Adjusting kV to Reduce Dose or Improve Image Quality - How to Do it Right

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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
Lower-kV Benefits – Reduced Radiation Dose

120 kV, CTDI$_{vol}$=5.18 mGy

100 kV, CTDI$_{vol}$=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?
- How can I safely pick lower kV imaging without sacrificing diagnostic image quality?
- Who is going to benefit from low kV imaging?
- 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 is twice that of 140 kV.
- Relative to iodine attenuation at 120 kV:
  - 70% higher at 80 kV
  - 25% higher at 100 kV

From Bodily et al. RSNA 2008
How does kV affect water enhancement?

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

Courtesy Dr. Lifeng Yu
Bruesewitz et al. RSNA 2009
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
Relative Contrast Differences due to Iodine Also Increase at Low kV

140 kV

80 kV

Macari M et al. AJR 2010
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
Technology Assessment Institute: Summit on CT Dose

Figure 5

10 cm

25 cm

40 cm

80 kV

100 kV

120 kV

140 kV

Courtesy Dr. Lifeng Yu
Low kV Imaging: Maintaining Image Quality

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

Guimaraes et al. RSNA 2008

- 116 pts undergoing 80 kV CT
- 2 – 3 mm slices
- 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
- Limited contrast dose
- Subtle attenuation differences
- Young patients
- Small and medium-sized adult patients
Limited IV access

80 kV

< 1 cc injection over 3 minutes
Limited IV access

2 cc/s with pedal access
Imaged at 85 sec
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
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

Maintain Radiation Dose ($\text{CTDI}_{\text{vol}}$)

Radiation Dose ($\text{CTDI}_{\text{vol}}$)
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 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 is achieved
- Make sure you are operating within tube limits

- Use a look up table with your technique charts
<table>
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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

- Iodine CNR is not a sufficient image quality index
- Must also constrain image noise
- We already know what noise levels we can tolerate

\[ \text{CNR} \geq \text{CNR}_{\text{ref}}, \quad \text{and} \quad \sigma \leq \alpha \cdot \sigma_{\text{ref}} \]

- Relative dose factor (RD)
  - Determine relative dose at each tube potential needed to achieve the same CNR as at the reference kV
  - Within the noise constraint \( \alpha \) (patient size, 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

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

Here's the idea

Consider 80 kV imaging

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

Improved contrast permits the noise level to increase

Here’s the idea

Consider 80 kV imaging

Noise by 70% \[ \uparrow \]
Contrast by 70% \[ \downarrow \]

\[ \frac{\text{Contrast}_{120}}{\text{Noise}_{120}} \geq 1 \]

Increased noise permits the dose reduction

Here’s the idea

Consider 80 kV imaging

\[ \frac{\text{Contrast} \times 70\%}{\text{Noise} \times 60\%} \geq \frac{\text{Contrast}_{120}}{\text{Noise}_{120}} \]

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

Consider 80 kV imaging

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

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

Here's the idea

Consider 80 kV imaging

\[
\frac{\text{Contrast by 70\%}}{\text{Noise by 40\%}} \geq \frac{\text{Contrast}_{120}}{\text{Noise}_{120}}
\]

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

The dose reduction will also decline.
# Optimal kV Settings

Optimal kV based on RD for different phantom sizes with different noise constraints

<table>
<thead>
<tr>
<th>Noise Constraint $\alpha$</th>
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$\alpha = 1.0$: Routine non-contrast exams  
$\alpha = 1.25$: Routine contrast-enhanced exams  
$\alpha = 1.5$: CTA with minimal noise constraint  
$\alpha = 2.0$: CT exams no noise constraint
Dose Reduction vs Phantom Size

Phantom Size

Dose Reduction
Workflow for kV Selection with Dose Reduction

• Acquire a CT radiograph (e.g., topogram, scout)
• Select a scanning protocol (mAs, pitch) at 120 kV
• Select the noise constraint parameter
  – CT angiogram: minimal noise constraint ($\alpha = 1.5$-$2.0$)
  – Routine contrast enhanced chest: moderate noise constraint ($\alpha = 1.1$-$1.25$)
  – Routine non-contrast enhanced chest: maximum noise constraint ($\alpha = 1.0$)
  – Routine contrast-enhanced CT enterography: moderate noise constraint ($\alpha = 1.25$)
• PhD’s - choose the most dose-efficient kV (*with the smallest Relative Dose*), and adjust the mAs, rotation time, and/or pitch
• MD’s – use the look-up table for your diagnostic task
patient lateral width

RD at each kV

Image quality index

Final output
How does this work in clinical practice?

- Two GI radiologists recently evaluated experience with two automatic kV selection tools based on this paradigm.
- Evaluated image quality, noise level, diagnostic confidence.
- Dose savings ranged from 0 – 55%, mean of ~ 20%.
- No non-diagnostic studies.
How do low kV images look different?

- More contrast, more noise
- Require modified window-level settings, based on radiologist preference

120 kV
17.3 CTDI$_{vol}$

100 kV
11.9 CTDI$_{vol}$
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 will integrate automatic kV selection tools into the CT system
  - Based on similar principles, but also take automatic exposure control and tube current limits into account
- Provide a new level of individualization for CT imaging (task + patient-specific)
- Combine low kV + noise reduction to reduce dose while increasing conspicuity
Lesion Characterization

20 patients

- 15 with HCC
- 3 with metastases
- 1 cyst
- 1 indeterminate

56 lesions

- 80% (45/56) hypervascular
- 20% (11/56) hypodense

Average size = 1.54 cm
# Lesion Conspicuity

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<th>Reader 2</th>
<th>Reader 3</th>
<th>Average</th>
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Conclusions

- Tube energy (kV) selection can benefit your patients
  - Limited IV access, renal insufficiency, iodine-sensitive pathology
  - Dose reduction
- kV selection is dependent upon patient size and diagnostic task (which affect the acceptable noise in the image)
- Several pathways to begin kV modulation in your practice
  - Look-up tables for dose-matched exams
  - Technique charts for specific diagnostic tasks that include patient size and kV
  - New automatic kV selection tools available by manufacturers
Thank you

Mayo CT Clinic Innovation Center and Dept. of Radiology

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