Image gently: Image quality and dose assessment in portable CXR in the NICU and PICU before and after implementation of a high-kVp technique

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Introduction

• Neonatal radiography is an essential tool in the care of patients in neonatal intensive care units (NICU).
• AP Chest and AP abdomen radiographs are the most common neonatal radiographs.
• Neonatal imaging is commonly carried out using portable radiography.
• Computed radiography (CR) has largely replaced film-screen cassettes in portable neonatal radiography
Introduction

• While neonatal radiography doses are generally low, the exposed population is at higher risk of stochastic effects of radiation.

• Quality control and dose surveys are important for assessment of neonatal radiographic practice.
Introduction and Motivation

- Quality control survey of neonatal radiography revealed the following:
  - No standardized technique chart was being followed
  - kVp/mAs and patient doses varied widely, depending on operator experience and training
  - Protocol parameters were not adjusted after introduction of CR. Low kVp (50-56) appropriate for film-screen cassettes still in use.
Quality Control Survey

No clear relationship between kVp and patient weight

Wide kVp range for a given weight
Wide range of doses for a given weight highlights the lack of technique standardization.
Purpose

- Implement weight-based technique parameters
- Reduce patient dose using a high-kVp technique
- Assess image quality
- Verify that image quality is not compromised
Methods

• Data collection (age, weight, gender, kVp, mAs) at pre-existing conditions for two months.
• Introduction of a weight based high-kVp technique chart
  – Tube potentials - 60 to 76
  – Tube current fixed at 0.5 mAs
• Data collection at new conditions for two months
Methods

- GE AMX4 portable x-ray system
- Fuji CR imaging plates and reader
- Tracked AP chest and abdomen for patients 0-3 months in the NICU and PICU at Hadassah Medical Organization
- Image quality assessment and dose estimation for high and low kVp image sets
<table>
<thead>
<tr>
<th>כמות משקל (ג')</th>
<th>_kvP</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1000 g</td>
<td>60</td>
<td>0.5</td>
</tr>
<tr>
<td>1000 g -- 1500 g</td>
<td>64</td>
<td>0.5</td>
</tr>
<tr>
<td>1500 g -- 2500 g</td>
<td>66</td>
<td>0.5</td>
</tr>
<tr>
<td>2500 g -- 3500 g</td>
<td>68</td>
<td>0.5</td>
</tr>
<tr>
<td>3500 g -- 4500 g</td>
<td>70</td>
<td>0.5</td>
</tr>
<tr>
<td>4500 g -- 5500 g</td>
<td>72</td>
<td>0.5</td>
</tr>
<tr>
<td>5500 g -- 6500 g</td>
<td>74</td>
<td>0.5</td>
</tr>
<tr>
<td>&gt; 6500 g</td>
<td>76</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Dose Estimation

• Portable GE AMX4 tube output characterized at various kVp settings
• Incident air kerma measured at 100 cm from x-ray tube using calibrated Pirahna solid state dosimeter (RTI Electronics, Mölndal, Sweden)
Dose Estimation

• Effective dose for each image estimated using PCXMC 2.0 Monte Carlo software
• Software inputs:
  – weight, height, beam area, kVp, incident air kerma, filtration, SID
PCXMC Dose Calculation Software

Monte Carlo data for this definition file have already been generated.

Header text:

Phantom data:
- Age: [Options]
- Phantom height: 44.50 Standard: 50.9
- Phantom mass: 1.90 Standard: 3.4

Arms in phantom

Geometry data for the x-ray beam:
- FSD: 87.16
- Beam width: 11.33
- Beam height: 9.99
- Xref: 0.0000 Yref: 0.0000 Zref: 15.0000

Projection angle: 270.00
Lat: 180 Ap: 270
Latl: 0 Pa: 90
(Cortical) X-ray tube
(Cortical) X-ray tube

Monte Carlo simulation parameters:
- Max energy (keV): 150
- Number of photons: 100000

Field size calculator:
- FSD: 110
- Image width: 10
- Image height: 24

Phantom exit image distance: 5.0

Draw x-ray field

Draw
Update Field
Stop

Rotation increment: -30
View angle: -270

Options:
- Skeleton
- Brain
- Heart
- Testes
- Spleen
- Lungs
- Ovaries
- Kidneys
- Thymus
- Stomach
- Salivary glands
- Oral mucosa
- Pancreas
- Uterus
- Liver
- Upper large intestine
- Lower large intestine
- Small intestine
- Thyroid
- Urogenital
- Kidney
- Bladder
- Prostate
- Pharynx/trachea/sinus

Quick
Sharp
Image Quality Assessment

- Two fellowship-trained pediatric radiologists blindly assessed images before and after technique change.
- Evaluation criteria based on the CEC image quality standards\(^1\)
- Criteria scored on a 4-point scale: (1) criterion definitely not defined, (2) criterion probably not defined, (3) criterion probably defined and (4) criterion definitely defined or (na) not applicable.
- Average score computed for each image

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Image Quality Criteria

- Reproduction of the thorax without rotation and tilting
- Reproduction of the chest must extend from the cervical trachea to T12/L1 (part of the abdomen maybe included for special purposes).
- Reproduction of the vascular pattern in central two-thirds of the lungs
- Reproduction of the trachea
- Reproduction of the proximal bronchi
- Visualization of the mediastinum
- Visibility of the tip of the endotracheal tube
- Visually sharp reproduction of the diaphragm
- Visually sharp reproduction of the costophrenic angles
- Reproduction of the spine
- Visualization of the retrocardiac lung
- Visibility of the tip of the umbilical catheter
- Visibility of the tip of the long line
- Visibility of bowel loops
- Visibility of the nosagastic tube
Statistical Analysis

• We used the 2-tailed t-test to check significance of change in:
  – Patient dose
  – Patient weight
  – Reader 1 score
  – Reader 2 score

• We used ANCOVA analysis to check significance of change in effective dose with x-ray protocol, patient age and weight.
<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>Percentage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (M/F)</td>
<td>163/91</td>
<td>63.9/35.7</td>
</tr>
<tr>
<td>Chests</td>
<td>221</td>
<td>86.7</td>
</tr>
<tr>
<td>Abdomens</td>
<td>32</td>
<td>12.5</td>
</tr>
<tr>
<td>Chest/Abdomen</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>High KVp</td>
<td>61</td>
<td>24</td>
</tr>
<tr>
<td>Low kVp</td>
<td>193</td>
<td>76</td>
</tr>
<tr>
<td>Total</td>
<td>254</td>
<td>100%</td>
</tr>
</tbody>
</table>
## Results - Averages

<table>
<thead>
<tr>
<th></th>
<th>kVp</th>
<th>mAs</th>
<th>Effective dose (uSv)</th>
<th>Image quality score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low kVp</strong> N=193</td>
<td>52.6</td>
<td>2.6</td>
<td>19.4 ± 8.0</td>
<td>3.26 ± 0.35</td>
</tr>
<tr>
<td><strong>High kVp</strong> N=61</td>
<td>65.3</td>
<td>0.53</td>
<td>9.6 ± 3.1</td>
<td>3.35 ± 0.36</td>
</tr>
</tbody>
</table>
Image Quality Score vs Effective Dose

Much narrower dose spread with new technique while maintaining similar IQ scores
High-kVp method results in reduced dose and narrower dose range
Image Quality vs kVp

Image Quality Score vs kVp

Low kVp vs High kVp
Statistical Analysis

• 2-tailed t-test results:
  – Dose change is significant (p<-0.0001)
  – Weight change is insignificant (p=0.072)
  – Reader 1 score change is significant (p=0.04)
  – Reader 2 score change is significant (p<0.001)

• ANCOVA analysis showed that x-ray protocol is the only parameter that effects effective dose significantly (p<0.0001)
Summary of Results

• Clinical image rating is not affected by introducing weight-based higher-kVp technique chart
• Average effective dose reduced by 50%
• Effective dose range reduced from [7.0-52.4] uSv to [5.9 – 19.9] uSv
• The change in protocol parameters is the single most significant factor contributing to dose reduction
Discussion

• Quality control survey revealed that the ALARA principle was not fully applied.
• Lack of standardized technique chart lead to wide variations in patient dose. The same patient could receive doses varying by a factor of 5 for the same examination.
• The dose-saving possibilities of digital imaging were not leveraged.
Discussion – Digital Imaging

• Film imaging is contrast limited. kVp choice depends on:
  – Narrow exposure range required by film
  – Beam penetration (requires higher kVp)
  – Subject contrast (requires lower kVp).

• Digital imaging is noise limited.
  – Wide range of useful exposure
  – Image Processing enhances image contrast
  – Enough exposure must reach the detector to avoid a noisy image
Increasing the kVp can deliver enough photons to the CR plate at lower mAs and lower patient exposure.

Film receptor gives optimal contrast over a narrow range of exposure.

Digital detector has a wide dynamic range, making it more tolerant than film of variations in exposure.
Discussion

- High-kVp protocol lowered patient dose significantly and reduced dose variations.
- The ‘significance’ in change in readers image quality scores is due to the narrow range of scores obtained.
- For all practical purposes, image quality not affected by change in kVp.
Conclusions / Lessons Learned

• Periodic quality control results in better patient care.
• “Imaging gently” is a team effort (physicists, radiologists, technologists, administration).
• Technique optimization should be carried out when new imaging modalities and techniques are implemented.
Conclusions / Lessons Learned

• Data is your best friend. We continue to record exposure and patient data for subsequent reviews.
• Data collected in this study will enable us to assess other aspects of quality control, such as positioning and collimation
• High-kV low-mAs technique enables marked dose reduction
• High-kV low-mAs technique dose not impair image quality