Ultra-Low Radiation Dose, Prospectively Gated Coronary CTA

State-of-the-art coronary CTA is now possible with radiation exposure less than that of a calcium score.

BY DAVID A. DOWE, MD

In the October 2006 issue of Diagnostic Imaging, I wrote a brief article describing the benefits of using prospective gating when performing coronary computed tomography angiography (PG-CCTA).

Since then, a number of software and technique improvements have occurred that make possible the use of PG-CCTA in the everyday clinical setting. In our practice, prospective gating is used in 98% of our coronary CTA patients as the initial and only scan technique. It has become rare for us to default initially to retrospectively gated or to reinject a patient to perform retrospectively gated CCTA (RG-CCTA) because of a failed prospective gated acquisition.

This article briefly describes the prospective gating acquisition protocol. I then present the ultra-low radiation exposure CCTA technique that results in radiation exposure at or below that of a coronary artery calcium score (CAC), compare the radiation exposure from cardiac imaging studies as they relate to CCTA, and finish with a potential new application, called the quadruple rule out, which may now be obtained at reasonable levels of radiation exposure.

BASICS OF PG-CCTA

Before PG-CCTA, the most effective radiation dose reduction technique was EKG dose modulation. EKG dose modulation is used when performing RG-CCTA and reduces the dose by decreasing the milliamperage (mA) of the x-ray beam in the systolic and near-systolic portions of the cardiac cycle where one is unlikely to be using the data to postprocess the coronary arteries (Figure 1). This results in an approximate 30% reduction in radiation exposure. What prevents this technique from reducing radiation dose further is that the x-ray beam remains on throughout the cardiac cycle, even when no images will be reconstructed during the reduced exposure, resulting in unnecessary radiation being delivered to the patient, which is inherent in all helical-acquired CCTA examinations (Figure 2).

Prospective gating avoids this extraneous radiation dose by completely turning off the x-ray beam during most of the cardiac cycle (Figure 3). The portion of the cardiac cycle that is to be radiated is selected before the scan, hence the term prospective. The radiated window (duration of the tube turned on) may be left wide, which makes possible the reconstruction of vessels in a range of cardiac phases. This ability comes at the expense of increasing radiation dose. Before the scan, the user must select the phase of the cardiac cycle in which they will not be reconstructing the coronary arteries. EKG dose modulation decreases radiation exposure by 30%.
which the reconstruction will be centered. I routinely use the 75% phase, which in patients with heart rates <65 bpm is safely within diastole. In the PG-CCTA protocol, there is a default time added to the window for the tube “on” time (dynamic padding) based on the patient’s heart rate. However, if the patient’s heart rate is <65 bpm, one can safely conclude that the postprocessing will be successful (ie, diagnostic images of all 15 American Heart Association coronary artery segments, with the single 75% phase for reconstruction). For this reason, I always override the default padding and manually enter a 10-msec pad.

**TABLE 1. WINDOW PADDING CENTERED AT 75%**

- At a heart rate of 60 bpm, the RR interval is 1,000 msec in length
- Using the rate determined by computer padding, we would irradiate 200 msec of the RR interval or 20% in addition to the 75% phase.
- Using the override padding we would radiate only 20 msec of the RR interval or only 2% in addition to the 75% phase

RR, relative risk.
tent in obtaining all 15 American Heart Association coronary artery segments at postprocessing. A drawback of PG-CCTA is that functional evaluation of the heart is not possible because images are not collected at all phases of the cardiac cycle.

**ULTRA-LOW-DOSE PG-CCTA**

Before one can consider the topics of spatial and temporal resolution as they pertain to CCTA, one must be able to obtain images with an adequate signal-to-noise ratio in order to visualize the coronary arteries. The demands for an increased signal-to-noise ratio are most apparent in obese and morbidly obese patients. In such patients, use of 650 to 800 mA may be necessary to obtain diagnostic images. In scanners with a tube current that is less powerful, it may be necessary to increase kilovolt potential (kVp) to 140 kVp (from the usual 120 kVp). Each incremental increase of 20 kVp results in a 38% increase in radiation exposure. Obviously, a reduction in 20 kVp decreases radiation exposure by 38% (Figure 8). It is important to titrate your technical factors to the minimum needed for patients of different body mass indices (BMIs). BMI is the only variable used to select the kVp and mA for both PG-CCTA and RG-CCTA. Out of the development of PG-CCTA has come the realization that image quality can be preserved in many patients by using 100 kVp instead of the 120 kVp routinely used with RG-CCTA. Using 100 kVp results in ultra-low radiation-dose CCTA. In many patients, the dose from this scan is equal to or less than that obtained from a CAC score (Table 2).

**RADIATION EXPOSURE FROM CARDIAC IMAGING EXAMINATIONS**

In my opinion, RG-CCTA was unfairly labeled as having excessive radiation exposures, and a long, ongoing battle has occurred over this point. In fact, when you compare the radiation dose resulting from RG-CCTA, it is in the range of single photon emission computed tomography (SPECT) sestamibi nuclear stress tests and less than the radiation exposure resulting from SPECT thallium or SPECT dual isotope nuclear stress tests.2,3 PG-CCTA has made this point moot. Taken to an extreme, 100 kVp, 10-msec padded PG-CCTA in a patient with a BMI <24 results in a 90% dose reduction when compared to SPECT sestamibi (Tables 3 and 4). PG-CCTA is becoming the first-line test in any patient suspected of having coronary artery disease because of (1) its superior sensitivity of a ≥50% stenosis (SPECT studies usually are not positive until there is at least a 70% stenosis),4,5 (2) its ability to detect eccentric plaque invisible to stress tests and many coronary catheterizations (the rupture of these same eccentric plaques accounts for up to 85% of all myocardial infarctions), (3) its lower cost, and now (4) its dramatic dose reduction. The only downside, as I see it, is the risk of injecting iodinated contrast and the lack of guidelines for determining which patients should be on statins when plaque is detected in patients with normal cholesterol profiles.6,7

**TABLE 2. PROSPECTIVELY GATED CCTA TECHNIQUE**

<table>
<thead>
<tr>
<th>BMI</th>
<th>kVp</th>
<th>mA</th>
<th>mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;25</td>
<td>100</td>
<td>450</td>
<td>1.6</td>
</tr>
<tr>
<td>25–30</td>
<td>100</td>
<td>550</td>
<td>2.3</td>
</tr>
<tr>
<td>30–32</td>
<td>120</td>
<td>650</td>
<td>3.7</td>
</tr>
<tr>
<td>&gt;34</td>
<td>120</td>
<td>800</td>
<td>4.6</td>
</tr>
<tr>
<td>CAC score</td>
<td>120</td>
<td>300</td>
<td>1.8</td>
</tr>
</tbody>
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Radiation dose is determined by BMI. Note that with a BMI <30, the radiation dose is near or below that obtained with a CAC score.

**TABLE 3. RADIATION DOSE FROM DIAGNOSTIC CARDIAC STUDIES**

- Cardiac catheterization = 3–30 mSv
- RG-CCTA = 7–20 mSv
- RG triple rule-out = 20–30 mSv
- SPECT thallium = 25.3 mSv
- SPECT sestamibi = 17–20 mSv
- PG-CCTA = 2–8 mSv
- PG, 100-kVp CCTA = 1–5 mSv
- PG triple rule-out = 9–12 mSv


**TABLE 4. ULTRA-LOW-DOSE TECHNIQUE**

- 100 kVp
- 450 mA
- 10 msec padding
- Prospective gating

Less radiation than a calcium score.
Less radiation than a coronary catheterization.
90% less radiation than a SPECT sestamibi.
TRIPLE, QUADRUPLE RULE-OUT EXAMINATIONS AND HALF-BODY CCTA

With the advent of 64-slice multidetector CT scanners using 4-cm detectors composed of 0.625-mm elements, it became possible to expand coverage in the z axis. Simultaneous arterial phase opacification of the thoracic aorta and coronary and pulmonary arteries became possible. Named the triple rule-out because of its diagnostic capability of ruling out aortic pathology, coronary artery disease, and pulmonary emboli in one scan, this exam has drawn major interest from physicians, especially those in the emergency department setting. In the emergency department, establishing the etiology of a patient’s symptoms is often difficult, resulting in 4% of patients with an acute myocardial infarction being errantly discharged. These patients have a threefold increase in mortality during the next 72 hours compared with their cohorts who are correctly admitted to the hospital. The cost to patients who undergo RG-CCTA triple rule-out examinations is radiation exposure in the 20- to 30-mSv range.

With the dramatic reduction in dose possible with PG-CCTA, it is now a reality to perform triple rule-out examinations with more acceptable levels of radiation exposure. This ability may usher in the era of CTA

<table>
<thead>
<tr>
<th>Table 5. CCTA Injection Protocols</th>
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<tbody>
<tr>
<td><strong>RG-CCTA</strong></td>
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<tr>
<td><strong>PG-CCTA</strong></td>
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<tr>
<td><strong>Phase 1</strong></td>
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<tr>
<td><strong>Phase 2</strong></td>
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<tr>
<td><strong>Phase 3</strong></td>
</tr>
</tbody>
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Figure 6. Images A and C are prospectively gated and images B and D are retrospectively gated. The images are indistinguishable with 70% dose savings.

Figure 7. Indistinguishable curved multiplanar reformatted images with prospectively gated (A) and retrospectively gated (B) CCTA on the same patient.

Figure 8. A 38% dose reduction results by reducing the kVp from 120 to 100.
examinations with even greater z-axis coverage. Quadruple rule-out examinations, which extend coverage from the skull base through the thorax, may be useful in patients with syncope, transient ischemic attacks, and cerebrovascular accidents resulting from carotid stenoses, and are now possible (Figures 9 and 10). Quadruple rule-out examinations require 20 mL more contrast compared with triple-rule out examinations (Table 5), as well as a 20-second breath hold but result in a radiation dose of 5.8 to 10 mSv, depending on the patient’s BMI. In the future, it is conceivable that the circle of Willis could be added to the examination, which may diagnose not only an embolic cerebrovascular accident but also the possible origin of the embolus. In essence, such an ability could result in a half-body CCTA.

CONCLUSION
PG-CCTA is now achievable in the overwhelming majority of patients who need CCTA. PG-CCTA requires a heart rate of <65 bpm, which is easily and safely achieved by the administration of beta blockers. Given the massive reduction in radiation exposure, I believe that PG-CCTA will soon become the standard of care and will likely force the hand of all CT vendors to develop this capability. I question whether the additional expense of dual-source CT scanners can be justified in an era in which low heart rates (requiring the use of beta blockers) are necessary to reduce radiation exposures to levels never before seen in cardiac CT and CCTA. Given that the radiation dose is now far less than that used with SPECT studies, CCTA should quickly become the initial examination used in patients suspected of having coronary artery disease.

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