Half-Scan vs. Multi-Segment Reconstruction for Computed Tomography Coronary Angiography

Considerations on the effects on image quality

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CT Coronary Angiography

Coronary artery visualization by multi-detector row (or better multi-slice) computed tomography ("coronary CT angiography", "coronary CTA") is rapidly entering mainstream cardiology. High accuracies have been reported for the detection of coronary artery stenoses by 16- and 64-slice CT and especially a high negative predictive value makes coronary CTA a useful tool in the assessment of certain patient populations with chest pain[1]. In a joint statement by several professional societies, led by the American College of Cardiology, the use of CT coronary angiography has been labeled an "appropriate" indication to rule out or establish the presence of coronary artery stenoses in several clinical situations[2]. Reliable visualization and analysis of the small coronary arteries, which typically have a diameter of 2 to 4 mm, require optimal image quality and maximum resolution.

Cardiac Motion

Rapid motion of the heart and coronary arteries and ensuing impairment of image quality are the major problems that may exist in CT coronary angiography. Insufficient image quality can lead to false-positive or false-negative findings, with the consequence of unnecessary further testing in the first case and of missed, potentially life-threatening, diagnoses in the latter. In order to avoid artifacts caused by motion, two aspects are important.

Firstly, with widely used single source computed tomography systems it is important to use data for image reconstruction that was acquired during a cardiac phase of relatively little motion of the coronary arteries (which is achieved by retrospectively ECG-correlated image reconstruction, usually in late diastole).

Secondly, it is essential to limit data used for image reconstruction to a short segment of the cardiac cycle. In order to reconstruct one cross-sectional image, data acquired from 180° of parallel data projections are necessary. Most computed tomography systems contain one x-ray tube, so that one-half rotation of the gantry is necessary to acquire data from 180°.

Half-scan Reconstruction

Reconstruction algorithms that use data from one continuous 180° sweep of the x-ray tube for image reconstruction are called "half-scan" reconstruction algorithms. Thus, the temporal resolution of these half-scan reconstruction algorithms corresponds to approximately one-half of the gantry rotation time (e.g. 330 ms gantry rotation time = 165 ms temporal resolution). All x-ray data used for reconstruction of a single cross-sectional image are acquired contiguously during the image acquisition window in one single heart beat.

Multi-segment Reconstruction
(or Multiphase Reconstruction)

Alternative approaches are so-called "multi-segment" reconstruction algorithms. These algorithms use less than 180° of data from a single heart beat. To compensate for the missing projections, data acquired in the next cardiac cycles is used to fill in the missing projections. This is done under the assumption that one cardiac cycle is absolutely equal to the next and data from several heart beats can thus be combined to reconstruct one single image. Theoretically, the window of data used for image reconstruction in each cardiac cycle can be substantially shorter than in half-scan reconstruction algorithms. However, multi-segment reconstruction algorithms use data from several heart beats to reconstruct one image so that the generated image is an "average" of several cardiac cycles. Since slight differences from one heart beat to the next can be assumed even in regular heart rhythms, and since substantial differences between consecutive heart beats must be assumed in situations e.g. of arrhythmia, the averaging of several cardiac cycles has severe drawbacks from a theoretical point of view (Figure 1). A definite benefit of multi-segment reconstruction over half-scan reconstruction has not been proven for the detection of coronary artery stenosis. However, several issues of concern exist as far as the use of multi-segment reconstruction for the visualization of the coronary arteries is concerned. They will be outlined below.

1. Variation of Heart Beats

Coronary artery visualization and analysis requires sub-millimeter resolution. However, from one cardiac cycle to the next, it cannot be expected that the coronary arteries return to exactly the same position, within a fraction of a millimeter. Thus, multi-segment reconstruction introduces averaging which slightly blurs the images and reduces image quality.

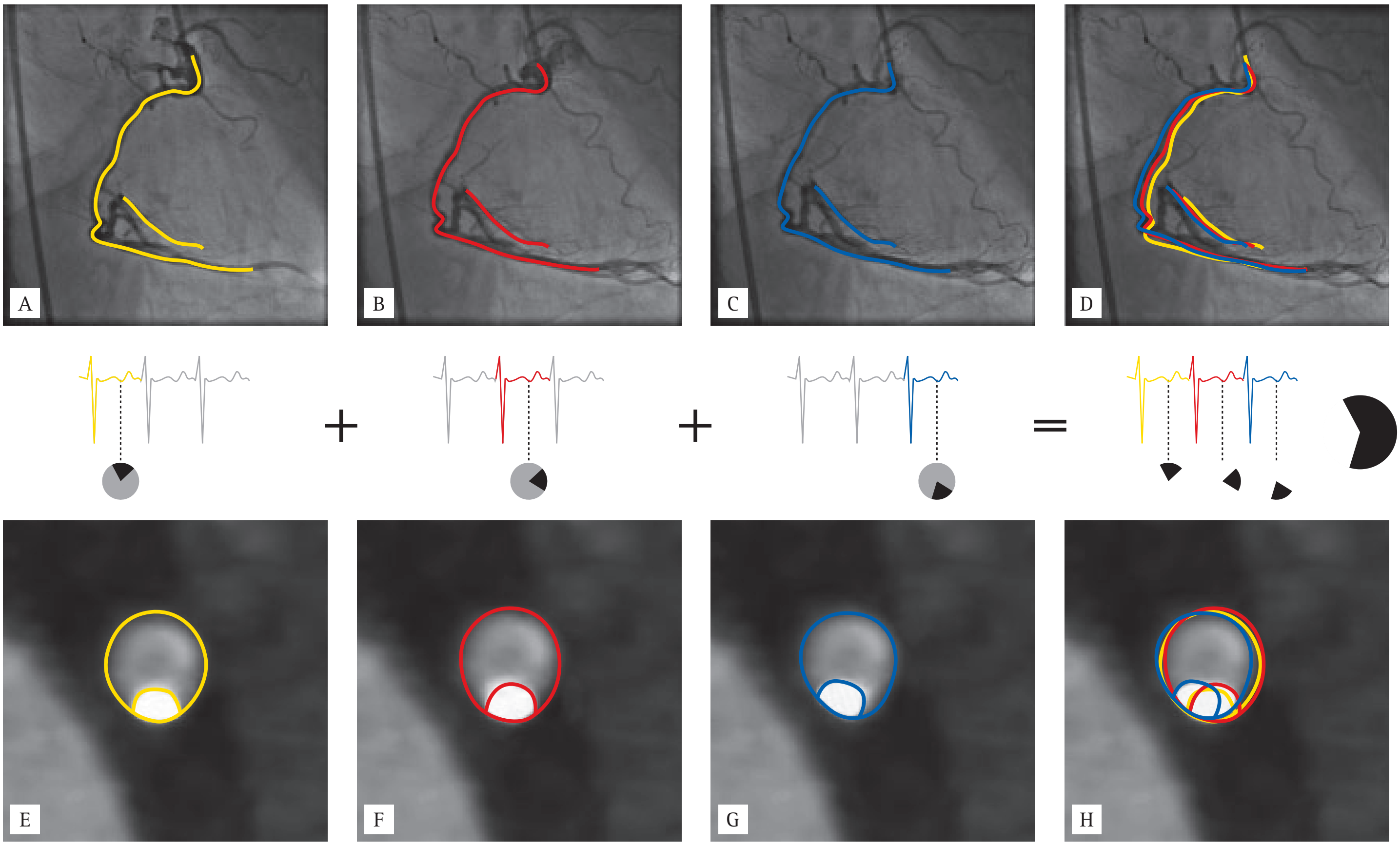


Figure 1 *displaying the general drawbacks of using data from subsequent heartbeats. This example shows the use of three segments. Figure 1A to 1C shows the angiography image of a right coronary artery (RCA) and colored outline in three subsequent heartbeats. In figure 1D the colored lines representing the positions and course of the RCA are projected on top of each other, clearly showing that variations of the position of coronary arteries in each subsequent heartbeat are common.*

Figure 1E to 1g shows a cross-section of a coronary artery including a calcified plaque. Coronary plaques adherent to the vessel wall are at slightly shifted positions in each heartbeat due to the vessel's motion. Figure 1H shows the result of a multi-segment reconstruction. Dedicated algorhithms fuse three projections into one image, thus small dimensioned outlines can not be clearly depicted and information is lost in the process.

2. Changes in Heart Rate During the Scan

Variability in the position of the coronary arteries from one cardiac cycle to the next will be especially evident if heart rate changes during the scan – with slower heart rates the diastolic filling period is longer and the heart will be more „expanded“ than with faster heart rates. Thus, the end-diastolic position of the coronary arteries may change and images reconstructed with multi-segment algorithms will be an average of several, non-identical cardiac cycles. With higher true temporal resolution of CT scanners using half-scan (or single-segment) reconstruction, heart rate variations are not a limitation and motion-free imaging becomes possible (Figure 2).

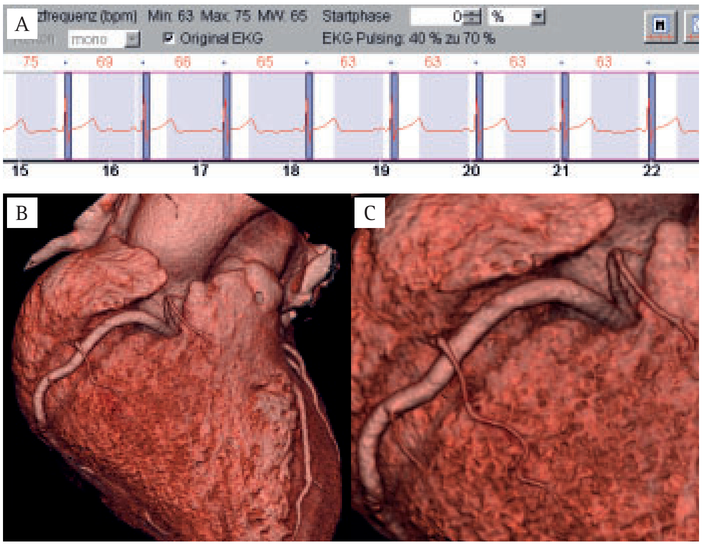


Figure 2: *Example of a patient in whom the rate of normal sinus rhythm changes during the scan. It drops from 75/min to 63/min during the initial phase of data acquisition (2A). Such changes in heart rate will affect duration of diastole and the extent of diastolic filling, thus leading to differences in the position of the coronary arteries from one cardiac cycle to the next – a disadvantage for multi-segment reconstruction. With half-scan reconstruction and a temporal resolution of 83 ms (SOMATOM Definition, Siemens AG), clear and motion-free visualization of the heart (right coronary artery) is achieved in spite of the heart rate variation (2B and 2C).*

3. Arrhythmias During Data Acquisition

Not only can the heart rate change during data acquisition (even if there is sinus rhythm throughout), it also is possible – and, in fact, not infrequent – that arrhythmias occur in the form of supraventricular or ventricular ectopic beats. Image quality of the single reconstructed image remains unaffected in the case of half-scan reconstruction because it is not necessary to average data from several heart beats (Figure 3).

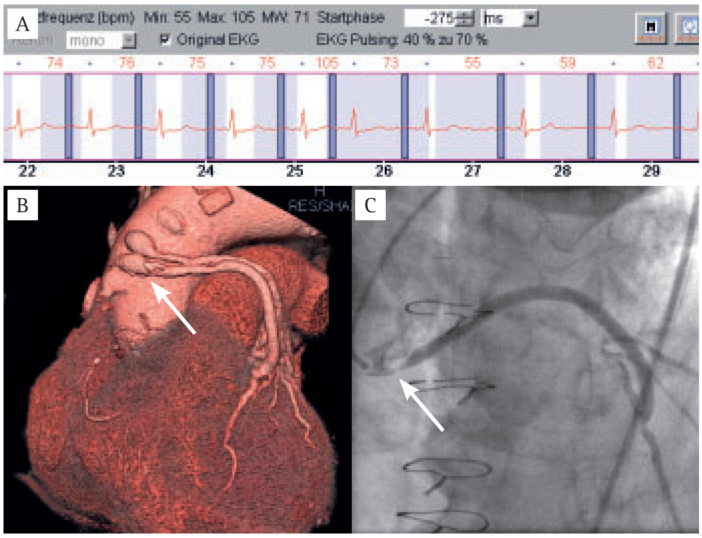


Figure 3: *78 year old patient with previous bypass surgery. Substantial supraventricular arrythmia occurred during the scan (3A). Half-scan reconstruction with a temporal resolution of 83 ms remains unaffected from the arrythmia and allows precise delineation of bypass grafts and a stenosis in the venous graft to the left anterior descending coronary artery (3B, Arrow). Angiography performed on the same patient confirms the finding (3C, Arrow).*

4. Reduced Pitch for Multi-Segment Reconstruction

In order to be able to use data from several cardiac cycles to reconstruct a cross-sectional image at any given z-axis position, the x-ray detector has to cover that position during several consecutive cardiac cycles. The more cardiac cycles are to be used for reconstruction, the slower the movement of the patient relative to the detector has to be. Thus, the pitch which is defined as the table movements during a 360° rotation devided by the collimated detector width has to be chosen low and in each given z-axis position, the patient will be exposed to radiation several consecutive times. This leads to dramatically increased radiation exposure compared to single-segment reconstruction approaches. In addition, since the overall scan time will be longer, more contrast agent must be given to the patient to ensure full enhancement of the blood pool during the longer period of data acquisition.

A further effect of this issue is, that exclusion of ectopic beats from the reconstruction process may not be possible using multi-segment reconstruction. Occasionally, ectopic beats will require to exclude one or several heart beats from reconstruction in order to avoid misalignment artifacts. However, in that case, it may occur that the z-axis position in question will not be covered by the detector in enough “regular” heart beats to allow multi-segment reconstruction. Thus, half-scan reconstruction and higher temporal resolution may be advantageous if ectopic beats must be excluded from image reconstruction. (Figure 4)

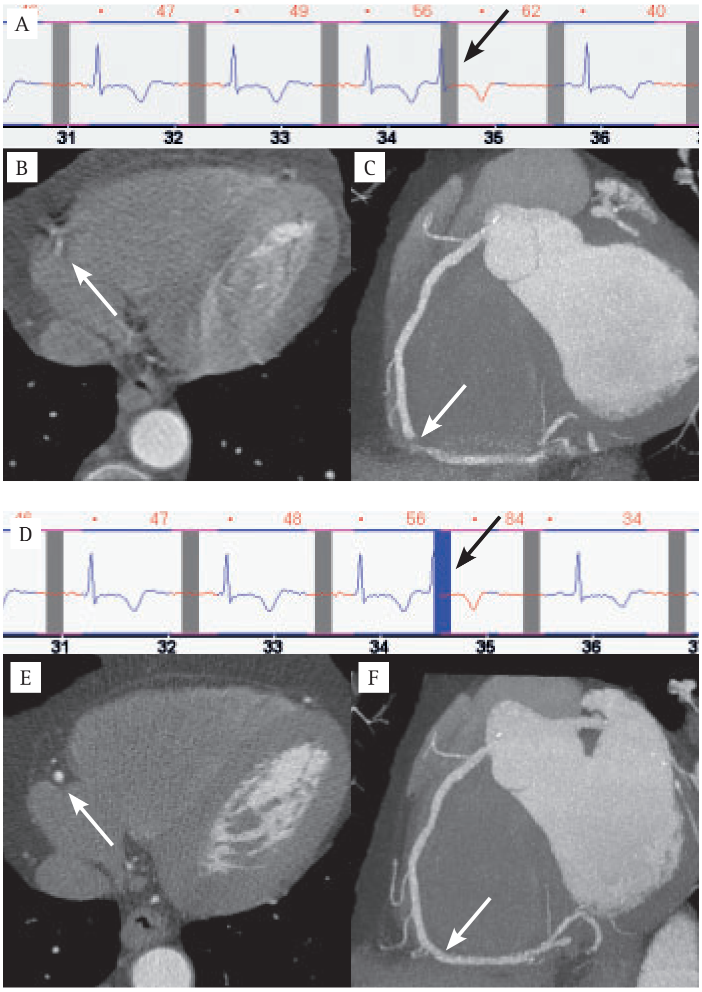


Figure 4: *Exclusion of an ectopic beat to avoid artifact in 64-slice CT.*

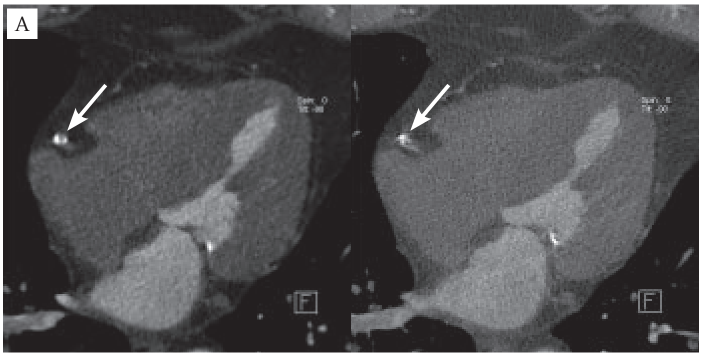
An ectopic beat has occurred during data acquisition. In the ECG trace, gray bars indicate the times during which data is used for image reconstruction (4A). Because of the ectopic beat, one of these data windows is in systole (arrow). This leads to artifacts which can be seen in the CT images at the level of the mid to distal right coronary artery (arrows, 4A and C).

After exclusion of the data acquired during the ectopic beat from image reconstruction in 4D (marked in blue), the right coronary artery is sharply delineated (arrows, 4E and F). Note that the exclusion of one beat from image reconstruction has led to a relatively long interval between two “accepted” beats (4D). For multi-phase reconstruction, this interval may have been too long and reconstruction would have failed.

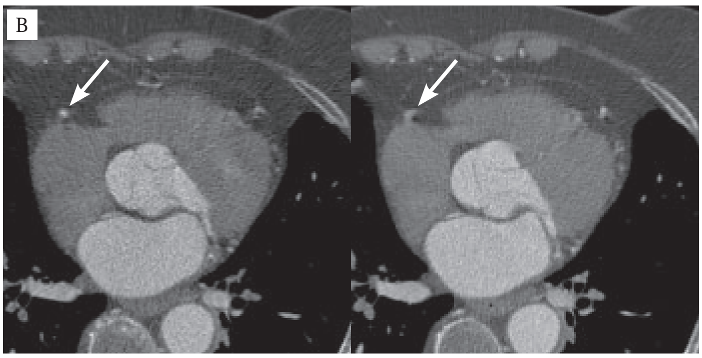
5. Examples

Multi-segment reconstruction may theoretically lead to shorter data windows used for image reconstruction (compensated for by using data from several consecutive cardiac cycles), but it does mostly not lead to elimination of motion artifacts or improved image quality. In fact, Magnetic Resonance coronary angiography uses extensive averaging of heart beats in their data acquisition and reconstruction process, but even though the theoretical resolution of magnetic resonance coronary artery imaging is below 0.5 mm, images never reach the crispness and sharpness seen in cardiac CT. This is the consequence of blurring which is caused by the averaging of usually 8 to 16 cardiac cycles.

In coronary CT angiography, multi-segment reconstruction does not reliably lead to elimination of motion artifacts. In fact, new artifacts may be introduced. Two examples are shown here. (Figure 5)



A: *57 year old female. Heart rate 68/min. Half-scan reconstruction yields good image quality of the right coronary artery. Multi-segment reconstruction at the same cardiac phase (40 % of cardiac cycle) shows obvious motion artifact of the right coronary artery (right, arrow).*



B: *73 year old male. Heart rate 72/min. Half-scan reconstruction (left) yields good image quality of the right coronary artery. Multi-segment reconstruction at the same cardiac phase (70 % of cardiac cycle) shows obvious motion artifact of the right coronary artery (right, arrow).*

6. Experience with Dual Source CT

Three publications have assessed reliability of visualization of the coronary arteries and image quality in Dual Source CT[3–5]. In all studies, no beta blockers were given. In one study, average heart rate was 71/min and 98% of all coronary artery segments were visualized free of motion artifacts[3]. Similarly, the authors of the second study state that robust image quality was achieved across all heart rates[4]. In all three studies, half-scan reconstruction was used in conjunction with Dual Source Computed Tomography, which yields a temporal resolution of 83 ms independent of heart rate. The third study from Scheffel et al.[5] assessed image quality after coronary CTA in 32 unblocked patients with high burden of coronary calcfication. The mean heart rate was 70.3 bpm and the mean Agatston score 821. Image quality was diagnostic in 414 out of 420 coronary segments (98.6%). This leads to the conclusion that the high temporal resolution of Dual Source CT has a positive impact on the artifacts caused by severe calcifications. The success of Dual Source CT in these three initial studies illustrates the importance of high true temporal resolution for visualization of the coronary arteries across all heart rates. (Figure 6)

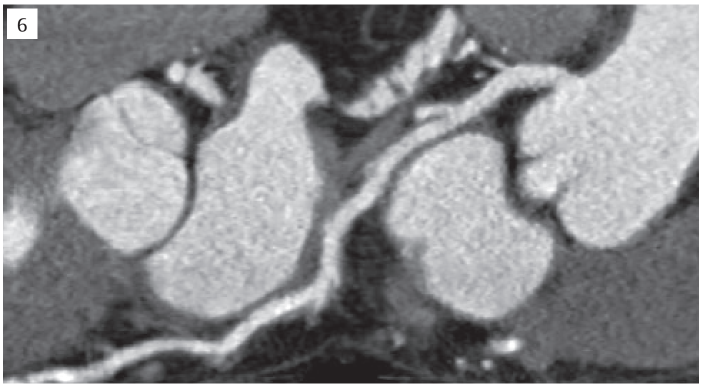


Figure 6: *Visualization of the right coronary artery at a heart rate of 109/min by Dual Source CT using half-scan reconstruction.*

Summary

Even though multi-segment reconstruction, as compared to half-scan reconstruction, offers nominally shorter data windows during each cardiac cycle that are used for image reconstruction, the fact that data from several cardiac cycles need to be combined to make up for the missing projections constitutes a severe drawback which has a negative influence on image quality. “Blurring” may occur because the coronary arteries do not return to exactly the same position from one cardiac cycle to the next. The reduced pitch may cause higher radiation dose and may require a larger amount of contrast agent. Irregularities of the heart rate and arrhythmias may be more difficult to compensate for than with half-scan reconstruction. Finally, the initial experience with Dual Source CT demonstrates that high true temporal resolution in combination with half-scan reconstruction allows reliable imaging of the coronary arteries even in high heart rates.

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