White paper

Reduction of contrast agent dose at low kV settings

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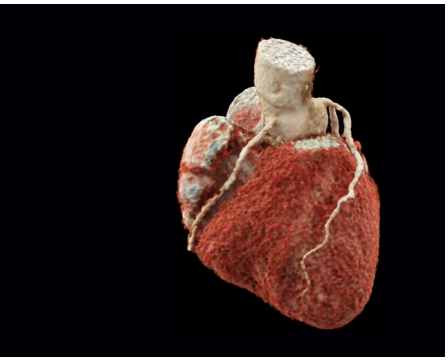

Introduction

Automated tube voltage selection enabled by Siemens Healthineers CARE kV* can be used for multiple clinical applications, with one of the most beneficial being contrast-enhanced scans with lower radiation dose but with consistent image quality.

This is an established method that is currently being used in clinical routine and that can help to reduce the radiation dose required. Overall, tube potentials between 70 and 100 kVp have been shown as most effective for clinical contrast CT examinations, depending on the specific situation.

With the advent of CT scanners with X-ray tubes powerful enough to produce high mA at low kV (e.g. SOMATOM go. Platform, SOMATOM Edge Plus, SOMATOM X.platform, SOMATOM Drive and SOMATOM Force, NAEOTOM Alpha), the same physical behavior of X-rays and iodine contrast agent can be used in clinical routine to reduce the amount of contrast agent instead of radiation dose.

This white paper briefly summarizes the scientific background and explains the principle of saving contrast agent dose instead of radiation dose.

Scientific background

The actual basis for low kV imaging is the mass attenuation coefficient, which is a property that depends on the chemical composition and density of a material and determines the specific absorption of X-ray beams by this material.

Figure 2 shows that for lower photon energies, the mass attenuation coefficient of iodine increases, whereas soft tissue is less energy-dependent. This means that with low kV imaging, and thus lower average photon energy, the iodine to soft tissue contrast in the CT image (in Hounsfield units, HU) will increase. This can be easily verified by scanning a static phantom with different iodine concentration samples at different tube voltages (Figure 3).

Due to the linear relationship between iodine concentration and enhancement, Figure 3 shows how much iodine can be saved if the attenuation is kept constant. For example, if an iodine enhancement of 300 HU is desired, the iodine concentration at 70 kV can be ~50% lower than the iodine concentration at 120 kV.

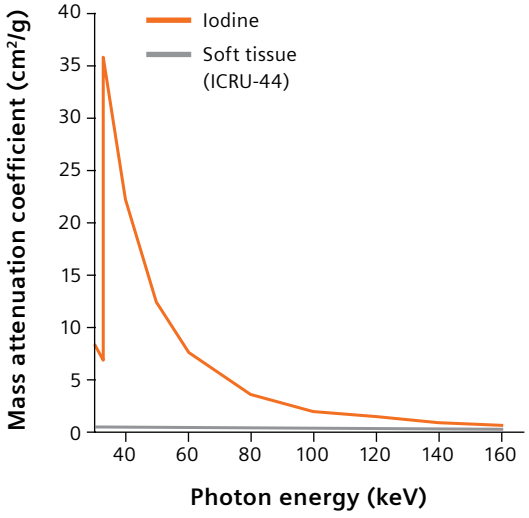

Figure 2. Mass attenuation coefficients for soft tissue and iodine at different photon energies. At lower energies, the difference in absorption between soft tissue and iodine increases, which results in a higher iodine contrast in the image. The K-edge of iodine leads to the spike visible at 33.2 keV. Data from NIST tables

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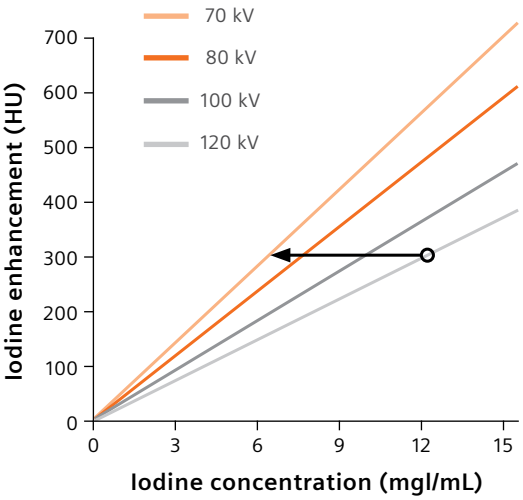


Figure 3. With static iodine phantoms, the increase in iodine enhancement (in HU) at a lower kV can be verified [data from iodine samples in 20 cm water phantom]. The arrow indicates how much iodine can potentially be saved in constant enhancement when going from 120 to 70 kV.

When comparing the relative iodine enhancement between all different kVs from 70 to 150 kV with each other, it is possible to calculate the potential change in iodine concentration with a decrease in kV while yielding the same iodine enhancement in HU (Figure 4).

reference kV		new kV	[Iodine] Change mg/mL
120	→	120	0
120	→	110	-0.10
120	→	100	-0.20
120	→	90	-0.30
120	→	80	-0.40
120	→	70	-0.49

New/Alternative kV

Reference kV	70 kV	80 kV	90 kV	100 kV	110 kV	120 kV	130 kV	140 kV	150 kV
70 kV	1	+0.18	+0.37	+0.58	+0.77	+0.97	+1.14	+1.36	+1.54
80 kV	-0.15	1	+0.16	+0.33	+0.50	+0.67	+0.81	+0.99	+1.15
90 kV	-0.27	-0.14	1	+0.15	+0.29	+0.44	+0.56	+0.72	+0.85
100 kV	-0.37	-0.25	-0.13	1	+0.12	+0.25	+0.36	+0.49	+0.61
110 kV	-0.44	-0.33	-0.23	-0.11	1	+0.11	+0.21	+0.33	+0.44
120 kV	-0.49	-0.40	-0.30	-0.20	-0.10	1	+0.09	+0.19	+0.29
130 kV	-0.53	-0.45	-0.36	-0.26	-0.17	-0.08	1	+0.10	+0.19
140 kV	-0.58	-0.50	-0.42	-0.33	-0.25	-0.16	-0.09	1	+0.08
150 kV	-0.61	-0.53	-0.46	-0.38	-0.30	-0.22	-0.16	-0.07	1

Figure 4. Table displaying the relative change in iodine concentration necessary when either lowering or increasing the tube voltage for constant HU enhancement from a vial of iodine within a 30 cm of water phantom. (Assuming a 1 mg/mL value of iodine as the baseline for each kV.)

Data from phantom experiments with static iodine concentration, patient results may vary depending on patient size.

120 kV,
120 mL contrast

80 kV,
40 mL contrast

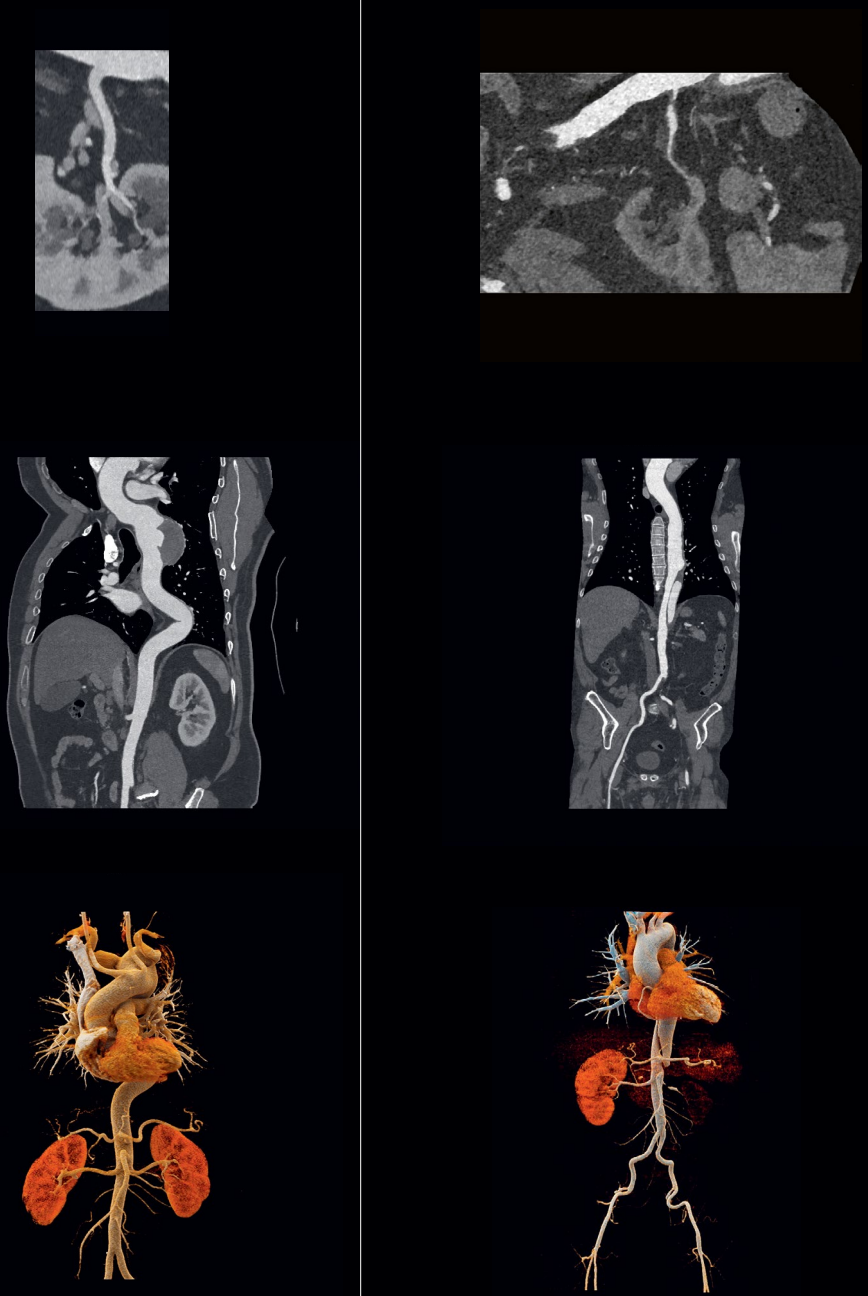


Figure 1. Clinical examples of two patients scanned with a default 120 kV protocol with 120 mL of contrast agent (left) and with a reduced kV protocol (80 kV) with only 40 mL on SOMATOM Force.

Courtesy of Radiologie Karlsruhe Karlstrasse and Universitätsklinikum Mannheim, Germany

The principle of saving contrast agent dose

The main aim of Siemens Healthineers CARE kV* is to maintain image quality when changing the kV, with image quality defined in terms of the contrast-to-noise ratio (CNR). Since it is directly dependent on enhancement, the CNR increases for lower kVs if radiation and iodine dose are fixed (Figure 5). This fact can be utilized to either save radiation dose or iodine dose while keeping the CNR constant; however, it is dependent on patient size. Before explaining the principle of saving contrast agent dose, the principle of saving radiation dose will briefly be reviewed.

Saving radiation dose

The starting point for saving radiation dose is the assumption that the same injection, protocol (amount, concentration and timing) of the reference protocol (R) would be used for all kVs, which inherently leads to an increase in iodine attenuation with decreasing kV.

As the iodine contrast increases, noise can be allowed to increase by the same extent to maintain the CNR. Then for each kV level, the respective tube current (mAs) required to reach the desired noise level is determined, as well as the corresponding radiation dose (CTDIvol). Finally, the kV level yielding the lowest radiation dose that can be achieved by the system will be chosen.

This methodology is schematically illustrated in Figure 6a.

Saving contrast agent dose

If the aim is to reduce the contrast agent dose instead of the radiation dose, the same steps need to be performed as when saving radiation dose. However, these four steps should be taken in the opposite order, as described on the next page and as illustrated in Figure 6b.

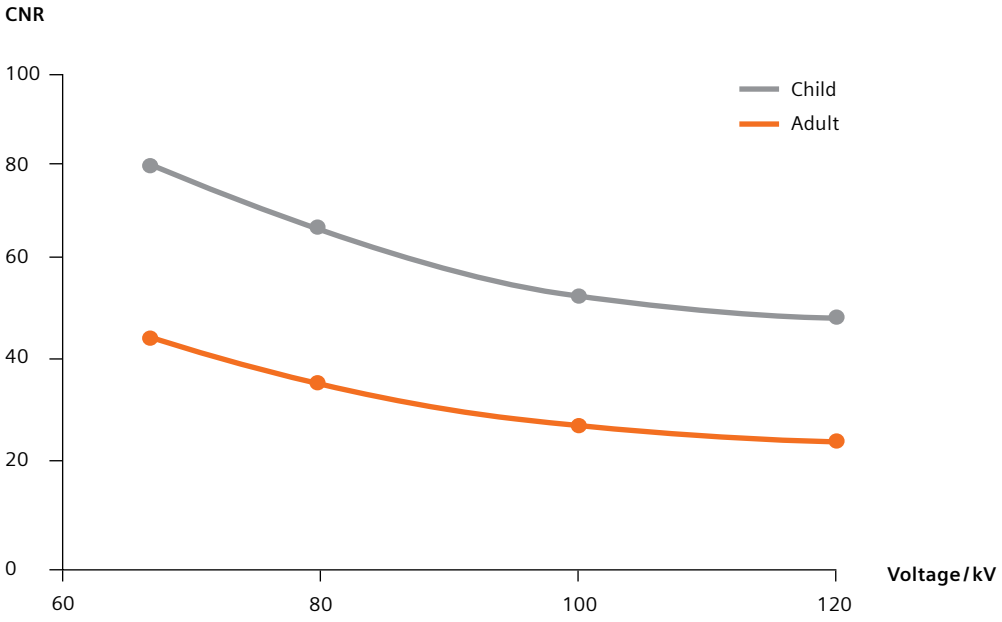
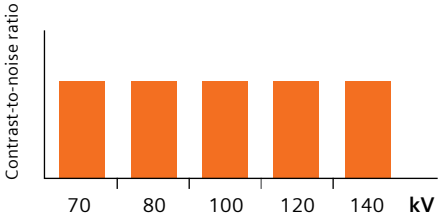


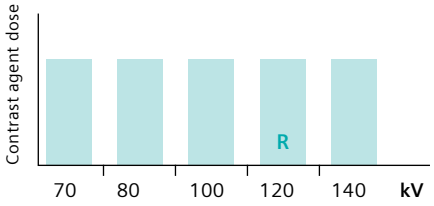
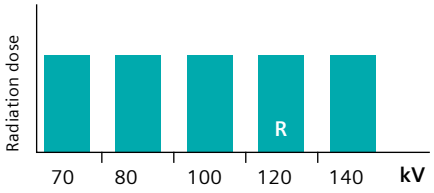
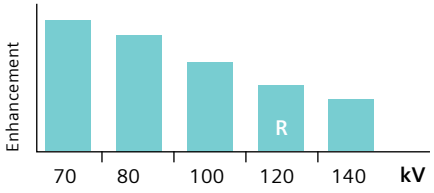
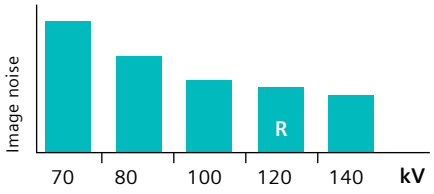
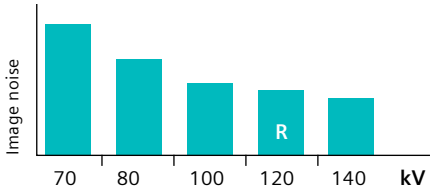
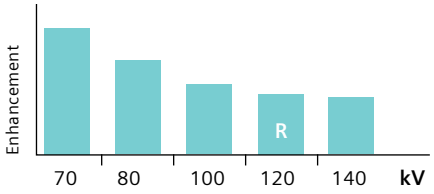
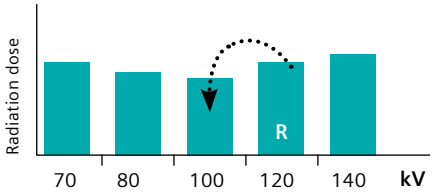
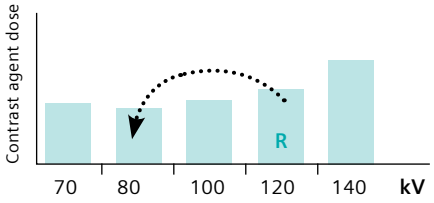
Figure 5. CNR increases for lower kV settings at fixed $CTDI_{vol}$ and fixed iodine dose.

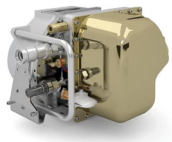
**Not available on the SOMATOM go.Now and SOMATOM go.Up*

Figure 6. Low kV imaging at constant contrast-to-noise ratio:
a) Principle of saving radiation b) Principle of saving contrast agent dose
R denotes the reference protocol.

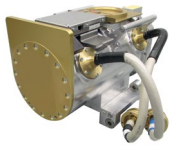
Aim: Constant image quality (CNR) for all tube voltages



	Save radiation dose (CARE kV)	Save contrast agent dose
Step 1	Starting point: Contrast agent dose is fixed	Starting point: Radiation dose is fixed
		
Step 2	How much iodine enhancement do you get?	How much image noise do you get?
		
Step 3	How much noise is needed to obtain required CNR?	How much iodine enhancement is needed to obtain required CNR?
		
Step 4	Which kV has the lowest radiation dose for the required noise?	Which kV has the lowest contrast agent dose for the required iodine enhancement?
		



Vectron



Straton MX Sigma

Athlon

Chronon

Step 1

When reducing the contrast agent dose (Figure 6b), the new starting point is the radiation dose ($CTDI_{vol}$) of the reference protocol (R), which should be kept constant for all kV levels. This can be achieved by adjusting the tube current (mA). Until now this step had not been possible in clinical routine due to certain technical limitations of CT systems: the X-ray tubes of existing CT systems were not powerful enough to produce sufficient tube currents at low kV settings to maintain the $CTDI_{vol}$ of the reference protocol. Consequently, measures to save iodine dose were only feasible in pediatric or very thin patients. However, with the Vectron™ tube with vastly increased tube power at low kVs (up to 2 x 120 kW, up to 2 x 1,300 mA at 70–90 kV, as integrated in NAEOTOM Alpha, SOMATOM Force, and SOMATOM X.platform) it is now possible to scan even obese patients at low tube voltages with sufficiently high mA and thus offer the possibility of contrast agent dose reduction. SOMATOM Drive with the Straton MX Sigma tube provides 2 x 100 kW and 2 x 650 mA at 70 kV, and 2 x 750 mA at 80 and 90 kV. SOMATOM Edge Plus with the Straton MX Sigma tube provides 100 kW and 650 mA at 70 kV, and 750 mA at 80 and 90 kV. SOMATOM go.Top and go.All with the Athlon tube provides 75 kW and 825 mA at 70 and 80 kV and 800 mA at 90 kV. SOMATOM go.Up and go.Now with the Chronon tube provides 32 kW and 400 mA at 80 kV.

Step 2

For each kV and mAs combination, the resulting image noise can be calculated using the topogram of the patient. It is important to stress that a specific radiation dose will not result in the same image noise at the different tube voltages. Particularly at a lower kV, the image noise will be higher for a given $CTDI_{vol}$. Although this effect is small, it reduces the contrast agent reduction potential that would be possible if one were to consider only the increased iodine enhancement at a lower kV.

Step 3

With the expected image noise calculated in step 2, the iodine enhancement that is required to preserve the desired CNR can be calculated for each kV.

Step 4

If the required iodine enhancement is known, the corresponding contrast agent dose at each kV can be calculated. Based on this, the tube voltage setting that requires the lowest iodine contrast agent dose to reach this enhancement level can be selected.

This principle works on every CT scanner; however, for meaningful savings of contrast agent dose a significant decrease in the kV is required (Figure 4). In the past, it has not been possible to keep the dose constant at all kV levels, as the X-ray tubes were not powerful enough to produce sufficient tube current (mA) at low kV levels. New X-ray tubes powering the new generation of scanners, like NAEOTOM Alpha, SOMATOM Force, SOMATOM Drive, SOMATOM X.platform, SOMATOM Edge Plus and SOMATOM go. Platform, now have sufficient power to fulfill this condition (Figure 7).

An additional technical enhancement that enables the success of this principle are the availability of iterative reconstruction methods (such as ADMIRE and SAFIRE) and integrated circuit detectors (Stellar detector) which help to reduce image noise at low kV scans and therefore allow for a diagnostic image quality even at low kV settings.

Low kV contrast CT scanning is feasible in clinical routine and, depending on user preferences, it can be used directly to reduce either radiation or iodine dose.

It is possible to use low kV imaging to save both radiation and iodine dose at the same time; however, the configuration of a suitable protocol is not easy and the reduction potential for both radiation and iodine is significantly less compared to the two methods described above.

> **The increase in iodine enhancement at lower kV can be utilized to reduce the contrast agent dose, while maintaining the image quality (CNR) at a given radiation dose.**

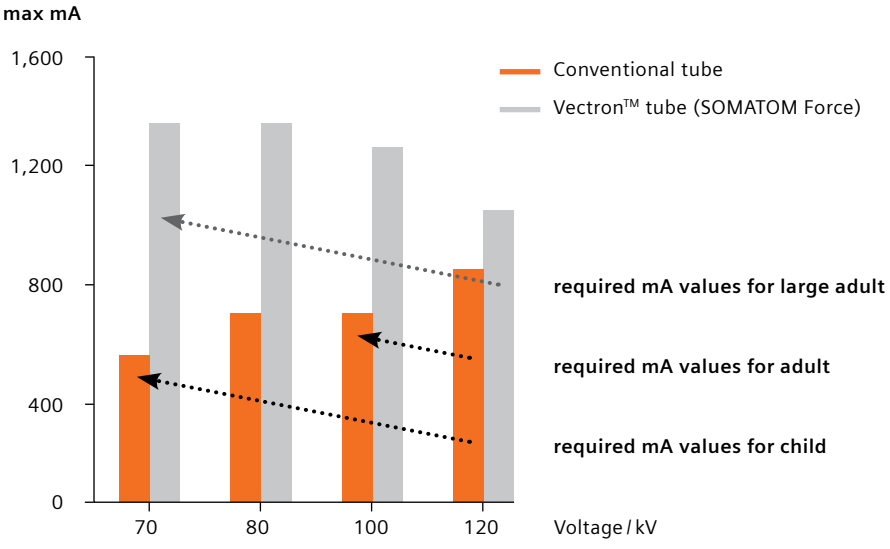


Figure 7: Maximum tube output at different kVs: With conventional tubes, sufficiently high mAs output at low kVs is only possible for pediatric examinations (black arrows). New CT tube generations, however, can overcome this limitation. This enables a significant reduction in the kV, not only in protocols for children, but also for large adult scans (gray arrow).

70 kV,
70 mL contrast

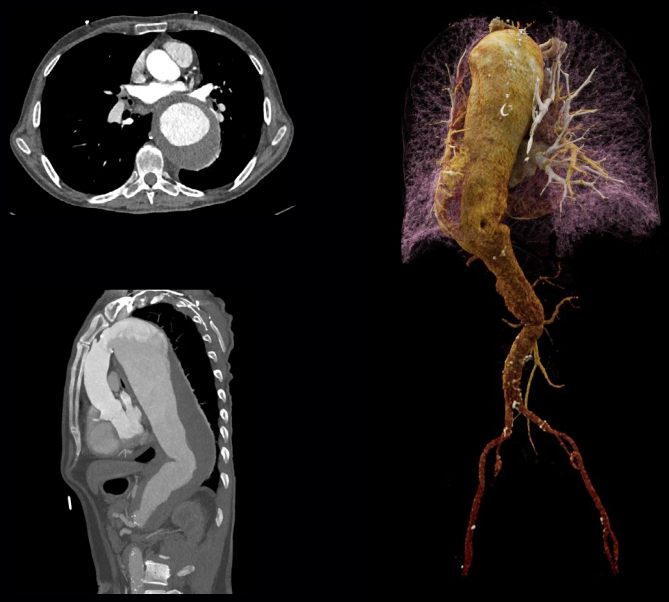


Figure 8: Clinical example of a patient scanned with a suggested 70 kV protocol with 70 mL of contrast agent on SOMATOM Edge Plus.

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80 kV,
30 mL contrast

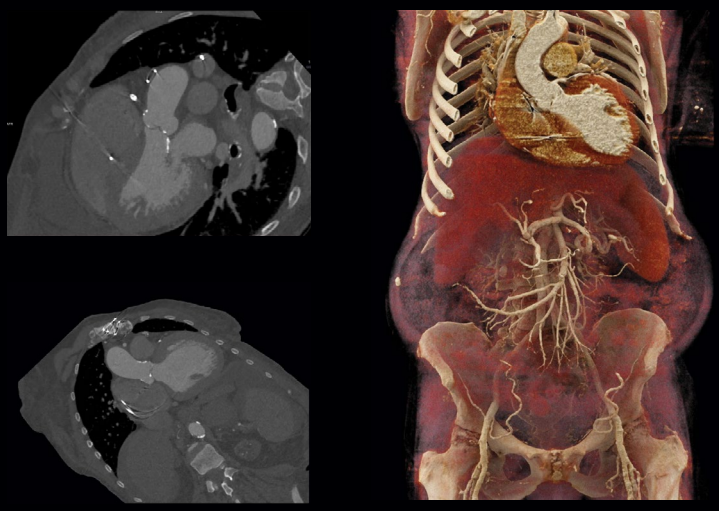

Figure 9: Clinical example of a TAVR patient scanned with a 80 kV protocol with 30 mL of contrast agent on SOMATOM Force.

Saving contrast agent in clinical practice

If one changes from a reference scan protocol to a low kV protocol and one decides to reduce the contrast agent dose, the contrast injection protocol must be adapted to reduce the iodine load.

The easiest way to adapt the iodine load seems to be a reduction of the contrast volume without changing any other injection parameters.

However, a reduction in contrast volume leads to a shorter injection duration and, thus, to significant changes in the contrast enhancement over time: peak enhancement occurs earlier, requiring adaptation of the scan delay, and scan timing becomes more critical because of a narrower enhancement curve.

To avoid these changes in scan timing, the preferred and most robust strategy to achieve contrast dose reduction is to keep the injection duration constant while reducing the iodine delivery rate (IDR).

Reduction of the IDR can be accomplished by lowering the iodine concentration and/or the volume and injection flow rate, which will lead to identical temporal enhancement curves for reference and low kV protocols.

As previously demonstrated in a pre-clinical animal study (Figure 8), peak width, peak height, and peak time remain the same with a reduction of the IDR. More practical details, for instance about setting the CTDIvol of reference protocols for lower kVs and adaptation of the bolus tracking parameters, can be found in the "How-to" guide, which provides step-by-step instructions for clinical application.

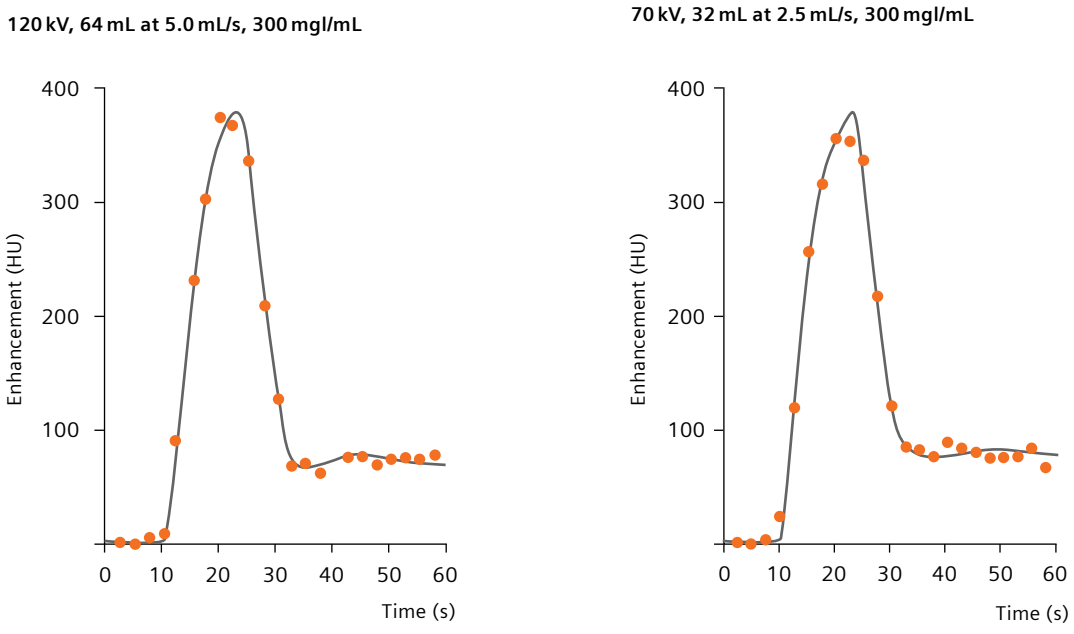

Figure 8: An animal study in pigs demonstrated that an identical temporal enhancement curve for the 120 kV reference protocol (left) and 70 kV protocol (right) can be obtained with constant injection duration and adapted IDR, while saving 50% in contrast agent.

Data courtesy of Lell et al.

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https://www.healthcare.siemens.com/medical-imaging/low-dose/order-guide-to-low-dose

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