"Optimal Dose Techniques and Image Quality: Can We Have Both?"

Introduction
Background

• Important to regularly investigate dose optimization strategies to ensure dose is “as low as reasonably achievable” (ALARA) while still producing images of diagnostic quality

• $\uparrow$‘ing the tube voltage (kVp) and $\downarrow$ ‘ing the tube current-exposure time product (mAs) shows particular promise.
  • Because the photons in the radiation beam have a higher energy and are more penetrating. Instead of being absorbed into the patients (as a lower kVp beam would), more of the beam is able to penetrate and exit the patient’s tissues, resulting in a lesser dose to patients.
The Problem

• Not being fully realized within radiology departments
• Why?
  • Do practitioners’ not find high kVp-low mAs images to be aesthetically pleasing? Of acceptable diagnostic quality?
  • Are they unable to visualize the relevant anatomical structures on these high kVp-low mAs images?
The Need for Research

• Although previous studies exist, a more robust and comprehensive approach is needed in terms of the number of participants and the number of anatomical areas
  • E.g., smallest study had only 2 radiographers, largest study had 6 radiographers and 2 radiologists
    • *This lessens the external validity (generalizability) of the results
  • E.g., Most studies have included only 1 anatomical area
    • This is a problem because different anatomical areas vary in thickness and require different technical factors (and result in different dose)
Aims of Our Work

- Investigate the utility of the high kVp-low mAs dose optimization strategy by examining practitioners’ assessments of aesthetic and diagnostic quality of images acquired using this strategy.

- To make a novel contribution to the literature by conducting a more robust and comprehensive version of previous studies by including many more participants, incorporating multiple anatomical areas, and explicitly investigating practitioners’ aesthetic preferences.
Brief Overview

- 91 practitioners blindly examined:
  - Three types of direct digital radiographic images
    - 1. ‘Standard’ image
    - 2. +20 kVp image
    - 3. +30 kVp image
  - For four anatomical areas of anthropomorphic phantoms
    - Pelvis
    - Chest
    - Skull
    - Hand
  - Rated (on a five point scale) each image on:
    - A. Perceived aesthetic quality
    - B. Perceived diagnostic quality
    - C. Visualization of anatomical structures
Methods
Participants

- Ethical clearance
- Invited all radiologists, residents, radiographers, and student radiographers from eight clinical sites within an Ontario LHIN
- 91 participants
  - 6 radiologists, 4 residents, 48 radiographers, 31 student radiographers, 2 PACS admin
  - 0.5 to 38 years experience (M = 11.44 years, SD = 11.29)
- Inclusion criteria: members of one of the above professional groups, and regularly acquire or review radiographic images
- No exclusion criteria
Anthropomorphic Phantoms

- The Phantom Laboratory
  - Tissue equivalent to adult male of average size, consists of real bone
  - Common in dose optimization studies (feasibility)
- Pelvis and Chest
  - Most common radiographic exams
  - Most common anatomical areas in dose optimization studies
- Skull
  - Common in developing countries due to cost of CT
  - Area for which high-quality exams are required for diagnosis (especially for non-accidental injury)
- Hand
  - Much thinner anatomical area
  - Not previously investigated in dose optimization studies

*European Guidelines on Quality Criteria for Diagnostic Radiographic Images* exist for all except hand
Radiographic Equipment

• All images were obtained using:
  • Carestream DR X Revolution Mobile Xray system at University Hospital – London Health Sciences Centre
    – Healing Arts and Radiation Protection Act of Ontario (HARP)
    – Radiation Emitting Devices Act of Canada (RED Act)
Radiographic Technique

• 50-inch SID (Vendor recommended)
• No object to image distance
• Degree of collimation - size of the detector. Remained consistent for all anatomical areas
• Pelvis and Chest - 6:1 linear grid; Skull and Hand - without a grid (standard practice at the clinical site)
• Acquired by a radiographer with 33 years of experience, and confirmed by a second radiographer with 25 years of experience
Image Acquisition

• ‘Standard’ Image
  • Pre-programmed technical factors
    • Confirmed these were representative across the LHIN
• +20 kVp Image
  • ↑ kVp by 20, ↓ 1 mAs setting, then acquired image
  • Recorded resulting EI and DAP – if within vendor’s acceptable limit for the system (between 1,300 – 1,500, +/- 150), another image was acquired at same kVp but ↓‘d mAs by another setting
  • Process repeated until image acquired with EI beyond vendor’s acceptable limit
  • From this series, image with the most similar EI to ‘standard’ image was selected*
• +30 kVp Image
  • ↑ kVp by 30, repeat process
## Technical Factors Used

<table>
<thead>
<tr>
<th>Radiograph</th>
<th>Tube Voltage (kVp)</th>
<th>Tube Current-Exposure Time Product (mAs)</th>
<th>Exposure Index Number</th>
<th>Dose Area Product (dGycm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis ‘Standard’</td>
<td>85</td>
<td>10</td>
<td>1406</td>
<td>3.7</td>
</tr>
<tr>
<td>Pelvis +20 kVp</td>
<td>105</td>
<td>4</td>
<td>1449</td>
<td>2.1</td>
</tr>
<tr>
<td>Pelvis +30 kVp</td>
<td>115</td>
<td>3.7</td>
<td>1472</td>
<td>2.0</td>
</tr>
<tr>
<td>Chest ‘Standard’</td>
<td>120</td>
<td>0.7</td>
<td>1543</td>
<td>1.1</td>
</tr>
<tr>
<td>Chest +20 kVp</td>
<td>140</td>
<td>0.9</td>
<td>1529</td>
<td>0.8</td>
</tr>
<tr>
<td>Chest +30 kVp</td>
<td>150</td>
<td>0.7</td>
<td>1552</td>
<td>0.8</td>
</tr>
<tr>
<td>Skull ‘Standard’</td>
<td>75</td>
<td>7.1</td>
<td>1395</td>
<td>1.1</td>
</tr>
<tr>
<td>Skull +20 kVp</td>
<td>95</td>
<td>2.5</td>
<td>1414</td>
<td>0.6</td>
</tr>
<tr>
<td>Skull +30 kVp</td>
<td>105</td>
<td>1.7</td>
<td>1397</td>
<td>0.4</td>
</tr>
<tr>
<td>Hand ‘Standard’</td>
<td>52</td>
<td>1.2</td>
<td>1239</td>
<td>0.1</td>
</tr>
<tr>
<td>Hand +20 kVp</td>
<td>72</td>
<td>0.28</td>
<td>1249</td>
<td>0.06</td>
</tr>
<tr>
<td>Hand +30 kVp</td>
<td>82</td>
<td>0.22</td>
<td>1330</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Preparing the Images for Participant Viewing

• Images were:
  • Stripped of identifying information
  • Randomized order (not necessarily viewed in order acquired)
  • Uploaded to PACS (calibrated by an installed program that constantly monitors the gray scale display function specification of the DICOM standard). All participants are familiar with this system.
  • Thus, the ‘type’ of image was not made known to participants to ensure authenticity of ratings (i.e., limit bias)
Image Quality Assessment Tool

• 3 questions for each of the 12 images
  • 1. Aesthetic quality
  • 2. Diagnostic quality
  • 3. Visualization of anatomical structures
# Image Quality Assessment Tool

1. Do you find **IMG#1** aesthetically pleasing (i.e. ‘pretty’)? Circle your answer.

<table>
<thead>
<tr>
<th>No, definitely not</th>
<th>Neutral</th>
<th>Yes, definitely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

1. How do you rate the overall diagnostic quality of **IMG#1**? Circle your answer.

<table>
<thead>
<tr>
<th>Very Dissatisfied (Inadequate for diagnosis, definite loss of information, the image should be rejected)</th>
<th>Dissatisfied (Poor image that impairs interpretation, important information could be lost, interpreter would consider rejecting)</th>
<th>Neither Satisfied or Dissatisfied (Acceptable for interpretation, bordering on loss of information)</th>
<th>Satisfied (Acceptable for interpretation, no loss of information)</th>
<th>Very Satisfied (Optimal for evaluating the appropriate category of information)</th>
<th>I Cannot Judge (Please explain why in this box)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
1. How satisfied are you that IMG#1 offers (circle your answer):

<table>
<thead>
<tr>
<th>Very Dissatisfied (Inadequate for diagnosis, definite loss of information, the image should be rejected)</th>
<th>Dissatisfied (Poor image that impairs interpretation, important information could be lost, interpreter would consider rejecting)</th>
<th>Neither Satisfied or Dissatisfied (Acceptable for interpretation, bordering on loss of information)</th>
<th>Satisfied (Acceptable for interpretation, no loss of information)</th>
<th>Very Satisfied (Optimal for evaluating the appropriate category of information)</th>
<th>I Cannot Judge (Please explain why in the boxes below)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. A visually sharp reproduction of the sacrum and its intervertebral foramina?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Participants’ Image Viewing Environment

• All participated:
  • During work hours (with permission)
  • Independently
  • In a private room at their clinical site
    • Low ambient light
    • PACS-quality reporting flat panel display with software to zoom, pan, and simultaneously display image pairs
  • No time restrictions
Results
Perceived Aesthetic Quality

Statistical Analysis

• For each anatomical area, conducted a one-way ANOVA with Tukey’s post-hoc analysis using data from all professional groups with image type as the factor
Perceived Aesthetic Quality

- Pelvis, Skull, and Hand: Standard image rated significantly (*, **, ***) higher in aesthetic quality than dose optimized images.

- Chest: No significant differences, images rated equal in aesthetic quality.

X-ray protocol

Significant differences indicated by * (p ≤ 0.05), ** (p ≤ 0.01), or *** (p ≤ 0.0001).
Perceived Diagnostic Quality

Statistical Analysis #1
• For each anatomical area, conducted a one-way ANOVA with Tukey’s post-hoc analysis using data from all professional groups with image type as the factor

Statistical Analysis #2
• For each anatomical area, conducted a two-way ANOVA with Tukey’s post hoc analysis with image type and professional groups as the factors
  • RRR: Radiologists and Radiology Residents
  • RRS: Radiographers and Radiography Students

Statistical Analysis #3
• For each anatomical area, percentage of participants who ‘passed’ (i.e., rated ≥ 3/5) each image was calculated
Perceived Diagnostic Quality - #1

- Pelvis, Skull, and Hand: Standard image rated significantly (*, **, ***) higher in diagnostic quality than dose optimized images.

- Chest: No significant differences, images rated equal in diagnostic quality.

Significant differences indicated by * (p ≤ 0.05), ** (p ≤ 0.01), or *** (p ≤ 0.0001).
Perceived Diagnostic Quality - #2

Pelvis, Skull, and Hand:
No interaction by position, but significant effect by image type.
(Profession did not impact ratings of diagnostic quality, both groups rated the standard higher than the dose optimized)

Chest:
Significant interaction by position, but no effect by image type.
Perceived Diagnostic Quality - #3

- Some differences between RRR and RRS
- Some instances of 100% pass rate (i.e., Skull)
- Many instances of near 100% pass rate (i.e., Hand)
- Drop off of pass rate as kVp increases
Statistical Analysis

• For each anatomical area, conducted a one-way ANOVA with Tukey’s post-hoc analysis using data from all professional groups with image type as the factor
Modified European Guidelines

- For each modified European Guideline criterion the standard image was rated significantly higher than the dose optimized images, except for criterion...
Modified European Guidelines – Cont’d

Warning: Not for diagnostic use

Diaphragm & lateral costo-phrenic angles

Retrocardiac lung & mediastinum

[Images of chest X-rays with annotations]
Modified European Guidelines – Cont’d

Visually sharp reproduction of the trabecular structure of the cranium
Modified European Guidelines – Cont’d

Adequate contrast to density to demonstrate soft tissue
Discussion
Perceived Diagnostic Quality

• For Pelvis, Skull, and Hand, ‘standard’ images rated significantly higher in diagnostic quality than high-kVp-low-mAs images (with no differences between professional groups)
  • However, all Pelvis, Skull, and Hand images were ‘passed’ as acceptable diagnostic quality (rated ≥ 3/5) regardless of acquisition protocol

**Although images were found to be appreciably different in diagnostic quality, they were also all found to be of acceptable diagnostic quality for clinical use, which is the relevant issue at hand**
Perceived Diagnostic Quality – Cont’d

• +20 kVp Pelvis, Skull, and Hand images
  • Passed by 100% of radiologists and radiology residents
    • Suggests +20 kVp may be a highly effective dose optimization strategy for clinical practice when imaging the Pelvis, Skull, and Hand
  • However...
Perceived Diagnostic Quality – Cont’d

• However… not passed by all radiographers and radiography students (82.6%, 98.7%, 97.3% for Pelvis, Skull, and Hand respectively)
  • Suggests issues for implementation of this strategy
  • Interestingly, this group did not pass the ‘standard’ image 100% of time either
    • Something is amiss
    • Is there an issue with radiographers’ perceptions of diagnostic quality?
      – Educational issue?
      – Issue of bias?
      – Confidence issue?
  • Notion supported by existing literature, i.e., Yelder & Davis (2009)
Perceived Diagnostic Quality – Cont’d

• Chest deviated from Pelvis, Skull, and Hand
  • No significant differences by image type – practitioners rated standard and dose optimized images to be equal statistically
  • Significant differences by professional group
    • RRR – Failed all chest image; RRS – Passed all chest images
      – Again something is going on...
      – May lend further evidence to possible educational / bias / confidence issue amongst radiographers?
        – Very troubling as chest is one of the most common exams
  • Deviation may be explained by:
    • Complexity of anatomical area (other dose optimization studies have seen this in certain areas of the chest)
    • Standard factors were already ‘dose optimized’ at this site
    • Use of phantoms
Perceived Aesthetic Quality

• For Pelvis, Skull, and Hand, ‘standard’ images rated significantly more aesthetically pleasing than the dose optimized images.
  • However, all Pelvis, Skull, and Hand images were ‘passed’ as acceptable diagnostic quality (rated ≥ 3/5) regardless of acquisition protocol

**Reinforces the importance of not conflating the frivolous question of aesthetic quality with the relevant clinical question of diagnostic quality**

• Again, situation of Chest deviated from other anatomical areas, no statistically significant differences in aesthetic quality were noted
Dose Savings

- Noted diminishing returns in dose savings
- +20 kVp image – Dose reduction between 54-72%
- +30 kVp image – Dose reduction remained essentially constant, between 0-2% further reduction. Thus, not advisable – not worth the risk of repeat.
Strengths and Limitations
Strengths & Limitations

• Major Strength:
  • Large sample size (10x’s more participants than largest comparable study reviewed) → more externally valid

• Limitations:
  • Relatively few radiologists (n = 6) compared to radiographers, although still among the largest of existent studies
  • Use of anthropomorphic phantoms
Future Directions
Future Directions

- Importance of including multiple anatomical areas
- +30 kVp seems unnecessary, other than for the skull (100% of RRR passed the +30 kVp skull image)
- Difference in pass rates between RRR and RRS suggests issue to be further investigated
  - Educational issue? Bias? Confidence issue?
  - Qualitative inquiry to gather practitioners’ opinions, beliefs, perceptions, and values regarding this dose optimization strategy is needed
  - Our results are forthcoming!
Concluding Thoughts

• Successfully polled and analyzed practitioners’ perceptions of aesthetic and diagnostic quality of ‘standard’ and high kVp-low mAs images

• Results revealed:
  • For the Pelvis, Skull, and Hand, the standard imaging protocol used within the LHIN could potentially be dose optimized by +20 kVp to more closely adhere to the ALARA mandate
Acknowledgements

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Thank you for your attention!

Questions?
References