Adjusting kV to Improve Image Quality or Reduce Radiation Dose

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DISCLOSURES

Research Support:
Siemens Healthcare

Off Label Usage
None
**Background**

- Majority of abdominal CT scans: 120 kV
- It is possible to reduce to 80-90 kV*
- Benefits of low-kV CT:
  - Radiation dose reduction**
  - Increased contrast provides increased conspicuity to enhancing lesions and structures ***

*Funama, et al., Radiology 2005
*Nakayama, et al., Radiology 2005
**Ende, et al., Invest Radiol 1999
**Huda, et al., Med Phys 2004
***Nakayama, et al. AJR 2006
*** Macari, et al. AJR 2010
Lower-kV Benefits –
Increased Iodine Contrast
Lower-kV Benefits –
Increased Iodine Contrast

140 kV

80 kV
Lower-kV Benefits – Reduced Radiation Dose

120 kV

CTDI\textsubscript{vol} = 5.18 mGy

80 kV

CTDI\textsubscript{vol} = 3.98 mGy

Lower-kV Risks –
Increased Noise or Artifacts
The appropriateness of using lower-kV is highly dependent on patient size and diagnostic task.
Overview

• How does kV affect iodine enhancement and noise?
• How does patient size affect this relationship?
• Who is going to benefit from low kV imaging?
• How can I safely pick lower kV imaging without sacrificing diagnostic image quality?
• How can I integrate lower kV imaging into my practice?
• How do lower kV images look different?
• Future of lower kV imaging
How does kV affect iodine enhancement?

- Iodine attenuation at 80 kV twice that of 140 kV
- Relative to iodine attenuation at 120 kV
  - 70% higher at 80 kV
  - 25% higher at 100 kV

How does kV affect water enhancement?

- Relative contrast changes only hold for high atomic number substances
  - Iodine, barium
  - *NOT* water, soft tissue, calcium

How does kV affect iodine enhancement?

80 kV
1193 HU

120 kV
695 HU
Relative Contrast Differences due to Iodine Also Increase at Low kV

120 kV

100 kV
Relative Contrast Differences due to Iodine Also Increase at Low kV

140 kV

80 kV

Improved Disease Conspicuity

Macari M et al. AJR 2010
Relative Contrast Differences due to Iodine Also Increase at Low kV

Improved Disease Conspicuity

Yanaga et al. AJR 2011
How does kV affect iodine noise?

For large patients, lower kV imaging can result in excessive beam hardening and other artifacts.

80 kV imaging with excessive artifacts limiting diagnostic quality
Low kV Imaging: Maintaining Image Quality

- Issue is noise (patient size)
  - Organ of interest
  - Measurements of size


- 116 pts undergoing 80 kV CT
- 2 – 3 mm thick images
- IQ, artifact, confidence
- Multiple pt size measures
**Association of Patient Size with Unacceptability**

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## Association of Patient Size with Unacceptability

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<td>Ileum</td>
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Dimension cut-offs (cm) that would achieve ≥90% sensitivity and ≥80% sensitivity for prediction of an unacceptable exam

* Likely underestimated due to small # of unacceptable cases (n=2 or 3)
Association of Patient Size with Unacceptability

- Lateral width the best predictor of acceptable image quality
  
  \(< 36 \text{ cm} \implies 80\text{ kV imaging acceptable}\)
  
  \(< 41 \text{ cm} \implies 100\text{ kV imaging acceptable}\)

- Larger patients may not be able to undergo low kV imaging

- Patient size selection only insures good quality
  
  - Dose reduction is considered separately (later)
Who is going to benefit from lower kV imaging?
Who is going to benefit from lower kV imaging?

- Limited IV access or suboptimal timing
- Limited contrast dose
- Subtle attenuation differences
- Young patients
- Small and medium-sized adult patients
Limited IV access or Suboptimal Timing

80 kV

< 1 cc/s injection over 3 minutes
Limited IV access or Suboptimal Timing

2 cc/s with pedal access
Imaged at 85 sec
Limited IV access or Suboptimal Timing

Restaging unresectable Islet Cell tumor

Chest CT at 80 seconds (to avoid compromise of abdominal timing)
100 kV Chest
Who is going to benefit from lower kV imaging?

- Limited IV access or suboptimal timing
- Limited contrast dose
- Subtle attenuation differences
- Young patients
- Small and medium-sized adult patients
Limited Contrast Dose

80 cc Omnipaque due to solitary kidney
Who is going to benefit from lower kV imaging?

- Limited IV access
- Limited contrast dose
- Subtle attenuation differences
- Young patients
- Small and medium-sized adult patients
Subtle Attenuation Differences

80 kV
45 HU diff_{lesion-liver}

120 kV
21 HU diff_{lesion-liver}
Who is going to benefit from lower kV imaging?

• Limited IV access
• Limited contrast dose
• Subtle attenuation differences
• Young patients
• Small and medium-sized adult patients
Low kV to Lower Radiation Dose

120 kV
17.3 mGy

100 kV
7.71 mGy
Who is going to benefit from lower kV imaging?

- Limited IV access
- Limited contrast dose
- Subtle attenuation differences
- Young patients
- Small and medium-sized adult patients
Who is going to benefit from lower kV imaging?

- Limited IV access
- Limited contrast dose
- Subtle attenuation differences
- Young patients
- Small and medium-sized adult patients

Maintain Radiation Dose ($\text{CTDI}_{\text{vol}}$) → Dose-match Look-up table (or $= \text{CTDI}_{\text{vol}}$)
Low kV Imaging While Maintaining Dose

- Limited IV access
- Limited contrast dose
- Subtle attenuation differences
- Size < 36 cm => 80 kV
- Size ≤ 41 cm => 100 kV

- Plug protocol from 120 kV scan and record CTDI$_{vol}$
- Change tube energy
- Adjust mAs upwards until CTDI$_{vol@120 kV}$ is achieved
- Make sure you are operating within tube limits

- Use a look-up table with your technique charts
### mAs Conversion for Siemens Scanners

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<th>mAs at 80 kVp</th>
<th>mAs at 100 kVp</th>
<th>mAs at 120 kVp</th>
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*Not all mAs settings may be possible
## mA Conversion for GE-64 Scanners

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*Not all mA settings may be possible*
Low kV Imaging While Reducing Dose

- More complicated
- Need to consider both patient size and diagnostic task into kV selection process
  - Greater the iodine contrast differences, the greater ability to reduce dose for smaller pts
- kV selection combined with lowering of dose-matched mAs
- Creates a new technique chart for each diagnostic task

General Strategy for kV selection

- Two items to consider
  - Iodine CNR (iCNR)
  - Acceptable noise level ($\alpha \cdot \sigma_{120kV}$)

\[
iCNR_{low\,kV} \geq iCNR_{120kV}
\text{ and }
\sigma_{lowkV} \leq \alpha \cdot \sigma_{120kV},
\]

$\alpha$ = a noise constraint unique to a diagnostic task

Here’s the idea

Consider 80 kV imaging

 Contrast by 70%
Here’s the idea

Consider 80 kV imaging

↑ Contrast by 70%

↓ Noise by 70%

Here’s the idea

Consider 80 kV imaging

\[
\text{Contrast by 70\%} \geq \frac{\text{Contrast}_{120}}{\text{Noise}_{120}} \geq \frac{\text{Noise by 70\%}}{\text{Contrast}_{120}}
\]

Here's the idea

Consider 80 kV imaging

Contrast by 70% ≥ Noise by 70%

Improved contrast permits the noise level to increase

Here’s the idea

Consider 80 kV imaging

\[
\frac{\text{Contrast by 70\%}}{\text{Noise by 70\%}} \geq \frac{\text{Contrast}_{120}}{\text{Noise}_{120}}
\]

Increased noise permits the dose reduction

Here’s the idea

Consider 80 kV imaging

Contrast by 70% ≥ Contrast$_{120}$
Noise by 60% ≤ Noise$_{120}$

As patients get larger (or task requires less noise), the acceptable increase noise ($\sigma$) becomes smaller.
Here’s the idea

Consider 80 kV imaging

Contrast by 70% ≥ Contrast

Noise by 50% ≥ Noise

As patients get larger (or task requires less noise), the acceptable increase noise (σ) becomes smaller.

Here's the idea

Consider 80 kV imaging

\[ \text{Contrast by 70\%} \geq \frac{\text{Contrast}_{120}}{\text{Noise}_{120}} \]

As patients get larger (or task requires less noise), the acceptable increase noise (\(\sigma\)) becomes smaller.

Dose reduction will be limited.
Low kV- Commercial Methods

- Considerations
  - Patient attenuation (~size)
  - Task (iCNR, α)
  - Scanner limitations

- Tube currents with CNR constraint:
  - Discard kV with conflict
  - Select kV with ↓ dose

Courtesy Dr. Katie Grant, Siemens Healthcare
Low kV- Commercial Methods

- Patient attenuation (~size)
- Task (CNR, \( \alpha \))
- Scanner limitations

Strength Setting

Dose saving optimized for:

<table>
<thead>
<tr>
<th>Strength Setting</th>
<th>Non-contrast</th>
<th>6 – 7 Routine</th>
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</table>
Low kV- Commercial Methods

20% Dose Savings
No Decrease in Conspicuity
Low kV- Commercial Methods

120 kV
17.3 mGy

100 kV
7.71 mGy

Iodine contrast-to-noise Ratio Equivalent
Low kV - Commercial Methods

Routine Abdominal CT

- Overall 20% dose reduction, but depends on patient size
- iCNR and image quality (EQC) identical in subset with comparisons @ 120 kV despite dose savings

Care kV Strength = 6

Yu et al. Mayo CT practice data. Submitted to RSNA 2011
The Grand Scheme

$kV$ Selection to Reduce Radiation Dose

- Part of an overall strategy, so don’t forget to eliminate...
  - unjustified exams
  - superfluous acquisitions (e.g., unenhanced, delayed)
- Should facilitate (not hinder) accomplishment of diagnostic task
- Performed with mAs reduction
- Synergistic with noise reduction
More dramatic dose reductions can be achieved if we permit noise levels to increase further.
Low kV & Noise Reduction

- 120 kV
- 18.89 mGy
- Routine dose and noise

- 100 kV
- Excessive noise
- 7.13 mGy

- Noise Reduction
- 7.13 mGy
- Lower dose and similar noise
24 yo man, abdominal pain

ER

5 mm slice
120 kV, 240 QRM
17.5 mGy CTDIvol

kV selection + dose ↓
3 mm slice
Base 120 kV, 160 QRM
100 kV, 207 QRM
6.2 mGy CTDIvol

Care kV Strength = 8 for CT enterography

kV selection + dose ↓
3 mm slice
SAFIRE, Strength 3
100 kV, 207 QRM
6.2 mGy CTDIvol
Low kV & Noise Reduction

- kV selection (100 kV)
- Lowered AEC setting (Quality Ref. mAs: 240 mAs → 180 mAs)
- Noise reduction method

CTDvol = 14.0 mGy  
CTDvol = 6.8 mGy
Low kV & Noise Reduction

Half-dose B43 Denoised 80kV

B40 Mixed 80/140 kV

Half-dose Low kV + Noise Reduction
3/3 readers rated conspicuity same/greater for ½ dose low kV with noise reduction

Ehman et al. AJR 2011 (in press)
Half-dose Low kV + Noise Reduction
4/4 readers rated conspicuity same/greater for ½ dose low kV with noise reduction

Paulsen et al. ARC 2010
How do low kV images look different?

- More contrast, more noise
- Require modified window-level settings, based on radiologist preference
How do low kV images look different?

100 kV, 8.9 mGy
2 mm slice
(12.2 mGy Rx’d @ 120 kV; 27% dose savings)
Future of Low kV Imaging

• 100 kV can be practically implemented already in most patients
  – Task-specific technique charts will include kV and mAs selection to perform most dose-efficient exam
  – 140 kV imaging may be most dose-efficient for large pts

• Manufacturers integrating automatic kV selection tools into CT systems
  – Based on iCNR, but also take automatic exposure control and tube current limits into account

• Provide a new level of individualization for CT imaging (task + patient-specific)
Conclusions

• Tube energy (kV) selection can benefit your patients
  – Limited IV access/suboptimal timing, renal insufficiency, iodine-sensitive pathology
  – Dose reduction

• kV selection is dependent upon patient size (attenuation) and diagnostic task (noise is limiting factor)

• Several pathways to begin kV modulation in your practice
  – Dose-matched exams
  – Technique charts & automated kV selection tools

• Seamless integration with noise reduction for greatest dose savings
Thank you

Mayo CT Clinic Innovation Center and Dept. of Radiology

http://mayoresearch.mayo.edu/CTCIC
The widely used relation “Radiation output CTDIvol is proportional to kVp^2 for the same mAs” is not accurate.

As shown above, the actual CTDIvol at 80 kVp is about ~50% lower on both GE and Siemens scanners for the lower kV’s.