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Dose Reference Levels

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IAEA Training Course on Medical Physics in Diagnostic Radiology
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Diagnostic Reference Levels (Guidance Levels)

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Relation of image quality and dose

- If an imaging task is optimized, higher dose results in better quality images
  - Better spatial resolution, because lower speed screen film combinations used
  - Better signal to noise ratio in digital images → better visibility of low contrast structures
- This is not the case in situations, where imaging parameters are not optimized. Examples:
  - Inappropriate technique factors, e.g. too low kVp in chest
  - Images routinely shot too dark
  - Inappropriate film chemistry (e.g., to little regeneration)
  - → will produce poor images with higher doses
- In situations where high doses are used,
  - images produced can even be of low diagnostic quality
  - or “better” than necessary for a sound diagnosis (→ indication based imaging)

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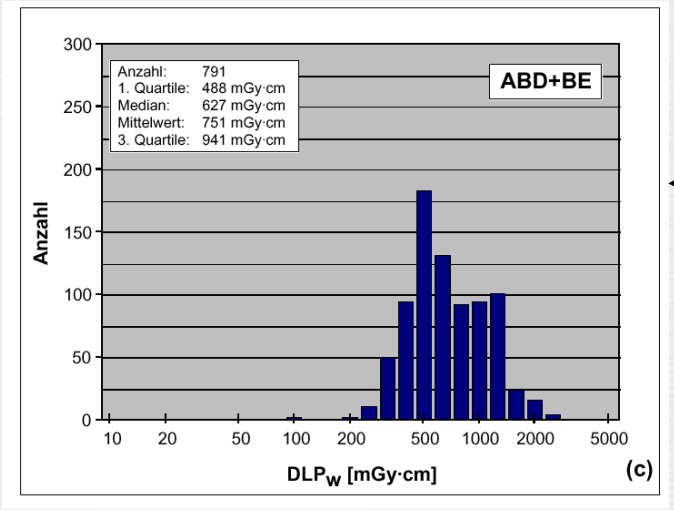
Typical dose distributions

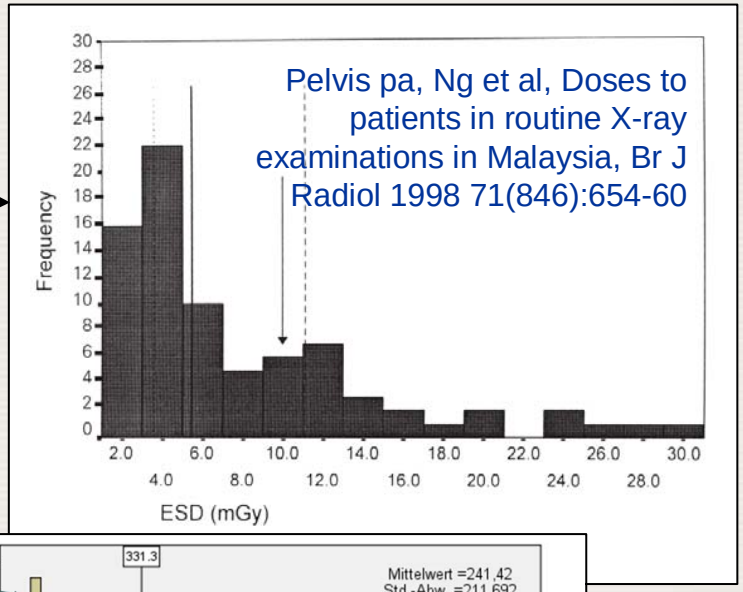
". . . even now, order of magnitude variations in patient doses are possible for the same diagnostic examinations " CoP, Appendix VII

- Numerous examples can be found in the literature:

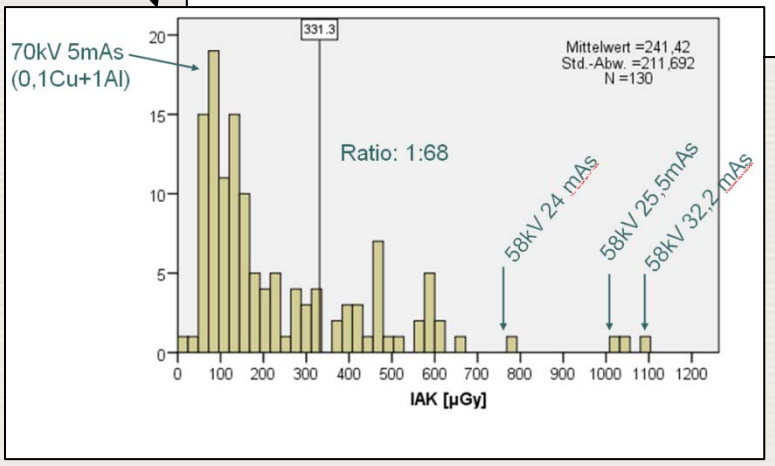


CT of abdomen and Pelvis, from Galanski et al. 1999
CT Expositionspraxis in der Bundesrep. Deutschland

Individual patients



Pelvis pa, Ng et al, Doses to patients in routine X-ray examinations in Malaysia, Br J Radiol 1998 71(846):654-60



Skull x-ray of 1year olds in Austria, Billinger and Homolka, 2008

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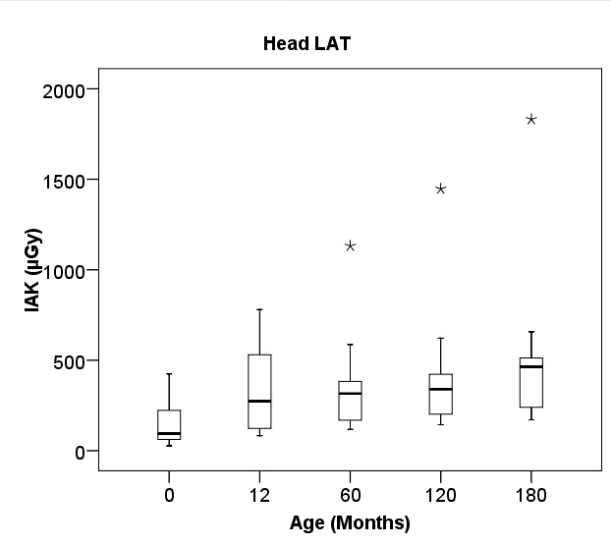
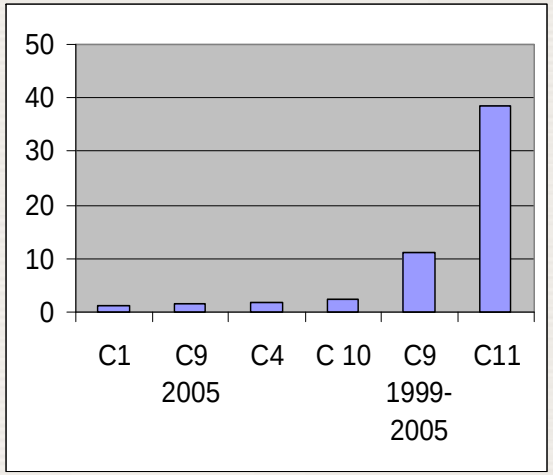
Variation in average patient doses

- Variation in individual patient doses is higher than variation in average doses, i.e. average doses typically used by a hospital for a standard examination (in projection radiography typically by a factor 5, much more in fluoroscopy)



Skull x-ray in children in Austria, Billinger and Homolka, 2008

Thorax x-ray of newborns, P_{KA}, Smans et al, Results of a European survey on patient doses in paediatric radiology, Rad Prot Dosim 129 (2008) 204-10



Factor > 10 is also found in average doses

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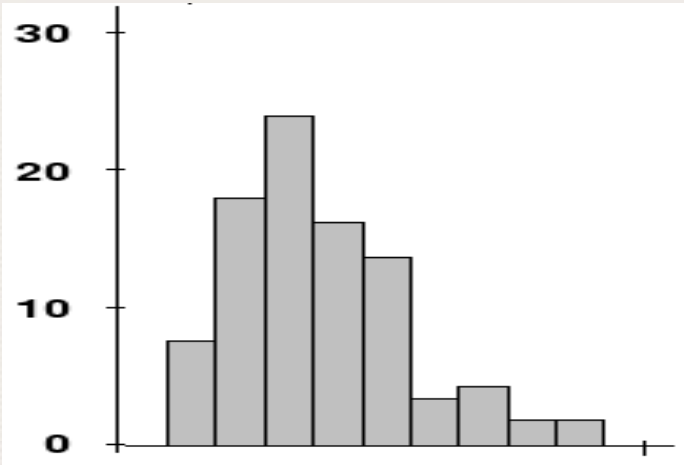
Diagnostic Reference Levels

- Typical dose distributions are right-skewed asymmetric distributions
  - Some users apply uncommonly high doses



- Reference values cannot be applied to judge appropriateness of dose to a *individual* patient
  - Individual patient doses exhibit a much higher variation than average doses
  - Use of dose limits is inappropriate in diagnostic radiology

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What are DRLs, and what are they not?

Basic concept

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Application of DRLs

- Values of measured quantities **above which** some specified action or decision should be taken
  - → Values must be specified
    and
  - Action must be specified

- DRLs will be intended for use as
  a convenient test for identifying
  situations where the levels of patient
  dose are unusually high.

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Guidance level for medical exposure (as defined by the BSS) are

- A value of applied dose, dose rate or activity to the patient for standard examinations
- to indicate a **level above which** there should be a review by medical practitioners in order to determine whether or not the value is excessive, taking into account the particular circumstances and applying sound clinical judgement
    - Does this mean in case of using higher doses on one patient or on average?
- selected by professional bodies in consultation with the Regulatory Authority

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What are DRLs

- a basis for the review of dose values applied
- dose values not exceeded on regular base, provided good radiographic practice is applied
  - for standard patients
  - undergoing standard diagnostic and interventional procedures
- DRLs serve as a means to identify situations where patient doses are unusually high

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What are they NOT?

- Static → DRLs require continuous updating
- DRLs are no limiting (maximum) values; the definition of dose limits is not appropriate in diagnostic radiology (ICRP 105 and others), and DRLs have to be applied with some flexibility, because in some individual situations application of higher doses can be required (ICRP 60)
- DRLs do not provide a guidance on the reason or a remedy in case they are exceeded
  - Instead: exceeding of DRLs triggers investigation
- A *carte blanche* that
  - image quality is appropriate
  - the examination is performed at an optimized dose level
- Provide a possibility for individual dose estimation

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Suitable dosimetric quantities for DRLs to be expressed as

- DRLs should be defined in easily assessable quantities
  - K_i
  - K_e
  - Incident kerma rate (fluoroscopy) (BSS)
    - Note: incident to patient, not incident to image intensifier or flat panel detector
  - P_{KA}, for fluoroscopy and GR (alternatively to K_i or K_e)
- CT: CT Air Kerma Index: C_{VOL}(CTDI) and/or CT Air Kerme Length Product $P_{KL,CT}$ (DLP)

- Effective dose or organ dose is usually not a suitable quantity, despite in mammography: MGD
  - In mammo entrance dose was widely used. New beam qualities and K-edge filter materials (as silver, e.g.) will be a good argument to change to mean glandular dose
- Also not suitable
  - Fluoroscopy time

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For which examinations and procedures should reference levels be defined?

- DRLs can only be defined for standardizable procedures to ensure to compare apples with apples

- DRLs should be defined for frequently performed procedures and are most important for potentially high dose procedures

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Introduction and determination of appropriate DRLs

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Definition of DRLs

- For first time definition of DRLs using the 3rd quartile of doses is recommended (ICRP, BSS)
- Institutions applying constantly average doses that exceed these, with which 75% of all institutions produce images (conduct interventions) and regard image quality appropriate for diagnostic confidence (interventional outcome), can be regarded as using unusually high doses
- → Image quality is not an issue in this approach!!
- → normally optimum dose values will be considerably lower than DRLs (although this depends on the histograms)
  - can be judged by looking at inter-quartile ranges, e.g.
- When updating DRLs, application of 3rd quartiles may not be appropriate (at some stage, review of clinical image quality and optimization potential may be a good idea. As before, dose histograms can provide some insight).

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How to derive reference levels

- DRLs are provided by
  - IAEA (BSS – old)
  - ICRP (102 for CT, e.g.)
  - European guidelines and publications (Radiation protection 109, e.g.)
  - National recommendations and regulations (NRPB and others)

- However, these DRLs may not necessarily be appropriate for all member states since
  - Diagnostic procedures may be differently defined (example: abdomen CT may be abdomen plus pelvis)
  - Available hardware and expertise may be different (different radiological devices or procedures may involve different dose levels)

  - → differences in DRL values between regions/member states

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Example of variation in DRLs between member states

Abdomen x-ray	Austrian DRL (P_{KA} in µGym²)	German DRL (P_{KA} in µGym²)
Newborns	6	
1 year	9	25
5 years	20	50
10 years	50	60
15 years	70	

Since doses found in a dosimetric survey were lower, no need to adopt the higher existing ones was seen

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DRL values - GR

Examination	**Entrance surface Air Kerma(Ke) per radiograph [mGy]**					
	Guidence level (IAEA)	Germany 2003	EU RadProt.109	Spain	UK 2002	Austria
Abdomen ap	***10***	10		10	6	8
Pelvis ap	***10***	10	10	10	4	6
Chest pa	***0,4***	0,3	0,3	0,3	0,2	0,3
Chest lat	***1,5***	1,5	1,5	1,5	1,0	1,2
Lumbar spine ap	***10***	10	10	10	6	10
Lumbar Spine lat	***30***	30	30	30	14	16
Skull ap/pa	***5***	5,0	5,0	5,0	3,0	4
Skull lat	***3***	3,0	3,0	3,0	1,5	3

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Reference levels for CT examinations

- Can be expressed in different quantities, like $C_W(CTDI_w)$, $C_{VOL}(CTDI_{vol})$, $P_{KL,CT}(DLP)$
- Should represent hole examination
- Preferably DLP (includes dose from bolus tracking, accounts for number of phases, scan lengths, etc.)

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Fluoroscopy

- Reference levels should be an integral dose quantity representing the whole examination
- Well suited: P_{KA}, including fluoro and images taken
- P_{KA} can be measured or calculated from generator data and collimation
- May be accompanied by dose rate values (incident air kerma rate)
    - Incident air kerma rates should be specified on phantoms rather than patients

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Paediatric reference values

- DRLs need to be defined for different groups
  - By size (height, weight): better correlation, but hard to apply
  - By age: easier to use in clinical practise, and therefore recommended
  - Age bands: variation of dose within clinics is larger than between smaller and older children → children grouped into age bands, average doses are then compared to dose reference corresponding to upper limit of the age band (e.g., 5 to 10 year olds to guidance level corresponding to a typical 10 year old, etc.)
- Typically age bands: newborns, 0-1 year, 1 to 5, 5 to 10, 10 to 15

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Guidance (or reference) levels
Practical aspects

- Still, a sound diagnosis is the first priority. Nevertheless, pronounced and frequent exceeding of reference levels indicates that with the equipment or procedure something is wrong

- DRL should always be applied in parallel to image quality evaluation (appropriate information for diagnosis shall be obtained)
  - Note: this is not in contradiction to the assumption that for defining reference values, image quality need not be an issue

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Issues under discussion

Open and controversial issues

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Is it appropriate to use DRLs for regulatory purposes?

- ICRP 73: *"Diagnostic reference levels are supplements to professional judgement and do not provide a dividing line between good and bad medicine. It is inappropriate to use them for regulatory or commercial purposes"*
- ICRP 103: "Dose constraints for patients are therefore inappropriate, in contrast to their importance in occupational and public exposure. Nevertheless, some management of patient exposure is needed and the use of diagnostic reference levels is recommended in Publication 73 with further guidance in Supporting Guidance 2"
  - The latter states:
- The purpose is advisory . . . diagnostic reference levels are not for regulatory or commercial purposes, not a dose constraint, and not linked to limits or constraints.
- Euratom 97/43: *"Member States shall ensure that appropriate local reviews are undertaken whenever diagnostic reference levels are consistently exceeded and that corrective actions are taken where appropriate"*
  - → Authority shall ensure corrective action is taken where appropriate → legislation →
- European radiation safety regulations usually require users of medical x-ray equipment to demonstrate that DRLs are on average not exceeded on regular basis for standard patients
  - → this is "regulatory use of DRLs" – but not as constraints or limits

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DRLs for different technologies

- Is it appropriate to define different DRLs for different technologies used for the same examination?
  - Pro: as long as different technologies are in use and are known to require different dose levels for appropriate image quality, each should be optimized
  - Con: if a technology cannot comply with DRLs it should not be used
  - Pro: setting DRLs to 75th percentile from a survey not differentiating between these technologies may result in image quality reduction below diagnostic requirements for the technology with higher dose requirements and be counterproductive
- Very careful consideration of possible impact advised, necessary to take socio-economic factors into account

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Reference levels for infrequently performed examinations and procedures

- Most important example: children
- Pro: No carte blanche to be issued if a centre performs some examinations infrequently
- Pro: typical dose levels for all – including the infrequent procedures – should be determined and compared to typical doses used by others
- Con: difficult to get enough data for both – definition of reference levels and patients for checking compliance with reference levels
  - Especially a problem in examinations/procedures where patient to patient variations are high, as in fluoroscopy
- Con: some infrequently performed procedures may be difficult to standardize
- Con: checking doses for the most common examinations may be regarded sufficient assuming that institutions applying good radiographic techniques associated with low or appropriate dose will do so also for the less frequently performed examinations (within the same modality)
  - This cannot be assumed in case if paediatric radiography. Institutions using optimized protocols for adult radiography may still be using extremely high doses for children

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To conclude…

- Comparisons with DRLs at national & local level can be very useful in assessing patient doses & indicating areas for optimization
- Comparing doses with DRLs necessitates users know their doses
  - This is very important, because practice has shown that the most often encountered situation where unusually high doses are used, is that the user has no idea about the dose applied → knowing is the 1st step towards optimization
- Be aware of uncertainties in the data (& in the DRLs)
- If only few patients' exposure data are available to compare to DRLs you may need to check if these patients are really "standard patients" with respect to size (and complexity of procedure for interventional radiology)
- Look at recorded technique data for indication of why doses are high (or low!)
- Be prepared to check methodology & assumptions

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Thanks to

- This presentation was compiled by several authors. Credits belong especially to

- Claire-Louise Chapple
- Donald McLean

Dose is the currency in which diagnostic information in x-ray imaging is paid for. Optimization means getting a good deal.

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