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Radiation Dose and Image Quality in Fluoroscopy
AAPM 2018, Nashville

Fluoroscopy Technology Tomorrow

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Scope of this talk

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Topic
“Fluoroscopy Technology Tomorrow”

My interpretation
“Dose and image quality related topics of interest for Medical Physics Experts (MPE) to come in the next few years”

Challenges
Hard to tell what is really coming
Knowledge about competition
Internal company policies restricting information sharing

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Dose optimization for the patient
AEC: Typical operation

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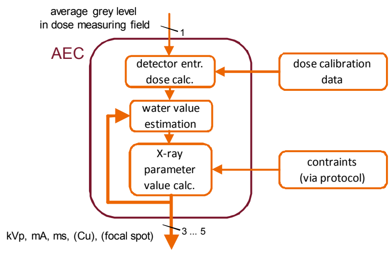
„Water Value“
Equivalent water thickness of object in the beam



Dose optimization for the patient
AEC: Typical copper pre-filtration

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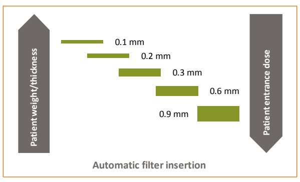
- Variable copper pre-filtration (0.1 mm – 0.9 mm)
- Automatically set according to the absorption of the X-ray beam by the patient
- Always maintain the lowest possible patient entrance dose without degrading image quality
- No user interaction required



Dose optimization for the patient
AEC: Focal spots

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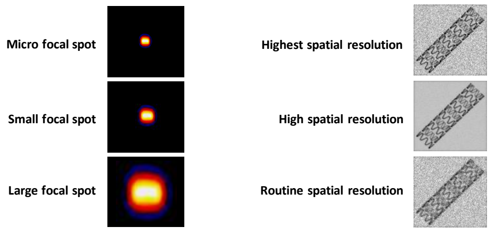
The smaller the focal spot, the lower the patient entrance dose



Dose optimization for the patient
AEC: Auto-adjust for "patient thickness"

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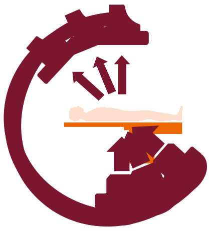
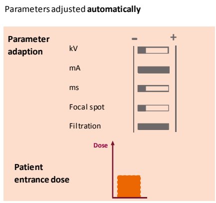
Automatic Exposure Control of a typical C-arm system





* M Dehairs et al 2017 Phys. Med. Biol. 62 6610

Dose optimization for the patient
AEC: Optimization for material of objects of interest

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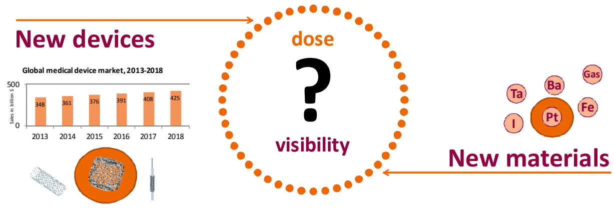

Source: Copyright © 2014 Kalorama Information, LLC; Global Market for Medical Devices, 5th Ed.

Dose optimization for the patient
AEC: Optimization for material of objects of interest

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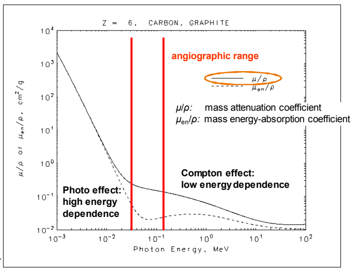
Example
Absorption over photon energy for:
Carbon

- Mainly Compton effect
- Mass absorption shows a weak variation over photon energy



Source of diagram: NIST

Dose optimization for the patient
AEC: Optimization for material of objects of interest

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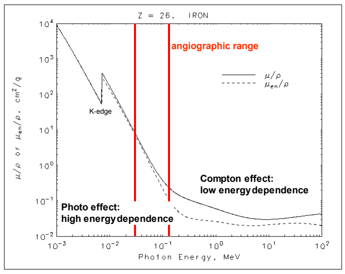
Example
Absorption over photon energy for:
Iron

- Mainly photo effect
- Mass absorption shows a strong variation over photon energy
- K-edge: 7.1 keV

Note:
- Iodine, K-edge: 33.2 keV
- Barium, K-edge: 37.4 keV



Dose optimization for the patient
AEC: Optimization for material of objects of interest

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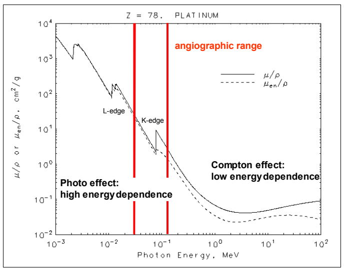
Example
Absorption over photon energy for:
Platinum

- Mainly photo effect
- Mass absorption shows a strong variation over photon energy
- K-edge: 78.4 keV
- L-edges: 11.6 … 13.9 keV



Dose optimization for the patient
AEC: Basic operation

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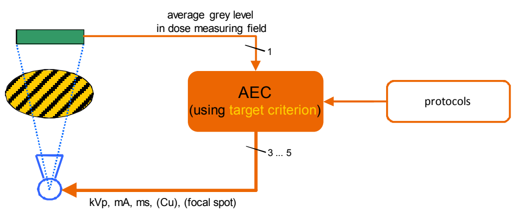
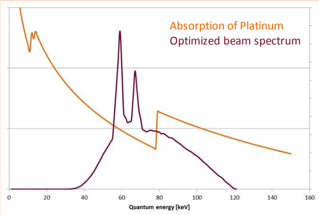


Dose optimization for the patient
AEC: Optimization for material of objects of interest



Idea:
- Adjust the beam spectrum to the absorption characteristics of the material of the object of interest
- Goal: Max. dose efficiency by optimal absorption

Implementation:
- New target function (FOM *)
- Optimization using pre-calculated database

Results *:**
- AEC applying new FOM vs. "const. det. entrance dose" can significantly increase imaging efficiency (e.g. 16%, 165%, 164% for iron, tantalum, platinum @ 20 cm WET **)

*** Dehairs et al, RSNA 2017, SSQ19-09

* FOM: figure of merit
** WET: water equivalent thickness = patient thickness

Dose optimization for the patient
AEC: Optimization for material of objects of interest

Summary
- Idea: AEC optimizes X-ray parameter values for material depended dose efficiency
- Results based on phantom
  - Baseline for comparison: AEC using const. detector entrance dose
  - Biggest benefit for material with high atomic numbers (e.g. tantalum, platinum)
  - Even significant benefit for iron (and iodine)

Implication for Medical Physics Experts
- Complex underlying physics
- New AEC criterion is more difficult to test

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Dose optimization for the patient
Clinical procedures, workflow and dose saving potential

Customized system

Dose saving potential

Hardware, Algorithms, Features
- Tube
- Detector
- Image processing
- AEC (Automatic Exposure Control)
- Dose monitoring
- ...

Customization / Configuration
- Protocols (fps, pps, dose, wake-up, ...)
- Config. of features
- ...

Usage / Workflow
- Protocol selection
- Acquisition vs. Fluoro
- X-ray on-time
- Collimation
- Patient - detector distance
- C-arm angles
- Dose control ...

Implementation time

Manufacturer **Application specialist** **User**

Dose optimization for the patient
Clinical procedures, workflow and dose saving potential

Summary
- Three levels of improvements in regards of dose saving:

Hardware, algorithms:	Manufacturer	long term improvements	moderate dose saving potential
Protocols:	Application spec.	short term tuning	medium dose saving potential
Clinical workflow:	User	immediate adjustments	high dose saving potential

Implication for Medical Physics Experts
- Dose analysis provides an overview (intra / inter institutional)
- Learn clinical requirements and typical workflows
- Enforce installation of dose saving features (incl. protocols)
- Enforce usage of dose saving features

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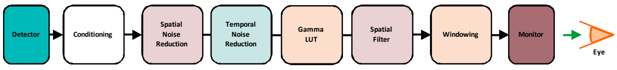
Dose reduction by image processing
Introduction

Typical image processing pipeline



Basic processing blocks:
- Look-up tables, windowing
- Spatial filters
- Temporal filters
- Any combinations

Basic goal:
- Transfer maximal information from detector into the eye / brain
- Consider the channel to the eye

Challenges:
- Grey level dynamics and resolution
- Spatial resolution
- Temporal resolution
- "Relevant information"

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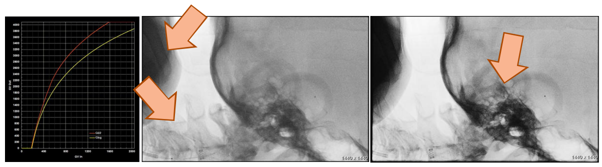
Dose reduction by image processing
Introduction

Challenges (e.g. Gamma)



Source images: Courtesy of Univ. of St. Gallen, CH

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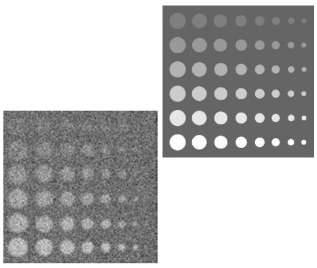
Dose reduction by image processing
Introduction

CNR (Contrast to Noise Ratio) vs. "Information"

More photons (i.e. higher dose) per image increase CNR (restrictions apply!)

Any other ideas to increase CNR (w/o increasing dose)?

→ Spatial filtering ?
→ Temporal filtering ?



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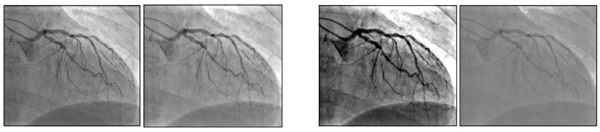
Dose reduction by image processing
Introduction

Virtual dose saving via spatial filtering / intra-frame processing
- Spatial noise reduction can increase CNR
  → „Virtual dose saving", but: Effect on signal / relevant information!
- "Thresholding" can "eliminate" noise and increase CNR
  → But: Effect on (small) signals , artifacts
- Gamma LUT / windowing / harmonization adjusts channel to the eye
  → Significant effect; important features



Courtesey of Univ. of St. Gallen, CH
Courtesey of Univ. of Erlangen, DE

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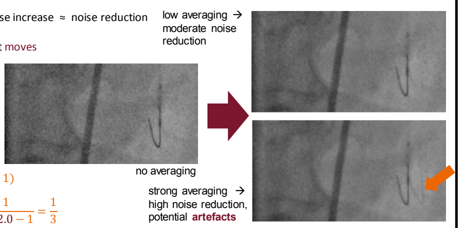
Dose reduction by image processing
Introduction

Virtual dose saving via temporal filtering

Temporal averaging → virtual dose increase ≈ noise reduction

But: Risk of *artefacts* when object moves



$$y(t) = \frac{1}{k}\,x(t) + \left(1 - \frac{1}{k}\right)\,y(t-1)$$

$$\sigma_{avg}{}^2 = \frac{1}{2k-1}\,\sigma^2;\ \text{e.g.:}\ \frac{1}{2*2.0-1} = \frac{1}{3}$$

Images: Courtesy of Univ. of Erlangen, DE

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Dose reduction by image processing
Some statements…

Virtual dose saving via temporal filtering
- Method only works when there is "no motion" → addl. a-priory knowledge needed → assumption(s)
  - Movement detection: discrimination of signal and noise needed → noise threshold
    → assumption(s); might work fine for "strong" signals
- Signal energy is distributed over several frames
  → better choice: one frame at higher dose? Work-around for weak tube?
  - CLEARstent, StentBoost, etc. (i.e. register, auto-shift / -rotate / -scale, average): assumption(s)

Virtual dose saving via spatial filtering
- Method work only for a "well-designed signal model" → addl. a-priory knowledge needed → assumption(s)
  - Discrimination of signal and noise needed → noise threshold → assumption(s); might work fine for "strong" signals
  - Artefacts and loss of (small) signal may result

Conclusion
→ There is <u>no</u> general "dose saving by spatial or temporal averaging"
Methods work fine with addl. a-priori knowledge / assumptions given
Methods fail if assumption is not fulfilled

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Dose reduction by image processing
Goals for processing

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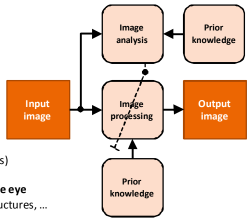
Adjust image processing to the clinical task
- Establish a-priori knowledge for the specific clinical task
  - → configure image pipeline → dedicated protocols
  - → use dedicated protocols
- Consider (image) context
  - Image analysis using large areas
  - Multiscale approach
  - Model-based approach (for finding devices, like wires and stents)

Optimize image presentation according to information channel to the eye
- Grey level dynamics, contrast (coarse and detail), noise, size of structures, …

Create image presentation "the user is used to" / the user prefers
- Image presentation is subjective
- There is no "one fits all"



Dose reduction by image processing
Implication for MPEs

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Test methods
- Image processing goes context sensitive → Think about your test method (in detail)!
- Usage of Images for Processing ("raw"):
  - Robust and reproducible measurement to be expected; good for a standardized basic test
- Usage of Images for Presentation ("processed"):
  - Reflects the clinical task / clinical performance; good for comparison of systems

Test objects (testing clinical performance)
- Consider highly adjustable and adaptive temporal filtering (with motion detection)
- Consider highly adjustable and selective for spatial filtering
- Consider signal-noise discrimination and thresholding

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Summary and outlook

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Take-home messages
- AEC: Material specific beam spectra increase dose efficiency
- Strict application of ALARA principle during clinical workflow offers big dose saving potential
- Dose saving via image processing requires a-priori knowledge and assumptions; use context information

Outlook for the "day after tomorrow"
- AEC: More sophisticated optimization criteria, that optimally reflects the user's need
- Image processing: Increased use of image context / image analysis
- General: Strong connection to different data sources to create context information for optimal adjustment of X-ray and image processing components

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Thank you!

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Image Quality

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