Tips and tricks in Multislice CT coronary angiography

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Abstract. The introduction of the multislice computed tomography (MSCT) scanners and their application to coronary imaging has created a new clinical imaging field. Even though MSCT coronary angiography has been reported to be able to detect significant stenoses with very high diagnostic accuracy, the clinical implementation is still difficult and the users are having difficulties in reproducing the results in literature, partly due to the limited experience in the field of coronary MSCT. Several details can be overlooked so that diagnostic mistakes are possible. In this paper we tried to collect a series of technical "tips and tricks" that might improve the quality of coronary imaging in the clinical practice. (www.actabiomedica.it)

Key words: Multislice Computed Tomography, coronary angiography, image reconstruction, technical optimization

Introduction

Computed tomography (CT) scanners producing from sixteen to sixty-four slices (multislice CT; MSCT) per rotation have been introduced in the radiologic practice. The increased spatial and temporal resolution has strengthened the performance in high-end applications such as MSCT coronary angiography (MSCT-CA) (1, 2). Nevertheless, though with exceptions, this technique has not yet entered the routine clinical practice. One common experience reported by the users is the lack of results comparable to the literature in the field of MSCT-CA.

There are several reasons for the *"lower-than-expected"* performance and the slow implementation of this technique. Among them, the quality and quantity of the cooperation between Radiology and Cardiology, the lack of training on both sides, the limited access to state-of-the-art technology, the lack of a database, and the one-push-button approach.

In our experience, MSCT-CA, even though it seems fast, easy and robust, requires significant experience, since several steps are necessary during the procedure in which the quality of the images can be jeopardized. Moreover, in spite of several limitations, manufacturers tend to let the users underestimate them for marketing reasons.

In this report, MSCT-CA will be dissected and the details that can improve or compromise the diagnostic result will be explained providing solutions for the users.

Patient selection

Clinical indication

In order to properly address the problem of patient selection, guidelines for the clinical implementation of MSCT-CA in patient care should be provided.

Currently, these guidelines are not present and therefore the discussion on the indications is based more on speculation than on evidences.

Based on current literature, the patient groups in which the diagnostic value of MSCT-CA is known are very few (3-6). Usually, these are patients with stable angina and/or atypical chest pain who should undergo coronary angiography (CA). In these patients CA should be performed at the current stage of knowledge. There is in fact no evidence regarding the benefit for the patient when MSCT-CA is performed instead of CA.

It is definitely more interesting to look for patients with poorer indication for CA. In this group there are patients at high cardiovascular risk, patients with unspecific symptoms, patients with unreliable/inconclusive stress testing, and patients undergoing valve surgery. In these patients a CA, whenever possible, should be avoided, on the contrary MSCT-CA may represent an additional/alternative tool for a comprehensive evaluation of the coronary tree.

Inclusion criteria

Heart rate (spontaneous or b-blocker induced) < 70 bpm and the ability to hold the breath for a time comparable to the scan time (3-5) represent the inclusion criteria for the scan. Both criteria are focused on avoiding motion artefacts. In the first case the problem derives from the residual coronary artery motion that is present within each phase of the cardiac cycle. Keeping the heart rate low allows a longer diastolic interval, therefore increasing the duration of the late diastole when the heart and the coronary arteries are almost motion-less. Even though MSCT-CA can be diagnostic at higher heart rates, motion artefacts progressively reduce the number of segments that can be reliably visualized (7).

The second criterion aims at avoiding respiratory-related motion artefacts. It is clear that when the patient is breathing during the scan information will be lost.

Exclusion criteria

High heart rate (> 70 bpm), previous allergic reaction to iodine contrast media, renal insufficiency (serum creatinine > 120 mmol/L), pregnancy, respiratory impairment, unstable clinical status and marked heart failure are the conventional exclusion criteria.

The problem associated with high heart rate has been already described in the previous paragraph. When a patient shows a mild to medium allergic reaction to iodinated contrast material the scan can be performed after a pre-treatment with anti-histaminic and corticosteroid drugs. For impaired renal function the administration of iodinated contrast material can be better tolerated if an iso-osmolar agent is used (8). In pregnancy and also in very young adults the scan should be performed only when the diagnostic information cannot be retrieved in any other way not involving radiation exposure. Respiratory impairment can prevent an adequate apnoea as well as an unstable clinical status.

Patient preparation

The heart rate (HR) of the patient should be assessed at presentation. Patients with a pre-scan HR≥65 bpm, are given 100 mg of metoprolol orally, unless contra-indicated, and the scan can be performed 45-60 minutes later.

Once the HR and the other inclusion/exclusion criteria are met, the patient can be positioned and connected to the ECG trace.

In this phase the variability of HR should be observed and a test apnoea with a duration comparable to the scan time should be performed. If at rest and during apnoea the HR remains stable the scan can go further. In some cases premature beats can be observed. They are not a contra-indication for the scan if the software allows editing of the ECG (see below). When editing is not possible, information can be lost at the premature beat level. In this case the patient should not undergo the procedure.

Contrast material

Administration

Contrast material should be administered through an antecubital vein. This is because high rates are required and larger veins are recommended. The antecubital access is also best because the cephalic and basilic veins that drain the antecubital region have almost no connections with other veins, therefore avoiding loss of contrast material (9).

The intravenous bolus of contrast material should be adapted to the specific scan protocol adopted. High intravascular attenuation and low beam-hardening artefacts in the right heart are the guidelines for an optimal MSCT-CA. In order to obtain high intravascular attenuation it is necessary to administer a bolus with a load of iodine per second. This can be obtained increasing the iodine content of the contrast material (350-400 mgI/ml) and/or increasing the rate of injection of the contrast material (3-4 ml/s). In order to reduce the beam-hardening in the right heart and to optimise the performance of the bolus a saline chaser should be added immediately after the main bolus (10). There is no evident advantage in using biphasic protocols (11). On average a bolus of 100ml administered at 3-5 mls, followed by a 40 ml saline chaser provides an optimal arterial enhancement (10).

Synchronization

In order to synchronize the arrival of the contrast material in the coronary arteries and the scan two techniques can be used (9, 12). The first technique is test bolus and the second is bolus tracking. From the clinical point of view there is little difference between the two techniques. Test bolus is easy to perform but it requires an additional administration of 20 ml of contrast material. Bolus tracking is more flexible but it requires a more experienced operator. For MSCT-CA bolus tracking is recommended and can be performed as follows: a region of interest is positioned in the ascending aorta and the triggering threshold is set at +100HU above the baseline attenuation. When the attenuation in the region of interest increases above the threshold the scan is triggered, breath-hold instructions are given to the patients (4-5s), and the scan starts.

MSCT-CA scan

The best scan protocol is the one that allows a high spatial resolution (thinner collimation), a high temporal resolution (faster gantry rotation), and a lower radiation exposure (prospectively ECG-triggered tube current modulation (13)) compatibly with a good signal to noise ratio (Figure 1). The following protocols are optimised for a 16-slice and a 64-slice MSCT-CA.

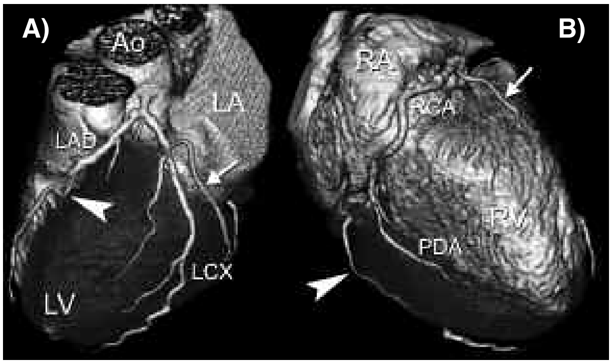

Figure 1. Three-dimensional volume rendering of a 64-slice MSCT-CA.
In the figure an example of coronary angiography performed with a Sensation 64 MSCT scanner (Siemens, Germany). The improved spatial (0.4^3 voxel) and temporal resolution (330 ms rotation time) provides excellent depiction of all main coronary vessels and their branches. In particular, the small diagonal branches of the LAD (A - arrowhead), the obtuse marginal branches of the LCX (A - arrow and B - arrowhead), the acute marginal branches of the RCA (B - arrow), and the PDA are shown.
Abbreviations: Ao = ascending aorta; LA = left atrium; LV = left ventricle; LAD = left anterior descending; LCX = left circumflex; RA = right atrium; RV = right ventricle; RCA = right coronary artery; PDA = posterior descending artery

The scan parameters for 16-slice MSCT-CA (based on Sensation 16®, Siemens, Germany) are: number of slices per rotation 64, individual detector width 0.75 mm, gantry rotation time 375 ms, effective temporal resolution 188 ms (with single segment reconstruction algorithm), kV 120, eff. mAs 700, feed/rotation 3.0 mm (8 mm/sec; pitch factor 0.25), and scan cranio-caudal direction.

The scan parameters for 64-slice MSCT-CA (based on Sensation 64®, Siemens, Germany) are: number of slices per rotation 64, individual detector width 0.6 mm, gantry rotation time 330 ms, effective temporal resolution 165 ms (with single segment reconstruction algorithm), kV 120, eff. mAs 900, feed/rotation 3.84 mm (11.6 mm/s; pitch factor 0.2), and scan cranio-caudal direction.

Image reconstruction

Image reconstruction is a key phase of MSCT-CA. When the scan is performed with correct indication and inclusion/exclusion criteria are met the reconstruction can be easily performed and a motion-free dataset can be obtained.

In literature the techniques that are reported to be effective are based on few reconstructions concentrated in the mid-to-end diastolic phase (temporal windows positioned around -400 ms prior to the next R wave or at 60% of the RR interval). Several approaches can be followed when performing the reconstructions. We can identify at least four different techniques (Figure 2): 1) percentage delay based on the R wave (14); 2) absolute prospective delay based on the R wave (14); 3) absolute reverse delay based on the R wave (14); 4) end of temporal window positioned on top of the P wave (15).

There is no evidence that one technique is best or that a defined protocol determines better results. Usually, the experienced user develops a mixture of these 4 techniques that depends on his/her experience, on the software/hardware capabilities, on the type of heart rate abnormalities that are included for the scan, and on the time available for the reconstructions. The phase providing most of the information is the mid-to-end diastole. In this phase the heart is in the iso-volumetric filling and motion is minimized. In several cases the tele-systolic phase can provide relevant information. In this phase the contraction of the myocardium is finishing and the motion of the coronary arteries is also minimized (Figure 3).

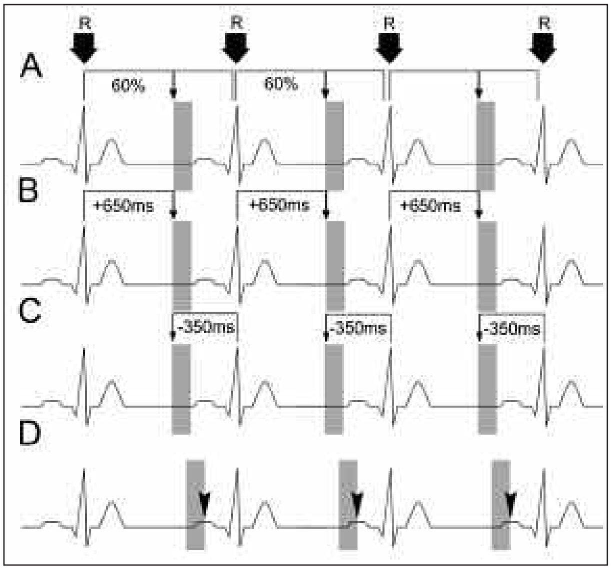

Figure 2. Retrospective ECG gating techniques.
In the figure different approaches to the ECG gating in MSCT-CA are displayed. In A probably the most common approach: percentage delay. The software calculates the distance between one R wave and the next and sets the temporal window at a defined position based on a percentage of the entire interval. In B, the absolute prospective delay is displayed. With this approach the temporal window is set with a fixed delay after the R wave. In C, the absolute reverse delay. This approach sets with a fixed delay the temporal window before the R wave. In D, a different approach is displayed. In this case the temporal window is set with its end on the top of the P wave. The aim of this last technique is to "hit" the very last moment of quiet before the systolic contraction

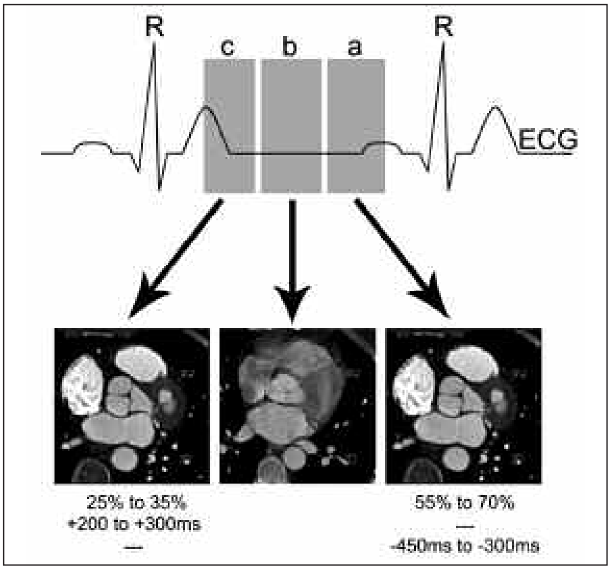

Figure 3. The position of the temporal reconstruction window. Regardless of the technique applied to set the temporal window there are some principles that can be taken into account when dealing with the reconstruction in MSCT-CA. When looking at the ECG trace, the operator should address 3 main areas. The first one (a) is the telediastolic phase. In this phase the heart is at the end of the filling just prior to atrial systolic contraction and the motion is minimized. The second phase (b) is the early-to-mid diastolic phase. In this phase the heart is filling and there is usually residual motion that does not allow proper coronary imaging. The third phase (c), is the telesystolic phase. In this phase the heart is in its isovolumetric contraction and motion is minimized. In this phase images can be as good as in the telediastolic phase and in a smaller percentage even better

An important feature of some ECG-gating software is the possibility to edit the position of the temporal windows within the cardiac cycle. This feature is particularly important when one or more abnormalities of the myocardial contraction are present during the scan. The usual abnormality is the premature beat (or extra-systole). When ECG trace and temporal window position can be edited, single premature beats surrounded by regular heartbeats can be easily ruled out (Figure 4).

The other reconstruction parameters are also relevant for a proper image performance. In particular, effective slice width is usually slightly thicker than the minimal collimation in order to improve the signal to noise ratio. The reconstruction increment should be around 50% of the effective slice thickness to improve the spatial resolution and the oversampling along the z-axis. The field of view should be as small as possible including the entire heart in order to fully exploit the image matrix that is constant (512*512 pixels). The filtering should be a trade-off between the noise and the quality of the image. Usually medium convolution filters are applied for coronary imaging. With prominent calcifications or coronary stents, higher filters, though increasing the noise of the image, usually improve the visualisation of the vessel wall or of the stent strut and the lumen (Figure 5).

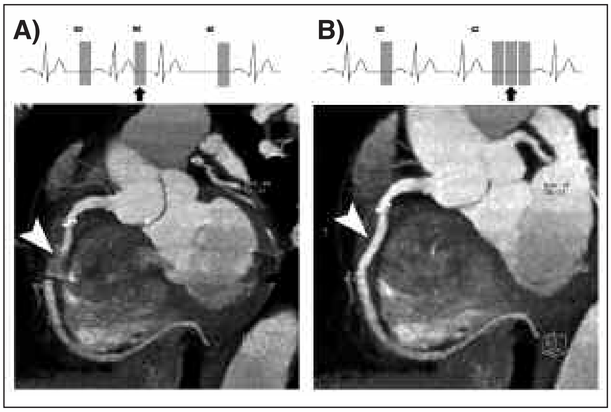

Figure 4. Editing of the ECG in case of premature beats. The occurrence of a premature beat is not infrequent even in normal patients. It may be more frequent when the patients have ischaemic cardiomyopathy. The presence of a premature beat may prevent the proper visualisation of one or more stacks of images. Its explanation is related to the mis-alignment of the temporal window in the diastolic pause before the premature beat (A – arrow in ECG track). This temporal window usually falls in a different position when compared to the others. The position is usually hitting a period of the cardiac cycle when the heart is moving. This results in motion artefacts that worsen the image quality or eventually do not allow the visualisation of the vessel (A – arrowhead). The solution to this problem (as long as the software allows it) is fairly simple. The operator should delete the temporal window during the premature beat and fill the next diastolic pause (which is longer than a normal one when the premature beat is triggered above or within the AV-node) with additional temporal windows (B – arrow in the ECG track) until the minimum heart rate interval is achieved. Doing so, it is possible to recover the data and obtain a diagnostic image quality (B – arrowhead)

Image evaluation

The evaluation of the images has not yet been standardized. In terms of reproducibility a performance of MSCT-CA is currently an operator-dependent technique (16).

The evaluation is usually performed following a classification in 15 or 16 coronary segments derived from the American Heart Association (17). This classification is helpful because it allows the operator to focus mostly on the segments that are relevant from the clinical point of view (Figure 6).

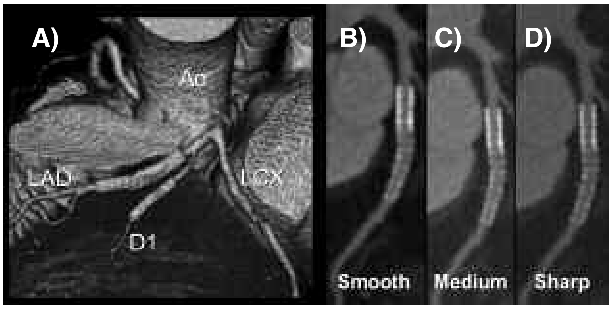

Figure 5. Effect of convolution filters on stent visualisation. Convolution filters may be useful to improve the visualisation of structures when there is a large differential attenuation. This is the case of stents in the coronary arteries. In A 3D volume rendering image a left coronary artery with two stents in the left anterior descending and in the first diagonal branch is shown. The stent in the left anterior descending is displayed in a curved multiplanar reconstruction in B, C, and D using progressively sharper convolution filters. The visualisation of the stents and the differentiation between their struts and the lumen within, is improved by sharp convolution filters.
Abbreviations: Ao = ascending aorta; LCX = left circumflex; LAD = left anterior descending; D1 = first diagonal branch

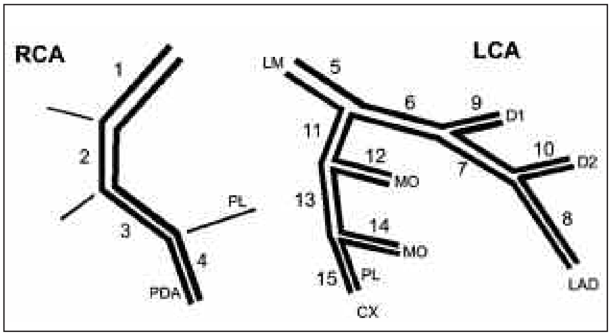

Figure 6. Classification of coronary segments.
The figure shows a scheme of the coronary tree divided into 15 segments following a modified classification of the American Heart Association (17). This classification includes most of the segments with a diameter above 1.5 mm.
Abbreviations: LCA = left coronary artery; CX = left circumflex; LAD = left anterior descending; LM = left main; MO = marginal branch; RCA = right coronary artery; D1 = first diagonal branch; D2 = second diagonal branch; PL = posterolateral branch; PDA = posterior descending artery

What has been reported in the literature until now showed the potential of MSCT-CA in the detection of significant stenosis defined as ≥ 50% lumen reduction (3-5). The evaluation has always been performed in a semi-quantitative fashion. No quantitative technique has been applied.

Even though no protocol has been standardized yet, protocols for image evaluation should be recommended.

Axial images should always be reviewed first. Scrolling the dataset gives a quick overview of the non-coronary information that might be present within the dataset. At the same time the location of cardiac structures (e.g. great vessels of the thorax, cardiac valves, atria, ventricles, …), including coronary arteries, can be screened for gross morphological abnormalities. The next step should be the use of multiplanar reconstructions (MPR). Dedicated planes can favour the visualisation of specific vessels. The main planes useful for the evaluation of coronary arteries are: 1) plane parallel to the atrio-ventricular groove (it allows the longitudinal visualisation of the right coronary artery and of the left circumflex) and plane parallel to the inter-ventricular groove (it allows the visualisation of the left anterior descending). On these planes a maximum intensity projection (MIP) algorithm can be useful. If calcifications are absent or mild a slab MIP of 5-8mm is usually optimal while if calcifications are evident the thickness should be reduced to 3mm. When the vessel is partially or completely displayed within one plane it can be helpful to perform a central-lumen line reconstruction (by manual or automatic vessel tracking). When dedicated software is used for this purpose the resulting image can be rotated 360° around its axis. In parallel an orthogonal view of the same vessel is displayed. This modality of visualisation is particularly helpful for the quali-quantitative evaluation of stenosis. Volume rendering is usually performed for overview and for communication purposes.

The report

A report for MSCT-CA should mirror the one already used in conventional coronary angiography. This approach will help the communication between the Radiologist and the referring Physician/Cardiologist. In these settings the indication for the scan has to be very clear. In fact, the report of a significant lesion in the proximal left anterior descending can have two different outcomes when the patient is symptomatic, atypically symptomatic, or overtly asymptomatic.

Artefacts

Artefacts are common in MSCT-CA but can be managed and ruled out or simply recognized. For this reason, even though they are caused by mistakes during the procedure or by intrinsic limitations of the technique, they can be addressed as a separate topic. An extensive and complete discussion on artefacts in MSCT-CA would require insight into the physics of scanning which is not the aim of this paper. Therefore, in Table 1 we tried to summarize the main types of artefacts and their causes.

Limitations

The patients with heart rates above 70 bpm were not enrolled in this study to prevent image degradation from other sources other than the ones analysed in our study.

Table 1. Classification, cause and management of artefacts

Artefacts	Description	Cause
Motion	High HR	Insufficient temporal resolution
	Irregular HR	Atrial fibrillation
		Other irregularities
		Insufficient of temporal resolution
	Premature beat	Too short diastolic phase
		Premature beat triggered during breath-hold
	Patient breathing	Poor patient instructions
		Stressed patient
		Different mother language
		Partial or total deafness
	Breath-hold control	Valsalva manoeuvre
		Too deep inspiratory breath-hold
Image contrast/noise	"Large" patient	High tissue absorption throughout the dataset
	"Very large" breast	High tissue absorption in the distal part of the dataset
Beam hardening	Streak artefacts	Contrast material (SVC and right heart)
		Calcium
		Stents
		Clips
Volume averaging	"Blooming"	Contrast material
		Calcium
		Stents
		Clips
Temporal window	Motion in segment 2	Sub-optimal selection of temporal window
	Diffuse but not heavy motion especially on the RCA	Sub-optimal selection of temporal window
	Heavy motion artefact in one isolated stack of images	Premature heart beat
	Heavy motion artefact in multiple stacks of images	Irregular ECG-wave
Missing data	Lack of information at a defined level of the scan range	Irregular ECG baseline
		Mis-triggering
		Extra low HR (<40bpm)
		Premature beat with border-line HR
	Missed LM	Scan start too low
		Patient apnoea during topogram was different from the one during the angiography scan
	Missed PDA	Scan ends too high
		Patient apnoea during topogram was different from the one during the angiography scan
Vessel enhancement	Poor enhancement	Extremely fast circulation time
		(young patients, congenital anomalies of the great vessels of the thorax and heart)
		Early-triggering BT
		Late-triggering BT
		Low rate
		Low iodine
		Low volume
		Wrist IV
		Partial extra-vasation
	No enhancement	Injector not connected
		Injector-tube disconnection
		Extra-vasation
Image quality	Noisy images	Too low mAs
		"Large" patient/breast

Abbreviations: BT = bolus tracking; CM = contrast material; ECG = electro-cardio-gram; HR = heart rate; IV = intra-venous; mAs = milli-Ampere per second; ml = millilitres; RCA = right coronary artery; ROI = region of interest; SVC = superior vena cava

Only mild heart rhythm irregularities could be included in the evaluation due to the still limited effective temporal resolution.

The scan of patients with mild heart rhythm irregularities does not allow to use X-ray reduction software such as ECG-pulsing (13). This is because the algorithm for dose reduction works with a prospective triggering based on the R wave. In the presence of heart rate abnormalities the location of the low dose period is variable and can fall within the diastole.

In addition, the presence of heart rhythm irregularities, with the exclusion of low heart rates, does not allow the application of multi-segmental reconstruction algorithms (18, 19). This is because the variable diastolic filling of the heart prevents a proper interpolation between the data originating from neighbouring heart cycles.

Conclusion

Multislice CT coronary angiography is a promising technique that s be performed by experienced operators. Its clinical outcome is strictly dependent on the optimisation of each step of the procedure.

References

1. Flohr TG, Schoepf UJ, Kuettner A, et al. Advances in cardiac imaging with 16-section CT systems. *Acad Radiol* 2003; 10: 386-401.
2. Cademartiri F, Lucchichenti G, van Der Lugt A, et al. Sixteen-row multislice computed tomography: basic concepts, protocols, and enhanced clinical applications. *Semin Ultrasound CT MR* 2004; 25: 2-16.
3. Nieman K, Cademartiri F, Lemos PA, Raaijmakers R, Pattynama PM, de Feyter PJ. Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. *Circulation* 2002; 106: 2051-4.
4. Ropers D, Baum U, Pohle K, et al. Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. *Circulation* 2003; 107: 664-6.
5. Mollet NR, Cademartiri F, Nieman K, et al. Multislice spiral computed tomography coronary angiography in patients with stable angina pectoris. *J Am Coll Cardiol* 2004; 43: 2265-70.
6. Martuscelli E, Romagnoli A, D'Eliseo A, et al. Accuracy of thin-slice computed tomography in the detection of coronary stenoses. *Eur Heart J* 2004; 25: 1043-8.
7. Nieman K, Rensing BJ, van Geuns RJ, et al. Non-invasive coronary angiography with multislice spiral computed tomography: impact of heart rate. *Heart* 2002; 88: 470-4.
8. Aspelin P, Aubry P, Fransson SG, Strasser R, Willenbrock R, Berg KJ. Nephrotoxic effects in high-risk patients undergoing angiography. *N Engl J Med* 2003; 348: 491-9.
9. Cademartiri F, van der Lugt A, Luccichenti G, Pavone P, Krestin GP. Parameters affecting bolus geometry in CTA: a review. *J Comput Assist Tomogr* 2002; 26: 598-607.
10. Cademartiri F, Mollet N, van der Lugt A, et al. Non-invasive 16-row multislice CT coronary angiography: usefulness of saline chaser. *Eur Radiol* 2004; 14: 178-83.
11. Cademartiri F, Luccichenti G, Marano R, Gualerzi M, Brambilla L, Coruzzi P. Comparison of monophasic vs biphasic administration of contrast material in non-invasive coronary angiography using a 16-row multislice Computed Tomography. *Radiol Med* 2004; 107: 489-96.
12. Cademartiri F, Nieman K, van der Lugt A, et al. IV contrast administration for CT coronary angiography on a 16-multidetector-row helical CT scanner: test bolus vs. bolus tracking. *Radiology* 2004: 233 (3): 817-23.
13. Jakobs TF, Becker CR, Ohnesorge B, et al. Multislice helical CT of the heart with retrospective ECG gating: reduction of radiation exposure by ECG-controlled tube current modulation. *Eur Radiol* 2002; 12: 1081-6.
14. Cademartiri F, Luccichenti G, Marano R, et al. Non-invasive angiography of the coronary arteries with multislice computed tomography: state of the art and future prospects. *Radiol Med* 2003; 106: 284-96.
15. Sato Y, Matsumoto N, Kato M, et al. Noninvasive assessment of coronary artery disease by multislice spiral computed tomography using a new retrospectively ECG-gated image reconstruction technique. *Circ J* 2003; 67: 401-5.
16. Cademartiri F, Mollet NR, Lemos PA, et al. Standard vs. User-Interactive Assessment of Significant Coronary Stenoses with Multislice Computed Tomography Coronary Angiography. *Am J Cardiol* 2004: 15; 94(12): 1590-3.
17. Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. *Circulation* 1975; 51: 5-40.
18. Dewey M, Laule M, Krug L, et al. Multisegment and half-scan reconstruction of 16-slice computed tomography for detection of coronary artery stenoses. *Invest Radiol* 2004; 39: 223-9.
19. Halliburton SS, Stillman AE, Flohr T, et al. Do segmented reconstruction algorithms for cardiac multi-slice computed tomography improve image quality? *Herz* 2003; 28: 20-31.

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