European Journal of Radiology 79 (2011) 161–171

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Review

Technical challenges of coronary CT angiography: Today and tomorrow

Ali Hassan[a,1], Sarfraz Ahmed Nazir[b,*], Hatem Alkadhi[c,2]

[a] Department of Radiology, Wexham Park Hospital, Slough, Berkshire, SL 2 4HL, United Kingdom
[b] Department of Radiology, John Radcliffe Hospital, Headley Way, Oxford, OX3 9DU, United Kingdom
[c] Institute of Diagnostic Radiology, University Hospital Zurich, Raemistrasse 100, 8091 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 14 September 2009
Received in revised form 14 February 2010
Accepted 17 February 2010

Keywords:
Coronary CTA
CAD
Coronary angiography
Cardiac CT

ABSTRACT

Rapid advancements in multidetector row computed tomography (MDCT) are beginning to revolutionise cardiac imaging applications. As a consequence, coronary CT angiography (CTA) is fast emerging as a highly effective, noninvasive imaging technique for the assessment of coronary artery disease (CAD). Technology is improving at a robust pace, which brings with it the benefits of superior spatial and temporal resolution as well as fast volume coverage, achieved through the development of systems with an increased number of detectors and shorter gantry rotation time, as well as the advent of systems equipped with dual-source X-ray tubes. The main power of CTA was thought to lie in its high negative predictive value in excluding coronary disease with a high degree of accuracy in patients with low probability for CAD. However, this rapid progress has meant that we are also adding to the growing list of additional potential applications of CTA that are possible with the technology. The aim of this review is to present an overview of the technical capabilities of cardiac MDCT relating to coronary CTA and other applications, the limitations of current technologies, as well as discuss political perspectives and how to address these in medical practice.

1. Introduction

Coronary artery disease is the leading cause of morbidity and mortality in industrialized countries. Medication, surgical revascularization or percutaneous balloon angioplasty with stenting form the mainstays of therapeutic options. The decision on whether to institute these therapies relies on the evaluation of the coronary artery lumen, provided in the main by direct catheter angiography. With supreme temporal and spatial resolution, invasive coronary angiography provides accurate, reliable, and reproducible evaluation of luminal status for narrowing, stenosis, and occlusion. However, despite it still being the gold standard for assessment, direct angiographic analysis is not without its limitations. In 2004, nearly 1.5 million diagnostic invasive coronary angiograms were performed in the United States alone, with a not insignificant overall complication rate of 3.6% and a procedure-related mortality rate of 0.1% [1]. Conventional catheter angiography also provides only limited information on the presence and type of atherosclerotic plaques not associated with luminal stenosis (i.e., forming a positive remodelling); on plaques that are vulnerable for rupture, eventually leading to thrombosis, occlusion, and myocardial infarction [2–4]. Thus it is obvious that a noninvasive method for visualizing coronary stenosis and plaques that addresses these issues would be cost beneficial, greatly aid diagnosis, and considerably reduces the number of purely diagnostic angiograms and associated morbidity.

Advances in multidetector-row computed tomography (MDCT) of the heart, coupled with the combined benefits of electrocardiogram (ECG) gating, has resulted in tremendous progress in the noninvasive imaging of the cardiovascular system and in particular the coronary vasculature. MDCT technology has been rapidly adopted to generate high-resolution contrast-enhanced angiograms of the heart and coronary arteries [5–8]. Cardiac CT angiography is able to provide information on the chronicity of the atherosclerotic process, the state of the coronary artery wall and allows for plaque characterisation; thus overcoming some of the shortcomings of direct catheter angiography.

The emergence of new diagnostic technologies is often accompanied by the controversy of challenging established methods and techniques. In this regard, coronary CTA is no exception where the debate has centred around its potential role in replacing conventional invasive coronary angiography. One of the major advantages of the latter is the ability to perform therapeutic interventions such as angioplasty and stenting of lesions identified during the same diagnostic procedure. However, recent outcome analysis studies challenge this notion and suggest that therapeutic interventions

* Corresponding author. Tel.: +44 01865220215; fax: +44 01865777430.
E-mail addresses: ahzh7@aol.com (A. Hassan), sarfraznazir@doctors.org.uk (S.A. Nazir).
1 Tel.: +44 01753 633000; fax: +44 01753 634825.
2 Tel.: +41 44 255 3662; fax: +41 44 255 4443.

0720-048X/$ – see front matter © 2010 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.ejrad.2010.02.011

should only be applied to patients with stenoses that result in proven haemodynamically significant alterations [9–11]. This decoupling of diagnostic and therapeutic pathways lends itself very well to less invasive procedures such as coronary CTA in the workup of appropriate patient groups. CTA therefore has a major role to play in reducing the number of unnecessary invasive coronary arteriograms in patients with normal or clinically non-significant coronary artery lesions [8,12,13].

During the course of this review, we aim to discuss the technical aspects of MDCT as applied to cardiac CTA and other applications, the current state of play of the technology, and its limitations. We also tackle the political issues related to the wider adoption of the technology in the practice of cardiological medicine and how these can be addressed.

2. Technical aspects of cardiac CTA

2.1. Spatial and temporal resolution

The demand from cardiac CT is of high spatial resolution, high temporal resolution, and true volume data sets. Thus the aim has been to develop advanced scanners providing super-fast gantry rotation times, submillimetre slice thicknesses and data sets consisting of many hundreds of slices with post-processing allowing isotropic reconstruction in any plane.

High spatial resolution is essential to enable visualization of small arteries and plaques and delineation of complex cardiac anatomy. Coronary arteries are small (1–5 mm). Therefore, in order to detect stenoses, cardiac MDCT scanners need to achieve submillimetre resolution. Not only that, isotropic resolution is the ideal as the resolution is required in 3 dimensions due to the tortuous course of the vessels. Cardiac CTA has a spatial resolution of roughly 0.4 mm, and although it is improving, it is inherently inferior in comparison with invasive coronary angiography (0.1 mm).

High temporal resolution is critical to minimise or eliminate motion artifact associated with the beating heart to make it possible to image the entire heart volume in a single breath-hold. Invasive coronary angiography boasts excellent temporal resolution of just 4–7 ms but in CT imaging of the coronary arteries, cardiac movements are the most important limiting factor. For heart rates of less than 70 bpm, a temporal resolution of less than 250 ms is sufficient for motion-free imaging in diastole, whereas a temporal resolution of 50 ms is needed in systole. With increases in heart rates, better temporal resolution is required [14]. The overall temporal resolution of current cardiac MDCT varies from 100 to 200 ms [15,16]. The most recent scanners are reaching true temporal resolution of between 75 and 83 ms [17,18]. Although the temporal resolution with MDCT depends on several variables related to the intrinsic characteristics of the scanner (gantry rotation time, number of detectors etc.), the utilisation of ECG-gating and the type of synchronization algorithm engaged is of prime importance and an essential component of cardiac CT. ECG-gating and synchronization allows data acquisition and image reconstruction at specific points in the cardiac cycle, optimizing image quality whilst also defining the type of information available to the clinician. There are 2 distinct methods of ECG-gating employed by cardiac CT.

2.2. Retrospective ECG-gating

In current practice, the vast majority of cardiac CT examinations are performed on MDCT scanners with retrospective ECG-gating. As the name suggests, there is continuous spiral CT acquisition centred over the heart synchronized with simultaneous ECG recording, and data acquisition during all cardiac phases (Fig. 1).

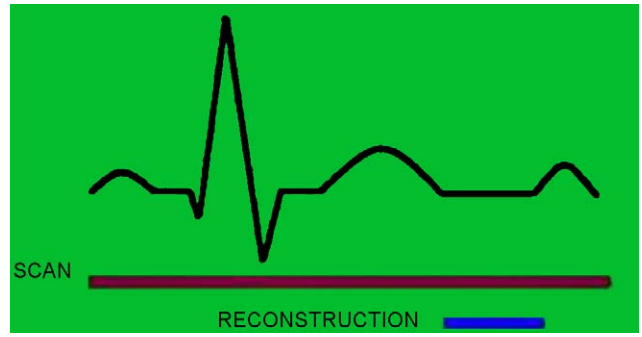

Fig. 1. Retrospective cardiac gating.

This then allows for subsequent retrospective image reconstruction in any given phase of the cardiac cycle. Data may be taken from a specific point in the cardiac cycle in order to generate an image during diastole or to select data from a different point in the cardiac cycle to generate an image during systole. This is beneficial as individual coronary arteries are optimally visualized in different phases of the cardiac cycle, particularly at higher heart rates. Accordingly, the right coronary artery (RCA) is better visualised in late systole, whereas other coronary arteries are best seen in diastole [19]. Multisector reconstruction algorithms have tried to improve temporal resolution further where X-ray projections of more than heartbeat are used to reconstruct an image. This does however require absolutely consistent data from two or more heartbeats. Retrospective gating also enables an evaluation of cardiac function. MDCT has been successfully been validated for the quantification of right ventricular (RV) and left ventricular (LV) function [20] and has been proved to be in excellent agreement with echocardiographic [21] and MR assessment of global ventricular function [22,23]. In addition, as reconstruction is possible throughout the cardiac cycle, retrospective gating can identify potential regional function and wall motion abnormalities. Measurements of regional LV function with MDCT are based on the assessment of systolic thickening by use of the 17-segment model proposed by the American Heart Association as in accordance with other cardiac imaging modalities. Qualitative assessment of regional LV function can be visually assessed by the change in wall thickness and the systolic thickening by use of cine loop displays of multiple cardiac phases (5–95% phases). MDCT determined regional LV function has been shown to correlate well with cardiac MRI [24,25] and echocardiography [26–28]. It must be borne in mind, however, that all of these functional analyses come at the expense of longer post-processing times.

Retrospective gating is heavily reliant on the patient being in normal sinus rhythm with a stable R–R interval during the scanning process. Arrhythmias can lead to data acquisition during an undesirable phase of the cardiac cycle and unless a very low pitch is used (approximately 0.2–0.4), omitting such data could result in significant coverage gaps. The reliance on such a very low pitch to avoid gaps in anatomic coverage is a limitation of retrospective gating methods. This means that each anatomic area of the heart may be scanned several times during data acquisition, which results in higher radiation dose. The entire cardiac cycle is imaged as the patient moves continuously through the gantry—receiving an X-ray dose of between 12 and 20 mSv along the way. The desire to minimize radiation dose, and the realization that the majority of useful information is acquired in diastole, led to the development of ECG modulation methods. This is where a lower tube current (mAs) is applied during the systolic phase. This results in an approximate 30–40% reduction in overall radiation dose.