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FULL PAPER

CT coronary angiography in atrial fibrillation: a comparison of radiation dose and diagnostic confidence with retrospective gating vs prospective gating with systolic acquisition

¹BENJAMIN CLAYTON, MB BS, ²CARL ROOBOTTOM, MB ChB (Hons) and ¹GARETH MORGAN-HUGHES, BM BS, MD

¹Cardiology Department, Derriford Hospital, Plymouth, UK

²Radiology Department, Derriford Hospital, Plymouth, UK

Address correspondence to: Dr Benjamin Clayton

E-mail: benjamin.clayton@nhs.net

Objective: To compare unmodulated, retrospective electrocardiographic (ECG) gating to prospective ECG gating with systolic acquisition for CT coronary angiography (CTCA) in patients with atrial fibrillation (AF), considering the radiation dose and the diagnostic confidence achieved with each technique.

Methods: A retrospective service evaluation was conducted before and after prospective gating with systolic acquisition replaced retrospectively gated imaging for patients with AF undergoing CTCA at our institution. 25 consecutive patients were examined in each group. The scan parameters and radiation dose information had been collected in a prospective fashion. The image sets were read by blinded, expert readers who rated their diagnostic confidence using a 5-point Likert scale.

Results: The radiation dose received by patients was significantly greater in the retrospectively gated group than those being scanned using prospective gating (21 vs 5.9 mSv, $p < 0.01$). The prospective gating technique was also associated with greater diagnostic confidence (mean, per-patient score 3.09 vs 3.78, $p = 0.02$).

Conclusion: Prospective gating with systolic acquisition appears to improve diagnostic confidence at a significantly reduced radiation dose compared with retrospective gating in patients with AF.

Advances in knowledge: The use of prospective gating with systolic triggering significantly reduces the radiation exposure to patients in AF undergoing CTCA. The same protocol also appears to improve diagnostic confidence.

INTRODUCTION

Motion-free imaging remains paramount to the success of CT coronary angiography (CTCA). Patients with atrial fibrillation (AF) often have both R–R interval variation and persistent relative tachycardia, making CT imaging challenging and degrading image quality. The prevalence of coronary artery disease in patients with AF is extremely high, particularly in those referred for CTCA, with estimates of >80% having some disease.¹ Furthermore, mortality in these patients is more than double that of patients without AF, predominantly owing to underlying cardiac pathology.¹ Accurate coronary imaging is therefore of potentially great benefit.

The conventional method for imaging patients with fast, or irregular, heartbeats is with retrospective electrocardiographic (ECG) gating, where image acquisition occurs constantly throughout a number of cardiac cycles, and suitable cycle phases are retrospectively extracted for image

analysis.² While this allows the maximum flexibility, to overcome variation in the length of R–R interval and facilitate assessment of the phases with the least motion blur, the cost in terms of radiation exposure is high. In patients in sinus rhythm, prospective gating, where the X-ray tube is turned on for a brief moment at a pre-determined phase of the cardiac cycle, results in better image quality with a radiation dose reduction of >75%.³ The usual preference is to image in diastole, where coronary motion is at its least, but the unpredictable R–R interval and shorter duration of diastole in tachycardia make this difficult in AF.

Some studies have considered acquisition of images earlier in the cardiac cycle. End systole (or more precisely, the period of isovolumetric relaxation which immediately follows) offers a small window of relative cardiac and coronary stability, which has been exploited to image both the aorta⁴ and the coronary arteries in patients with AF.^{5,6} This seems intuitive, owing to the reduced time from

detection of the R wave to scanning which, in combination with aggressive heart rate control,⁷ would minimize the opportunity for interruption by the next ventricular contraction. Studies of “systolic triggering” have been limited, demonstrating improvement in both image quality and radiation dose but still with only moderate image quality in more than one-third of patients.⁶

At our centre, we have recently undertaken a service improvement initiative to review and rationalize our CT protocols. We subsequently use prospectively gated, systolic triggering as our default method of acquisition for patients in AF. We therefore undertook analysis of CTCAs before and after the introduction of this technique, with the primary outcome measure being radiation dose and the secondary measure being diagnostic confidence.

METHODS AND MATERIALS

Study methods and ethical review

All CT scans were undertaken at a single, tertiary referral centre, Derriford Hospital, Plymouth, UK. The study was reviewed by our institutional Research & Development board and registered locally as a clinical service evaluation. Further ethical review was waived owing to the retrospective nature of the study, and informed consent was not required.

Patient selection

We reviewed the clinical radiology information system to retrieve image sets on two groups of 25 consecutive patients with AF undergoing cardiac CT. One group was selected from patients immediately prior to September 2013, when we began prospective gating in AF, and the second group comprised 25 patients immediately after this change. Patients were excluded where image quality was suboptimal for reasons other than heart rate or rhythm (failure to breath-hold, contrast timing error etc.) Demographic information and scan acquisition data were extracted from the clinical report, which is recorded contemporaneously at the time of image acquisition, and the scanner data sheet.

Image acquisition and reconstruction

The CT acquisition protocol was as follows. All patients underwent a standardized, unenhanced scan in 1.25-mm axial slices, without overlap, for the purposes of calcium scoring. Patients with a minimum heart rate of >50 beats per minute and a maximum heart rate of >60 beats per minute received intravenous metoprolol, titrated in 5 mg aliquots.⁷ Imaging was performed on a 64-detector row CT scanner (DiscoveryTM CT750 HD, GE Healthcare, Milwaukee, WI), with either prospective or retrospective gating. For prospective ECG gating with systolic triggering (45% R–R interval), 100 milliseconds of padding (additional tube-on time either side of the R–R interval) was applied, as per standard departmental protocol when imaging patients with heart rate variability. 0.625-mm slices were taken at 0.5-mm intervals to cover the cardiac volume. Retrospectively gated acquisition was undertaken without dose modulation with the pitch set to 0.2. In both cases, tube parameters were adjusted according to patient body mass index (BMI), with the same parameters selected regardless of gating mode. 100 ml ioversol (Opivist 350; Covidien, Dublin, Ireland) was administered (125 ml for bypass graft studies) at a reducing rate (initially 6.5 ml sec^{−1} reducing to

5.5 ml sec^{−1} over 17 sec), followed by a saline bolus. Aside from the gating mode, all other acquisition parameters were consistent between the groups.

Images were reconstructed in a standard fashion, using a 50/50 blend of filtered back projection and iterative reconstruction (adaptive statistical iterative reconstruction, GE Healthcare) and standard kernel, at 5% phase intervals, including the 45% (of the R–R interval) phase.

Image analysis

The images were anonymized in a random fashion and reviewed by two expert readers, each with more than 10 years' experience of cardiac CT. These were reviewed for stenosis assessment and diagnostic confidence. The latter was recorded on a 5-point Likert scale for each coronary segment >1.5 mm diameter, thus: 5—excellent image quality with minimal motion artefact, not affecting diagnosis; 4—mild motion artefact but diagnostic confidence maintained; 3—moderate artefact with little diagnostic doubt; 2—significant motion artefact with diagnostic uncertainty, correlative imaging essential; 1—study uninterpretable owing to motion artefact. Segments graded 3 or greater were considered to be diagnostic for the purposes of the study.

Outcome measures

The outcome measures were image quality by gating method and total study radiation dose. The secondary outcomes were diagnostic confidence by patient and artery.

Statistical analysis

Statistical analysis was performed using SPSS® Statistics 21 (IBM Corporation, Armonk, NY; formerly SPSS Inc., Chicago, IL). Chi squares were performed for categorical variables and Mann Whitney *U* test was performed for continuous variables, with a significance level of 0.05. Image quality scores were analysed on a per-patient and per-vessel basis, both by lowest image quality score and by mean image quality score, tested with the Kruskal–Wallis test for independent samples. Pearson's test was used for correlation measures. *Post-hoc* power was estimated using G*Power 3.1.9.2 (Heinrich Heine Universität, Düsseldorf, Germany).⁸

RESULTS

50 patients were identified, having excluded three for non-AF reasons (two failed to breath-hold, one poor contrast timing due to contrast pump failure). The patient demographics are presented in Table 1. There was no significant difference in gender, BMI, heart rate (absolute or degree of variability) or calcium score between the two groups.

The radiation dose was significantly higher for patients in the retrospectively gated group than those being scanned using prospective gating. The mean volume CT dose index (CTDI_{vol}) was 17.58 in the prospectively acquired group and 50.82 in the retrospectively acquired group ($p < 0.01$). The mean dose-length product was 212 mGy cm^{−1} compared with 761 mGy cm^{−1}, respectively (approximately 5.9 vs 21 mSv using a 0.028 cardiac-specific conversion factor⁹) (Table 2).

Table 1. Demographics

Demographic	Prospective	Retrospective	<i>p</i> -value
Mean age (years)	66 (SD 43–88)	62 (SD 43–82)	0.11
Male	80%	68%	0.18
Bypass graft studies (<i>n</i>)	1	1	0.31
Median calcium score	113 (IQR 31–287)	25 (IQR 0–129)	0.41
Mean BMI (kg m ⁻²)	28 (SD 19–38)	29 (SD 17–40)	0.74
Beta blocker use			
Patients receiving beta blockers (<i>n</i>)	10	8	0.77
Median dose (mg)	15 (range 5–40)	12.5 (range 2.5–40)	0.26
Mean high heart rate (bpm)	89 (SD 47–130)	90 (SD 52–129)	0.73
Mean low heart rate (bpm)	61 (SD 29–93)	62 (SD 39–83)	0.50
Heart rate variation	30%	30%	0.65
Prevalence of CAD	24%	16%	

BMI, body mass index; CAD, coronary artery disease (stenosis $\geq 70\%$); IQR, interquartile range; SD, standard deviation from the mean.

757 coronary artery segments were evaluated for image quality (373 in the prospectively gated group and 384 in the retrospectively gated group). The proportion of diagnostic segments was 85% and 63%, respectively ($p < 0.001$). At a patient level, image quality was better in the prospectively gated group than the retrospectively gated group regardless of whether it was based on a mean of every analysed segment (3.78 vs 3.09, $p = 0.02$) or the lowest rated segment within each patient (2.36 vs 1.64, $p = 0.01$). Image quality was better in the prospective group for the analysis of each major coronary vessel (Table 2).

There was no significant correlation between image quality and maximum heart rate, minimum heart rate, or variability as a percentage of maximum heart rate, in either group or when combined (Table 3). The correlation between absolute heart rate

variability and image quality was statistically significant in the retrospectively gated group only.

We undertook a *post-hoc* estimation of power for the primary outcome of radiation dose. This was calculated assuming an α -error probability of 0.05 and a calculated effect size of 2.2. The power of the study was calculated at 1.0.

DISCUSSION

This study demonstrates that the use of end-systolic, prospective gating can significantly reduce the radiation exposure for patients in AF undergoing CTCA, and that the image quality is at least comparable to retrospectively gated studies (Figure 1). Importantly, this has been achieved using standard 64-multidetector row CT technology rather than using dual-source or wide detector array scanners.

Table 2. Outcome measures

Outcome measure	Prospective	Retrospective	<i>p</i> -value
Radiation dose			
Volume CT dose index	17.58 (SD 2.1–33.0)	50.82 (SD 11.4–90.2)	<0.01
Calcium score	1.34 (SD 0.6–2.0)	1.35 (SD 0.4–2.3)	
Dose-length product (mGy cm ⁻¹)	212 (SD 26–397)	761 (SD 11.7–1511)	<0.01
Calcium score	18 (SD 7–27)	19 (SD 5–32)	
Image quality			
Per-patient (mean)	3.78	3.09	0.02
Per-patient (lowest)	2.36	1.64	0.01
Per-vessel–right coronary artery	3.69	3.31	0.02
Per-vessel–left anterior descending (including left main)	4.05	3.15	<0.01
Per-vessel–circumflex	3.55	2.94	<0.01

SD, standard deviation from the mean.

Table 3. Heart rate and image quality correlation

Heart rate measure	Correlation with IQ	<i>p</i> -value
Retrospective gating		
Maximum HR	0.01	0.95
Minimum HR	0.38	0.06
Absolute HR variability	0.42	0.04
HR variability as a percentage of maximum	0.37	0.07
Prospective gating		
Maximum HR	0.18	0.40
Minimum HR	−0.06	0.80
Absolute HR variability	−0.02	0.34
HR variability as a percentage of maximum	−0.03	0.32
Combined		
Maximum HR	0.07	0.61
Minimum HR	0.16	0.27
Absolute HR variability	0.12	0.42
HR variability as a percentage of maximum	0.07	0.63

HR, heart rate; IQ, image quality.
Bold value indicates significance.

The use of CT in patients with AF is expanding considerably. In addition to the identification of CAD, which is highly prevalent in this cohort,¹ CT is increasingly used for the evaluation of the heart prior to AF procedures, to identify left atrial or pulmonary venous abnormalities,¹⁰ the proximity of at-risk structures¹¹ or for fusion with intraprocedural, electrophysiological maps.¹² The exclusion

of coronary disease is important where Class Ic antiarrhythmic drugs are being considered.¹³ Finally, patients with paroxysmal AF may be referred in good faith owing to sinus rhythm at the time of consultation, but arrive for their CTCA in AF.

Various methods have been employed to facilitate coronary imaging in AF. Reducing average heart rate and heart rate variability in patients with AF improves image quality¹⁴ and some authors have even considered inducing short periods of asystole for fluoroscopic imaging.¹⁵ In recent years, a number of technological advances have improved the temporal resolution of CT, helping overcome the difficulties of heart rate variability while maintaining radiation dose reduction. Wide-detector scanners can image the heart in a single heartbeat, although the appropriate phase of the cardiac cycle must still be decided.¹⁶ This either has to be accurately chosen or else the entire cardiac cycle must be imaged, which adds to the X-ray exposure time and therefore radiation dose.¹⁷ The ability to dose-modulate for more than one target phase is being tested,¹⁸ but again the phases must be chosen prospectively to benefit maximally from radiation-reducing techniques. The improved temporal resolution of dual-source scanners should also be of benefit when imaging patients with a tachyarrhythmia,¹⁹ and the diagnostic accuracy of these scanners appears promising when compared with invasive coronary angiography, even without attempts at heart rate control,²⁰ but results are variable,²¹ radiation dose remains a significant issue,^{20,22} and the technology has not always been compared with conventional scanners.^{18,21}

There did not appear to be a particular heart rate threshold for satisfactory image quality in either group. The only case in the prospectively gated group with an image quality score of <3 had a heart rate range of just 55–75 beats per minute. Conversely, the highest heart rate in that group was 133 in a case which received the fourth highest score for image quality. There was no correlation between image quality and any heart rate measure, except heart rate variability in the retrospectively gated group

Figure 1. Illustrative comparison of prospective and retrospective gating in atrial fibrillation. Both right coronary artery images were assessed as good examples with only mild artefact. (a) A prospectively gated study undertaken with a dose-length product of 83 mGy cm^{−1} (body mass index 24 kg m^{−2}, acquisition heart rate 63–74 bpm, 10 mg IV metoprolol)—there is a small step artefact in line with the arrow, which also highlights a contrast boundary due to the axial acquisition. (b) A retrospectively gated study undertaken with a dose-length product of 367 mGy cm^{−1} (body mass index 27 kg m^{−2}, acquisition heart rate 68–87 bpm, 15 mg IV metoprolol)—there is a slightly larger area of motion blur in the proximal artery (arrowheads).

which was weakly correlated. This is likely to be a statistical aberrancy and has little applicability to clinical practice.

This study is limited by its retrospective nature. The patient and scan information, including scanner settings and radiation dose, is all collected prospectively but given the clinical nature of the decision to scan there may well be some selection bias. Some patients may not have been scanned at the operator's discretion. However, remarkable similarity in patient demographics suggests that the impact of selection bias is likely to be very small. Furthermore, there may be limitations due to the inability to completely blind the image analysis to the gating method. This is inherently discernible to any experienced reader from a single phase examination, even before multiple phases are used (there will be more phases available from retrospective acquisition). Firm conclusions about the superiority of the diagnostic confidence of prospectively gated studies may therefore be questionable.

Owing to limitations in our scanner technology, it was not possible to prospectively select the timing of acquisition using the time from the R peak. Instead, the scan was triggered at a specified phase of the R–R interval, based on the scanner's calculation of preceding R–R intervals. In AF, where there is significant R–R variation, this approach may be less accurate. Furthermore, it cannot be adjusted in cases where the activation time is prolonged, such as with bundle branch block or extrinsic pacing. While we reconstructed images based on absolute time from the R wave, acquisition in this fashion would be preferable, as utilized in other studies (Figure 2).²¹

In summary, although CT diagnosis is highly achievable in AF, the radiation dose remains high.²³ Because such patients are difficult to image, most major literature has excluded those

Figure 2. Prospective gating methods in atrial fibrillation. (a) Arrows represent predicted mid diastole (70–75% R–R interval) based on the preceding R–R interval; if this is used to time image acquisition, subsequent R waves may occur before or during acquisition, impacting on cardiac motion and therefore image quality. (b) Arrows represent predicted end systole (40% R–R interval) based on the preceding R–R interval; this method is less likely to be affected by subsequent R waves. (c) Arrows represent end systole based on time from R wave; this is likely to be the most consistent method.

without rate-controlled sinus rhythm, resulting in a relative paucity of data for such groups, and their exclusion from clinical access to this useful modality. For patients in sinus rhythm image quality is superior with prospectively gated studies³ and the routine use of prospective gating in AF therefore offers the potential for both dose reduction and improved diagnostic accuracy.

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