Optimisation of image quality and patient dose in radiographs of paediatric extremities using direct digital radiography

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The Image Quality Issue

- Issues with image quality (IQ) of infant (0 – 1 years) extremity radiographs – “blurry”, “flat” & “noisy”
- Default protocols still follow 1996 European Commission guidelines\(^{(1)}\) for film-screen
- High $kV_p$ & added Copper filtration
- Digital detectors (DDR) offer a number of advantages
- Time for change?
- A white paper from Philips\(^{(2)}\) indicating low $kV_p$ & no added filtration

\(^{(1)}\) Rep. EUR 16261, EN, 1996.
\(^{(2)}\) Hess R, Neitzel U. Optimizing image quality and dose for digital radiography of distal pediatric extremities using the contrast-to-noise ratio
Aim: Dose Vs. Image Quality

- Can the exposure parameters be changed to result in an improved IQ?
  - Lower kV and no Cu filtration
  - Improved Inherent contrast - higher proportion of interactions via the Photoelectric Effect
  - Only ~ 10% reduction in receptor dose by lowering $kV_p$ (57 to 40)

- Can this improvement in IQ be achieved whilst keeping the patient dose fixed?
  - Only critical organ in the beam is the red bone marrow
  - Paediatric extremities offer little attenuation:
    - Lower energy X-Rays contribute to image formation as they are not absorbed in the patient
Patient Dose:

- Effective Dose ($E$) – correlates with the risk of radiation induced stochastic effects
- Monte Carlo simulation using PCXMC v2.0 software
- $E$ for a lateral ankle of 1 year old patient and a fixed input air Kerma

Image Quality:

- Require high contrast and low noise
- Contrast-to-Noise ratio (CNR)
  - $CNR = \frac{S_1 - S_2}{\sigma_1}$
  - where $S_1$ & $S_2$ are the signals in Regions 1 & 2 and $\sigma_1$ is the noise in Region 1
Phantom Study: Exposure Parameters

- Infant foot phantom:
  - Real skeletal structures
  - Water equivalent mould

- Default parameters for < 1 y.o lateral ankle - $55\,kV_p$, 0.1 mm Cu. & 1.4 mAs

- Parameters investigated:
  - 40, 45, 50, 55, 60 & 64.5 $kV_p$
  - With and without 0.1 mm Copper
Phantom Study: Fixed Effective Dose

- Fixed E to that given by default exposure parameters

- Fix E by modulating the set mAs for variance in:
  a. Tube output
  b. Computed E

- 12 images each acquired at the same E and therefore same risk to the patient
Phantom Study: CNR Quantification

- CNR between tibia and adjacent soft tissue:
  - $\text{CNR} = \frac{(S_1 - S_2)}{\sigma_1}$

- $\text{CNR}_{\text{cor}}$ : corrected CNR for discreet mAs stations available
  - $\text{CNR}_{\text{cor}} = \text{CNR} \times \sqrt{\frac{mAs_{\text{calc}}}{mAs_{\text{set}}}}$

- Requires a quantum noise limited system:
  - Maximum peak DQE deviation of 15% between doses 0.91 to 9.31 $\mu$Gy

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Phantom Study: CNR Results

Fixed Effective Dose

- No Cu
- 0.1 mm Cu

CNRcor vs Tube Potential (kV)
CNR Comparison

- Highest and lowest CNR measurements simulated on *ImageJ*

\[ \text{CNR} = 12.0 \quad \text{CNR} = 6.3 \]
Phantom Study: Subjective Clinical IQ

- Phantom images were scored by 3 consultant radiologists and 1 reporting radiographer
- IQ was assessed based on European CEC guidelines
- 3 point scoring scale for sharpness, noise, cortex/trabecular pattern & overall acceptability

- 12 Images in total:
  - 40, 45, 50, 55, 60 & 64.5 kV$_p$
  - No Copper & 0.1 mm Copper
  - The mean total score across all 4 observers was calculated
Phantom Study: Clinical IQ Results

Fixed Effective Dose

Mean Total IQ Score vs. Tube Potential (kVp)

- No Cu
- 1mm Cu
Discussion (1)

Optimum Beam Quality:

‘40 kV_p & no added Copper filtration’

This has been confirmed with:

a. Quantitative CNR phantom measurements  
b. Subjective phantom clinical image quality scores
1. Old European Guidelines recommend additional filtration for all pediatric imaging. However:

- There are no critical superficial organs in pediatric extremities

- Deterministic effects not a concern in planar radiography
2. Paediatric extremity provides little attenuation:
   - Smaller fraction of low kV X-rays absorbed in patient
   - ↑ inherent contrast and ↑ image quality
   - Receptor dose variation within 20% of default for all beam qualities used

3. Lower beam quality does not increase E:
   - No critical radiosensitive organs – fraction of red bone marrow
   - For a fixed air Kerma: E for 55 kV + 0.1mm Cu is almost double E for 40 kV and no Cu
     - i.e. lower E for the lower energy spectrum
Verification of Optimised Beam Quality

- Final verification on real clinical images of post mortem babies
- 5 observers (4 radiologists and 1 reporting radiographer) each scored 10 lateral ankle images acquired using both the default and optimised beam quality
- Mean Total IQ scores of all 5 observers across each of the two sets of 10 images:
  - Default (55 kV<sub>p</sub>, 0.1 mm Cu.): 7.9 (σ = 0.9)
  - Optimised (40 kV<sub>p</sub>, no Cu.): 11.6 (σ = 0.3)
- Mann-Whitney U-Test: probability results obtained if no difference in the images is < 0.1 %
Conclusions

- Infant distal extremities:
  - ‘40 kVp & no additional Copper filtration’
  - Better IQ with no dose penalty
  - Reduction in the number of repeats & less ‘wasted’ dose on ‘un-diagnostic’ images

- Being widely adopted in the U.K, Europe & Australia
- Published in BJR, March 2015
DIY Methodology

- **Check Image Quality at lower beam quality with fixed E**

1. Check local default protocol: kV, filtration and mAs
2. Measure output (µGy) at fixed distance and fixed mAs for a) default beam quality, b) 40 kV<sub>p</sub> & no Cu.
3. Compute E at fixed incident air Kerma for a) default beam quality, b) 40 kV<sub>p</sub> & no Cu.
4. Calculate the mAs modulation ratio (M):

\[
M = \frac{output_{\text{def}}}{output_{40}} \times \frac{E_{\text{def}}}{E_{40}}
\]

5. The mAs required for the 40 kV<sub>p</sub> & no Cu beam quality:

\[
m\text{As}_{40} = M \times m\text{As}_{\text{default}}
\]

- Will see an improvement if Copper filter used as default
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References mentioned in text:

