CARE kV

Automated Dose-Optimized Selection of X-ray Tube Voltage

White Paper

Katharine Grant, PhD, and Bernhard Schmidt, PhD

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Conventional dose modulation approaches, such as CARE Dose4D™, modulate only the X-ray tube current (mAs), while the X-ray tube voltage (the kV setting) is left unchanged. However, there exists a large potential for dose reduction in optimizing the X-ray tube kV setting.[1-7]

For example, in a study conducted by Siegel et al (2004), reducing the tube voltage from 140 kV to 80 kV resulted in a 78% decrease in radiation dose to pediatric patients. In another study on cardiac patients, PROTECTION 1[8], the use of 100 kV tube voltage was associated with a 53% reduction in radiation dose compared to conventional 120 kV scan protocols. In a busy environment, the technologists and reading physicians often have insufficient time to assess the attenuation of each patient.

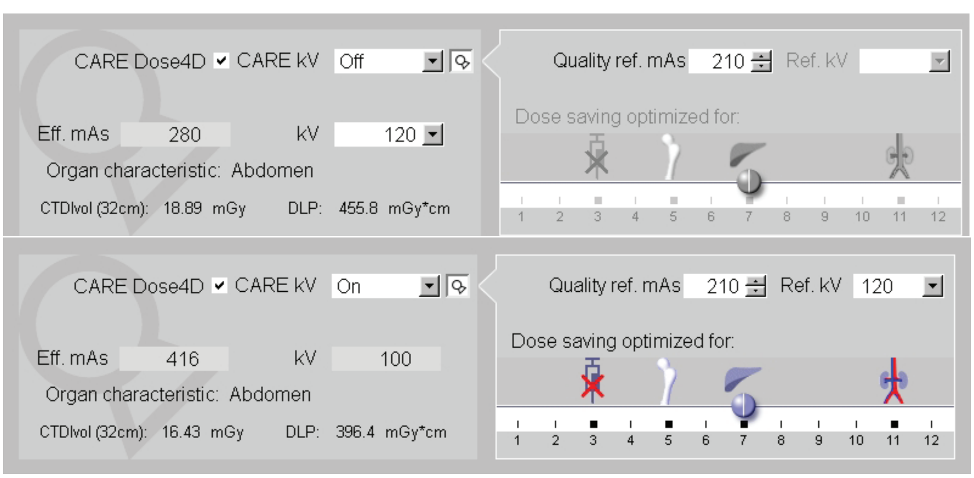
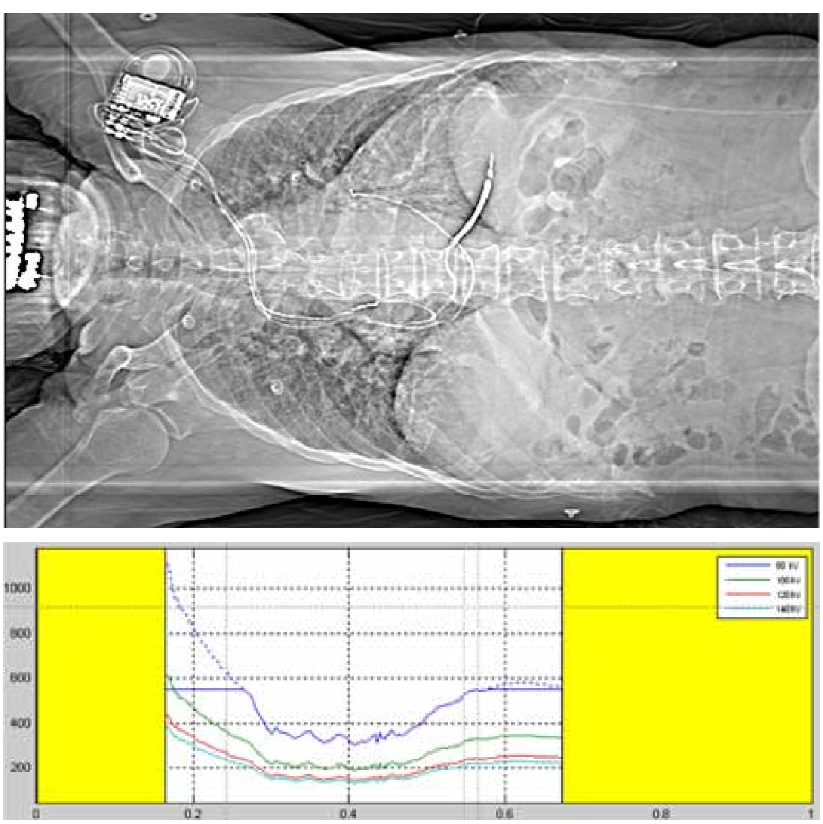


Figure 1.
Example image of the CARE kV user interface. The top panel illustrates the CARE kV tool in the "Off" position; no automatic dose optimization will occur and the user-provided Quality Reference mAs and Reference kV will be used for the exam. In addition, CARE Dose4D will operate as usual. With the CARE kV tool turned "On", the Quality Reference mAs and Reference kV of the specific exam are used to determine and maintain image quality for each exam, in conjunction with the CARE kV slider, which is used to indicate the type of exam being performed, allowing the tool to optimize dose for each specific exam. The optimal kV and mAs settings are now shown on the left panel and will be implemented in the scan. There also exists a "Semi" mode, in addition to off and on, which allows the user to force a specific kV but still allows for some dose optimization.

In addition, determining the optimal scan settings for individual patients is time-consuming and challenging given the interrelationship among kV, mAs, dose, contrast, and noise. Given these barriers, it is not surprising that in routine scanning tube voltage (kV) is rarely optimized to the patient and the indication. To utilize this significant unused possibility in aiding dose reduction, Siemens has developed a tool, CARE kV, that automatically recommends the optimal kV setting for each individual patient for each specific exam. CARE kV uses information gathered by the topogram and provided by the user in the slider bar, to optimize kV and mAs so that a user-chosen contrast-to-noise ratio is maintained, and thus optimal image quality and lowest dose are achieved.

The main goal behind CARE kV is to keep the contrast-to-noise ratio, the key parameter for image quality, the same. For each patient exam, the topogram and the corresponding attenuation information is used to determine the optimal kV to achieve the optimal dose efficiency for the entire length of the scan. In other words, patient-specific mAs curves are calculated for all kV levels (Figure 2) based on the given scan range, patient anatomy, and user-selected contrast behavior (identification of scan type or tissue of interest) necessary to deliver the desired image quality. The estimated dose is then calculated based on these kV-specific mAs curves for all of the kV levels to determine the optimal dose efficiency (Figure 2). Once the



Patient Length (z-axis) →

Figure 2.
The contents of this figure illustrate how kV-specific mA curves are calculated based on the attenuation from a specific patient topogram along the z-axis, given user-provided protocol and contrast information. The yellow opaque areas block out the mA curves outside the user-selected scan range, while the dotted lines of the mA curves indicate those portions of the curve that cannot be achieved due to system limitations (i.e., tube current limits) or due to the duration of the scan. In this exam, 100 kV (as indicated by green line) would be the optimal setting given the user-provided protocol and contrast information. Given slight adjustments to scan range or pitch, for example, a lower dose may be achieved.

optimal settings are determined, the tool checks the system to see if the optimal setting is possible (due to tube current limits, pitch settings, scan range, etc.). If this setting is not possible, the next best kV setting is suggested (Figure 3).

For a given image sharpness (spatial resolution) and slice thickness, the quality of CT images is mainly characterized by two parameters: contrast and noise. Improving either or both of these parameters will render a better image and enable the reading physician to make a more precise diagnosis. For example, if the contrast increases but the noise remains unchanged, the image quality improves.

Often, iodine contrast agent is administered to improve contrast and the visibility of the organ structures in CT images (particularly in CT angiographies). Image contrast increases with lower X-ray tube voltage since low energy X-rays are more strongly absorbed by iodine than by the surrounding tissue. However, in order to maintain low noise levels at low voltages, the tube current usually requires an upward adjustment. Most importantly, for a constant contrast-to-noise ratio in CT angiographic studies, the radiation dose can be significantly reduced by choosing 80 kV or 100 kV tube voltages instead of 120 kV.

kV	mAs	Pitch	CTDI
80	462	1.00	—
100	297	1.00	-20%
120	210	1.00	11.00
140	147	1.00	+5%

Figure 3.
Example table of the parameters considered by CARE kV. In this example exam, 120 kV at 210 mAs with a pitch of 1.0 was the routine protocol, and the user selected a “Liver” contrast setting along the slider bar. The information gathered from the topogram, along with the user-provided contrast information, allowed the optimal kV to be selected for this patient and exam. The kV selection in light blue (100 kV) allows for a 20% dose reduction. The white selection (80 kV) could be achieved under different parameters, such as lower pitch, but at the current settings is not possible.

For larger patients who have higher X-ray attenuation, the output current of the X-ray tube at lower kV settings may not be sufficient to produce the required contrast-to-noise ratios. For these patients, higher X-ray tube voltages will be necessary, despite a resulting reduction in iodine contrast. The benefit to larger patients will be improved image quality without a significant increase in radiation.

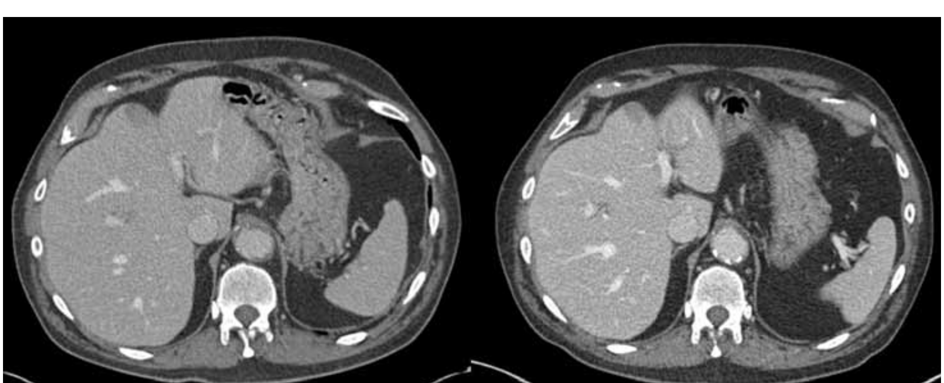


Figure 4.
Images showing dose savings of 14% using CARE kV on a patient with a prior CT exam on the same scanner for comparison. Original image on left (120 kV, eff. mAs 199), ref. mAs 240, CTDI 15.31 mGy. CARE kV on right (100 kV, eff. mAs 324) ref. mAs 337, CTDI 13.33 mGy. Images Copyright 2010, Mayo Foundation for Medical Education and Research.

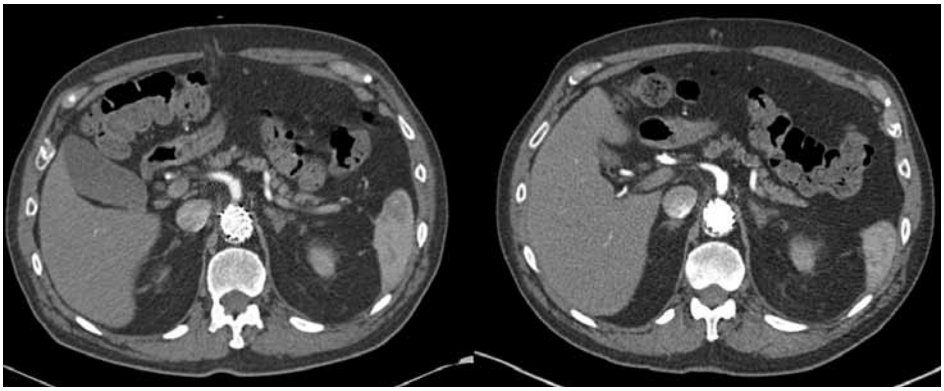


Figure 5.
CTA exam: Images illustrate the improvement in image quality between the original routine exam settings (Left: 120 kV, ref. mAs 250, CTDIvol 18.52 mGy), in comparison to the CARE kV provided exam settings (Right: 100 kV, ref. mAs 337, CTDIvol 14.32 mGy). Images Copyright 2010, Mayo Foundation for Medical Education and Research.

In order to maintain the same noise level at lower kVs, a significant increase in mAs is necessary. However, in high contrast exams, the effective mAs can actually be dropped resulting in a decreased dose. The most obvious results (and most significant dose reductions) are apparent in conducting a CT angiogram since the CT values of iodine-enhanced vessels at 80 kV are approximately two times higher than at 140 kV. Thus, the noise level can be twice as high while still maintaining the original contrast-to-noise ratio, allowing for acquisition at a significantly reduced dose. In non-contrast exams, there is no additional benefit gained from contrast improvement at lower kV. However, the CARE kV tool will still work to optimize the scan settings to the individual patient.

Several clinical sites internationally have tested the CARE kV prototype tool. These sites have already experienced significant dose reductions for a multitude of exams types and patient sizes.

CARE kV is most beneficial in contrast exams such as CT angiograms, CT enterographies, CT urograms, routine abdomen/pelvis imaging, and cardiac and pediatric examinations. In a pilot study conducted by Fletcher et al (RSNA 2010) assessing the potential for dose reduction by adapting the kV, the dose was reduced by approximately 20% on average in patients who underwent either a CT enterography or a CT urogram. In this study of 60 patients, two blinded radiologists compared image quality across similarly sized patients (30 images

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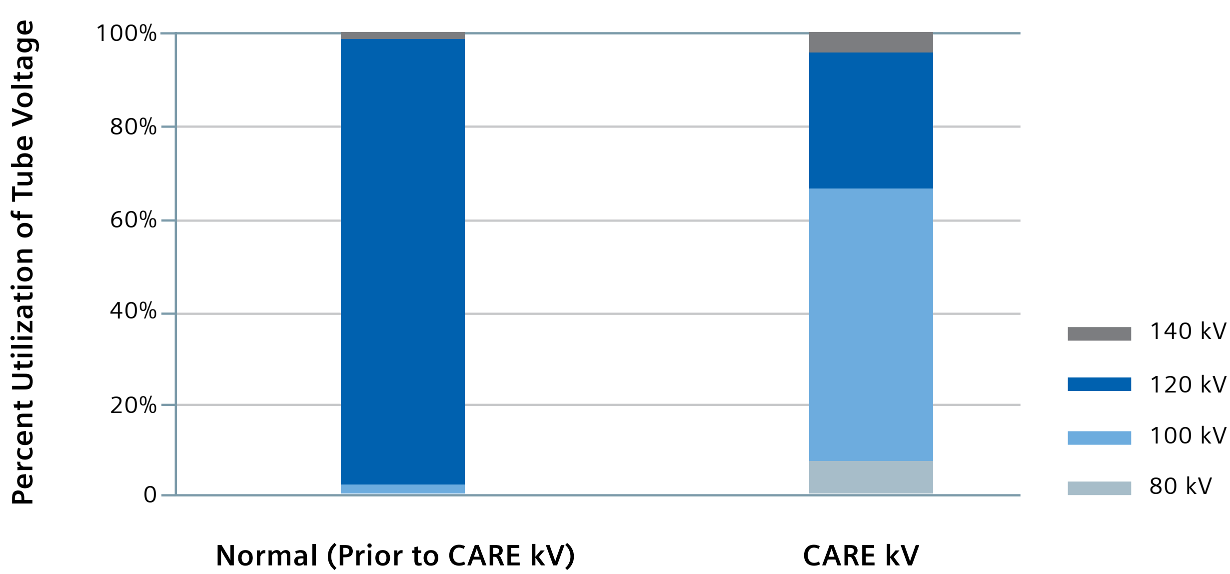
with the original protocol and 30 using the kV and mAs settings recommended by CARE kV). Researchers assumed that the original protocol was at the lowest possible dose level prior to using CARE kV. Dose savings were calculated based on the estimated CTDIvol both before and after CARE kV was used to adapt kV and mAs settings. Image noise and quality did not significantly differ between the control and test group.

CARE kV requires that CARE Dose4D be turned on and works simultaneously with the dose modulation provided by CARE Dose4D: the optimized kV is held constant but the mAs is still modulated. This tool can be especially beneficial in optimizing and reducing dose at sites that do not have a dedicated physicist on staff. CARE kV is yet another tool that allows Siemens CT users to improve and individualize patient care.

As found in the graph below, early experience with CARE kV at 6 different customer testing sites shows a remarkable shift away from traditional scanning at 120 kV, which is used for over 97% of scans when CARE kV is not applied. These sites included academic institutions and community hospitals, with a wide range of clinical specialties including cardiac, neuro, vascular, body, pediatric, and ER imaging. All sites experienced a consistent shift toward lower kV and lower doses. In the first three months of CARE kV use, 71% of patients scanned on the scanners equipped with CARE kV were scanned at a setting other than 120 kV, with 67% below 120 kV.



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Local Contact Information

Siemens Medical Solutions USA, Inc.
51 Valley Stream Parkway
Malvern, PA 19355-1406
USA
Phone: +1-888-826-9702
www.usa.siemens.com/healthcare

Global Business Unit

Siemens AG
Medical Solutions
Computed Tomography
Siemensstr. 1
DE-91301 Forchheim
Germany
Phone: +49 9191 18-0
www.siemens.com/healthcare

Global Siemens Headquarters

Siemens AG
Wittelsbacherplatz 2
80333 Muenchen
Germany

Global Siemens
Healthcare Headquarters

Siemens AG
Healthcare Sector
Henkestrasse 127
91052 Erlangen
Germany
Phone: +49 9131 84-0
www.siemens.com/healthcare

Legal Manufacturer

Siemens AG
Wittelsbacherplatz 2
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Germany

www.siemens.com/healthcare

Order No. A9115-11314-C1-4A00 | Printed in USA 04-2011 |