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Prospectively gated low-dose CCTA: 24 months experience in more than 2,000 clinical cases

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Abstract Cardiac CT exams have recently come under increased scrutiny because of their relatively high radiation dose. The most effective way to lower the dose of coronary computed tomography angiography (CCTA) exams is with the use of prospective gating. This allows for a significant reduction in effective radiation dose when compared to retrospective ECG gating while image quality is maintained or improved. We reviewed data from 2,124 consecutive cardiac CT exams, including 1,978 CCTA's and 146 CCTA's post CABG. With effective heart rate control, prospective gating was used for 92.1% of the CCTAs and 83.2% of CCTAs following CABG. The prospectively gated CCTAs had a mean effective dose of 3.1 ± 1.5 mSv, CCTAs following CABG had a mean dose of 6.4 ± 2.3 mSv. We review our experience using prospective gating in specific areas to include patient selection, patient preparation, use of β- and calcium-channel-blockers for heart rate control, selection of gating technique and scan parameters, radiation dose, and post-processing techniques.

Keywords Cardiac · Coronary · MDCT · Prospective gating · Radiation dose

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Introduction

Prospective gating technique has been designed specifically to reduce the radiation dose of coronary computed tomography angiography (CCTA) exams by limiting X-ray exposure to a brief predetermined diastole window and eliminating overlapping areas of exposure. The more commonly performed retrospective gating is performed with continuous X-ray exposure in a low-pitch helical mode resulting in multiple overlapping regions of X-ray exposure and relatively high effective radiation doses. Prospectively triggered cardiac CT technique uses a "step-and-shoot" data acquisition in which a series of transverse images are acquired while the patient is stationary, and then the patient translates to the next position while the X-ray beam is off. Prospectively triggered technique for cardiac CT has been adapted for use on several current CT systems, including 64- and 320-row multi-detector-row CT (MDCT), and on the dual source CT (DSCT) [1–11].

Compared to retrospective gating technique, studies with prospective gating have reported a 77–87% effective radiation dose reduction (Table 1) [3, 5–7, 9]. Image quality has been reported to be either improved [2, 3] or equivocal [5, 6] as compared with retrospective gating. Scheffel et al. [10] recently directly compared prospectively gated CCTA with conventional coronary angiography for depicting coronary stenoses of at least 50% diameter reduction; they reported a patient-based sensitivity, specificity,

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Table 1 Summary of the currently published studies that have used or evaluated prospective gating for coronary CT angiography

Study	Scanner type	*n*	Max HR scan criteria (bpm)	PG dose (mSv)	RG dose (mSv)	Change (%)	% Segments diagnostic	Major findings
Earls Radiology 2008 [3]	64-MDCT	82 RG, 121 PG	70	2.8	18.4	−83	98.6	IQ PG > RG; segment assessability PG = RG
Shuman Radiology 2008 [5]	64-MDCT	50 RG, 50 PG	75	4.2	18.2	−77	98.9	IQ PG > RG but = when adjusted for chest diameter
Husmann EHJ 2008 [4]	64-MDCT	41 PG	65	2.1			95.0	IQ inversely prop to HR, HU, BMI. 98.9% segments assessable below HR 63, 85.2% above HR 63
Hirai Radiology 2008 [6]	64-MDCT	75 Both PG and RG	75	4.1	20	−79	98.9	IQ, stenosis detection, and grade PG = RG
Earls Int J Cardiovasc Imaging 2009	64-MDCT	156 RG 1822 PG	70	3.1	17.2	−82		Effective dose CCTA post CABG PG 6.4 mSv versus RG 30.8 mSv. PG used in 92.1% of all CCTA; 83.2% of CCTA post CABG
Rybicki Int J Cardiovasc Imaging 2008 [9]	320-MDCT	6 RG, 34 PG	71	6.7	12.6–14	−50	99.8	Initial use of PG with 320 scanner; used wide phase window
Gutstein JCCT 2008 [7]	64-DSCT	162 RG 42 PG	70	1.5 100 kV 3.1 120 kV	16.7	−85		HR > 70, >10 bpm variability, CS > 400, BMI. 30, age > 65 all may predict lower IQ based on RG reads
Scheffel Heart 2008 [10]	64-DSCT	120 PG	70	2.8			98.0	Compared with CA; patient-based sensitivity, specificity, PPV and NPV 100, 93, 94 and 100%
Stolzmann Radiology 2008 [11]	64-DSCT	90 PG	70	1.2 100 kV 2.6 120 kV			97.9	HR a significant effect on motion artifacts (AUC = 0.818), variability significant effect on stair-step artifacts (AUC = 0.79).

PG prospective gating, *RG* retrospective gating, *HR* heart rate, *CS* calcium score, *PPV* positive predictive value, *NPV* negative predictive value, *BMI* body mass index, *IQ* image quality, *HU* Hounsfield units, *AUC* area under curve positive- and negative-predictive values of 100, 93, 94 and 100%, respectively. These values compare favourably with test characteristics determined for coronary CT images obtained with a retrospectively gated technique [12–16].

Prospectively gated cardiac CT has several limitations for clinical use. Image quality degrades at higher heart rates, so a maximum heart rate of 65–75 beats per minute (bpm) has been recommended [3–11]. Image quality may also degrade due to heart rate fluctuation during acquisition [7, 11]. Finally, images acquired with prospective gating can not be used for either regional or global functional analysis of the heart because the number of reconstructed phases typically covers only a small portion of the cardiac cycle.

Despite these limitations, in our clinical practice, we have successfully used prospective technique in ~90% of routine clinical CCTA studies, and in about 80% of CCTA exams following coronary artery bypass grafting (CABG) [17]. This has saved a tremendous amount of cumulative effective radiation dose to this patient population.

The purpose of this paper is to share our clinical experience with using prospective gating over the last 24 months. During that time we have performed over 2,000 prospectively gated CCTA studies. We believe that with careful patient selection and screening and with effective use of β-blockers for heart rate control, prospective gating can be used in a high percentage of cardiac CT exams. This paper will review our experience in multiple areas including patient selection, preparation, β-blockade, scanning parameters, radiation dose, and post-processing techniques.

Patient selection

Currently there are no universally accepted absolute indications for cardiac CT angiography. A discussion of appropriate clinical indications for CCTA is beyond the scope of this manuscript and is available elsewhere [18]. In our practice, the most common clinical indication for CCTA is in patients in whom prior nuclear myocardial perfusion imaging was either indeterminate or was clinically suspected to be either false positive or false negative (Fig. 1). Patients with chest pain syndrome at low to intermediate risk constitute the second largest group. Other indications include evaluation of known or suspected coronary anomalies, evaluation of new chest pain or ischemia after coronary revascularization.

There are numerous contraindications to all types of CCTA; these include allergies to iodinated contrast, renal insufficiency, arrhythmias, inability to perform a breath hold, inability to follow instructions, inability to lay supine and motionless, and high coronary calcium scores. In our lab, these contraindications are the same for CCTA performed with retrospective or prospective gating.

Additional limitations for prospective technique have been recognized and are discussed below. Because of these limitations, it is important to carefully select which patients will benefit from the

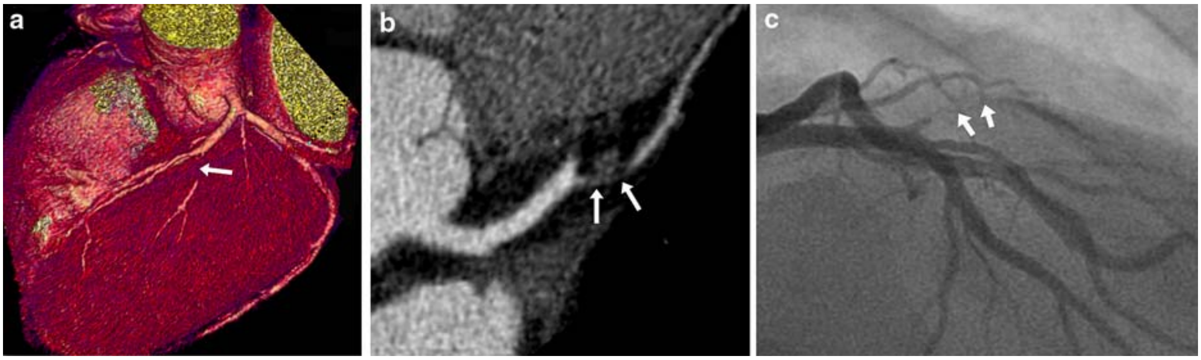

Fig. 1 Prospectively gated CCTA performed on a 56-year-old woman with chest pain. Nuclear myocardial perfusion exam showed a small reversible anterior wall defect, this was felt to possibly be false positive and a CCTA was ordered. 3D volume rendering of the CCTA depicts a proximal stenosis (*arrows*) of the first diagonal (*left*). Curved planar reformation shows a focal high grade stenosis due to a soft plaque (*arrows*, *center*). Conventional angiography confirmed the first diagonal stenosis (*arrows*, *left*). The effective dose of the CCTA was 2.2 mSv

technique and which patients will not be successfully scanned. Prospective gating has three additional contraindications not consistently observed with retrospective gating: a heart rate of >70, >10 bpm of observed heart rate variability, and the need for performing quantitative or qualitative functional analysis of the left or right heart.

Patients with higher heart rates have a decreased diagnostic accuracy in MDCT coronary angiography [19]. In general, heart rates <65 bpm result in significantly improved image quality [20]. Image quality also degrades at higher heart rates in patients imaged with prospective gating. Previous studies with prospective gating have used an upper HR limitation of between 65 and 75 bpm [3–11]. Husmann et al. [4] found image quality of prospectively gated studies to be inversely related to heart rate; 98.9% of coronary segments were assessable at HRs below 63 bpm, but only 84.5% were assessable at HRs above 63 (84.5%). The reason for this image quality degradation in patients with higher heart rates is unclear. However, at higher heart rates reconstruction of data during end-systole or early diastole improves image quality as compared to the usually performed mid-diastole, however, late systolic phase images are usually not available with prospective gating. Therefore it is critical to have a lower HR to maximize image quality and diagnostic accuracy. We prefer to have a heart rate of 67 bpm or less, although we accept heart rates of 68 or 69 if there is little variability.

Heart rate variability is the difference between the maximum and minimum heart rates during a short observation period. Heart rate variability has been independently correlated with overall image quality for retrospectively gated CCTA [21, 22]. We have found that image quality degrades if a heart rate acceleration or deceleration coincides with data acquisition. While increased heart rate variability did not correlate with decreased image quality in one prior report, it did correlate with increased stair step artifact in another [4, 11].

Cardiac functional analysis is not available with prospective gating. If there is a clinical need for performing quantitative or qualitative functional analysis of the left or right heart, then retrospective gating must be employed. Retrospective gating allows reconstruction of images at any point during the cardiac cycle, if images are rendered at serial increments throughout the cardiac cycle they can be analyzed quantitatively; cardiac volumes, ejection fraction, stroke volume etc. can be determined. Additionally area of abnormal wall motion can also be defined. None of these can be determined on a prospectively gated study because only limited data for a short period during diastole is acquired.

For use of prospective gating the heart rate has to be below 70 bpm, there must be been <10 bpm of heart rate variability and there needs to be no need of cardiac function analysis. If all three of these criteria are met, and none of the more general contraindications for CCTA are present, then the patient is a good candidate for use of prospective gating. If either heart rate criteria are exceeded or if a cardiac function analysis is needed or has been ordered, then a retrospectively gated exam should be prescribed (Fig. 2).

Patient preparation

Patients are kept NPO for 2–3 h prior to the exam. Caffeine and nicotine are withheld for at least 12 h, if possible. The most critical preparation involves slowing and stabilizing the patient's heart rate. A lower heart rate increases the relative proportion of the cardiac cycle spent in diastole and limits motion artifact. We have noted that the heart rate frequently rises with the anxiety of being placed on the scanner and with the injection of contrast material. A decrease in heart rate has also been noted during the initial seconds of breath-holding.

In order to control heart rates, and improve image quality, we rely on oral β-blockers, administered on site approximately 30–60 min prior to the CT exam. Calcium channel blockers are used if β-blockers are contraindicated. Contraindications for β-blocker therapy include asthma, atrioventricular conduction block, heart failure, diabetes, and Raynaud syndrome. Our heart rate control protocol is administered by a full-time registered nurse (RN) under the supervision of the attending radiologists (Table 2).

If the patient's resting heart rate exceeded 55 bpm and there is no contraindication to β-blockade, oral metoprolol is given before the CT. The dose of metoprolol ranges from 12.5 up to 200 mg; the dose depends on a sliding scale based primarily on the patient's HR. However, the BMI, perceived anxiety

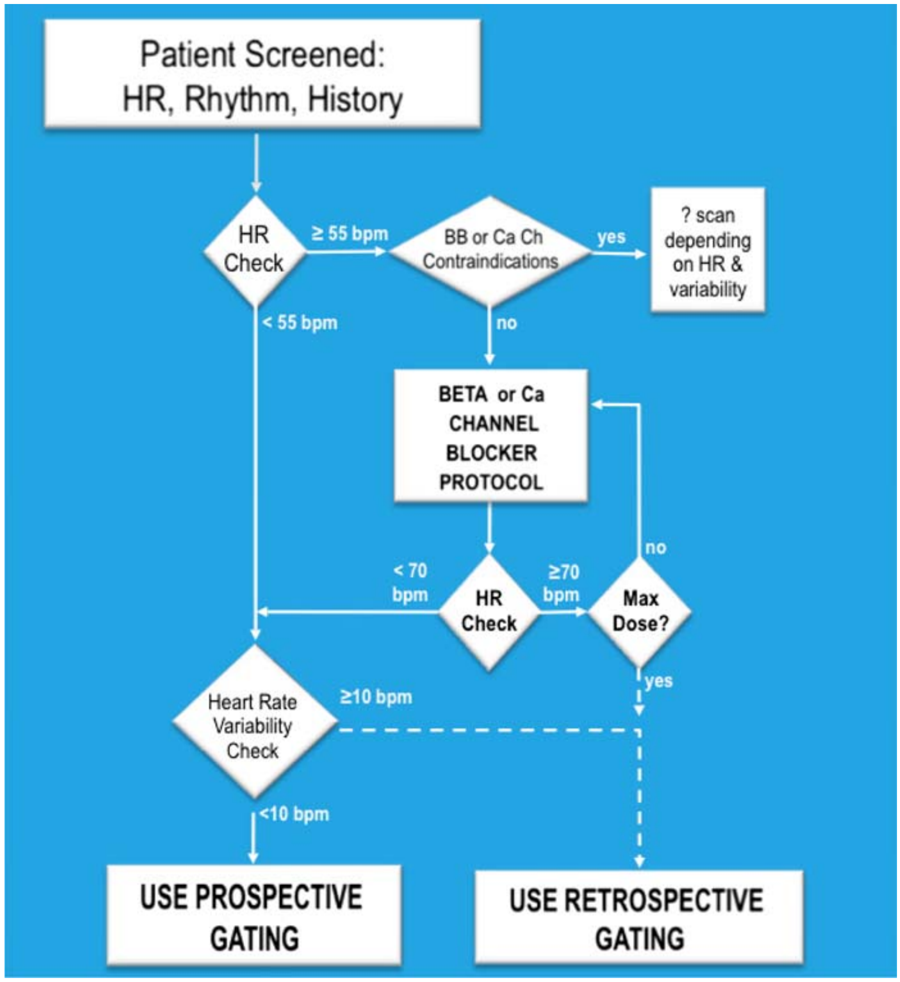

Fig. 2 Selection of CCTA scanning technique depends on heart rate (*HR*) and HR variability. Patients with presenting HR of <55 bpm virtually always undergo prospectively gated CT. Above 55 bpm, patients receive varying amounts of beta (or calcium channel) blocker depending on HR (Table 2). All patients with a resulting HR of <70 bpm who demonstrate <10 bpm of variability undergo prospectively gated CT, the remainder are scanned with retrospective gating. (*BB* β-blockers, *Ca Ch* calcium channel blockers, *HR* heart rate, *bpm* beats per min)

level, and clinical history are considered in the decision. After ~30 min repeat vital signs are acquired and an additional dose(s) of metoprolol is given if the patient's heart rate is not lowering satisfactorily.

In cases where oral medication is insufficient to bring the patients heart rate below 70 bpm, we use 5 mg intravenous aliquots of metoprolol given at 5-min intervals, up to a maximum total intravenous dose of 20 mg. When β-blockers were contraindicated and the heart rates is >70 bpm we use oral or intravenous diltiazem. The decision to use diltiazem and its dose and route of administration is usually made in conjunction with the referring physician.

All patients also receive 0.4 mg of sublingual nitroglycerine spray 2–4 min before the cardiac CT, unless contraindicated. Sublingual nitroglycerin dilates the coronary arteries and allows more branches to be visualized without negatively affecting image quality [23, 24]. Nitrates enlarge the diameter of nonstenotic segments and have less effect on stenotic segments, increasing the detection of obstructive lesions [25]. Use of sublingual nitroglycerin spray instead of other nitrate preparations may be more efficacious and may cause fewer side effects [26]. Prior to the administration of nitroglycerin, patients are questioned regarding recent use of Viagra® (sildenafil), Cialis® (tadalafil), or Levitra® (vardenafil). Severe side effects, including very low blood pressure and death, have been reported in patients given nitroglycerin within 24 h after use of these phosphodiesterase type 5 inhibitors.

In review of our prior 24 months of using prospective technique, at presentation ~1,312 (58.7%) of 2,234 patients had a heart rate of <70 bpm meeting our first criteria for use of

Table 2 Summary of our current heart rate control algorithm

Beta blocker protocol			Calcium channel blocker protocol		
Oral metoprolol protocol			Oral dilitiazem protocol		
Loading	Consider anxiety level, BMI, history		Loading	Consider anxiety level, BMI, history	
	HR 55–60	12.5–25 mg		HR > 70	Consider doubling OP dose
	HR 60–65	25–50 mg			
	HR 65–70	50–100 mg			
	HR 70–80	100–150 mg			
	HR > 80	100–200 mg			
Redosing	Wait 30 min, do not exceed 200 mg				
	HR > 70	25–50 mg			
Intravenous metoprolol protocol			Intravenous diltiazem protocol		
Loading	5 mg iv metoprolol over 1–2 min		Loading	10 mg iv diltiazem over 2 min	
	Repeat every 5 min to max of 30 mg			Repeat every 10 min to max of 40 mg	

Oral metropolol is used in a large majority of cases, intravenous (*iv*) metoprolol occasionally is used to supplement the oral dose. Calcium channel blockers are used infrequently in cases of elevated (>70 bpm) HR in patients with contraindications to β-blockade

prospective gating. We did not check heart rate variability at presentation but based on experience another 10–20% of patients would likely have also failed to meet that criterion. Therefore, at most, approximately one half of patients meet the criteria to use prospective gating before pharmacologic heart rate control.

Those patients who do not meet the criteria enter into the heart rate control protocol (Table 2). Review of medical records showed that 239 (10.7%) of 2,234 patients had a HR of <55 bpm and received no additional medication (Fig. 3). Another 317 (14.2%) had a HR of 55–59 bpm and received 12.5–25 mg of metoprolol to minimize heart rate variability. Between 50 and 200 mg of metoprolol were given to 1,634 (73.1%) patients who had a HR of 60 or greater. Finally 44 (2.0%) received a calcium channel blocker because they had a HR of >70 and contraindications to β blockade. Our average dose of oral metoprolol has been 102.1 ± 52.4 mg (range 12.5–200 mg). A single oral dose was used in ~84% of cases. An additional 7% of patients received one or more intravenous doses of metoprolol. Considering all patients who received β-blockers at any dose, the mean time from the first dose to being cleared for imaging was CT scanning has been 46.9 ± 17.3 min (range 10–105 min).

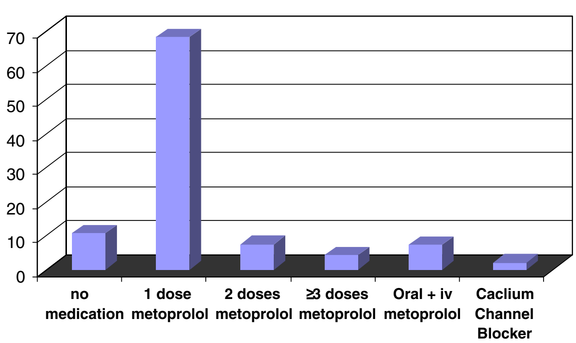

Fig. 3 Summary of medications received for heart rate control

Patient selection of prospective versus retrospective gating

Our protocol to lower the heart rate is effective, and the protocol has substantially increased the number of patients for which prospective gating can be used to lower patient radiation dose. In our algorithm to determine if an individual patient is imaged with prospective versus retrospective gating (Fig. 2), we attempt to scan all patients with prospective technique. The exception is patients with a clinical indication for retrospective gating; this is most commonly patients for whom cardiac function is requested or otherwise clinically required. These patients are imaged with retrospective gating.

After receiving medication, when necessary, at the time of their diagnostic CT scan, 95.0% of our

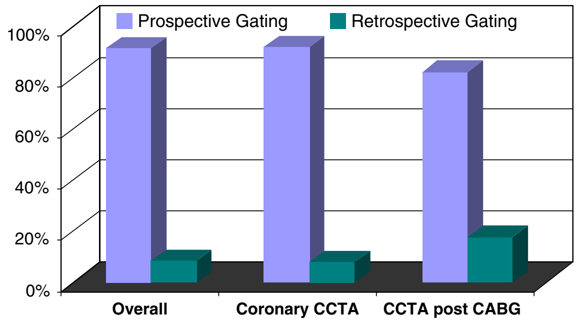

Fig. 4 A large majority of patients were scanned using prospective gating. This included 91.5% of all patients, 92.0% of coronary CCTAs, and 82.0% of CTAs following CABG

patients had a heart rate of <70 bpm, 93.7% had <10 bpm of observed HR variability, and 90.5% met both criteria. As a result of the protocol as outlined above and after use of the selection algorithm detailed in Fig. 2, prospective gating was used for 92.1% of all CCTAs and 83.2% of all CTAs following CABG (Fig. 4).

Scanning parameters

CT examinations were performed using a 64-MDCT (LightSpeed VCT XT, software version 7.1, GE Healthcare, Chalfont St Giles, England). This system has a rotation time of 350 ms, fixed single-sector reconstruction with a temporal resolution of 175 ms, detector aperture of 0.625 mm, scan field of view 20 cm, 350–800 mA, and tube voltage of 100–120 kV. The scan sequence includes a scout scanogram, low dose axial scout or calcium-scoring scan, test bolus scan, and cardiac CT angiogram.

All patients received contrast media (iodixanol 320, VisipaqueT, GE Healthcare, Princeton, NJ, USA) via a dual headed injector (OptivantageT DH, Covidien, St Louis, MO, USA). Timing of the contrast used a 20 ml test bolus at the level of the aortic root administered at 5.5 ml s^{-1} while sequential scans were performed every two for 30 s. Timing of the main injection (60–80 ml at 5.5 ml s^{-1}) was determined by the time to peak aortic enhancement from the test bolus, plus 8 s to allow for coronary artery filling. The contrast is infused through an 18- to 20-gauge catheter placed in the right antecubital vein; the injection is followed immediately by a 50-ml saline flush. The saline flush diminishes beam-hardening contrast artifact within the right ventricle and facilitates delivery of the entire contrast volume in a short bolus.

The CCTA exam covers 20 mm above the left main orifice to just below the apex of the heart for coronary studies, CCTA after CABG exams extended coverage to the thoracic inlet to include the entire left internal mammary artery. Coronary scans were performed in a cranial to caudal direction, bypass exams were scanned in the caudal to cranial direction.

Prospectively gated CCTA exams used widely available software (Snapshot Pulse, GE Healthcare, Chalfont St Giles, England). This was prescribed using 3–8 incremental 64 × 0.625 mm (40 mm) image groups requiring 2–7 table translations of 35 mm with 5 mm of overlap. The interscan delay was approximately 0.6–1.0 s; this requires skipping a cardiac cycle between acquisitions of successive image groups. The milliampere ranged from 300 to 800 depending on the patients Body Mass Index (BMI) and chest circumference as determined by the technologist's prior experience. Because of the short tube-on time in prospectively gated exams, the maximum milliampere is available when needed (Fig. 5), as opposed to retrospective technique when the highest tube milliampere may not always be used because of tube heating considerations due to longer scan times. The minimum scan time at each axial location was 230 ms (180° plus a fan angle), which translates to an effective temporal resolution of 175 ms with the half-scan weighting.

A 75% (mid-diastole) phase was targeted for all subjects. Depending on the amount of perceived beat-to-beat variability, additional "padding" of tube on time was used. Padding turns the tube on prior to and leaves it on after the minimum required 230 ms. This allows the reconstruction to adapt to minor heart rate variations and produce consistent image quality, since the reconstruction window can be modified retrospectively to ensure identical cardiac phase from scan to scan. Actual padding in the study ranged from 0 ms in very stable patients to 200 ms in less stable heart rates, this was chosen by the technologist based on observation of the ECG rhythm.

The milliampere used for the prospectively gated coronary subjects (mean 551 ± 123, range 300–800) was not significantly different than that used for retrospectively gated studies (mean 547 ± 43, range

Fig. 5 Prospectively gated CCTA performed on a 56-year-old 305 lb woman (BMI 54) with chest pain and an equivocal stress thallium study. Scout view of the chest depicts large breasts and chest wall tissue. Despite the high BMI, a prospectively gated exam was performed using 800 mA and had an effective dose of 3.2 mSv. Curved planar reformations of the RCA (*left*), LAD (*center*) and circumflex (*right*) depict no evidence of atherosclerosis or coronary stenosis

350–771) ($P > .05$). However, in CCTA after CABG exams, a higher milliampere was used for the prospectively gated studies (mean 533 ± 43, range 350–800) than for the retrospectively gated exams (mean 491 ± 155, range 300–744) ($P < .01$).

Radiation dose

Radiation estimates for CT examinations of the heart are expressed using the volume computed tomography dose index [$CTDI_{vol}$ (in Gy)], dose length product [DLP (in mGy × cm)], and effective dose [E (in mSv)]. The CT system estimates the $CTDI_{vol}$ and DLP for each CTA acquisition series. E was then calculated by multiplying the DLP by conversion factor k (0.017 $mSv \times mGy^{-1} \times cm^{-1}$) [27]. The radiation dose data presented below is for the diagnostic CT angiogram only. The examination also includes scout scanograms, low dose axial scout or calcium-scoring scan, and a test bolus scan. Together, these sequences add an additional 1.2–2.3 mSv to the examination, and the dose of these additional sequences was similar for both groups.

We reviewed data from 2,234 consecutive patient records. Because of high or unstable heart rates, inability to perform a short breath hold, or excessive coronary calcium, CT exams were not performed on 39 patients (1.6%). A total of 71 records had insufficient data and were excluded from analysis.

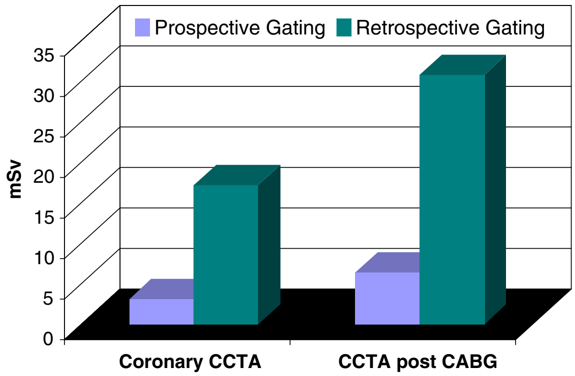

Fig. 6 For the coronary CCTA studies, the mean effective dose of the prospectively gated studies was 3.1 ± 1.5 mSv, 82% lower than the retrospectively gated exams was 17.2 ± 2.7 mSv ($P < .001$). For the CCTAs performed after CABG, the mean effective dose of the prospectively gated studies was 6.4 ± 2.3 mSv, 79.3% lower than the dose in the retrospectively gated CTs 30.8 ± 4.8 mSv, ($P < .001$)

The remaining 2,124 studies were included in the analysis, this included 1,978 CCTA's and 146 CCTA's post CABG. All examinations were performed for clinical reasons.

For the 1978 CCTA exams, the effective dose of the prospectively gated studies was 3.1 ± 1.5 mSv (range 0.60–7.9 mSv), the effective dose of the retrospectively gated exams was 17.2 ± 2.7 mSv (range 8.7–22.0 mSv) ($P < .001$) (Fig. 6). In children and low BMI patients, very low dose exams were routinely obtained, frequently with effective doses of <1 mSv (Fig. 7). The amount of padding averaged 33.5 ms (range 0–200 ms). The effective dose increased proportionally with the amount of padding selected, averaging 2.15 mSv with 0 ms of padding and increasing to 7.89 mSv with maximum padding of 200 ms.

For the 146 CTAs following CABG, the effective dose in the prospectively gated studies was 6.4 ± 2.3 mSv (range 2.8–10.8 mSv), the dose in the retrospectively gated CTs was 30.8 ± 4.8 mSv (range 17.4–37.3 mSv), ($P < .001$) (Fig. 6). The amount of padding averaged 26.9 ms (range 0–150 ms). The average effective dose increased proportionally with the amount of padding selected, averaging 4.99 mSv with 0 ms of padding and increasing to 10.8 mSv with padding of 150 ms.

Post processing

Prospectively gated CCTA exams are processed in a similar manner to retrospectively gated CCTA exams. In our routine processing and interpretation of CCTA exams we rely mainly on review of axial images as well as reconstruction of curved planar reformatted (CPR) images. CPR images are generated on an independent workstation by creation of a center-line through each coronary artery and branch. Coronary

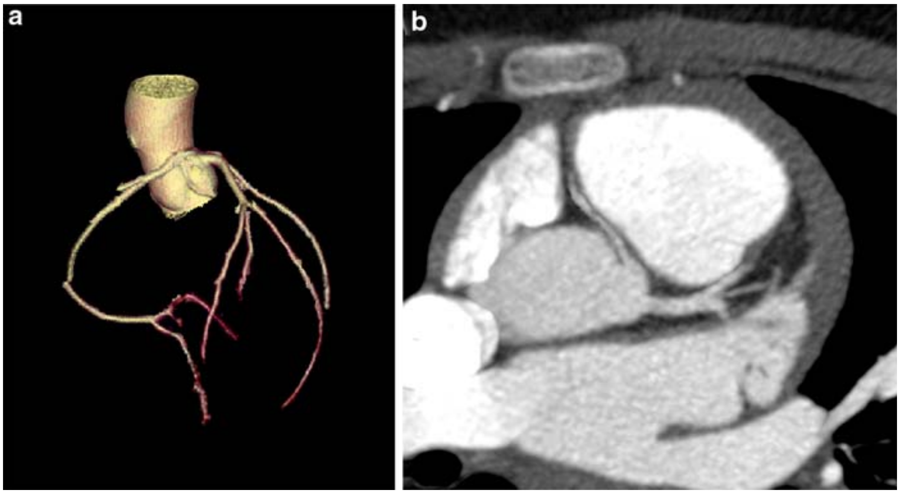

Fig. 7 Very low dose (0.84 mSv) prospectively gated CCTA performed on a 12-year-old girl with chest pain and an abnormal cardiac echocardiogram. 3D volume rendering of the coronary arteries depicts a anomaly of the RCA which arises from the left sinus of Valsalva, adjacent to the left main orifice (*left*). Curved planar reformation shows that the anomalous RCA clearly passes between the aorta and pulmonary outflow tract (*right*)

stenoses are detected by inspection of the coronary wall and assessing the effect of any plaques on lumen diameter. The narrowed diameter is compared to adjacent normal vessel diameter to determine the relative percentage of lumen narrowing.

With prospectively gated CCTA there will always be less cardiac phases available for reconstruction because of the limited tube-on time, even if a wide "padding" interval was selected. Retrospectively gated exams can be reconstructed at any point throughout the cardiac cycle. With prospectively gated exams, reconstruction can only be performed at the target phase, usually 70 or 75% from on R wave until the next. When additional tube on-time "padding" is available and has been selected, additional phases can be reconstructed. With maximal (200 ms) padding and a typical heart rate of 60 bpm, the reconstruction is available usually from $\sim$55 through 95%.

Typically, however, we use <50 ms of padding, and in very stable heart rates, we select 0 padding. In these cases only a narrow reconstruction window is available. We believe that the increased image quality of prospectively gated exams, especially in patients with adequate β-blockade, allows us to make a confident diagnosis is a vast majority of cases, even when limited cardiac phases are available.

Conclusion

Radiation dose has increasingly become is a concern for cardiac CT [16, 28]. Without any preparation, about 50% of our patients would fail our criteria for use of prospective gating. However, with careful heart rate control, $\sim$90% of clinical out-patients are able to undergo low-dose cardiac CT scanning using prospective gating.

Use of prospective gating reduces the effective radiation dose to the patient by up to 87% as compared with retrospectively gated techniques [3–11]. Lower dose reduces the long-term risk to the patient of developing a radiation-induced malignancy [16, 28]. The National Research Council's Committee on the Biological Effects of Ionizing Radiation recent report (BEIR VII) concluded that a dose of 10 mSv would cause an average of one in 1,000 lifetime cancers [29]. Based upon these estimates, use of prospective gating (3.1 mSv) rather than retrospective gating (17.2 mSv) for CCTA reduces the average risk of inducing a fatal cancer from 1/571 to 1/3333 (BEIR VII estimate).

With adequate preparation and careful patient selection, most patients can have a diagnostic CCTA exam with prospective gating and their effective radiation dose, and subsequent risk of developing a radiation-induced malignancy can be greatly reduced. We believe prospective gating technique has great promise to become a commonly utilized method for coronary CT angiography.

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