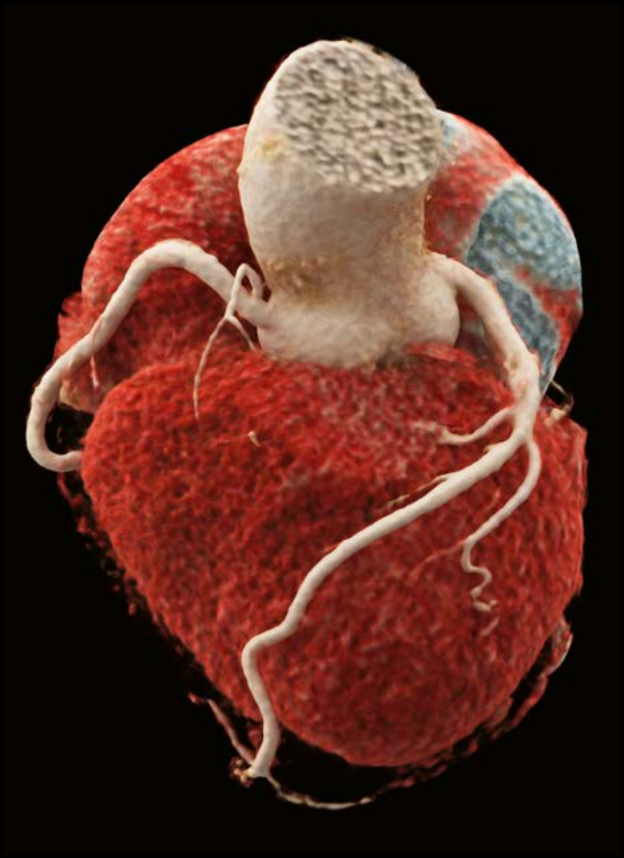
White paper

Cardiac imaging – When native temporal resolution matters

Clinical benefits of Dual Source CT



siemens-healthineers.us/cardiac-ct-imaging

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Introduction

For decades CT imaging has been gaining relevance for the diagnosis of cardiac disease. The clinical benefits in this field have been investigated and proven by several studies, e.g., on coronary computed tomography angiography (cCTA) (e.g., by SCOT Heart) [1,2]. The latest ESC Guidelines underline these benefits and recommend cardiac CT as initial test for ruling out coronary artery disease (CAD). Additionally, CT imaging is acquiring an important role also for multiple other cardiac-related issues (e.g., pre-surgical planning) [3].

ESC Guidelines 2019[1]

Coronary CTA is recommended as the initial test for diagnosing CAD in symptomatic patients in whom obstructive CAD cannot be excluded by clinical assessment alone (class I). Coronary CTA should be considered as an alternative to invasive angiography (class IIa) [3].

In the last years, several CT technologies have been introduced to overcome persistent challenges such as coverage of the heart, spatial resolution, patient dose, etc. These improvements certainly had positive impact on cardiac CT Imaging. But the biggest challenge in cardiac CT remains the motion of the heart itself.

And finally, there are significant differences in the overall quality between the various types and generations of available products on the market. Especially the rotation speed of the tube detector system and the resulting temporal resolution are essential requirements for high diagnostic image quality because CT scanners must assure very fast data acquisition to allow for visualization of the small vessels and cardiac structures without any motion. Furthermore, the ability to reduce radiation dose is gaining in higher importance [4].

Dual Source CT scanners are the only type of CT scanners on the market that offer the highest intrinsic temporal resolution of $\leq$83 ms. This intrinsic temporal resolution is well understood to be crucial for high quality imaging independent of the heart rate of the patient.

As a result, different cardiac fields enjoy unique benefits, such as accurate assessment of coronary lesions or valves (e.g., for TAVI/TAVR planning). Further, this innovative imaging technique plays a significant role in the diagnosis of congenital heart abnormalities. Besides these established procedures, there is even more untapped potential to discover for future approaches that are explored in this paper.

Temporal resolution

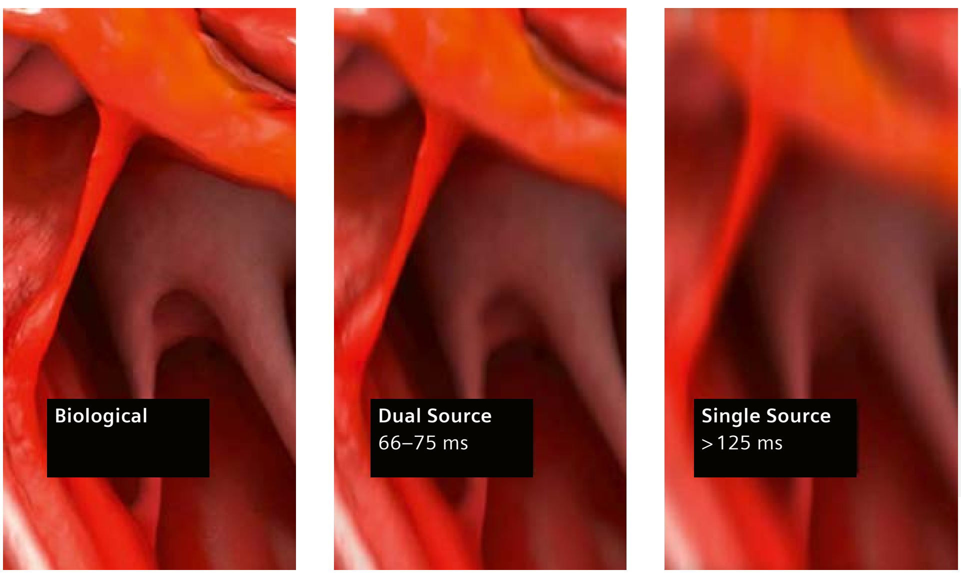
Fast temporal resolution is a fundamental image quality parameter of cardiac CT. Only with fast temporal resolution is it possible to resolve fast-moving objects (e.g., the heart). Technically, it can be compared to the shutter speed of a camera. The faster the shutter speed, the easier it is to take sharp images of fast-moving objects. When we talk about cardiac CT, temporal resolution is primarily achieved through fast gantry rotation time and partial scan reconstruction. To further increase temporal resolution, one often-used method is multisegment reconstruction. Data required for this type of image reconstruction is selected from multiple cardiac cycles. To achieve improved temporal resolution, this method can only be effectively achieved at specific heart rates because the heart rate and the gantry rotation time are practically not synchronized. For data that stems from more than one cardiac cycle, the detector needs to cover the same position within the cardiac cycle, which cannot always be assured.

Other methods used to positively affect temporal resolution are software-based algorithms that correct motion artifacts during image reconstruction. Most of them claim to increase the diagnostic performance of cCTA. Although an improvement in the images can be seen in patients with a low heart rate, in some cases the algorithms still struggle to correct high motion artifacts, as demonstrated in a recent paper [5].

[1] 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes

This is clearly due to the fact that the intrinsic temporal resolution is too low [5].

In contrast, the introduction of Dual Source CT technology put forward a unique technique to further increase intrinsic temporal resolution. It consists of two tube and detector sets arranged at approximately 90-degree angles to each other. It therefore provides intrinsic temporal resolution equivalent to a quarter of the gantry rotation time and independent of the patient heart rate. This truly allows us to go beyond conventional CT imaging.



120 +

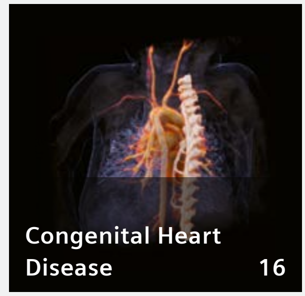
published studies confirm the benefits of high temporal resolution of Dual Source CT in cardiac imaging.[2]

Figure A
Figure A demonstrates the impact of temporal resolution on the image quality of cardiac structures.

[2] *Based on PubMed search results*

Contents






Advantages of Dual Source CT in different clinical fields

Coronary Artery Disease

Coronary computed tomography angiography (cCTA) is known as the most sensitive non-invasive diagnostic method for detecting coronary artery disease (CAD) [3,6]. It provides valuable information to predict the anatomical extent and potential risk for future cardiovascular events. Furthermore, this approach is associated with a significant reduction in mortality and non-fatal myocardial infarction [3,7].

To achieve diagnostically useful cCTA images, there are different requirements that need to be considered when acquiring this image data. One major challenge for CT imaging remains coronary motion. It is known to be a source of non-diagnostic coronary segments especially if patients are suffering from a high and irregular heart rate [6]. But how can you overcome this challenge?

Systolic imaging with Dual Source CT

CT image acquisition with consistently good image quality is not an easy task, especially when beta blockers to lower and control the heart rate are contraindicated. Overall, the challenge is the short temporal window for "motion-free" acquisition in such conditions (see Fig. B). Therefore, motion artifacts mainly affect the diagnostic quality of the images when the temporal resolution of the CT scanner exceeds the "motion-free" interval (typically seen in diastole) (see Fig. B).

In those challenging conditions, one reliable strategy is to scan during the end-systolic phase of the cardiac cycle. Several studies have proven that this phase remains stable irrespective of heart rate and variability. But the ability to scan patients in the end-systolic phase (i.e., in a temporal window of 100 ms) depends on the intrinsic temporal resolution of the CT scanner. Multiple studies have demonstrated the superiority of Dual Source technology for end-systolic scanning compared to Single Source technology [6,8,9].

With a temporal window far below 100 ms, a Dual Source scanner provides acceptable end-systolic reconstruction at any heart rate (Fig. B), in a large proportion of patients [6,8]. It was clearly shown that CT scanners without a fast temporal resolution (below 83 ms) could not provide high diagnostic image quality at high and irregular heart rates while keeping the dose low [10]. The temporal resolution of these scanners simply cannot fit in the end-systolic phase (see Fig. B). In contrast, Dual Source CT provides images of full diagnostic image quality under any circumstances, even in patients with atrial fibrillation. Miller et al. have demonstrated that Dual Source CT scanners provide good quality scanning even at heart rates of HR ≥ 90, where 80.6% of the cases were still interpretable [6] (Fig. C). Furthermore, the authors concluded that even the need for aggressive HR control by beta blockers prior to scanning can be decreased [6].

Recently Jin et al. compared wide-coverage detector technology with Dual Source CT with regards to qualitative and quantitative image analysis. They concluded that image processing efficiency and image quality of cCTA was higher on Dual Source CT than on wide-coverage detector CT (processing efficiency was assessed to be two times higher with Dual Source CT) [5]. Although software to "freeze" the motion of the heart was applied, images acquired with wide detector systems mostly showed motion artifacts in patients with a high heart rate. They underscored that this was caused by the low temporal resolution of the wide-coverage detector system that could not be compensated using that software-based method [5].

Figure B shows ECG traces for different heart rates (60 bpm and 80 bpm). The positions of the end-diastolic window (orange bars) and the end-systolic window (grey bars) are depicted including their position in relation to R peaks where end-systolic targeted acquisitions have been performed.

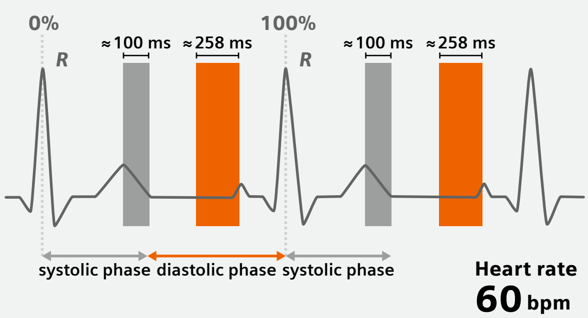


Figure B.1
At low heart rates (e.g., 60 bpm) the "motion-free" interval (diastolic phase) is ≈258 ms long. This period is sufficient to acquire "motion-free" images of the heart even with lower temporal resolution (e.g., 150 ms). The diastolic phase of the cardiac cycle is dependent on the heart rate. The end-systolic remains stable.

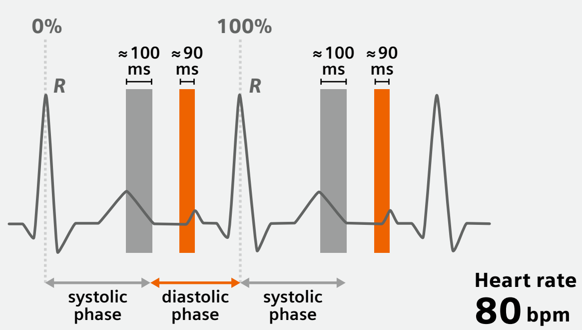


Figure B.2
At higher heart rates (e.g., 80 bpm) "motion-free" interval is not wide enough (≈90 ms) to catch the heart movement, especially for systems with a lower temporal resolution.

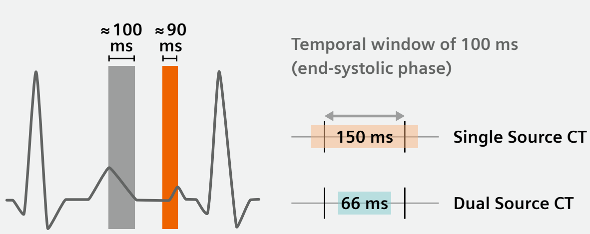


Figure B.3
With a temporal resolution far above 100 ms Single Source scanners cannot fit in the end-systolic phase. The superior temporal resolution of Dual Source CT allows for confidence in end-systolic image acquisition. The acquisition window can be limited without compromises. Therefore there is no need to retrospectively acquire the full R-R cardiac cycle. The result is motion-free images.

Clinical example: Benefits of systolic imaging for image quality

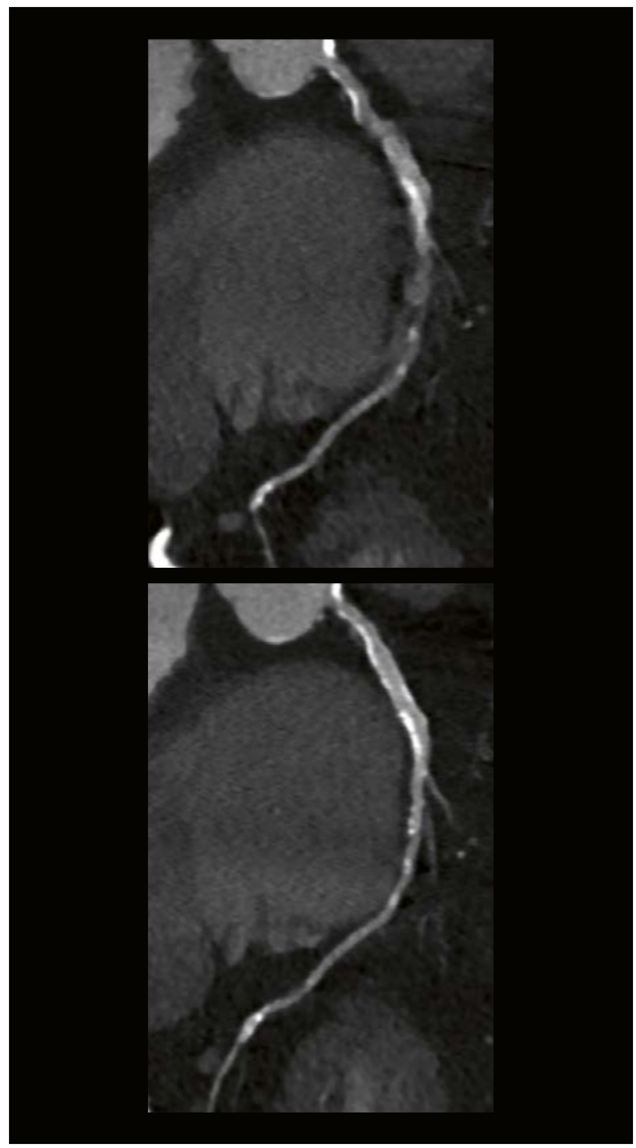


Figure C
Clinical images showing heavy calcified RCA; acquired on Dual Source CT with an unstable heart rate of 49-101 bpm. Image on left was acquired in the diastolic phase; image on right was acquired in the end-systolic phase. Images indicate the opportunity for improved image quality in end-systole (especially for high and unstable heart rates), which is a result of fast temporal resolution.
Courtesy of Baylor Scott & White Heart and Vascular Hospital, Dallas, US

Another challenge when performing cCTA imaging is the adverse exposure to potentially harmful ionizing radiation [11].

A large international study, PROTECTION VI (4,006 patients, 61 international site studies)[3], recently investigated the feasibility of tube voltage reduction in clinical practice to increase the safety of cCTA by reducing the dose overall. They concluded that the usage of low kV for cCTA can lead to lower radiation exposure and lower contrast volumes. Furthermore, they demonstrated that the use of low kV for cCTA is underused in daily practice and should be considered much more often instead of conventional imaging due to the positive impact (e.g., noninferior image quality). Here a qualitative image quality rating of 97.6% was reached by using ≤80 kVp. Additionally the median dose-length product for conventional 110–120 kVp scanning was reduced by 68% with the use of 80–100 kVp [11].

"The rate of very low-tube potential imaging of ≤80 kVp was significantly higher in Siemens scanners when compared with all other vendors [11]."

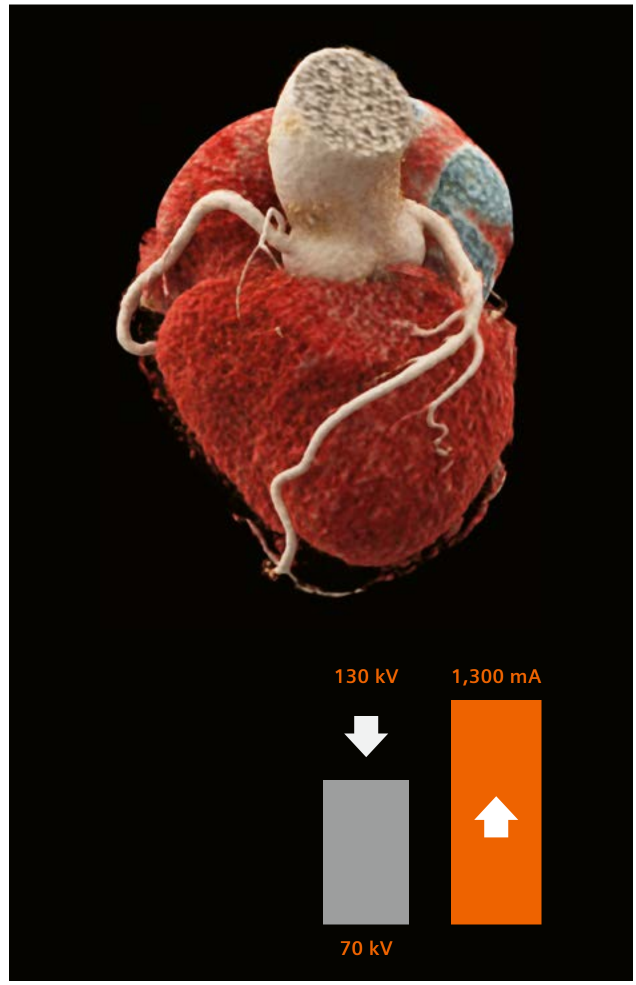


Figure D
Third-generation Dual Source CT enables performing coronary CTA at low kV while maintaining the image quality thanks to its double-power Vectron X-ray tubes with high power reserves at every kV value (up to 1,300 mA at 70 kV) and the Stellar^{Infinity} detectors that can detect even very low signals.
Picture on top courtesy of Bootou City No. 8 Hospital, Bootou, China

The unique imaging chain of Dual Source CT enables sharp and contrast-rich images at high speed and low dose (Fig. D). Even in obese patients, 70–80 kVp can be used without compromising contrast-to-noise ratio (see Fig. E).

It can be concluded that the combination of high-power x-ray tubes and fast temporal resolution in Dual Source CT enables qualitatively high image quality even at low-kV. Furthermore it enables low dose and low-contrast media scans [11,12].

[3] *cCTAs of 4,006 patients from 61 international study sites were analyzed with regard to very low (80 kVp), low (90 to 100 kVp), conventional (110 to 120 kVp), and high (130 kVp) tube potentials*

Clinical example: Low kV imaging with Dual Source CT

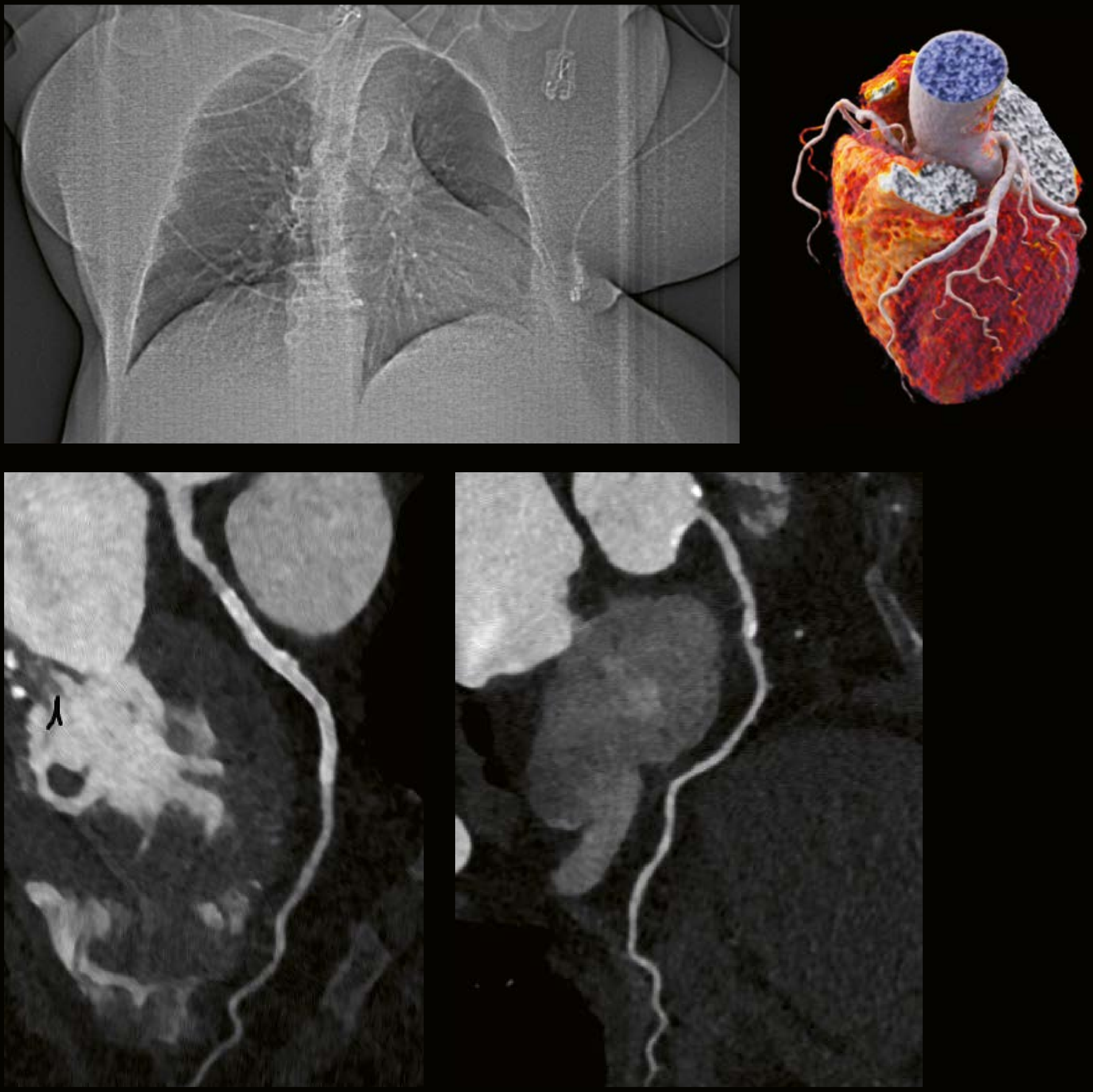


Figure E
80 kV scan of an obese patient.
Courtesy of Clinique Pasteur Toulouse, Toulouse, France

Dual Source CT for hemodynamic assessment of coronary artery stenosis

Fractional flow reserve assessment with Dual Source CT

Within the field of hemodynamic applications, the quality of the CT images greatly affects the reliable assessment of the hemodynamic relevance of coronary artery stenosis. One method to assess the hemodynamic relevance of a coronary lesion is the non-invasive calculation of the fractional flow reserve (FFR). Although invasive FFR is the gold standard, several studies have demonstrated that CT-based FFR is a good non-invasive alternative. It has a high sensitivity and moderate specificity in identifying ischemia caused by intermediate coronary stenoses. Furthermore, it has the potential to significantly reduce the number of invasive coronary angiograms.

It is well known that CT-based FFR is highly sensitive with respect to the quality of the CT image (especially to motion blurring). Therefore several requirements need to be considered to allow for an accurate assessment of CT-based FFR. In a large clinical cohort study, Pontone et al. identified the characteristics that increase the risk that the dataset will not be suitable for a FFR_{CT} analysis [13].

The main reason for the inability to perform FFR_{CT} analysis was the presence of motion artifacts (64% in the clinical cohort [13]). The authors compared different available technologies from different vendors. In all cohorts it was shown that Dual Source CT scanners and their fast temporal resolution achieved the lowest rejection rate when performing FFRCT compared to other scanners (see Fig. G). The authors came to the conclusion that besides other factors (e.g., heart rate control), a greater use of Dual Source technology would optimize scans [13].

In addition to FFR, CT perfusion is another established method to assess the hemodynamic relevance of a coronary stenosis and evaluate the ischemic impact on the myocardium.

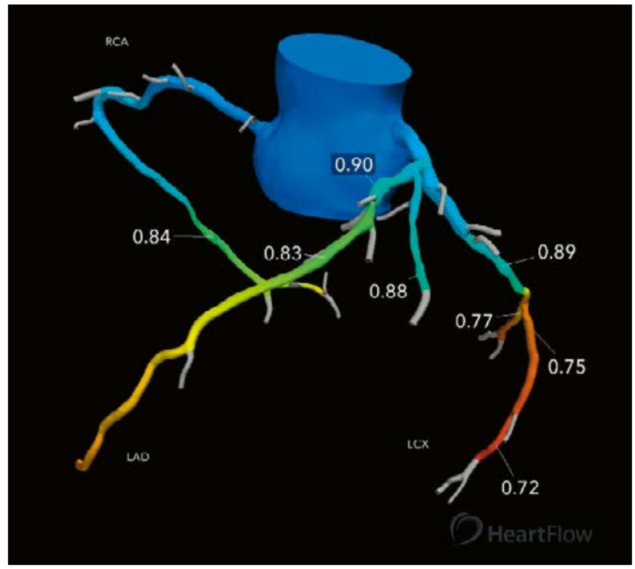


Figure F
73-year-old male, check-up due to chest pain on exertion. Scan findings: plaque in all three vessels; moderate stenosis in LAD and LCX. Retrospectively analyzed with the HeartFlow FFR_{CT} in LCX distal to stenosis was 0.75; non-significant FFR_{CT} findings in RCA and LAD.
Courtesy of Medscan Barangaroo, Sydney, Australia

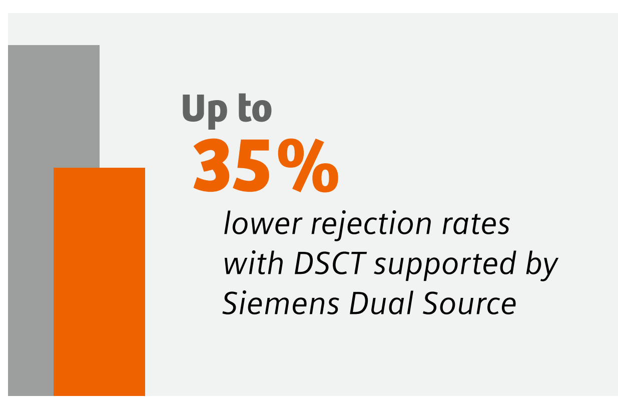


Figure G
Results from the ADVANCE Registry clearly demonstrate the benefits of Dual Source CT. Up to 35% lower FFR rejection rates can be achieved with Dual Source CT [13].

Myocardial perfusion assessment with Dual Source CT

CT perfusion can be performed as either a single static acquisition or a dynamic acquisition in order to measure the blood flow through the myocardium.

There is a clear difference between static myocardial perfusion CT (e.g., based on dual energy CT (DECT) imaging and dynamic myocardial perfusion CT (CT-MPI)). Static perfusion imaging refers to a single reference point of myocardial blood volume, whereas multiphase dynamic perfusion allows for quantification of real myocardial blood flow [14].

For both approaches it is essential to acquire data at a fast temporal resolution to overcome motion artifacts. Seitun et al. demonstrated in a publication that different vendor-specific CT technologies have been developed to perform dual-energy acquisitions. They outlined that finally the use of second- or third- generation Dual Source CT scanners with high temporal resolution (75 ms or 66 ms) could help to discriminate between motion artifacts due to irregular or high heart rates and true perfusion defects, thus avoiding false positive findings [15].

Dynamic CT perfusion is often associated with high radiation dose because several acquisitions in different phases of the cardiac cycle need to be done. Recent studies have analyzed the possibility to perform low-dose myocardial perfusion imaging when using a third-generation Dual Source CT. Loewe et al. have measured a high diagnostic accuracy of dynamic CT-MPI with Dual Source CT compared to FFR (invasive and non-invasive) as well as a significant reduction of radiation dose [16]. The radiation dose of dynamic CT-MPI could be reduced to an average level of 3.6 mSv on the platform of third-generation Dual Source CT [16]. Another study showed a mean radiation dose of 3.2 mSv, which correlates well with the result of Loewe et al. [17].

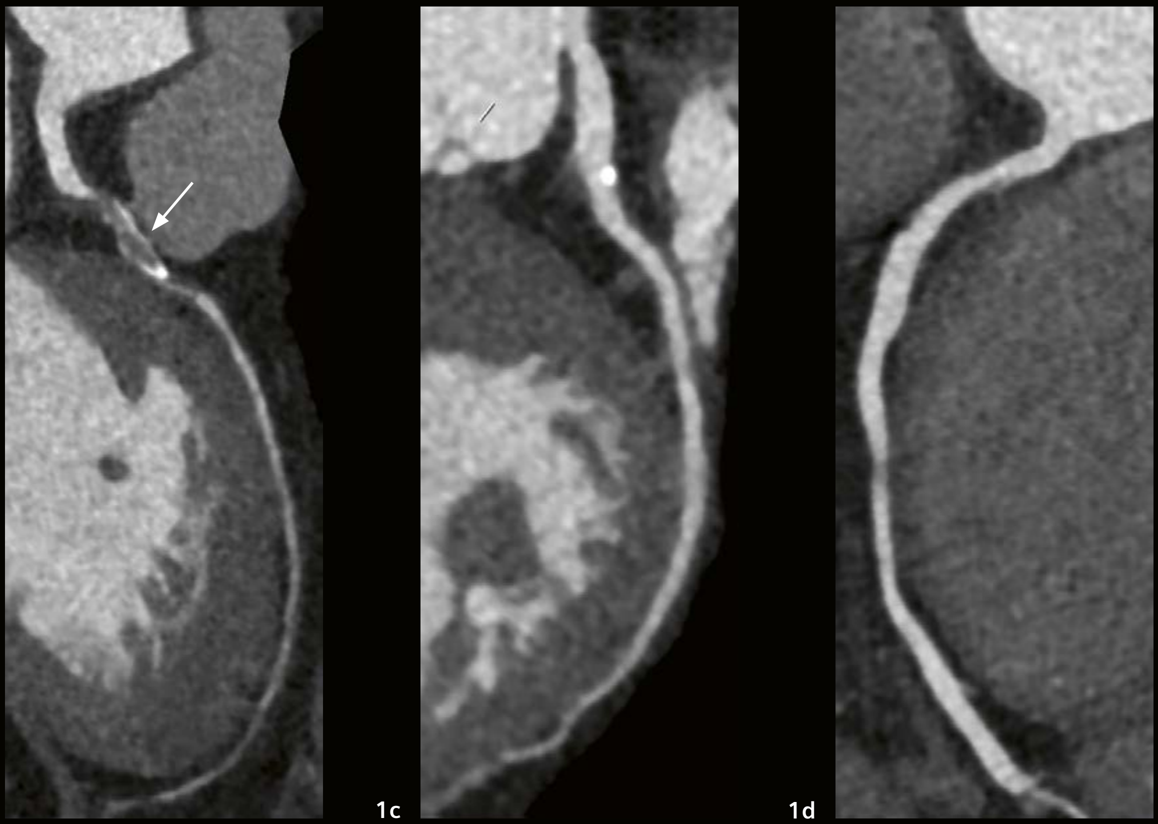
Besides the dose, the z-coverage of the detector is also an often-discussed topic in myocardial perfusion with CT. There are different technologies on the market allowing for state-of-the-art perfusion imaging. Schoepf et al. have investigated that just a few of the available studies that performed dynamic CT-MPI used a Single Source CT scanner with 160 mm z-coverage of the detector, whereas most of the studies performed myocardial perfusion using a Dual Source CT system with a shuttle mode to provide full heart coverage [18]. They concluded that Single Source CT with large detector coverage has two main disadvantages: 1. slower temporal resolution (140 ms) compared to ≤ 83 ms with a Dual Source CT system, and 2. cone beam artifacts [18]. They pointed out that a lower temporal resolution may cause image blurring and induces a less robust multi-segment reconstruction.
As demonstrated in the paper, a slower temporal resolution will enhance the need for the application of beta blockers which can have an anti-ischemic effect and may influence the results of the perfusion study [18]. Finally, it can be expected that the diagnostic value of those perfusion images is significantly affected.

Clinical example: Dynamic myocardial perfusion with Dual Source CT

A systolic ECG-triggered sequential shuttle mode was used with an absolute delay of 250 ms, which is insensitive to extra-systolic events and improves myocardial perfusion evaluation since the myocardium is thicker in systole. It is also very robust for high and varying heart rates, which are common in severe cases; in this patient the heart rate varied from 65 to 105 bpm over both examinations [19].

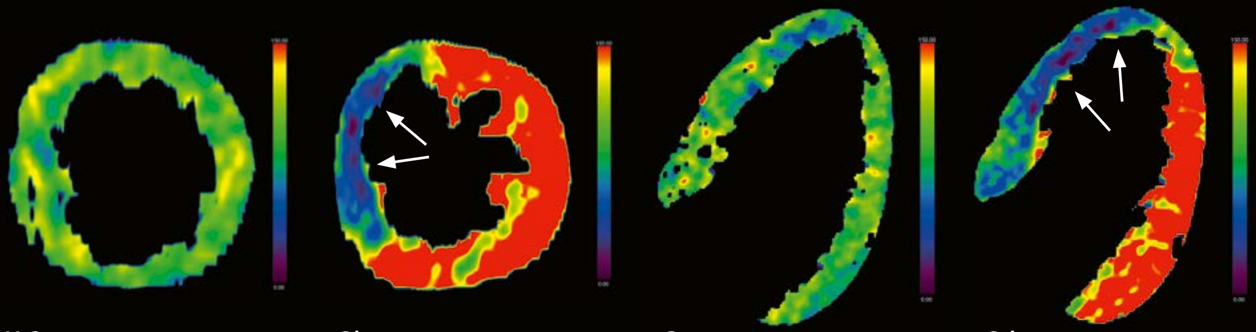
Pictures courtesy of William Harvey Research Institute, Barts Heart Centre and Queen Mary University of London, London, UK

H.1a



H.1b 1c 1d

Figure H.1
Cinematic VRT (Fig. 1a) and curved MPR (Figs. 1b–1d) images show a severe stenosis in the proximal LAD (Fig. 1b, arrow) caused by both calcified and non-calcified plaques. No significant stenosis can be visualized in the Cx (Fig. 1c) and RCA (Fig. 1d) [19].



H.2a 2b 2c 2d

Figure H.2
MBF images in both short (Figs. 2a and 2b) and long (Figs. 2c and 2d) axis reveal large anterior and septal defects under stress (Figs. 2b and 2d, arrows), and no perfusion defect at rest (Figs. 2a and 2c). Compared to a normal MBF of 95 mL/100mL/min at rest, MBF under stress is significantly reduced to 65 mL/100mL/min in the affected areas and increased to 165 mL/100mL/min in the remote areas [19].

Dual Source CT for coronary artery Calcium scoring

Coronary artery Calcium scoring (CaScore) resulting from an unenhanced ECG-triggered CT is a well established screening method to detect coronary artery calcifications. It is associated with excellent cardiovascular risk stratification and management as well as prognosis of clinical outcomes [7,20,21].

The most commonly used Calcium scoring grading method is the Agatston score (AS); other scores are the volume score and the mass score [7,20].

The latest innovations and technical improvements in CT scanners such as fast temporal resolution, iterative reconstruction, low tube voltage, prospective ECG triggering, and high-pitch image acquisition allow for reducing the radiation dose into the sub-mSv range for cCTA. Yet CaScore is still routinely performed with a fixed kVp (i.e., 120 kVp) and reaches an average radiation dose of 1 to 1.5 mSv [21,22].

Calcium scoring with tin filtration

With the introduction of the third-generation Dual Source CT, Tin Filter acquisition became available and offers the possibility to reduce the radiation dose even further. This is assured by absorbing low-energy X-rays (energy range between 30 and 50 keV) with the Tin Filter (see Fig. I). This energy range makes no contribution to the measured signal and the resulting image quality, but increases image noise and radiation dose. By applying the Tin Filter, the mean energy of the X-ray spectrum is shifted to a higher level. An essential benefit of this new acquisition technique is that the original algorithm of the calcium score can be used because the mean energy of the tin pre-filtered 100 kVp spectrum (Sn100 kVp) and the standard 120 kVp spectrum are similar. Therefore, a straight forward use of Sn100 kVp scans for Ca scoring is possible [21,23].

Tesche et al. prospectively investigated this unique approach of Dual Source CT and demonstrated the advantages of using tin pre-filtration to perform the CaScore. Initial results indicated excellent correlation with Agatston scores ($r = 0.99$, $p < 0.0001$), agreement of Agatston score categories ($k = 0.98$) and percentile-based cardiac risk categorization ($k = 0.98$) when compared with the standard 120 kVp CaScore protocol [21].

Furthermore, the authors indicated that tin filtration reduced the effective radiation dose by 75%, with a mean dose of 0.19 mSv. This is roughly equivalent to two chest X-ray exams while maintaining imaqe quality [21].

Recently Vingiani et al. confirmed this in their paper. Additionally, that group investigated the feasibility of an automated tube voltage selection (ATVS) patient tailored CaScore protocol on Dual Source CT. This patient specific ATVS approach applies the ideal kVp level based on the patient’s characteristics [24].

The authors applied the reconstruction algorithm (Sa36) and were able to reduce the dependence of the Agatston scores to the kVp level (e.g., the overestimation of Agatston scores with a low kVp protocol) [24].

The results of the study show that the combination of a patient-tailored protocol for CACS, using an ATVS-based approach and a kV-independent reconstruction algorithm result in an excellent correlation of Agatston scores compared to the standard 120 kVp acquisition, with no significant differences between the scores [24]. The authors conclude that this approach allows for high accuracy compared to the standard 120 kVp scanning, while significantly reducing radiation dose [24].

It is quite clear that the benefits of dose reduction while maintaining image quality are not limited to Ca scoring. Essential benefits have been demonstrated on cCTA on page 6. It is well understood that equivalent results can be assured for Ca scoring as well [24].

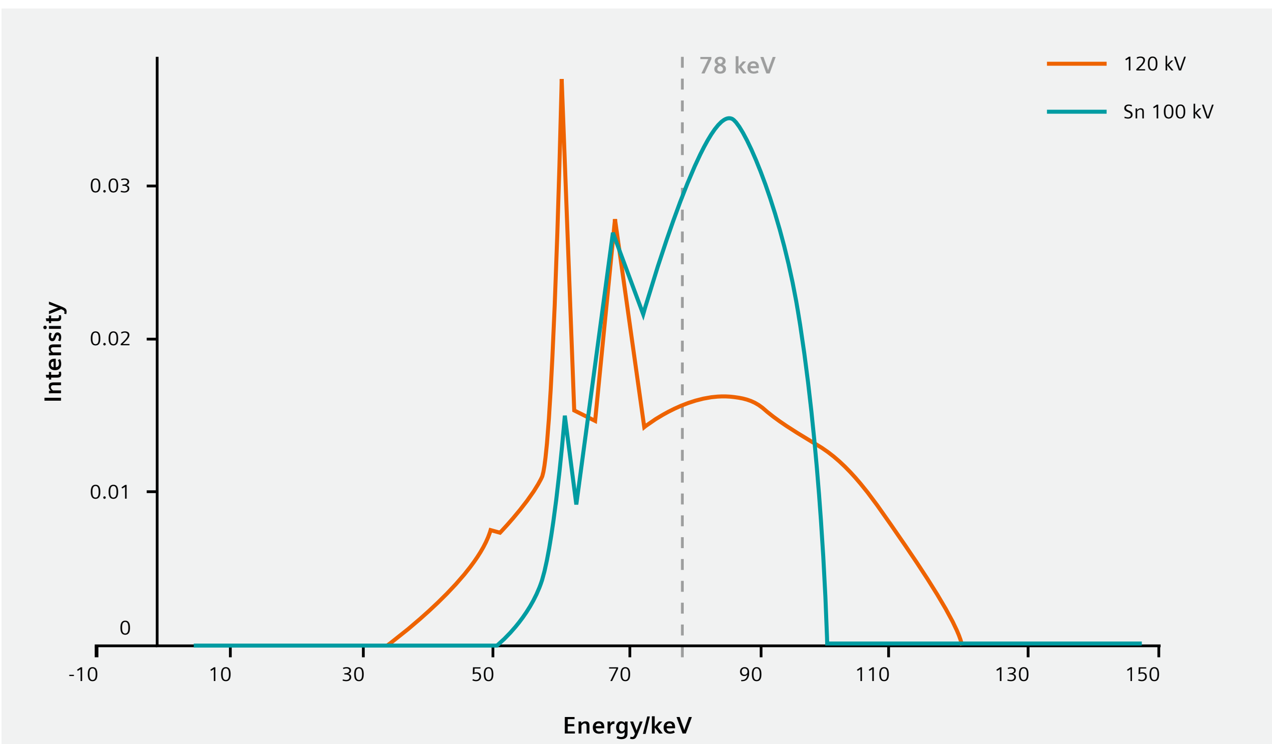


Figure I
Orange: 120 kV spectrum with standard pre-filtration.
Petrol: 100 kV spectrum with standard pre-filtration plus the additional Tin Filter (Sn 100 kV), showing that the average mean intensity is similar even with different X-ray potentials [25].

Advantages of Dual Source CT in different clinical fields

Structural Heart Disease

Globally minimally invasive image-guided procedures to treat structural heart diseases are expected to grow 14%[4] in the next couple of years.

For structural heart diseases in patients with an intermediate to high surgical risk, CTA allows for multiple benefits. These include the ability to assess suitability for percutaneous transcatheter aortic valve replacement, aortic annulus sizing, and peripheral access planning as well as for reliable assessment of coronary arteries [26].

Due to age of the patients and comorbidities, heavy coronary and valve calcification as well as movement of the cardiac structures, the challenges on the diagnostic performance of coronary CT are quite high. Several studies investigated a new ultra-high-pitch protocol with very low acquisition time, which was introduced with the third-generation of Dual Source CT scanners. That ultra-high pitch protocol allows reducing any motion artifacts [26].

Schicchi et al. evaluated the image quality and the diagnostic performance of third-generation Dual Source CT using an ultra-high-pitch protocol for TAVI/TAVR planning and coronary tree assessment [26].

To overcome the challenge of the motion of the cardiac structures, all exams were acquired in the end-systolic phase. As demonstrated in the beginning of this paper, the fast temporal resolution of the Dual Source CT scanner ensures appropriate CT imaging in the end-systolic phase. With it, the authors were able to achieve constant high image quality because this phase remains constant even in increased or arrhythmic heart rates. This benefit was already substantiated on page 4.

Besides the mentioned challenges of high calcification and blurring due to motion, another challenge in this clinical field is that the patient group often suffers from decreased renal function, which might be a contraindication for CT owing to the need for contrast media usage. Here it is desirable to minimize the amounts of injected contrast media and keep the dose as low as possible to reduce the incidence of renal dysfunction.

In the Protection IV trial [11], it was demonstrated that with Siemens scanners low-tube voltage cCTA is a highly effective technique for contrast media reduction as well as for radiation dose reduction. But is it also applicable for scanning structures of the heart to perform pre-surgical planning?

Indeed, several studies have reported success using low tube voltage techniques for TAVI/TAVR planning with Dual Source CT systems, which finally allowed significant reduction of the amount of contrast media [27,28].

Most recently, Onoda et al. investigated using low-voltage CTA before transcatheter aortic valve implantation and provided a comparison with the conventional tube voltage group [4].

They introduced the usual amount of contrast media used for routine CT acquisition in TAVI/TAVR procedure planning, which is in the range of 80–120 ml. In their study the volume of contrast media was set according to the body weight. With that, using 70 kV tube voltage, they were able to reduce the amount of contrast media to 30.9 ml on average (= 9.27 gl). They clearly concluded that with this approach it was possible to reduce the contrast media volume by more than 50% compared with the average volume of contrast media reported in the literature [4].

Bittner et al. showed that 38 ml of contrast media using a third-generation Dual Source CT system allows comprehensive imaging for procedural success [28]. They concluded this corresponds to a reduction of contrast media by 50%. Another study investigated contrast media usage in CTA for TAVI/TAVR screening and clearly indicated a reduction of contrast media dose for CTA using a third-generation Dual Source CT system (70 kV, 40 ml contrast media) compared to CTA using a second-generation Dual Source CT system (100 kV, 60 ml contrast media) [29].

Finally, it can be concluded that low tube voltage CTA using Dual Source CT is suitable to perform procedural planning for TAVI/TAVR. Because of its outstanding temporal resolution, it maintains image quality while reducing contrast media volume and dose, which is crucial for patients suffering from renal dysfunction.

The broader use of CT as a pre-TAVI/TAVR procedure could lead to a reduction of unnecessary Invasive Coronary Angiography (ICA) in the future. As a consequence, it has the potential to reduce the cumulative

[4] *Based on DRG (Decision Research Group) data report from 16.03.2018 (CAGR calculated from 2019–2024)*

radiation dose and contrast volume and to improve risk management [26].

Additionally, pre-procedural planning for minimally invasive MV repair/replacement (TMVR) and transcatheter tricuspid valve repair/replacement (TTVR) are on the horizon and can also be seen as an increasing trend.

This poses new challenges to the imaging system. The quality of the right-heart scan used for pre-procedural planning of tricuspid valve repair/replacement highly depends on the technical functionalities of the available CT scanner. Read how Dual Source CT can make a difference here on page 18.

Clinical example: Mitral valve insufficiency – Pre-operative dynamic CT assessment with Dual Source CT

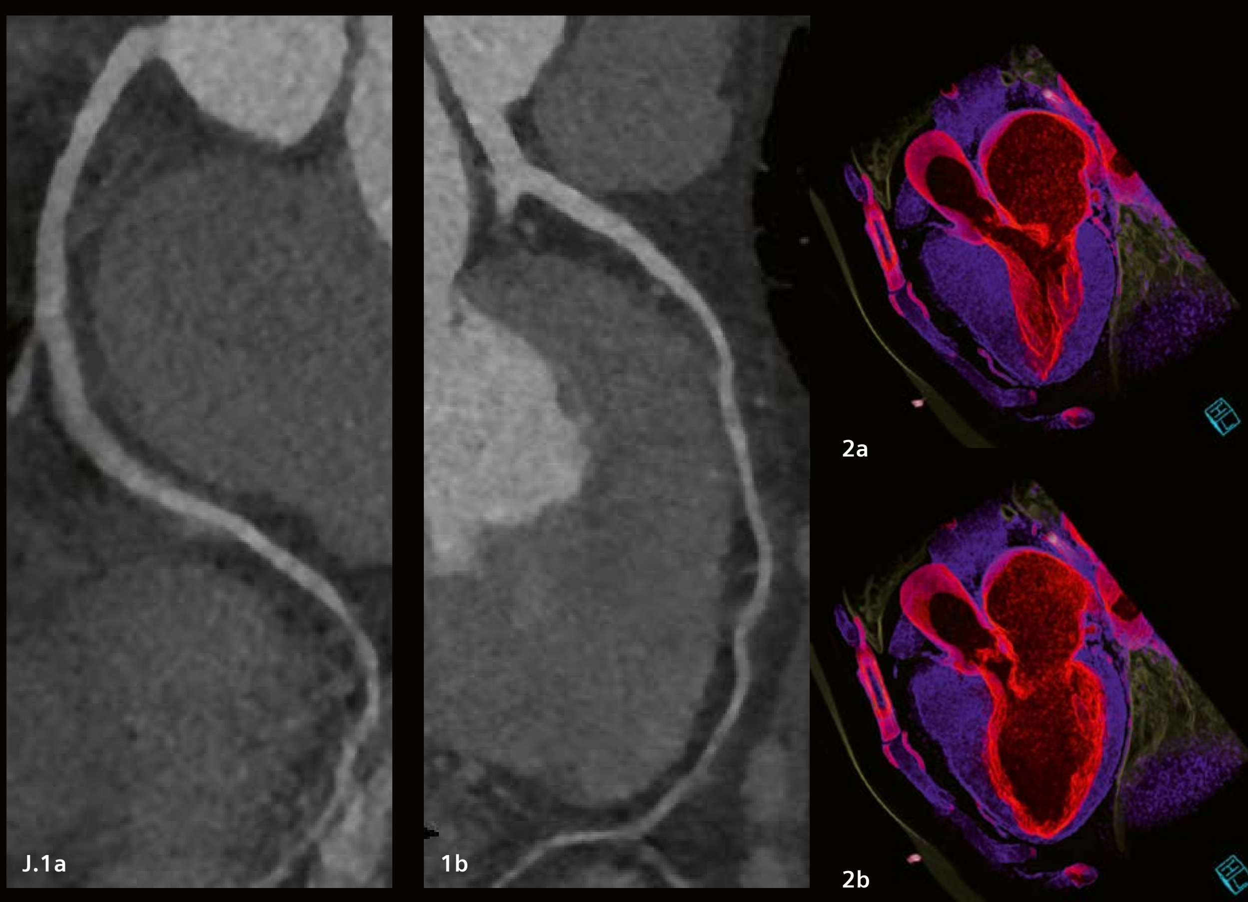


Figure J
Left and center: Curved MPR images show normal coronary arteries, except for a mild stenosis (about 30%) in the distal LAD (Fig. 1b) and the RCA (Fig. 1a) [30].
Right: VRT images of the LV long axis show the prolapse of the thickened anterior leaflet of the MV at the ES (Fig. 2a) and ED (Fig. 2b) [30].
Courtesy of Huai'an No. 1 People's Hospital, affiliated with Nanjing Medical University, China

Advantages of Dual Source CT in different clinical fields

Congenital Heart Disease

Cardiovascular Imaging plays a key role for diagnosis and further treatment of congenital heart disease (CHD). In general, echocardiography is used as the initial imaging modality, but multimodality imaging approaches are also gaining relevance. An excellent imaging modality for congenital heart disease is MRI to identify both structural and functional anomalies/disorders [31].

"Dual Source CT predominates in the field of congenital heart disease."

Ed Nicol, MD
Consultant cardiologist at Royal Brompton Hospital

However, cardiac MRI can be quite cumbersome in pediatric patients. Sedation may be required to avoid movement of the patient during the long examination times (up to 1 hour). Coronary artery imaging in children is more difficult than in adults owing to smaller vessel sizes, increased cardiac motion due to higher heart rates, and increased respiratory motion due to more rapid breathing, which make the outcome of the scan unpredictable. The visualization of small structures such as the tiny coronary arteries can be difficult because of low spatial resolution and slow temporal resolution [31,32]. CT can be an alternative imaging modality.

At first glance, the use of CT seems inappropriate, because it is well understood that consequences of radiation effects are more critical in pediatric patients [32]. Additionally, the high heart rate, complexity and variety of diseases can be challenging too.

With Dual Source CT, it is possible to overcome these challenges. Senoner et al. reported that with a third-generation Dual Source CT, radiation dose is extremely low (0.22 mSv), and even significantly lower than with second-generation Dual Source CT [31], which makes CT for pediatric patients less critical. Another study investigated the feasibility of prospective ECG-triggered high-pitch Dual Source CT to assess coronaries of pediatrics. The results of their study show that in total 94.2% of the coronary segments were covered with diagnostic image quality [32].

With Dual Source CT, CHD acquisitions can be performed at the lowest dose and without sedation. In addition, it provides accurate and consistent high-quality results. This can be assured by means of different technological advantages, namely temporal resolution, low kV imaging (70 kV) and high-pitch scanning with ECG synchronization to enable single beat cardiac assessment even during breathing and without motion artifacts. As a consequence, Dual Source CT can be used as an alternative to MRI [33].

Clinical example: Congenital heart disease CT imaging with Dual Source CT

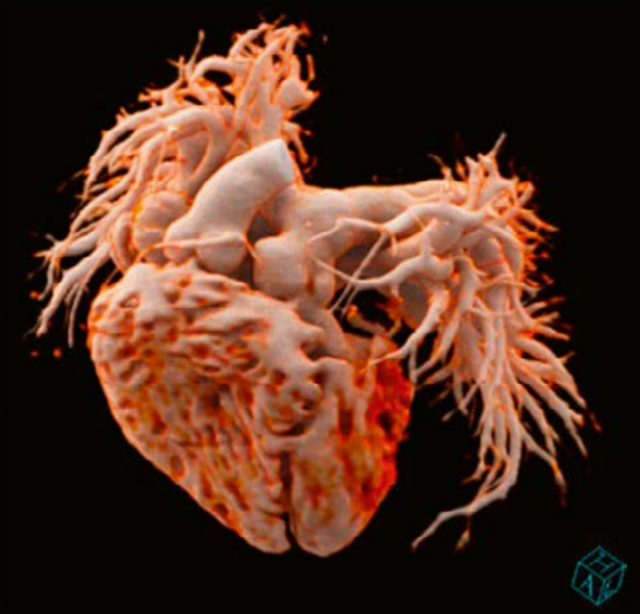


Figure K
Top left: 80 kV scan of a neonate;
free breathing CT with Flash mode completed in 0.27 s
Courtesy of Heart Hospital (HCor), São Paulo, Brazil

Top right: 70 kV scan of a 4-month-old baby;
free breathing CT with Turbo-Flash mode completed in 0.25 s
Courtesy of Hôpital Calmette – CHU de Lille, Lille, France

Bottom right: Follow-up 80 kV scan of a 14-year-old child;
free-breathing CT with Turbo Flash mode completed in 0.25 s
Courtesy of Hôpital Calmette – CHU de Lille, Lille, France

Beyond – Explore new clinical opportunities

Discover the untapped potential of Dual Source CT

As we have seen Dual Source CT is an established technology with a high number of benefits. These benefits are relevant for all "standard" cardiac fields, whether it be coronary artery disease, structural heart disease or congenital heart disease. But is there still something new to explore?

For example, why not use Dual Source CT for specific applications instead of MRI or transesophageal echocardiography (TEE)? Or even use Dual Source CT images to plan leaflet repair for tricuspid regurgitation?

Let's deep-dive into some potential future topics our customer recently explored.

Myocardial extracellular volume assessment with Dual Source CT

Cardiomyopathy is the third leading cause of heart failure in the United States and it is associated with muscular or electrical dysfunction of the heart [34]. Myocardial fibrosis is an important indicator of myocardial damage. It is quite common to evaluate myocardial fibrosis with non-invasive techniques like MRI or CT perfusion.

The assessment of myocardial extracellular volume (ECV) fraction has been studied as a new approach, as increased ECV can be associated with fibrosis [34,35].

Here, the reference standard for non-invasive assessment of ECV is cardiac MRI. However, it is not available everywhere and is contraindicated, e.g., in for patients with metal implants and other challenges. One alternative here could be Dual Source CT. It has the potential to save examination time. Cardiac MRI typically requires long examination times (45–60 min) and whole-heart ECV by cardiac MRI requires 18–20 breath-holds. On the other hand, the examination time for cardiac CT is relatively short (15–30 min) and whole-heart ECV estimation by cardiac CT requires only a few breath-holds [34].

Studies have shown that ECV can be successfully measured with single-energy computed tomography (SECT) and dual-energy CT (DECT). These results showed a good correlation between ECV measurements derived from CT and equilibrium MRI [34,35].

Recently, Abadia et al. demonstrated that ECV can be assessed using a DECT approach with only one delayed iodine-enhanced acquisition [34]. They reported that this approach provides similar results when compared to multiphase SECT [34]. Furthermore, Dual Source CT has the potential to lower the radiation dose by replacing a true non-contrast scan with a virtual non-contrast DECT reconstruction. That is possible because the Dual Source system can be operated at different tube potentials, leading to maximum spectral separation, which results in an optimal material differentiation.

In can be concluded that with Dual Source CT it is feasible to reliably assess myocardial extracellular volume fraction because dedicated benefits (e.g., fast temporal resolution) can be assured. Furthermore, limiting factors known from MRI (e.g., metal implants or claustrophobia) do not apply, which make this approach feasible for the clinical routine.

Use of Dual Source CT to plan of leaflet repair for tricuspid regurgitation

Although minimally invasive interventions of the tricuspid valve are not yet fully established, transcatheter tricuspid valve interventions are rapidly evolving. Therefore, the need for appropriate imaging solutions (e.g., CT) is increasing to accurately assess the anatomy of the valve and the right ventricular function, especially in patients with a high surgical risk [36,37].

Because the assessment of the tricuspid valve poses new challenges, like complexity of the geometry, the quality of the CT image that is used for pre-procedural planning highly depends on the temporal resolution of the available CT scanner.

Furthermore, patients who undergo tricuspid valve repair (TTVr)/replacement often suffer from a high heart rate and atrial fibrillation, which can cause image blurring [36].

Lopez et al. recently investigated the usage of Dual Source CT systems in this context. The authors came to the conclusion that with fast native temporal resolution and specific contrast protocols for image acquisition, this CT imaging technique will play an important role [37]. It allows for accurate assessment of the tricuspid valve anatomy as well as the comprehensive functional assessment of right ventricular function and remodeling (pre- and post-TTVr) [36,37].

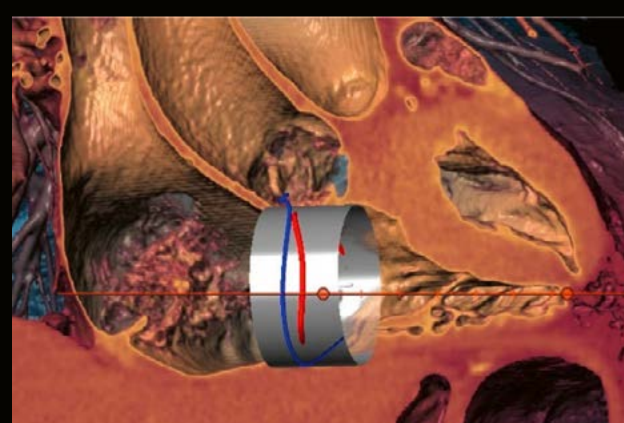
"Since atrial fibrillation is quite common in patients with significant TR, motion/misregistration artifacts can cause blurring, distortion and inadequate visualization of the cardiac structures. For such patients, higher temporal resolution dual-source CT scanners (preferably < 80 ms) can improve image quality and analysis." [36]

In addition, smooth opacification of the right heart together with the advantages of the scanner will allow for outstanding image quality of the tricuspid valve; the results from Lopez et al. were perfect. Fig. L shows how outstanding the image quality can be using a Dual Source CT.

Although guidelines promote TEE as the imaging modality to assess tricuspid regurgitation (TR) severity, Hashimoto et al. indicated in a recent publication that TEE can lead to an underestimation of the true extent of right heart disease [36]. Additionally, complex right ventricle (RV) geometry often leads to incomplete and inadequate visualization of the entire RV by 2D TTE [36]. As 46% of patients undergoing tricuspid valve surgery suffer from postoperative RV dysfunction, which is associated with high in-hospital mortality, the authors investigated if pre-operative CT cardiac assessment could provide essential information for predicting postoperative RV dysfunction [36]. They found that in addition to functional and remodeling quantification, cardiac CT can provide information regarding the mechanism of TR, TV/leaflet anatomy, motion and visualization of the valve gap with the best fluoroscopic angles to help define the correct therapy strategy [36].

Clinical example: Mitral and tricuspid valve regurgitation – pre-operative dynamic CT assessment with Dual Source CT

77 y/o female with history of mitral and tricuspid valve regurgitation, a potential candidate for transcatheter valve therapy. Images below show CT angiography for coronary and valve study, in the presence of atrial fibrillation (85–104 bpm). The image shows high quality assessment of the tricuspid valve thanks to Dual Source technology.



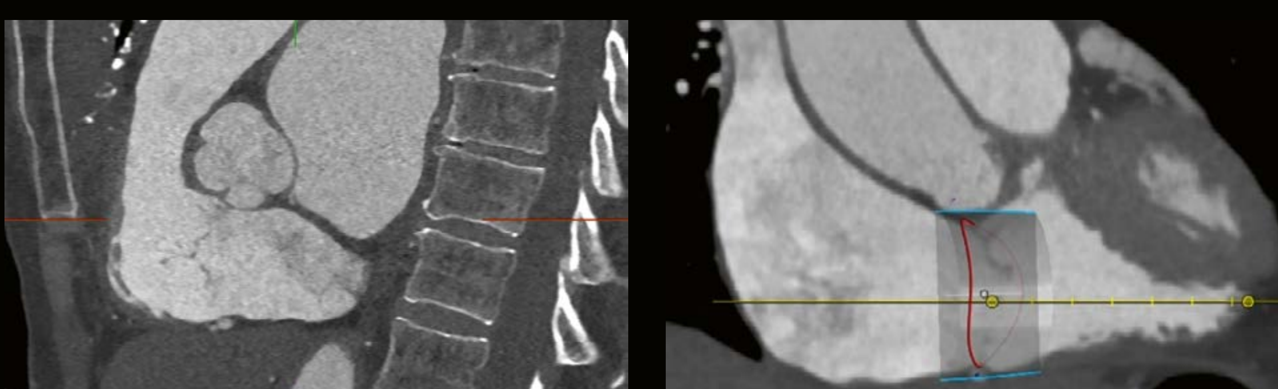


Figure L
Courtesy of Minneapolis Heart Institute, Abbott Northwestern Hospital, Minneapolis, MN, USA

Detection of left atrial appendage (LAA) thrombi with Dual Source CT instead of TEE

In patients with atrial fibrillation, one side effect is the development of a thromboembolism, which can be associated with morbidity and increased mortality [38]. This potential risk needs to be considered prior to catheter ablation because navigating the catheter inside the left atrium may dislodge the thrombus and cause thrombo-embolic complications. Today TEE is the gold standard prior to catheter ablation to exclude the presence of thrombi in the left atrium or left atrial appendage.

However, this imaging modality is semi-invasive, time-consuming and uncomfortable for patients, and studies indicate that it bears potential risks, such as esophageal lesions [38].

Li et al. investigated the diagnostic performance of DECT-derived iodine concentration (mg/ml) compared to conventional enhancement measurements (Hounsfield Units (HU)) and the reference standard TEE to detect left atrial appendage (LAA) thrombi and differentiate thrombi from circulatory stasis in atrial fibrillation (AF) patients referred for catheter ablation (see Fig. M) [38]. The comparisons of the diagnostic accuracy of the different modalities showed that DECT-derived iodine concentration was associated with improved diagnostic accuracy [38].

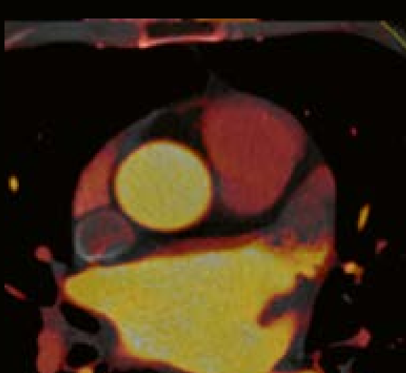
The authors reported radiation doses (2.45 ± 0.54 mSv) in DECT using a third-generation Dual Source CT system which are well below the dose (7.5 mSv) that results in DNA damage [38]. The reason for that is that third-generation Dual Source CT systems are equipped with Stellar detectors, which are more sensitive to electron influx and hence more dose-efficient.

The pre-condition here again is that the scanner provides both a fast native temporal resolution (≤ 83 ms) and the ability to significantly reduce dose while keeping image quality high. Otherwise the interpretation of the images can cause false-positive/false-negative readings.

The authors are convinced that dual-energy cardiac CT may be clinically useful for detecting and ruling out intra-cardiac thrombi in AF patients and should be understood as an alternative diagnostic tool to TEE.

Clinical example: LAA thrombi detection with Dual Source CT

A 62-year-old woman with atrial fibrillation.
The images show improved diagnostic accuracy of DECT compared with conventional SECT and TEE in detecting LAA thrombi.



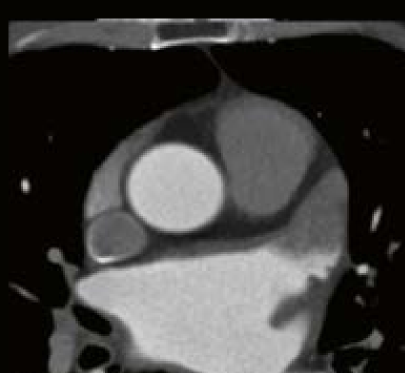


Figure M
Left: Iodine map shows partial filling defect in the LAA (true negative finding)
Center: Conventional enhancement CT shows a filling defect in the LAA (false positive finding)
Right: TEE shows severe spontaneous echo contrast without a thrombus
Courtesy of Minneapolis Heart Institute, Abbott Northwestern Hospital, Minneapolis, MN, USA

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