

Standards of practice of computed tomography coronary angiography (CTCA) in adult patients



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Foreword

Together with the Royal College of Physicians (RCP) and the British Society of Cardiovascular Imaging (BSCI), The Royal College of Radiologists (RCR) has produced this document, which brings together the latest guidance on departmental standards of practice required to deliver safe computed tomography coronary angiography (CTCA) to adult patients.

Appropriate training of all healthcare professionals involved in delivering CTCA to adult patients with known or suspected coronary artery disease is essential, together with the most appropriate and up-to-date CT scanners with the ability to modulate dose.

We would like to take this opportunity to thank those who have worked together to produce this document, with special thanks to Dr Stephen Harden, who chaired the document development working party (for a full list of working party members and contributors please see Appendix 1).

The RCR has committed to reviewing all relevant publications in line with the recommendations of the Francis report and, where appropriate, applying the category of standard defined by Francis (fundamental, enhanced or developmental).¹ This document contains standards that fall within the enhanced category.

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1. Recommended standards

Standard 1

Staff should be trained in cardiovascular CT according to national/international guidelines, undertake continuing professional development (CPD) activities in CTCA and cardiovascular CT and should be trained in basic life support techniques (page 5) (for CTCA training guidelines see www.scct.org and www.bsci.org.uk).^{2,3}

Standard 2

All patients should receive a letter/information leaflet giving an outline of the procedure, the preparation required and local site details (Appendix 2).

Standard 3

All patients should have a risk assessment by a member of staff to ensure that it is safe for them to undergo the scan (Appendix 3).

Standard 4

Provided it is safe and practical to do so, heart rate-controlling drugs should be administered so that the patient's heart rate is <65 beats per minute during the scan (Appendices 4–6).

Standard 5

The scanner used should be specifically set up for CTCA and be of 64 slices or greater, with cardiac software and electrocardiogram (ECG) gating (page 9).

Standard 6

Prospective ECG gating should be the firstline default technique, used whenever possible and practical. Retrospective ECG gating should only be used in specifically selected cases (page 10).

Standard 7

The radiation dose administered should be as low as possible, commensurate with diagnostic image quality. Radiation doses and image quality should be routinely and regularly audited and benchmarked against other national centres (Appendix 7).

Standard 8

The iodinated contrast medium delivery protocol should be adjusted for each patient group and according to the scanner being used (page 13).

Standard 9

The patient should be reviewed by an appropriately qualified member of staff prior to discharge from the scanning department (page 15).

2. Introduction

CTCA has become a well-recognised imaging technique in the investigation of patients with chest pain. The indications for CTCA are also established and it is part of nationally and internationally recognised imaging pathways. Its clinical utility means that increasing numbers of UK centres are establishing CTCA imaging programmes.

Recommendations exist for CTCA training, accreditation and revalidation requirements for radiologists and cardiologists (www.bsci.org.uk, www.scct.org) and there are guidelines on how these should be reported.²⁻⁴ This document focuses on departmental standards of practice for CTCA in adult patients from the time of acceptance of the referral to the time that the patient leaves the imaging department having had the scan. The emphasis is on achieving a good procedural outcome, with diagnostic-quality images obtained in an environment in which the safety of the patient is paramount.

This document is divided into sections of recommended best practice before the start of the scan, during the scan and once the scan has been completed. Radiologists and cardiologists will be used to administering intravenous contrast medium and the urgent management required to treat the complications which sometimes occur with its use.

As a result of the frequent need to administer heart rate-controlling drugs, CTCA practitioners also need to be aware of the potential complications and interactions of these drugs and how they should be managed. All members of the CTCA team should have frequent and up-to-date training in basic life support, and at least one member of the team should be trained in immediate life support. Resuscitation facilities should be immediately available.

It is important for the CTCA imaging team to establish close links with referring clinical teams. A clear understanding of how the scan is performed and the information it is capable of providing will mean that appropriate patients are referred for this investigation. For example, a statement on the referral letter or request card to the effect that there are no known contraindications to the administration of beta-blockers, glyceryl trinitrate (GTN) or intravenous contrast medium is very helpful to the imaging team, although does not obviate the need for the safety checks this document outlines. It is also important that the referring clinical team is aware that this test involves ionising radiation. The referrer and the CTCA imaging team must follow the trust's ionising radiation medical exposure regulations (IRMER) procedures for carrying out medical exposures with ionising radiation.⁵ A medical member of the CTCA imaging team will act as the IRMER practitioner and will be responsible for confirming that the investigation and the associated radiation dose can be justified.

These guidelines have been created using a combination of evidence-based practice and an accepted consensus of expert opinion of best practice where this evidence does not exist. A list of the contributors to this document is given in Appendix 1.

Standard 1

Staff should be trained in cardiovascular CT according to national/international guidelines, undertake continuing professional development (CPD) activities in CTCA and cardiovascular CT and should be trained in basic life support techniques (for CTCA training guidelines see www.scct.org and www.bsci.org.uk).^{2,3}

3. Patient information prior to CTCA

The patient should understand why the CTCA is being performed, having discussed this with the referring doctor before the procedure. However, it is important that the CT department performing the scan sends additional information to the patient before they attend. This may take the form of a patient information leaflet which explains the details of the procedure to help reduce patient anxiety. The patient should be encouraged to bring a list of all of their current medications with them. An example patient information leaflet is provided in Appendix 2.

Standard 2

All patients should receive a letter/information leaflet giving an outline of the procedure, the preparation required and local site details (Appendix 2).

4. Important patient-specific information before the scan

When the patient attends the CT department, they should have their height and weight measured to enable the body mass index (BMI) to be calculated. The patient's blood pressure and heart rate should be recorded. There are important details of the patient's past medical history, current health and current medications that must be documented before the scan is performed.

The specific questions relating to contrast administration are the same as those for other iodinated contrast medium-based tests. These focus on history of allergy, recent contrast administration, use of metformin and renal function.

The questions relating to beta-blockers focus on specific contraindications. It is important to determine if the patient is asthmatic as beta-blockers should be administered with caution in asthmatic patients and not used in patients with severe asthma. Beta-blockers should not be administered in patients taking verapamil, in patients with severe aortic stenosis, restrictive physiology, second- or third-degree heart block or a history of transient loss of consciousness.

GTN is usually well tolerated, although it should not be used in patients taking sildenafil (Viagra [Pfizer, USA]) or other such phosphodiesterase inhibitors due to the risk of profound hypotension.

An example checklist to be completed with the patient prior to the scan is given in Appendix 3. This checklist has been created through the amalgamation of departmental checklists that have been used by UK cardiac CT departments over several years, and the contained list of questions and checks are regarded as best practice.

Standard 3

All patients should have a risk assessment by a member of staff to ensure that it is safe for them to undergo the scan (Appendix 3).

5. Safe drug administration in preparation for CTCA

Heart rate control

Heart rate reduction to <65 beats per minute (bpm) to minimise the likelihood of motion artefacts on derived images should be achieved in all patients in which it is safe and practical to do so. The development of high-specification CT scanners (for example, dual-source, >64 slice scanners) means the likelihood of diagnostic image quality is higher than for 64-slice CT when heart rate control is not achieved, but image quality is improved even on these high-specification CT scanners when the heart rate is <65 bpm.⁶

Beta-blockers

Beta-blockers should be used as the firstline drugs for the lowering heart rate before a CTCA. They can also have the beneficial effect of reducing ectopic activity and the heart rate variability. Beta-blockers should not be administered to patients already taking verapamil due to the risk of ventricular standstill and cardiac arrest.

Metoprolol is the most commonly used beta-blocker in this context. It can be administered intravenously or orally.

Intravenous dosing in CTCA

Metoprolol can be administered intravenously with the patient on the scanner table. This method is now firstline in many UK centres and has the advantage of heart rate control being achieved quickly. Although the beta-blocker administration protocol is a matter of local choice, a typical dose regime is as follows:

- Starting dose of 5 mg intravenously over one minute followed by a saline flush, with re-administration of the same dose every 2–3 minutes until the heart rate is <65 bpm
- The maximum recommended intravenous (IV) dose of metoprolol quoted in the *British National Formulary* is 15 mg, although doses up to 30 mg have been quoted in the literature.^{7,8} Some UK centres titrate up to 50 mg without reported adverse events, and although there are reports of higher doses being administered, the benefit of these high doses is questionable.⁹

Oral dosing in CTCA

Metoprolol is the most commonly used and studied beta-blocker in this setting. In patients with a resting heart rate >65 bpm the following regimes are typical:

- 50–100 mg one hour prior to CTCA; or
- 50 mg 12 hours previously followed by a further 50 mg one hour before the scan.

These oral doses are then followed by titrated IV metoprolol if the heart rate remains >65 bpm.¹⁰

More detailed pharmacokinetics are provided in Appendix 4.

Monitoring

All patients should have their blood pressure and pulse measured and recorded before and after the administration of beta-blockers. This should be done every 15–30 minutes and the patient should be seated or laying where they can be seen and monitored by staff, ideally in a dedicated monitoring bay.

Treatment of symptomatic bradycardia/hypotension

Patients who suffer symptomatic bradycardia and/or hypotension should be treated with atropine and/or glucagon, as detailed in Appendix 5. Consideration should be given to a printed copy of Appendix 5 being clearly displayed on the wall of the scan room. IV fluids may be used for patients with symptomatic hypotension in the absence of bradycardia. Other therapies, including transcutaneous pacing, temporary IV cardiac pacing and calcium gluconate (such as in the setting of calcium channel blocker overdose) should be administered by emergency, cardiology or critical care personnel. These treatments and staff members should be readily accessible whenever beta-blockers are administered.

Other non-beta-blocker drugs for heart rate control

Calcium channel blockers

Calcium channel blockers, such as diltiazem and verapamil, can be used to lower heart rate, such as in patients where beta-blockers are contraindicated, but these are generally not recommended. These drugs should only be administered following discussion with, or under the supervision of, a cardiologist in those cardiac CT units that are radiology-led.

Ivabradine

Ivabradine reduces the depolarisation of the sino-atrial node (SAN) which leads to a reduction in heart rate. There is some evidence of its use in lowering heart rate in patients prior to CTCA, but it should be prescribed only following discussion with the cardiology team.¹¹

Coronary artery vasodilation with GTN

The administration of 1–2 sublingual GTN tablets or 1–2 puffs of sublingual GTN spray (400–800 micrograms [mcg]) is recommended just prior to the scan.¹² The time to peak effect is around six minutes so timing of its use is important. Although there may be some secondary reflex tachycardia, this does not seem to be a problem in practice. It may, however, lead to further beta-blocker administration. Most centres use GTN routinely to increase coronary artery diameter, but there is no data to suggest this increases the accuracy of CTCA.

Headache is the most common side-effect of GTN administration (~10%) and patients may feel slightly light-headed. GTN should be used with caution in patients with a systolic blood pressure <90 mmHg or severe aortic stenosis. Concomitant use with phosphodiesterase inhibitors, such as sildenafil, is contraindicated as it can result in significant hypotension (Appendix 3).

Record keeping of drug administration

It is crucial to keep an accurate record of the drugs administered in CTCA. An example of a drug administration and observation checklist is provided in Appendix 6.

Standard 4

Provided it is safe and practical to do so, heart rate-controlling drugs should be administered so that the patient's heart rate is <65 beats per minute during the scan (Appendices 4–6).

6. Iodine-based contrast safety

The preparation for contrast medium administration to the patient should be in accordance with the RCR guidance on *Standards for Intravascular Contrast Agent Administration to Adult Patients*, Second edition.¹³

Specific recommendations

- When a patient has a relative contraindication to the administration of IV iodinated contrast medium, measures to reduce the possibility of contrast reactions or nephrotoxicity should be followed.
- Contrast should be used with caution in patients with borderline or compromised renal function.
- The physician must be familiar with the manifestations of potential adverse reactions to the contrast medium.
- The physician should be familiar with the treatment of, and be available to treat, any adverse reactions to IV contrast medium.
- All of the cardiac CT team should have had training, and demonstrate current competence, in basic life support.

7. CT scanner technical requirements

CT technology for cardiac imaging is evolving rapidly. Historically, scanners from all vendors have had similar capabilities but over recent years manufacturers have developed a range of solutions for advanced cardiac CT. The new-generation CT scanners offer improvements intended to address the previous limitations of CT for cardiac imaging, particularly with improvements in temporal and spatial resolution, image misregistration and artefact reduction. This has resulted in recent National Institute for Health and Care Excellence (NICE) guidance demonstrating the utility of CTCA in patients in who CT imaging has traditionally been challenging, as long as one of the newer generation scanners with dedicated cardiac capability is used.¹⁴

Choice of technology

The choice of scanner technology will ultimately depend on a number of factors. This is likely to reflect current preferences or service agreements and the requirements of the existing service. It should be recognised that in all but the very highest volume centres, the CT scanner will be used for non-cardiac imaging for a considerable amount, if not the majority, of the time.

General considerations

Minimum requirements

- The department must comply with the *Ionising Radiation Regulations 1999* and the *Ionising Radiation (Medical Exposures) Regulations 2000*, and subsequent amendments.^{5,15}
- A maintenance, servicing and repair programme must be in place for all scanners within a department (required by UK law).
- The working life of a cardiac CT scanner should be around seven years, in keeping with the manufacturer's recommendations for maintenance. This may be shorter in centres with high throughput.¹⁶
- A quality assurance programme should be in place, supervised by appropriately trained radiographers and medical physicists (required by UK law).

Scanner capabilities

Minimum requirements

- ECG gating with prospective and retrospective gating capability is required.
- Dose modulation with the ECG phase should be available for retrospectively gated scanning to reduce the radiation dose to the patient.
- Pre-scan contrast timing assessment, either by automated or visual bolus tracking or with assessment of a test bolus, must be possible.

Hardware specification

Minimum requirements

- A 64-detector row (or above) scanner is required.¹⁷ The non-diagnostic rate of scanners with fewer detector rows is 10% greater than those with 64 detectors.

- The detector width must be 0.625 mm or less.
- The gantry rotation time should be <350 milliseconds (ms).¹⁸
- The Z-axis (craniocaudal direction) coverage must be at least 20 mm, and at least 30 mm is recommended (unless a dual-source scanner is used) to ensure a realistic scan time (and therefore breath-hold) and to minimise misalignment artefact.¹⁹
- The Z-axis resolution must be at least 8 line pairs per centimetre (lp/cm) at 10% modulation transfer function (MTF).
- The temporal resolution must be less than 175 ms for a single sector.
- The scan plane resolution must be at least 12.5 lp/cm at 10% MTF.

Recommended best practice

- The Z-axis coverage should be approximately 30–40 mm or greater.
- New-generation technology should be available when imaging patients who are difficult to scan.¹⁴ Where this is not available in the department, it must be accessible to a service via a cardiac network or other local arrangement.

Standard 5

The scanner used should be specifically set up for CTCA and be of 64 slices or greater, with cardiac software and ECG gating.

8. Scanning modes

ECG gating is essential for coronary artery imaging. To minimise vessel motion, points of relative cardiac rest are selected for image acquisition, usually at mid-diastole, or end-systole for slightly higher or variable heart rates. Previously, ECG gating has been either retrospective (helical) or prospective (axial) but the advent of wide-detector arrays and dual-source scanners has blurred these traditional boundaries.

Prospectively gated image acquisition takes place only at the required phase of the cardiac cycle, which is anticipated by the scanner, based on the patient's ECG (Figure 1C, opposite). This 'step-and-shoot' acquisition generates axial slices during sequential cycles which are then combined to create the final volume. Scanners with wide detector arrays (up to 160 mm in the Z-axis) have the potential to image the entire heart prospectively in a single heart beat; this enables scanning of patients with arrhythmias (including atrial fibrillation [AF]) with no misregistration artefacts.¹⁹ Prospective ECG gating should be the firstline default technique, used whenever possible and practical as it permits a considerable reduction in radiation dose without reduction in image quality.²⁰

Where the heart rate exceeds the recommended threshold for standard prospective gating, additional tube-on time may be used, a technique known as 'padding' (Figure 1D, opposite). This allows a greater proportion of the cardiac cycle to be imaged and, although this means a higher radiation dose than with standard prospective gating, it should be used in preference to retrospective gating where possible.

Retrospectively gated image acquisition occurs with the X-ray tube continuously on over a number of cardiac cycles. During the scan, the projection data are tagged with the point in the ECG cycle at which they were acquired. The required points of the R-wave to R-wave (R-R) interval are retrospectively selected on the patient's ECG (Figure 1A, opposite) and the corresponding projection data are used to reconstruct the images at these points. This can be used as a problem-solving tool, for example, in patients with very high heart rates. Retrospective ECG gating should only be used in specifically selected cases. The pitch should not be less than 0.2. Adaptive technologies should be used to permit the deletion of data from premature ventricular beats, the insertion of undetected R peaks, and the shifting of R peaks to adjust for arrhythmia during retrospective gating.²¹

The potentially high radiation dose of retrospective gating can be minimised with dose modulation.²² This is where the radiation dose is reduced significantly in parts of the cardiac cycle where there is likely to be significant cardiac motion, such as during systole, and increased to diagnostic levels during mid-to-late diastole (Figure 1B, opposite). With the exception of cases where there is significant heart rate variability (such as atrial fibrillation), dose modulation techniques should be used with the narrowest selectable window of diagnostic tube current.²³

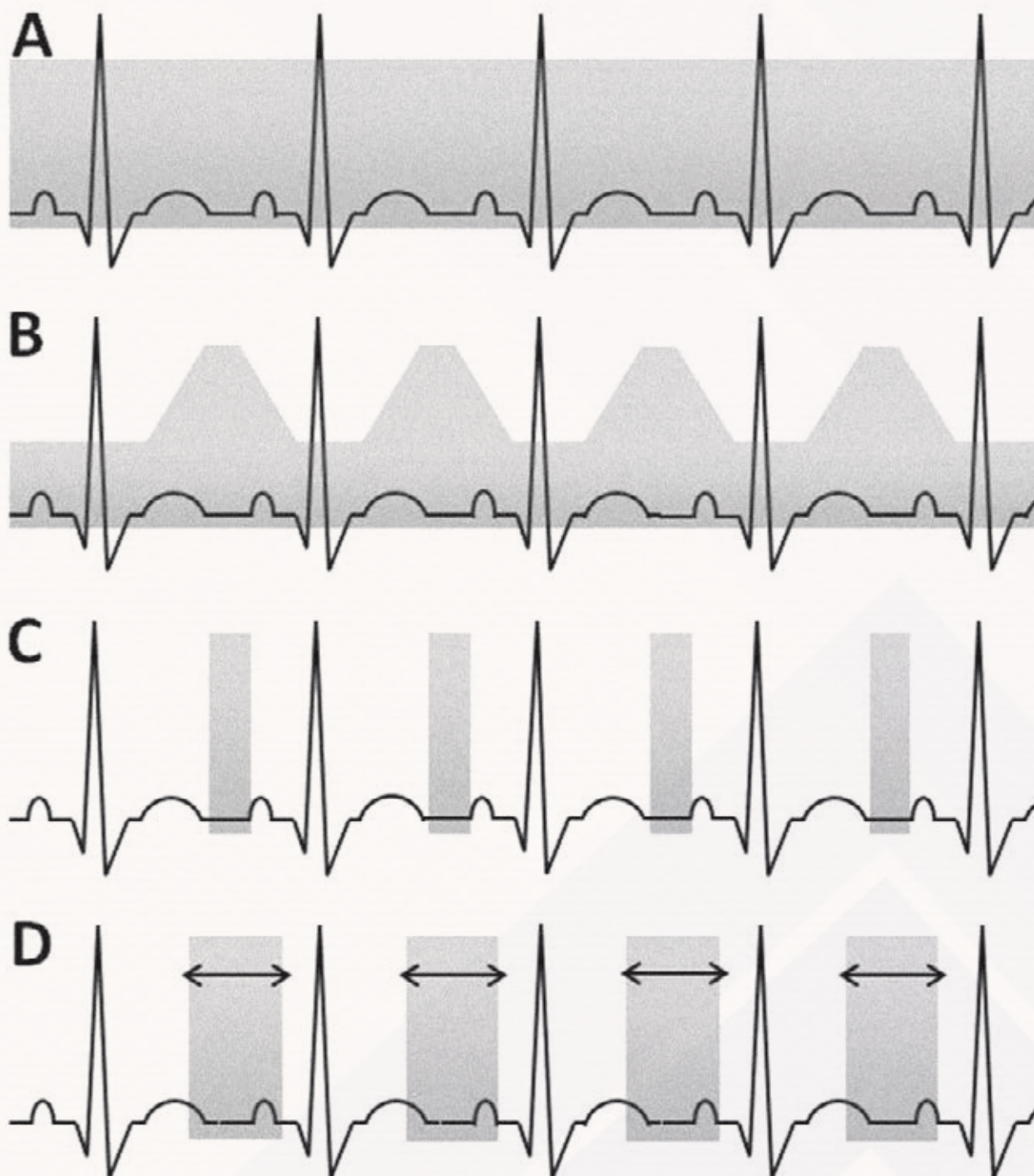
Dual-source scanners are also capable of prospective, helical acquisition using both X-ray sources to allow a high pitch acquisition.²⁴ A heart rate of <60 beats per minute is generally required to provide a sufficiently long period of diastasis. The second X-ray source has a smaller field of view than the first, but it is sufficiently large for cardiac imaging.²⁵

Standard 6

Prospective ECG gating should be the firstline default technique, used whenever possible and practical. Retrospective ECG gating should only be used in specifically selected cases.

Figure 1. ECG gating techniques

The grey bar represents diagnostic levels of radiation. A = retrospective gating; B = retrospective gating with dose modulation; C = prospective gating; D = prospective gating with padding. During 'step-and-shoot' prospective gating (C and D), the radiation is delivered on alternate or every third heart beat according to the patient's heart rate, as the scanner moves or 'steps' to the next image position during subsequent heart beats.



9. Image quality and radiation dose optimisation

The objective is to obtain diagnostic-quality images while delivering the lowest reasonably achievable radiation dose to the patient. Image quality and radiation dose are intrinsically linked.

Setting the image quality

Temporal resolution is optimised by using the lowest gantry rotation time available – typically 350 ms or less. Dual-source scanners have intrinsically better temporal resolution than single-source scanners, without any impact on patient dose, because the necessary projections are acquired in half the scan time than for a single-source scanner. Multiphase reconstructions incur a dose penalty over single cardiac phase ones because they require projection data to be acquired over a longer part of the cardiac cycle. Multi-segment reconstructions incur a dose penalty over single-segment ones because they require projection data to be acquired using retrospective ECG gating, whereas single-segment reconstructions can be generated from data using prospectively gated acquisitions which are generally more dose-efficient.

Spatial resolution is determined by the reconstruction kernel and the slice thickness. It is also affected by the data sampling density (which, on some scanners, can be changed by toggling between normal- and high-resolution modes) and to a lesser extent by the reconstruction field of view.

Both the reconstruction kernel and slice thickness affect image noise. If the slice thickness is reduced from 1.2 to 0.6 mm, image noise will increase because image noise is inversely proportional to the square root of the slice thickness. To compensate, mAs can be doubled, but this, in turn, will double the patient's dose of radiation. In practice, a more modest increase in mAs is often sufficient because the superior spatial resolution of thin slices compensates for the increase in image noise. To optimise spatial resolution in CTCA, a slice thickness of less than 1 mm is required, and high-resolution mode should be considered.

Contrast resolution is determined by the iodine concentration in the coronary arteries, the tube voltage setting and the image noise. The sensitivity to iodine is higher at lower tube voltages, so 80 or 100 kVp are preferable for CTCA. If the tube voltage is reduced without changing the mAs, the dose to the patient will drop, but image noise will increase. Lower energy X-ray beams may fail to penetrate through the anatomy of medium and large patients, leading to streak artefacts. The optimum choice of tube voltage is therefore a compromise dependent on the size of the patient.

Setting scan protocol parameters to optimise the radiation dose

- The displayed predicted computed tomography dosage indicator_{vol} (CTDI_{vol}) can be used to monitor how patient dose might change when scan parameters are varied. The displayed dose length product (DLP) also includes the effect of scan range.

- Where possible, prospective ECG gating should be used.
- In specifically selected cases where retrospective ECG gating is required, mA modulation techniques should be used to keep the radiation dose as low as possible.
- The scan range should be tailored to each patient. If possible, the scan range must be set inferior to the shoulders to avoid the prescribed mAs being set for the width of the shoulders rather than the thorax. The greater the detector coverage, the harder it is to tailor the scan range to the patient's anatomy. In retrospective ECG-gated CTCA, the irradiated length may be up to 60 mm longer than the imaged length due to helical over-ranging. Adaptive collimators will reduce the amount of over-ranging present.
- Scan protocols should be size-specific. This is achievable by activating tube current modulation with patient size, or setting mAs according to patient weight or BMI.
- The tube voltage should be routinely reduced to 100 kVp for small and medium patients; iodine contrast agent is more conspicuous at lower tube voltages. The mAs can be increased modestly to compensate for the increase in image noise. (The prescribed CTDI_{vol} should still be lower at 100 kVp than at 120 kVp.) For very small patients, 80 kV can be used, with 120 kV used only in large patients.
- Iterative reconstruction should be critically considered if it can be built into the CTCA protocol.

Auditing patient doses

The DLP is the standard radiation dose measure used in CTCA. Estimation of effective dose introduces additional uncertainties and is not necessary for the purpose of optimisation. The DLPs used in the department should be subject to regular internal audit and benchmarked against those of other UK centres. The BSCI has established a national departmental radiation dose audit for CTCA, and CT departments should consider submitting radiation dose data to allow benchmarking. A more detailed list of data that should be collected in addition to DLP levels is given in Appendix 7.

References

Further recommended reading on this topic can be found in references 23, 26 and 27.

Standard 7

The radiation dose administered should be as low as possible, commensurate with diagnostic image quality. Radiation doses and image quality should be routinely and regularly audited and benchmarked against other national centres (Appendix 7).

10. The use of iodinated contrast medium in CTCA

A 20-gauge or larger right antecubital IV catheter is the preferred administration route for iodinated contrast for CTCA. To minimise the risk of contrast extravasations, all catheters should first be tested with a rapidly injected bolus of sterile saline to ensure that the venous access is secure and effective. A right arm cannula is preferable to avoid artifacts from undiluted contrast media in the left brachiocephalic vein where it crosses the midline.

To obtain optimal diagnostic accuracy in CTCA, it is essential that coronary artery contrast enhancement is homogenous and constant throughout the entire scan range. In addition, the contrast enhancement should be sufficiently intense to allow visualisation of small vessels but not so intense that it causes beam hardening artefact. The contrast medium infusion protocol for CTCA therefore needs to be adjusted for each patient group.

Major factors that determine the intensity and homogeneity of contrast enhancement in the coronary arteries are BMI, cardiac output, the iodine dose and the rate at which contrast medium (CM) is injected.^{28–31} The ideal iodine delivery rate is between 1–2 g/s depending on the kVp used.³²

Although greater intracoronary attenuation during CTCA leads to higher diagnostic accuracy in evaluating stenosis, very high degrees of enhancement may mean the density of contrast overlaps that of coronary artery calcium, which can obscure calcified plaques.

Contrast infusion rates typically used for CTCA are higher than for general CT (up to 7.0 ml/s). The ideal situation is for maximal contrast enhancement in the ascending aorta and the left ventricle and little or no contrast in the right side of the heart. A saline chaser infusion is usually used immediately following the contrast medium injection through a dual-head power injector at the same rate as the contrast injection; this can decrease streak artifacts in the superior vena cava and maximise the effect of the contrast dose by flushing contrast out of the arm veins. Some centres prefer a mixture of contrast and saline to follow the pure contrast bolus which leads to increased right heart opacification, allowing a better assessment of the right heart structures.

The length of time for which this opacification is required will be dependent on scan coverage and the time taken to scan (which will be scanner-specific) so it is vital that the contrast protocol is tailored to the clinical question. For example, imaging a patient that has had previous coronary artery bypass graft surgery means that a 25% increase in contrast volume will typically be required as the scan will need to start from the level of the internal mammary artery origin.

Intravascular contrast attenuation can be optimised by decreasing the tube voltage (to 100 or 80 kVp) which increases the opacification of the blood vessels because of an increase in the X-ray absorption of iodine at lower photon energies. This will also decrease radiation dose if the tube current is kept constant. However, this will increase image noise which may mitigate the effect of the increased vascular opacification. If image noise is kept constant by increasing the tube current, it is possible to produce equivalent image quality and contrast opacification with equivalent radiation dose, compared with higher kVp techniques using lower doses of IV contrast medium. This reduction in contrast dose reduces the risk of nephrotoxicity and can allow substantial cost savings.²⁹ Due to the fact that lower tube voltages produce fewer photons (for a given mA), low kVp scanning is not possible in very obese patients.

Contrast protocols

Providing precise recommendations on contrast regimens which cover all clinical scenarios and CT scanner types is very difficult. However, a typical example of injection flow rates for CTCA using a 64-slice CT system for coronary artery imaging is given in Table 1 (assuming a contrast concentration of 350 mg/ml). Contrast volumes are typically lower with CT scanners capable of single heart beat acquisition (either wide-area detector or high pitch dual-tube scanners).

Table 1. Potential contrast protocol for a 64-slice CT scanner using a contrast concentration of 350 mg/ml

kVp	Flow rate (ml/s)	Contrast volume (ml/s)	Saline volume (ml/s)
80	3.5	60	25
100	5.0	75	35
120	6.5	95	50
140	7.0	100	60

Timing of the scan acquisition following contrast injection

Due to substantial variations in the time required for the IV contrast injection to reach the targeted vascular anatomy, an assessment of patient-specific circulation time is required. Circulation timing can be performed using two techniques: the test bolus technique (using 10–15 ml of contrast medium at the same flow rate and via the IV site to be used during the CTCA acquisition) or the bolus tracking and trigger technique. The choice of technique is a matter of personal operator or unit preference and is also dependent on the scanner technology used.

Standard 8

The iodinated contrast medium delivery protocol should be adjusted for each patient group and according to the scanner being used.

11. Patient care during and after the scan

The patient's heart rate and rhythm should be monitored continuously via the ECG on the scanner console.

Immediately before the scan starts, the breath-hold requirements of the scan should be explained to the patient together with common expected sensations caused by the intravenous contrast medium.

Once the scan has been completed, the patient should be warned that they may experience light-headedness on sitting up and getting off the scanner table, particularly if beta-blockers have been administered. A member of staff should be with the patient as they get off the scanner table and should escort them to the changing room.

The length of time the patient remains in the imaging department after the scan is a matter of local choice, but will depend on the presence of patient symptoms related to the drugs or contrast medium administered. Current RCR guidelines for patients undergoing a contrast-enhanced CT scan state that the patient should wait in the department for 15 minutes before leaving, or 30 minutes if there is an increased risk of contrast reaction. If the patient has persisting symptoms relating to heart rate-controlling medication, they should remain monitored in the department until these resolve; advice and review from the on-call cardiology or general medicine team may be required.

The department should take the opportunity to capture periodically formal feedback from patients on their opinions of the experience of the procedure. This may take the form of a patient-satisfaction survey or a patient-experience questionnaire. Examples of these are available on the RCR website (www.rcr.ac.uk/patientfocus).³³ This feedback should be routinely reviewed and discussed as part of a regular service evaluation, together with a review of cases with complications and cases of 'near-miss' incidents. This will help the department to refine protocols and continue staff training to ensure high-quality and safe patient care.

Standard 9

The patient should be reviewed by an appropriately qualified member of staff prior to discharge from the scanning department.

Approved by The Royal College of Radiologists Clinical Radiology Faculty Board: 27 June 2014.

Approved by the British Society of Cardiovascular Imaging: 18 June 2014

Approved by the Royal College of Physicians: 8 July 2014

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Appendix 2. Example patient information leaflet

Having a computed tomography coronary angiogram

This leaflet gives general information about a computed tomography coronary angiography (CTCA) scan. It does not replace the need for personal advice from a qualified healthcare professional. Please ask us if you have any questions.

What is a CTCA scan?

A CT (computerised tomography) scan is a special X-ray test that allows us to take detailed images of the body. A CTCA scan takes pictures of your heart and coronary arteries. This allows us to see any narrowing or blockage of the arteries around your heart.

How is a CT coronary angiography scan carried out?

Our radiographer will ask you to lie on a special bed. We will place sticky patches called electrodes on your chest so that the ECG can monitor your heart during the test. We can then trigger the scanner to take a picture at a certain point during your heartbeat. This gives us high-quality images of your heart. The bed moves through the scanner so we can take pictures of your heart and arteries.

We will give you an injection of X-ray contrast (sometimes called dye) so that we can see your heart and arteries clearly. The dye is usually safe but you should tell us if you have any allergies. The dye will pass through your system.

It can be difficult for us to get a clear picture if your heart is beating too quickly. We will check your heart rate when you arrive and if it is faster than the ideal rate, we may give you some medication to slow it down, probably a drug known as a beta-blocker. This may be in the form of a tablet or an injection. Please try to avoid driving or cycling to or from your appointment as the medication can make you drowsy. It is a good idea to ask someone to come with you to the appointment. The medication can take up to an hour to start working, but as soon as your heart rate is slower we will perform the scan. You will probably not notice any side-effects from this medication but it is important that you tell us if you suffer from asthma.

We may also give you another medicine in a spray form or in a tablet form under your tongue just before the scan. This is to open up the arteries in the heart as much as possible to make it easier to assess them on the scan. You might get a slight headache or feel a little dizzy from this.

When you breathe, it can cause the image to blur. To help us get a clear picture of your heart, we will ask you to hold your breath for no more than 15 seconds at some point during the scan. We will practise this with you before your scan and go through exactly what you should expect during the procedure.

How long will the scan take?

The scan itself should only take around 15 minutes. Please remember that we have to prepare for the scan and may have to give you medication as described above. Please be prepared to stay for over an hour.

How should I prepare for the scan?

You can eat as normal and should continue to take your medication as prescribed. Please bring a list of your current medication.

However, if you have diabetes and are taking metformin, you should contact the CT department in advance of your scan.

If you are asthmatic and use an inhaler, please bring it with you to your appointment.

You should be able to return to your normal daily routine after your scan and you can eat and drink as normal.

What are the benefits of a CTCA scan?

A CTCA scan gives detailed pictures of your heart, which help us to make a diagnosis or assess any health problems. We can then suggest the best treatment for you. Although other tests provide information on how well your heart is functioning, only a CTCA scan gives us enough information about the structure of your heart.

Is there any risk to me from the radiation used in the scan?

The amount of radiation used to perform a CTCA scan is small and kept to an absolute minimum. We are exposed to natural background radiation all the time from the ground and the atmosphere and this test is equivalent to about four years' worth of natural background radiation. We believe that the benefits of having the scan outweigh the risks. Radiation can cause cell damage which may, after many years or decades, become cancerous. We estimate that by having this examination your natural lifetime risk of developing cancer may increase very slightly from 33% to 33.04%.

We aim to make sure that every patient fully understands the risks and benefits of the procedure. Please ask if you have any questions. Please also let us know if you are pregnant.

What happens if I don't have the scan?

If you don't have this scan, your doctor will have less information to diagnose or assess your health problem. This will make it harder for us to give you the best treatment for your condition.

How will I get my results?

We will send the results to the hospital consultant who referred you for the scan.

Further information

If you have any other questions before you come for your scan, you can ask your family doctor, the doctor that has sent you for the test or the X-ray department. You can also find further information at the following website: www.rcr.ac.uk/patients

(INSERT DIRECTIONS TO THE HOSPITAL AND SCANNING DEPARTMENT HERE)

Example patient information

Appendix 3. CTCA patient safety questionnaire

Patient details			
Date		Patient name	
Radiologist		Hospital ID	
Radiographer		Date of birth	
Nurse		Last menstrual period	
Height		Weight	
Pre-procedure checklist (to be completed by radiographer or nurse)			If yes:
Have you had a previous severe allergic reaction?	Yes	No	Discuss with radiologist.
Have you had a reaction to contrast medium (X-ray dye) in the past?	Yes	No	
Do you have asthma?	Yes	No	
If yes, do you use an inhaler?	Yes	No	
Are you currently wheezy or is the asthma poorly controlled?	Yes	No	Do not give beta-blockers.
Have you taken Viagra (sildenafil) within the last 24 hours?	Yes	No	Do not give glyceryl trinitrate (GTN).
Do you have a history of heart disease such as heart failure, heart block, heart valve disease or a family history of heart disease?	Yes	No	Do not give GTN if severe aortic stenosis. Do not give beta-blockers if heart failure or 2nd/3rd degree heart block.
Are you taking verapamil?	Yes	No	Do not give beta-blockers.
Do you have diabetes?	Yes	No	
Do you take metformin?	Yes	No	Check recent urea and electrolytes (U+E).
Do you have or have you had high blood pressure?	Yes	No	
Do you have kidney problems, kidney failure or have you ever been on dialysis? If so please specify.	Yes	No	
Do you have gout, liver disease, myeloma or peripheral vascular disease?	Yes	No	
Have you had heart surgery or stents inserted?	Yes	No	
Do you have a pacemaker or implantable defibrillator?	Yes	No	
Do you consent to the use of your CT images for research, audit or teaching?	Yes	No	
For female patients: Could you be pregnant?	Yes	No	
Are you breast feeding?	Yes	No	
Medications			
Allergies			

Print name:

Patient's signature:

Date:

Appendix 4. Pharmacokinetics of beta-blockers used for heart rate reduction prior to CTCA

Beta-blockers work by diminishing sympathetic activation of the heart, decreasing heart rate and myocardial contractility. The available beta-blockers differ in their cardioselectivity although this is relative and dependent on dose: the higher the dose used, the less cardioselective the beta-blocker. Blockade of beta-1 adrenoceptors leads to reduction in heart rate and contractility; beta-2 adrenoceptors are found in bronchial smooth muscle and cause bronchoconstriction when inhibited. It is therefore preferable to use beta-1 selective adrenoceptor antagonists in the setting of heart rate control.

The most commonly used beta-blocker prior to CTCA in the UK is metoprolol. There is some usage of atenolol, with 100 mg given orally one hour before the scan; IV atenolol is used infrequently in the UK. Given the higher lipid solubility of metoprolol, peak plasma concentrations after oral ingestion are achieved more quickly (90 minutes versus 120–240 minutes with atenolol), with an effect on systolic blood pressure seen within 15 minutes. In contrast, peak plasma levels are seen usually within five minutes when given intravenously.

Both metoprolol and atenolol have similar half-lives (up to seven hours), although renal dysfunction increases the half-life of atenolol (>27 hrs if estimated glomerular filtration rate (eGFR) <15 ml/kg/1.73 m²). The half-life of metoprolol is unaffected by renal function as it is metabolised almost exclusively by the liver.

Esmolol has also been used for heart control prior to CTCA. It is a cardioselective beta-1 adrenoceptor antagonist with an extremely short half-life (nine minutes) but is available only as an IV preparation.

The effects of beta-blockers may be potentiated when administered in patients on other long-term rate-controlling agents (calcium channel blockers, digoxin, amiodarone). The effects of metoprolol and propranolol in particular may be potentiated when co-administered with inhibitors of cytochrome P450, such as fluoxetine, paroxetine, propafenone, quinidine, sertraline and amiodarone. However, these are unlikely to cause issues for short-term beta-blocker dosing used in CTCA.

Appendix 5. Treatment of adverse events after heart rate-lowering medication

Seek assistance from clinician covering the scan session if the patient experiences:

Bradycardia

- Heart rate <40 bpm or <50 bpm and symptomatic
- Atropine 600 mcg IV every 2–3 minutes up to a maximum of 2,400 mcg
- If persistent and following beta-blockade/calcium channel blockade: administer 50 mcg/kg IV glucagon (one vial mixed with 5% dextrose)
- Bleep on-call cardiology/general medical specialty registrar (StR).

Hypotension

- If it is in the setting of bradycardia, treat as above
- Otherwise, give 250 mL 0.9% sodium chloride ('normal saline') IV bolus
- Bleep on-call cardiology/general medical StR.

Cardiac arrest

- Call for help
 - Start basic life support in accordance with published guidelines
 - A second staff member should dial the cardiac arrest team giving location (CT scanner, building x, level x) and nature of emergency (adult cardiac arrest), and bring the resuscitation trolley.
-

Appendix 6. Monitoring checklist for adult patients receiving beta-blockers for lowering heart rate +/- sublingual GTN for CTCA

Prescriptions and observations

Time	HR	BP
Baseline observations		
β-Blockers Contraindications (C/I) and cautions checked? <input type="checkbox"/>		
C/I – Hypotension (BP <90/60 mmHg), asthma (bronchospasm), severe peripheral vascular disease, severe aortic stenosis, uncontrolled heart failure, sick sinus syndrome, 2nd/3rd degree heart block, on verapamil		
Agent	Metoprolol 50–100 mg po <input type="checkbox"/> Metoprolol 5–30 mg IV <input type="checkbox"/>	
Dose mg		
Dose mg		

Glyceryl trinitrate Contraindications and cautions checked? <input type="checkbox"/>		
C/I – Hypersensitivity to nitrates, hypotension (BP <90/60 mmHg), use of Viagra, Cialis or Levitra within last 24 hours, hypertrophic cardiomyopathy, aortic stenosis, cardiac tamponade, constrictive pericarditis, mitral stenosis, known severe anaemia		
400–800 mcg sublingually just prior to CT scan <input type="checkbox"/>		

Discharge observations		

Drugs prescribed by:

Given by:

Signature:

Signature:

Time patient discharged from department:

Print name:

Signature:

Notes:

Appendix 7. Auditing patient radiation doses in CTCA

Beta-DLP data can be easily obtained by interrogating the radiology information system. Unfortunately, the data is of limited use for benchmarking and optimising scan protocols. A more detailed dose audit which collects CTCA patient demographics and heart rate characteristics is necessary. The department's medical physics expert should be involved for best results. The recommended data required for each patient for CTCA dose audit is as follows.

- A sample of at least 60 examinations is desirable, including:
 - Patient demographics (sex, weight or BMI)
 - Previous ischaemic heart disease (coronary artery bypass grafting [CABG], stents)
 - Acquisition heart rate and heart rate variability
 - Scan protocol selected
 - Cardiac phases imaged
 - $CTDI_{vol}$ and DLP for each scan series
 - Total DLP.
 - Dose indicators for the standard 70 kg subject are calculated as follows.
 - Data for patients with weight in the range 60–80 kg or a BMI of 20–30 can be selected. Patients undergoing CTCA are typically heavier than the general population, so the average patient may be closer to 80 kg than 70 kg in weight. It may therefore be more appropriate to select data in the range 70–90 kg but this remains to be determined.
 - The median $CTDI_{vol}$ and DLP for each series and the median examination DLP are calculated for each type of scan protocol in clinical use and, if there is sufficient data, for slow, medium and fast heart rates.
 - The dose distribution for the patient population is calculated as follows.
 - Data for each type of scan protocol in clinical use is selected.
 - $CTDI_{vol}$ and DLP are plotted against patient size (weight or BMI) and heart rate. The variation of $CTDI_{vol}$ with patient size and heart rate provides an insight into how the tube current prescription (manual or automatic) varies with these parameters.
 - It may be possible to fit a polynomial curve to the data to predict the $CTDI_{vol}$ and DLP for subjects of other sizes and heart rates.
-

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