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Recommendations for accurate CT diagnosis of suspected acute aortic syndrome (AAS)--on behalf of the British Society of Cardiovascular Imaging (BSCI)/British Society of Cardiovascular CT (BSCCT).

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GUIDELINES & RECOMMENDATIONS

Recommendations for accurate CT diagnosis of suspected acute aortic syndrome (AAS)—on behalf of the British Society of Cardiovascular Imaging (BSCI)/British Society of Cardiovascular CT (BSCCT)

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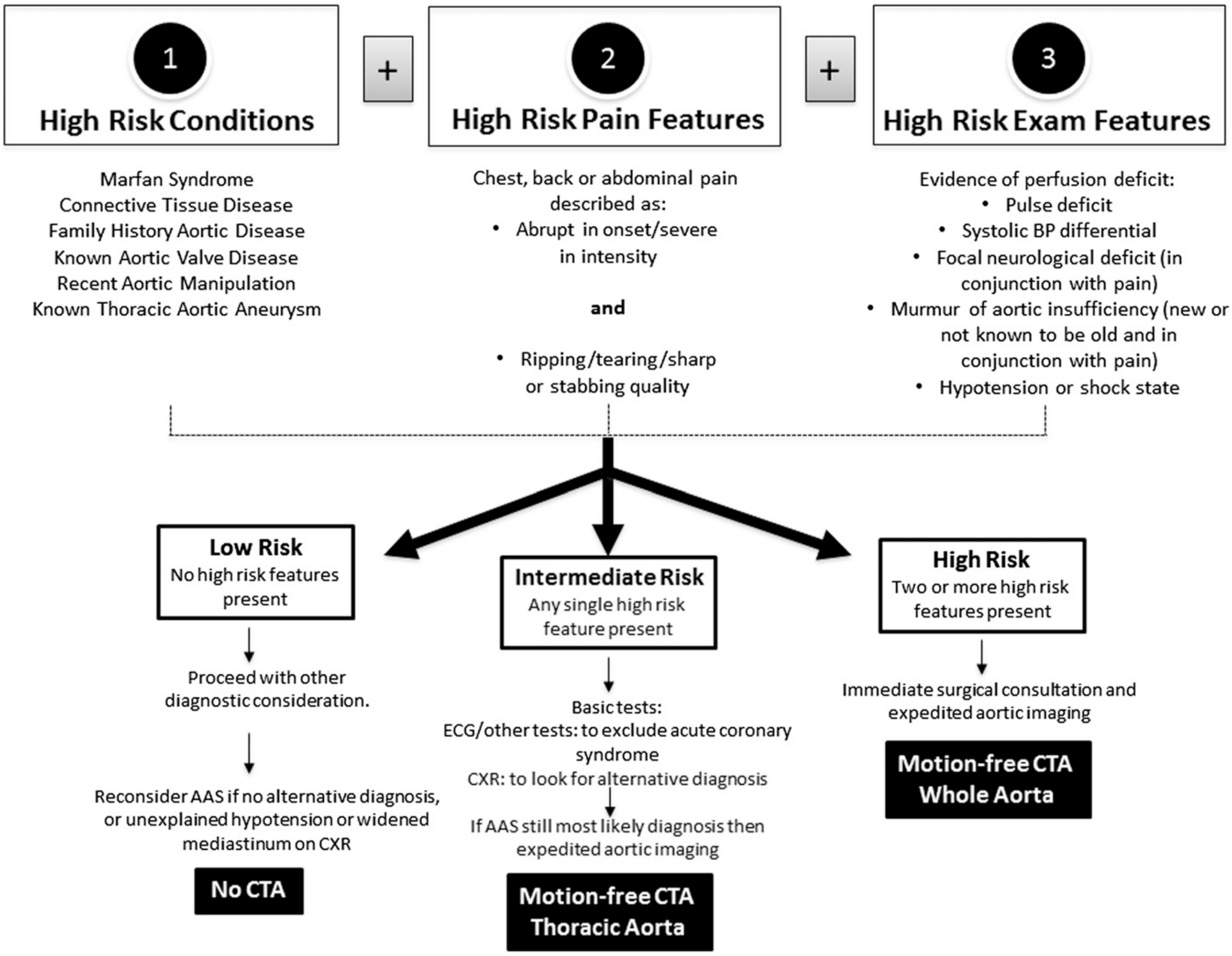
ABSTRACT

Accurate and timely assessment of suspected acute aortic syndrome is crucial in this life-threatening condition. Imaging with CT plays a central role in the diagnosis to allow expedited management. Diagnosis can be made using locally available expertise with optimized scanning parameters, making full use of recent advances in CT technology. Each imaging centre must optimize their protocols to allow accurate diagnosis, to optimize radiation dose and in particular to reduce the risk of false-positive diagnosis that may simulate disease. This document outlines the principles for the acquisition of motion-free imaging of the aorta in this context.

INTRODUCTION

Timely and accurate assessment of suspected acute aortic syndrome (AAS) is vital in this potentially life-threatening condition with significant pre-hospital and in-hospital mortality rates of up to 20% and 30%, respectively.[1] There are many definitions of AAS; however, for the purpose of this document, AAS is defined as aortic dissection, intramural haematoma and the complications arising from penetrating atherosclerotic aortic ulcer.[2–4] These are not mutually exclusive and may represent variations on the same disease spectrum.[4–7] Different classifications of aortic dissection exist,[8,9] but to avoid confusion, we recommend using the most recently proposed classification of defining dissection as follows: Type A, involving the ascending aorta; Type B, limited to aorta portion distal to left subclavian artery; and Type B with aortic arch involvement, involving the arch (between the innominate and left subclavian arteries) but not involving the ascending aorta.[10] The classification reflects the current management approach, which supports that Type B dissection can be managed conservatively. With recent advances in CT scanning technology and increasing expertise in cardiovascular CT, the purpose of these recommendations are to outline the best practice for the investigation of suspected AAS so that unequivocal diagnosis can be made based on imaging. Specifically, accurate motion-

Figure 1. Risk stratification for acute aortic syndrome and appropriate management strategy.



free imaging is vital to eliminate the possibility of false-positive diagnoses, needless patient transfer and potentially disastrous unnecessary surgery, all of which have been reported.[11–16]

Assessment of pre-test likelihood

Recommendation 1

> Assessment of pre-test clinical probability of AAS should be performed using American College of Cardiology Foundation (ACCF)/American Heart Association (AHA) guidance.[17]

Initial evaluation of AAS should be based upon careful history and clinical examination (*i.e.* assessing for peripheral pulse deficits and potential end organ damage secondary to dissection) resulting in the ability to determine a pre-test likelihood of AAS. A summary of pre-test likelihood is shown in Figure 1 which categorizes patients into low, intermediate or high likelihood of AAS.[17]

Recommendation 2

> Patients deemed to have intermediate or high risk should proceed to have imaging to establish a definitive diagnosis. In patients with low clinical risk, an alternative diagnosis should be considered but definitive imaging may also be required.

Patients with high-risk conditions such as those with increased wall stress (*e.g.* hypertension, phaeochromocytoma, cocaine use) and aortic medial abnormalities (*e.g.* Marfan, Loeys–Dietz, Ehlers–Danlos, Turner syndromes, inflammatory vasculitides) have increased risks of developing thoracic aortic aneurysm and dissection.[18–23] High-risk clinical features and examinations should also be borne in mind, allowing for appropriate patient selection for imaging. Pre-test likelihood assessment should be performed to exclude other causes and select appropriate patients for timely imaging.

Imaging modality and technique

Recommendation 3

> When imaging is deemed appropriate, CT scan is the imaging modality of choice in acute scenario.

Transthoracic echocardiography Transthoracic echocardiography usually allows adequate assessment of the aorta and can often diagnose involvement of the aortic root and proximal ascending aorta. However, other segments (*e.g.* the aortic arch, proximal descending aorta and abdominal aorta) are sometimes difficult to see owing to inadequate acoustic window. The value of transthoracic echocardiography is further limited in non-standard patients (*e.g.* abnormal chest wall configuration, obesity, pre-existing pulmonary emphysema, or patients on mechanical ventilation).

Transoesophageal echocardiography The proximity of the oesophagus to the aorta allows high-quality images of the aorta to be obtained. The high accuracy of transoesophageal echocardiography for the diagnosis of aortic dissection has been reported previously.[24,25] The largest series examining ascending aortic dissection shows a sensitivity and specificity of 96.8% and 100%, respectively.[26] The main drawbacks of transoesophageal echocardiography are sedation requirement and access to appropriate expertise.

CT The accuracy of CT in the diagnosis of aortic dissection is high with sensitivity and specificity ranging around 98–100%. As per evidence based on the International Registry of Acute Aortic Dissection registry[27] and the Spanish Registry of Acute Aortic Syndromes,[28] CT is already the preferred imaging modality and was used in 74% and 77% of patients in each registry, respectively. One of the major drawbacks of CT is the pulsation artefact which is addressed in this article.

MRI MRI has very high sensitivity (97–100%) and specificity (94–100%) for the diagnosis of aortic dissection.[29,30] MRI is free from ionizing radiation, but limitations are low availability and time taken for examination (even in experienced sites, imaging time can be 20–30 min) means lack of suitability in acute setting.

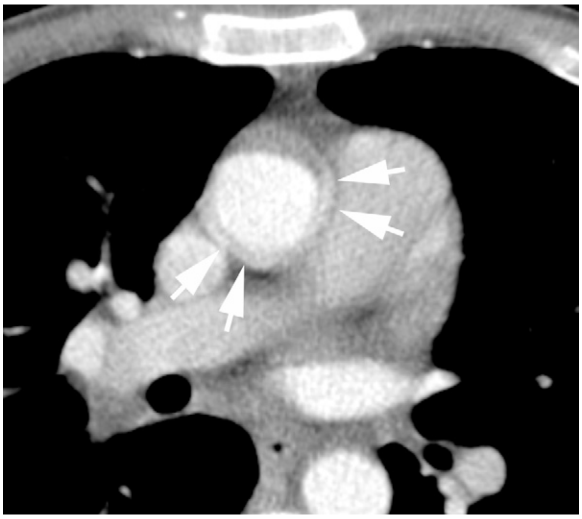
Given the available evidence, CT is recommended as the imaging modality of choice in the acute scenario because of accuracy, ease of access and relatively quick examination time.[5,31] Once AAS is confirmed, in addition, echocardiography may be used to assess complications such as aortic valve dysfunction, pericardial tamponade, or wall motion abnormalities, but this should not delay definite surgical management. In equivocal cases of acute intramural haematoma, a characteristic "echo-free space or echolucent area" within the thickened aortic wall that may be sought in supportive of diagnosis.[31–34] MRI/MR angiogram is not recommended in acute scenario but is useful in the context of follow-up of known aortic dissections, particularly in young patients[35] in line with the as low as reasonably practical principle of radiation dose optimization.

Recommendation 4

> All CT scans should be performed with the aim of producing motion-free images of the aortic root, which is prone to pulsation artefact (Figure 2).

In systems with 64-detector-row arrays (or 80-detector-row arrays—these systems may be configured as 128 or 160 slices per rotation systems depending upon technical details of reconstruction), this should involve routine use of electrocardiogram (ECG) synchronization.[36,37] Prospective triggering should be used where possible in order to reduce radiation dose. Retrospective gating usually incurs a penalty of significantly higher radiation dose. A dose–length product (DLP) for retrospective thoracic CT angiogram can be as high as 2547 mGy cm^{-1},[38] although there are specific instances where this may have to be performed (see Specific protocol examples section). Broad detector array systems, *e.g.* 128 detector rows (*e.g.* Philips iCT; Philips, Andover, MA), 256 detector rows (*e.g.* GE Revolution; General Electrics, Milwaukee, WI) or 320 detector rows (*e.g.* Toshiba Aquilion One; Toshiba, Irvine, CA) or dual-source systems, should be optimized to allow motion-free imaging which may not require ECG synchronization if temporal resolution is rapid enough, but this depends upon scanner capabilities.

Figure 2. Ungated CT angiogram of the aorta demonstrating pulsation artefact (arrows).



Recommendation 5

> A non-contrast ECG synchronization CT scan should be performed to look for a rim of hyper-attenuation around the aortic wall (Figure 3).

This should be performed prior to the contrast-enhanced study. The use of a non-contrast scan may reduce the likelihood of false-negative diagnosis on contrast studies in cases of isolated subtle intramural haematoma. Incidences vary but range from 6% to 30%.[17,39–41] In addition, a non-contrast scan may enable the visualization of acute haemorrhagic content within the aortic wall that can be associated with the other forms of AAS[2] and also localized rupture into the pericardium. Where possible, a low-dose setting should be utilized. The non-contrast scan does not need to encompass the whole aorta and can be limited to covering from aortic arch to diaphragmatic sulcus.

Coverage

Recommendation 6

> Coverage should be limited to thorax from aortic arch to diaphragmatic sulcus in the first instance, unless the patient is deemed high risk or has known disease.

Figure 3. Non-contrast CT demonstrating typical appearance of a hyperattenuating crescentic ring that can be seen in acute intramural haematoma (arrowheads).

Initial coverage should be as for a CT Thorax (covering aortic arch to diaphragmatic sulcus). As the diagnostic rate for positive findings may be as low as 2.7%,[42,43] coverage should be limited in the first instance in patients with intermediate pre-test probability in order to avoid unnecessary radiation dose. If the scan proves positive, then a repeat scan can be performed with extended coverage to the common femoral arteries to allow for endovascular access planning and to fully delineate the full extent of the dissection. In those patients deemed "high risk" for dissection following risk assessment, particularly with abdominal and/or lower limb symptoms/signs, it is reasonable to perform complete coverage of the entire aorta and to include the iliofemoral arteries from the outset. In addition, in situations where there is known aortic dissection, extended coverage is mandatory.

Premedication

In the acute setting, we do not advocate the use of beta-blocker medication to slow the heart rate (HR).

Patient size

Patient size or body mass index (BMI)-adjusted tube current/voltage should be employed for maximum dose optimization. As a general rule, lower BMI will allow for the use of flow tube voltage (kVp) and provided that tube current is also optimized, dose can be reduced. Lowering kVp will affect image contrast and will allow for the use of less iodine intravenous contrast (see Recommendation 8 section).

Scan initiation and contrast Regime

Recommendation 7

> A dedicated injection protocol should be used, taking into account the speed of scan acquisition and coverage with the aim to achieve adequate contrast concentration of at least 250 HU in the aorta.

There are three distinct methods of scan initiation that may be used.

(a) Fixed delay: this must take into account the contrast injection rate, contrast concentration, table feed speed, scanner detector width and perceived patient cardiac output. This is effectively a prediction and is not recommended.

(b) Test bolus: this technique will allow homogeneous contrast enhancement and takes into account the patient's haemodynamic status. However, a disadvantage is that it requires a small increase in the overall contrast medium dose for the test bolus (usually $\leq$20 ml).[44] Lower tube voltage protocols for test bolus imaging can be used to reduce radiation further.[45]

(c) Bolus tracking: with a region of interest placed in the ascending thoracic aorta, the scan is commenced once a predetermined threshold Hounsfield unit has been reached. It should be noted that in AAS, there is a risk that if the region of interest is incorrectly placed (*e.g.* as can occur in the false lumen of a dissected aorta), inappropriate triggering may occur. The operator should be aware that manual initiation may be required in this instance.

The contrast injection should be given *via* the right arm to eliminate the streak artefacts that might be caused by injection from the left side, obscuring assessment of head and neck vessels that may potentially be involved. The amount of contrast and rate of injection depends upon the speed of scan acquisition, tube voltage, patient size and *z*-axis coverage, as well as the iodine concentration used and whether a saline bolus chaser is used. The aim is to achieve adequate contrast concentration of at least 250 HU in the aorta.[46] The use of a saline flush is recommended as this produces a higher contrast peak opacification for any given iodine flux and makes most efficient use of administered contrast.[47]

On the most recent generation of CT scanners, it is now feasible to use low tube voltage for routine imaging of the aorta, even in large-sized patients (often in conjunction with iterative reconstruction techniques). Owing to the greater photon absorption of iodinated contrast at energies nearer 70 kVp, this results in greater relative vascular enhancement. This in turn allows for smaller volumes of contrast to be used at lower flow rates (iodine delivery rates of 1.3–1.5 $g\,s^{-1}$). Similarly, the use of high-pitch dual-source systems need less iodine delivery rate but owing to acquisition speed, adjustment of the acquisition delay may be required.[48] Biphasic or triphasic injections should be considered to reduce contrast dose, produce a uniform enhancement pattern without affecting the maximal enhancement and also minimize artefacts from dense contrast material within the superior vena cava. Patient-specific protocols can also be employed and may achieve more uniform contrast enhancement.[49]

Recommendation 8

> The key to adequate contrast opacification is to achieve an iodine delivery rate of at least 1.6 $g\,s^{-1}$ (ideally up to 2 $g\,s^{-1}$) when using a tube voltage of 120 kVp.

The two factors to consider when calculating iodine flux are the iodine concentration of the contrast media and the injection rate, *i.e.* 300 mg of iodine per millilitre injected at 6.7 ml s^{-1} *vs* contrast media of 400 mg of iodine per millilitre injected at 5 ml s^{-1}. It is worth noting that patient factors also affect iodine delivery rate (*i.e.* cardiac output and weight). Therefore, it is recommended that contrast volume should be determined based on the patient's weight, usually delivering at least 300-mg iodine per kilogram for examinations of the whole aorta with 64-detector row systems. However, advanced broad detector array or dual-source systems may permit lower volumes in view of their increased speed of acquisition.[48]

If using a 64-detector-row CT for the entirety of the aorta, a decrease in aortic enhancement in the descending aorta may be observed when using a biphasic protocol. However, the decrease in aortic enhancement usually does not fall below diagnostic acceptability and often remains above the 250 HU.[50] Whilst the aim is to get uniform enhancement throughout the entire aorta, but in the descending and abdominal aorta, this may on occasion be difficult to achieve. However, in most cases, the abdominal aorta can be delineated sufficiently to visualize the dissection and the perfusion of the mesenteric and renal arteries without a need for a repeat examination. Moreover, intramural haematoma and penetrating atherosclerotic ulcer are relatively rare in the abdominal aorta. Multiphase injection protocols may enable more uniform vascular enhancement throughout the entire aorta, and if available should be considered.[51]

Optimizing CT parameters

Although diagnosis of AAS can be made using non-gated CT techniques, image quality at the aortic root is often suboptimal owing to motion artefact. This limits the diagnostic confidence and may on occasion mimic aortic dissection, leading to unnecessary further investigation and treatment, including sternotomy/thoracotomy. The prevalence of aortic motion artefacts with non-gated CT has been reported to be high as 57–93% in some series.[52–54] With ECG synchronization, the occurrence of this artefact is less common, allowing motion-free visualization of the aortic root and proximal coronary arteries in almost all cases.[55,56]

To allow for prospective acquisition of the aorta, systems with detector coverage of at least 32 mm in the *z*-axis are recommended to make breath-holding possible during the whole scan acquisition. ECG synchronization must be available to allow co-registration with heart rhythm. Scanners with ≥64 detector rows should be used in conjunction with narrow reconstructed slice thickness (<1 mm) in order to provide adequate multiplanar reformats, preferably with isotropic resolution utilizing small voxel size through the use of a small field of view tailored to the aorta.

Specific protocol examples

For each scanner type, it is important that dedicated protocols are used and optimized. The protocols outlined below should be used as a guide, and variations may exist depending on differing parameters as outlined above. These protocols are advocated based upon expert British Society of Cardiovascular Imaging user recommendations and in collaboration with UK application specialists.

Basic concept

For a 64-detector-row system (including "128-slice" scanners and similar), prospective ("step-and-shoot") acquisition should be employed where possible with phase selection based on HR. This is because the phase with minimal motion of the aortic root varies with HR. At HR <65 beats per minute (bpm), this is usually the end-diastolic phase. With HR >65 bpm, this is usually end-systolic phase.[55] Where phase selection is not adjustable (*e.g.* on a scanner with prospective helical acquisition with diastolic phase acquisition only for slow HRs), then a retrospective protocol may need to be employed for patients with faster HRs. Retrospectively gated acquisitions can be used but should be only employed where no prospectively triggering alternative exists. Iterative reconstruction algorithms should be used where deemed appropriate to allow reduced radiation dose.[57–59] For larger detector array or high-pitch dual-source systems, ECG synchronization may not be necessary for motion-free imaging of the aorta. A summary of all the protocols can be seen in Table 1. Further discussions are as follows.

Single-source systems: standard detector coverage—64- and 80-detector row scanners (including "128- and 160-slice" systems)

Although, step artefact may be problematic in coronary imaging, this does not affect diagnostic confidence in the visualization of the aorta. The advantage of adopting prospective triggering is a significant reduction in radiation dose compared with non-gated and retrospectively gated acquisitions. There may be a role for retrospective gating when the HR is fast (*i.e.* >100 bpm) or in systems where the threshold for prospective triggering under a pre-defined HR cannot be overridden (Table 1). When retrospective acquisition is used, dose modulation outside the 30–80% cardiac cycle should be applied.[38,60]

Prospective triggering is recommended with phase selection taking into account the patient's HR.[55,61,62]

Regular HR <65 bpm: prospective with end-diastolic triggering.
HR >65 bpm or irregular HR: prospective with end-systolic triggering.

For scanners that cannot utilize prospective triggering in a "step-and-shoot" manner at HR >65 bpm, the following protocol should is recommended.

Regular HR <65 bpm: prospective with end-diastolic triggering.
HR >65 bpm or irregular heart rate: retrospective gating with dose modulation.

For scanners that have a retrospective mode with adaptive dose modulation, this may be used as an alternative for fast HRs. This mode can be used to automatically tighten the dose modulation during retrospective acquisition. However, it is worth noting that the use of this mode should be performed with caution in irregular/variable HRs, where scanner may widen the modulation window and dose may increase significantly.

In addition, dose modulation outside the acquisition window should be set at the lowest possible value if adjustable (this is vendor-specific but ranges from 4% to 20%), therefore lowering overall dose further in retrospective acquisition.

Table 1. Summary of scanning parameters for different types of CT scanners

Single source	
64- and 80-detector row scanners (including "128- and 160-slice" systems)	
HR < 65	Prospective gating with end-diastolic acquisition
HR > 65	Prospective gating with end-systolic acquisition
Exception	Where phase selection is not adjustable (*e.g.* on a scanner with prospective helical acquisition with diastolic phase acquisition only for slow HRs) There may be a role for retrospective gating (*e.g.* when the HR is >100 beats per minute) When retrospective acquisition is used, dose modulation outside the 30–80% cardiac cycle should be applied For scanners that have a retrospective mode with adaptive dose modulation, this may be used as an alternative for fast HRs
128-, 256- or 320-detector row scanners (including "256- and 640-slice" systems)	
128–256 detector rows	
HR < 75	Prospective gating with end-diastolic acquisition
HR > 75	Prospective gating with end-systolic acquisition
320 detector rows	
HR independent	Non-gated helical acquisition with the middle 8-cm coverage (160 × 0.5 mm) can be used to image the thoracic aorta in 1–2 heartbeats with motion-free imaging of the aorta
Exception	If dedicated coronary assessment is required (*e.g.* in the context of known AAS or a high pre-test probability), then use following
HR < 65	Prospectively triggered ECG synchronization with 70–80% single pulse per volume
HR > 65	Prospectively triggered ECG synchronization with 30–80% single pulse per volume
Dual source	
HR-dependent	HR-dependent prospectively ECG-synchronization protocols can be applied similar to the systems above
HR < 65	Prospective gating with end-diastolic acquisition
HR > 65	Prospective gating with end-systolic acquisition
	In a system that allows for high-pitch acquisition in conjunction with wide detector arrays, traditional ECG synchronization may not be required *e.g.* a pitch of >3 and gantry rotation time 0.28 s permit coverage of 9.6–11.6 cm s^{-1}

AAS, acute aortic syndrome; ECG, electrocardiogram; HR, heart rate.

For scanner types that only use prospective helical scanning during diastolic phase at HR <65 bpm, retrospective gating should be used above this threshold. In this setting, the following protocol is recommended.

Regular HR <65 bpm: prospective helical scanning with end-diastolic triggering.

HR >65 bpm or irregular HR: retrospective gating with dose modulation.

Where a variable helical pitch function is available, this allows seamless switching to non-gated scanning with increased pitch outside the coverage for the heart. For example, for thorax only, one would scan variable helical pitch caudocranially. ECG synchronization only used within the heart, followed by ungated acquisition for the rest of the thorax to the apices. If extended coverage of whole aorta is required, scan can be performed craniocaudally, using ECG synchronization in the thoracic portion, and then changing pitch and switching to ungated acquisition for the remaining abdominal and pelvic coverage.

Single-source systems: broad detector coverage—128-, 256- or 320-detector-row scanners (including "256- and 640-slice" systems)

For large detectors systems with increased *z*-axis coverage, the scanning time can be reduced. 128-detector-row scanners usually have a detector width of 8 cm. Imaging the entire thoracic aorta therefore requires more than one transverse section (and often 3–4 sections). It is recommended that a prospectively triggered approach is used, as with the 64-slice scanners. Recommendations are as follows:

Regular HR <75 bpm: prospective with end-diastolic triggering.
HR >75 bpm or irregular HR: prospective with end-systolic triggering.

Where the ability to switch from gated to non-gated scan acquisition is available, this should also be utilized to minimize dose.

320-detector systems have a detector width of 16 cm; this coverage may be adequate to image the thoracic aorta in 1–2 rotations, and with this rapid acquisition, ECG synchronization may not be required. Non-gated helical acquisition with the middle 8-cm coverage (160 × 0.5 mm) can be used to image the thoracic aorta in 1–2 heartbeats with motion-free imaging of the aorta.

However, if dedicated coronary assessment is also required (*e.g.* in the context of known AAS or a high pre-test probability), then prospectively triggered ECG synchronization (HR <65 bpm 70–80% single pulse per volume, HR >65 bpm 30–80% single pulse per volume) covering the entire thoracic aorta should be performed. This will require 2 volumes of 16 cm (320 × 0.5 mm) for adequate coverage. Several investigators have reported similar protocols previously.[63,64]

Dual-source systems

Dual-source systems have improved temporal resolution and thus allow higher tolerance for accelerated HRs. If temporal resolution <100 ms can be achieved, HR-dependent prospectively ECG-synchronization protocols can be applied. For example, if the HR is <65 bpm, the optimum phase is at end diastole. For HRs >65 bpm, the optimum phase is at end systole.[65,66]

In a system that allows for high-pitch acquisition in conjunction with wide detector arrays, traditional ECG synchronization may not be required.[67–71] For example, using a pitch of >3 and gantry rotation time 0.28 s permits coverage of 9.6–11.6 cm s^{-1} with reduced radiation dose.[68,70,72]

CONCLUSION

This document outlines the different methods of scan acquisition with an emphasis on the importance of performing motion-free imaging of the aorta in suspected AAS in order to provide accurate diagnosis. This is by no mean an exhaustive coverage of the multiple scanners available but should encompass most scanners being used routinely in UK practices. It serves to outline the basic principle of motion-free aortic imaging using the currently available evidence and expert opinions of the BSCI/BSCCT. With continuing rapid advancement of CT technologies and the need to standardize image acquisition coupled with an obligation for dose optimization, these recommendations should allow centres to adopt protocols specific to their scanners for timely and accurate assessment using the basic principles outlined in this document. Acquisition is only one aspect of the scan and to properly implement this imaging strategy, centres must also adopt appropriate reporting facilities (*e.g.* picture archiving and communication system must be able to manage ECG-gating data sets, including handling of multiphasic reconstruction of retrospective acquisition), radiographer's training, as well as reporting expertise. In terms of implementation, it has been shown that application of ECG gating by adequately trained staff has no impact on the workflow of the CT examination in acute setting.[73]

We envisage that definitive diagnosis of ascending aortic pathology, eliminating false-positive scans, should become routine practice and that no patient should undergo sternotomy/thoracotomy or other intervention without an optimal AAS CT scan.

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