Radiation Dose with Dual Source CT

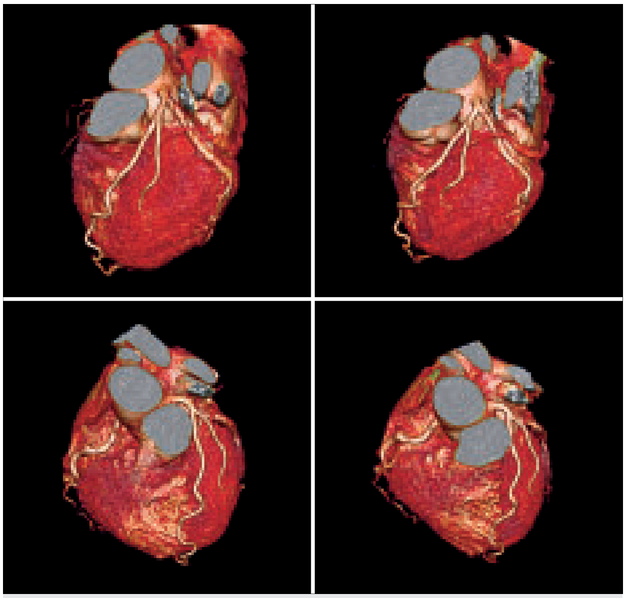
T. Flohr, H. Bruder, K. Stierstorfer, C. McCollough
Article from the customer magazine Medical Solutions, June 2006

www.siemens.com/healthcare-magazine

Radiation Dose with Dual Source CT

Reducing radiation dose is a major concern in cardiac CT. With dedicated dose-reduction mechanisms, however, radiation dosage in Dual Source CT can be efficiently reduced to a level well below that of single source CT.

By Thomas Flohr, PhD, Head of Physics and Application Development; Herbert Bruder, PhD; Karl Stierstorfer, PhD, Physics and Application Development, Siemens AG, Medical Solutions, CT Division; and Cynthia McCollough, PhD, Director of the CT Clinical Innovations Center, Mayo Clinic, Rochester, MN, USA

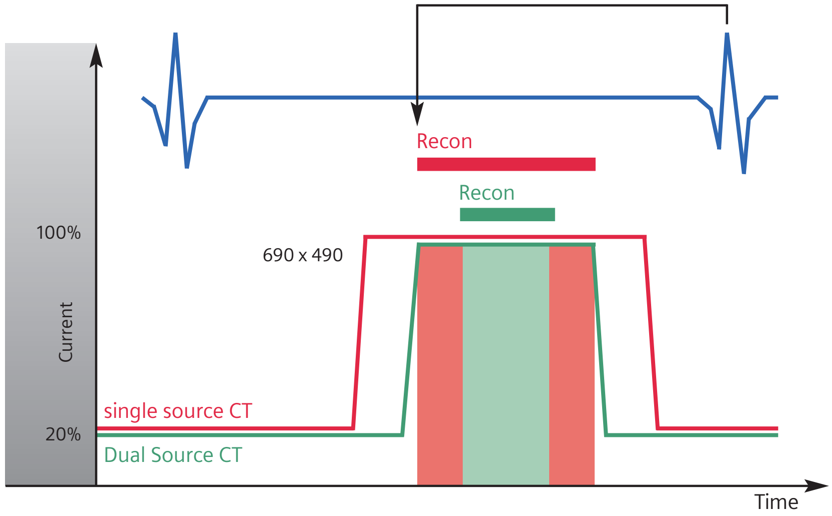


[1] **VRT RENDERINGS** of a 59-year-old male patient with suspicion of RCA stenosis. The mean heart rate of the patient during the scan was 85 bpm.
Left: diastolic reconstruction at 65% of the cardiac cycle.
Right: end-systolic reconstruction at 28% of the cardiac cycle.
In both cases, the coronary arteries are clearly depicted with little or no motion artifacts.

Temporal resolution better than 100 ms in combination with sub-millimeter spatial resolution and examination times below 10 s to cover the entire heart volume are considered prerequisites for a successful implementation of cardiac CT into routine clinical algorithms. SOMATOM® Definition is a Dual Source CT (DSCT) scanner with 0.33 s gantry rotation time and 2 x 32 x 0.6 mm collimation in combination with z-Sharp™ Technology for the simultaneous acquisition of 2 x 64 overlapping 0.6 mm slices. With these technical specs, it can fulfill these requirements: temporal resolution as good as 83 ms independent of the heart rate for coronary CTA and functional evaluation. Through-plane resolution of 0.4 mm can be routinely achieved for the evaluation of stents and severely calcified coronary arteries. The scan time for a 120 mm scan volume ranges between 5 and 9 s, depending on the patient's heart rate. First clinical experience has already demonstrated a considerably increased robustness of the method for the imaging of patients with high heart rates [Fig. 1].

In addition to their benefits for cardiac examinations, DSCT scanners also show promising properties for general radiology applications. First, both X-ray tubes can be operated simultaneously in a standard spiral or sequential acquisition mode, in this way providing up to 160 kW X-ray peak power. These power reserves are not only beneficial for the examination of

ECG-controlled Tube Current Modulation



[2] ILLUSTRATION OF ECG-controlled tube current modulation for the evaluated DSCT system. For coronary CT angiography, the image reconstruction window should be located within the window of maximum tube current. The temporal width of the image reconstruction window is 83 ms for the DSCT; it is 165 ms for a single source CT at 0.33 s gantry rotation time. For the DSCT, the temporal width of the window of maximum tube current can be selected by the user. It can be much shorter than for a single source CT system, thereby reducing radiation dose to the patient.

exceedingly obese patients, whose numbers are dramatically growing in western societies, but also to maintain adequate X-ray photon flux for standard protocols when very high volume coverage speed is necessary. Among them are acute-care situations, where the scanner has to be operated with fast gantry rotation (0.33 s) and at high pitch (p = 1.5). Additionally, both X-ray tubes can be operated at different kV-settings and/or different pre-filtrations, in this way allowing dual energy acquisitions.

A major concern in cardiac CT is high radiation dose to the patient, which is mainly caused by the highly overlapping data acquisition due to the low spiral pitch required for gapless volume coverage in each phase of the cardiac cycle.

In cardiac DSCT, both X-ray sources have to be simultaneously operated at the power level needed for single source CT, since each of them contributes only a quarter rotation to an image slice. Without further optimization, DSCT would increase radiation dose to the patient by almost a factor of two. With dedicated dose reduction mechanisms, however, radiation dose can be efficiently reduced to a level well below that of single source cardiac CT. The three major steps to radiation dose reduction are:

- use of a new, optimized ECG-pulsing with shorter exposure windows that can be reliably applied even in the presence of arrhythmia;
- use of single-segment reconstruction at all heart rates that enables efficient adaptation of the spiral pitch to the heart rate;
- use of an optimized cardiac beam-shaping filter that avoids unnecessary exposure outside the central heart region.

Efficient ECG-controlled Tube Current Modulation

In cardiac CT, ECG-controlled modulation of the X-ray tube current is applied to restrict the time interval of maximum exposure to those cardiac phases where diagnostic image quality is required [Fig. 2]. The plateau of high dose must extend over the data range needed for image reconstruction plus additional ranges for retrospective optimization of the cardiac phase used for image reconstruction. In single source CT, image reconstruction requires a high dose plateau of at least half the gantry rotation time at iso center, and the data range needed for phase optimization has to be larger than in DSCT due to the lower temporal resolution. In DSCT, image reconstruction requires a high dose plateau of only a quarter of the gantry rotation time at iso center. Consequently, the time interval with full dose can be much shorter, which results in reduced radiation exposure compared with single source CT. The potential for dose reduction depends on the heart cycle length, and, hence, on the patient's heart rate. For

DESPITE TWO X-RAY SOURCES, the SOMATOM Definition enables cardiac CT scanning with only half the radiation dose compared with single source systems.

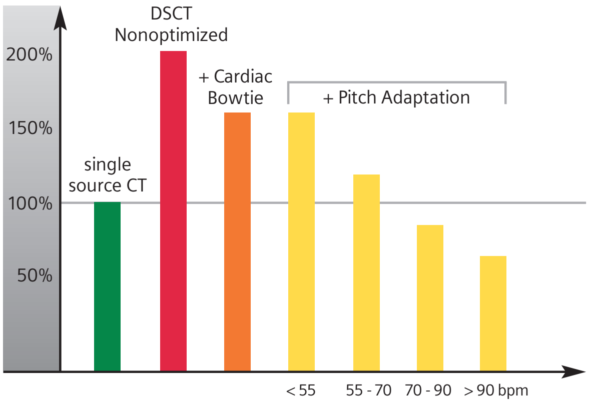
ECG-controlled modulation of the tube current, a prospective method is needed to estimate the time of the R-peak for the next cardiac cycle. Using conventional approaches, the mean value of some preceding heart cycles is used to estimate the next RR-interval. This method fails if the patient's heart beat is arrhythmic. For DSCT, a much more robust algorithm for prospective estimation of the cardiac cycle length by refined analysis of the patient's ECG has been developed and implemented. This algorithm takes non-rhythmic heart beats, such as extra-systoles, into account, and can also be applied in case of arrhythmia.

Adaptation of Spiral Pitch to the Patient's Heart Rate

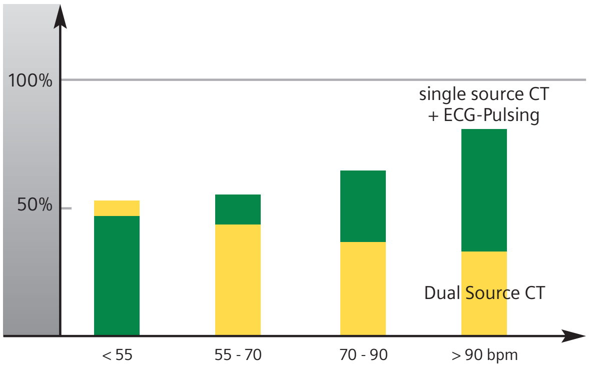
In single source CT, improved temporal resolution is obtained at the expense of limited spiral pitch and correspondingly increased radiation dose to the patient. For a so-called single-segment reconstruction, the table has to travel so slowly that each z-position of the heart is seen by a detector slice during each phase of the cardiac cycle. Consequently, the patient's heart rate determines the spiral pitch: if the heart rate goes up, the spiral pitch can be increased, too. If multi-segment reconstructions are applied at higher heart rates to improve temporal resolution, the spiral pitch has to be reduced again: for a 2-segment reconstruction, each z-position of the heart has to be seen by a detector slice during two consecutive heart beats; for a 3-segment reconstruction during three consecutive heart beats; and so on. In general, manufacturers of single source CT scanners recommend an adaptive approach for ECG-gated cardiac scanning: the pitch of the ECG-gated spiral scan is kept constant at a relatively low value of 0.2 – 0.25, and more segments are used for image reconstruction at higher heart rates to improve temporal resolution. Up to a certain threshold heart rate, a single-segment reconstruction is performed; if the heart rate increases this threshold, two or even more segments are used. Even if a certain adaptation of the pitch is available, as proposed by some manufacturers, the range of variation is very small, e.g., between 0.2 and 0.25.

Using a DSCT system, a temporal resolution of a quarter of the gantry rotation time is achieved independent of the patient's heart rate. Single-segment reconstruction using data from one cardiac cycle for image reconstruction can be applied at all heart rates. Since multi-segment reconstruction will not be required, the spiral pitch can be efficiently adapted to the patient's heart rate and significantly increased at elevated heart rates, compared with single source CT systems that have to use multi-segment reconstruction at higher heart rates. Pitch values ranging from 0.25 at lower heart rates up to 0.5 at high heart rates are possible, resulting in coverage of the entire heart volume within 5–9 s with 2 x 32 x 0.6 mm collimation. The increased pitch at higher heart rates does not only reduce the examination time, but reduces the radiation dose to the patient. At constant tube output

Comparison of Relative Radiation Dose



[3] RELATIVE RADIATION DOSE for ECG-gated scanning with single source CT and DSCT, assuming equivalent image noise. For both systems, no ECG-controlled dose modulation is used. The single source CT system is operated at a pitch of 0.2, a typical value for ECG-gated coronary CTA. The non-optimized DSCT system (also operating at a pitch of 0.2) increases radiation dose by almost a factor of 2.
With an optimized cardiac bowtie-filter, the dose increase is reduced to a factor of 1.53. With additional pitch adaptation, the radiation dose for the DSCT system is only 80 percent of the radiation exposure with single source CT at clinical relevant heart rates of 70 – 90 bpm.



[4] RELATIVE RADIATION DOSE for ECG-gated scanning with single source CT and DSCT, with ECG-controlled dose modulation, using the same scaling as in Figure 3. For single source CT, the window of full dose is 400 ms, for DSCT it is 210 ms. The relative dose with single source CT increases with increasing heart rate, due to the decreasing dose reduction effect of ECG-controlled dose modulation and the constant spiral pitch. The relative dose with DSCT decreases with increasing heart rate. At clinical relevant heart rates between 70 and 90 bmp the radiation exposure with DSCT is only about 50% of the radiation exposure with the single source CT system.

(constant mA) and fixed gantry rotation time, higher pitch is directly equivalent to reduced patient dose: an ECG-gated examination that is performed at a pitch of 0.4 instead of 0.2 results in only 0.2/0.4 = 0.5 times the radiation dose. Using the evaluated DSCT scanner, the patient's heart rate is monitored before the examination; the lowest heart rate observed during the monitoring phase is taken and an additional safety margin of 10 bpm is subtracted to automatically adjust the pitch.

Optimized Cardiac Beam-shaping Filter

Because patient thickness decreases at the periphery, the X-ray beam can be attenuated by shaped filters to reduce radiation intensity in the scan-plane (in the fan-angle direction) with increasing distance from the iso center. In cardiac CT, the region of interest, the heart, is centered within the thorax, and radiation can, in principle, be restricted to a cardiac field of view (FOV) of about 25 cm in diameter. Thus, the radiation dose outside the cardiac FOV can be reduced by an optimized beam-shaping filter and by the smaller scan field of view of the second X-ray tube-detector system.

The effects of the three dose-saving steps are summarized in Figs. 3 and 4. In Fig. 3, the relative radiation dose for ECG-gated cardiac CTA with DSCT is compared with the dose for a corresponding single source CT system, both without ECG-pulsing. Dose reduction for DSCT comes from the cardiac bowtie filter and the adaptation of the pitch to the patient's heart rate. In Fig. 4, the effect of ECG-gated dose modulation is additionally taken into account for both systems. Applying the three dose-saving steps, dose reduction up to a factor of two compared with single source CT can be demonstrated for ECG-gated spiral scanning.

Further Reading

[1] Flohr, T, et. al.: First performance evaluation of a dual-source CT (DSCT) system, Eur Radiol. 2006 Feb; 16(2):256-68.
[2] Achenbach, S., et al.: Contrast-enhanced coronary artery visualization by dual-source computed tomography – Initial experience. Eur J Radiol. 2006 Mar; 57(3):331-5.