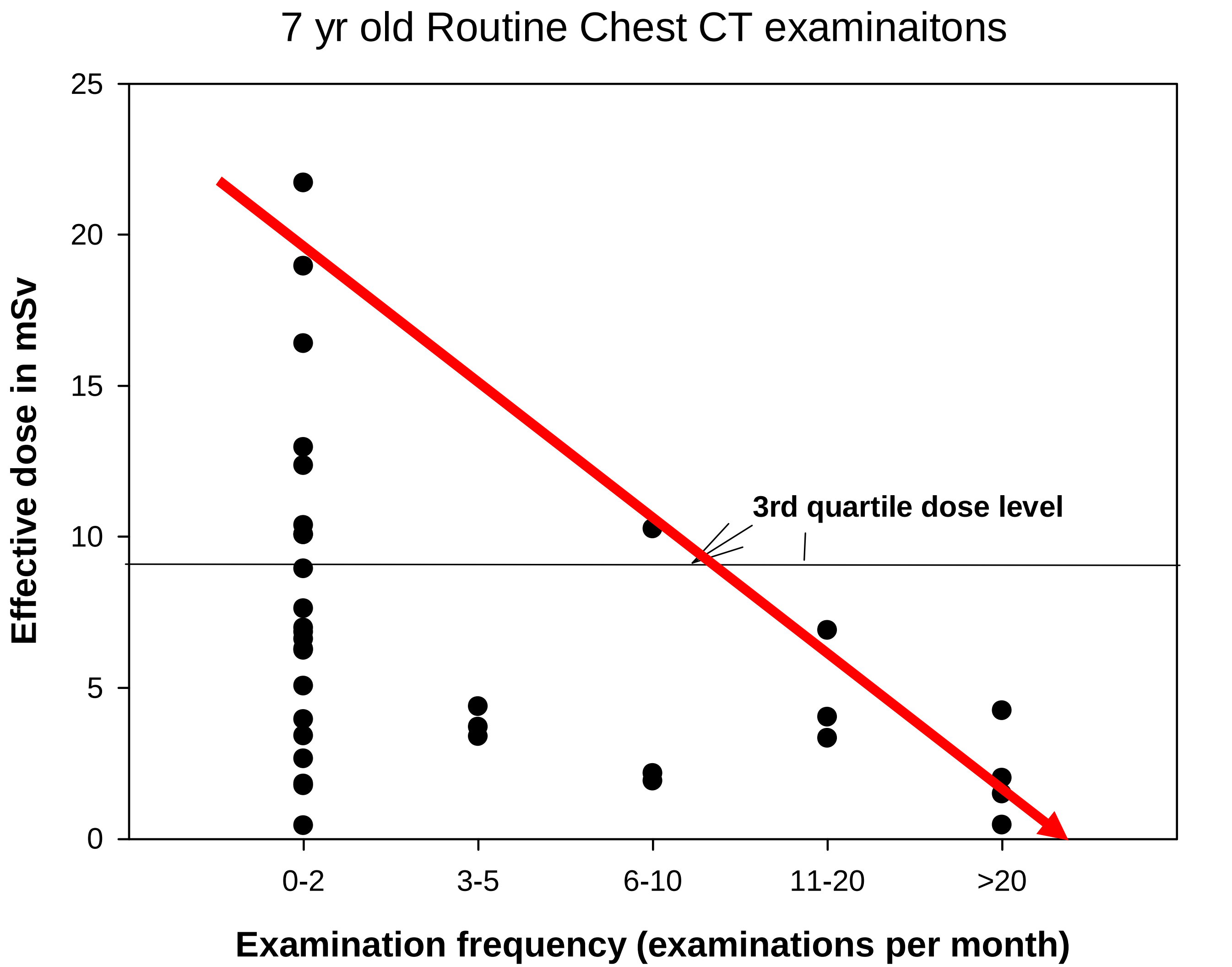
Trend for ↓ dose with ↑ exam freq



Factors are reduced for patient age

Procedure	Age	kVp	mAs	% drop	eff mAs	% drop	Pitch
CT Abdo & pelvis	Adult	124.41	209.07	100.00	177.59	100.00	1.26
	7 year	120.88	123.04	58.85	108.91	61.33	1.29
	8 week	118.08	67.63	32.35	53.76	30.27	1.41

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Moss McLean Australasian Radiology (2005) 50, 33-40

Optimization for children

- *Establish baseline techniques for an adult head and abdomen CT.*
  - *determine the C_{vol} for an adult body phantom and an adult head phantom*
  - *C_{vol} of the adult abdomen or head phantoms should not exceed DRL (25 and 75 mGy typically)*
- *Determine the appropriate mAs for a paediatric thorax, abdomen and head CT*

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mAs Reduction Factors for the Paediatric Abdomen and Thorax

Room #: ____________ **CT Unit:** ________________ **Date:** ________________

Abdomen Baseline:	kVp	mA	Time (sec)	Pitch Abdomen	Pitch Thorax
	fill in	fill in	fill in	fill in	fill in
		Abdomen		Thorax	
PA Thickness (cm)	**Approx Age**	**mAs Reduction Factor (RF)**	**Estimated mAs = BL x RF**	**mAs Reduction Factor (RF)**	**Estimated mAs = BL x RF**
9	newborn	0.43		0.42	
12	1 yr	0.51		0.49	
14	5 yr	0.59		0.57	
16	10 yr	0.66		0.64	
19	15 yr	0.76		0.73	
22	small adult	0.90		0.82	
25	med adult	1.0	fill in	0.91	
31	large adult	1.27		1.16	

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Reduction Factors for the Paediatric Head

Room #: ________ **CT Unit:** ____________ **Date:** ____________

Head Baseline:	kVp	mA	Time (sec)	Pitch	Filter
	fill in	fill in	fill in	fill in	fill in

PA Thickness (cm)	Approx Age	Head	
		mAs Reduction Factor (RF)	Estimated mAs = BL x RF
12	newborn	0.74	
16	2 yr	0.86	
17	6 yr	0.93	
19	med adult	1	fill in

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Thank you for your attention