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EDITOR'S COMMENT

Crown years for non-invasive cardiovascular imaging (Part IV): 30 years of cardiac computed tomography

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2013 is a remarkable year in cardiovascular medicine from a historical point of view. It can be considered a crown year for non-invasive clinical cardiovascular imaging as we can look back on 60 years of echocardiography, 40 years of nuclear cardiology, 30 years of cardiovascular magnetic resonance imaging, and 30 years of cardiac computed tomography. In previous Editor's Comments, 60 years of echocardiography, 40 years of nuclear cardiology, and 30 years of cardiovascular magnetic resonance have been described (Parts I, II, and II) [1–3]. In this Editor's Comment (Part IV) we will briefly look back to the roots of cardiac computed tomography and its main achievements over the past 30 years.

Thirty years of cardiac computed tomography

Although already in 1979 the Nobel Prize in Physics and Medicine was awarded to Sir Godfrey Newbold Hounsfield and Allan MacLeod Cormack for their discovery of computed tomography (CT), the research group directed by Charles Higgins (San Francisco, USA) were, in 1983, among the first to report that CT of the heart offers great promise for a definite application in cardiovascular clinical practice [4]. It was stated that '*CT may eventually find its most important and clinically useful application in the diagnosis and management of heart disease*' [4]. At that time electron-beam CT scanners provided useful clinical diagnostic information in patients with heart disease. Electron-beam CT already allowed anatomic evaluation of the heart in patients with arrhythmogenic right ventricular dysplasia, intra-cardiac shunts, congenital heart disease, hypertrophic cardiomyopathy, and coronary artery bypass grafts [5]. In 1984, the first cine-CT images were generated visualising myocardial wall thickening and motion [6]. After these initial cardiac CT investigations, the history and development of cardiac CT was directly associated with technological improvements occurring with each successive generation of CT scanners. Consequently, the true modern era of cardiac CT began in 1994 with the introduction of single-slice helical cardiac tomography [7]. With the advent of 4-slice CT in 1999 [8], multi-slice CT was introduced for cardiothoracic imaging to be followed by 16-slice tomography in 2002 [9]. Available since 2004, 64-slice CT systems were considered a prerequisite for successfully integrating cardiothoracic CT into routine clinical algorithms [10]. These developments were followed by the clinical introduction of dual source CT, 265-slice scanners, and 320-slice scanners between 2005 and 2010 [11–13]. By virtue of the strongly increased temporal and spatial resolution of these advanced scanning devices, the diagnostic accuracy of multi-slice CT angiography in coronary artery disease (CAD) has been significantly increased. Over the past 10 years multi-slice cardiac CT has become a standard non-invasive imaging modality in the USA, Japan and Europe (in particular Germany). In the Netherlands, research groups from Leiden (LUMC), Rotterdam (ErasmusMC), and Utrecht (UMCU) have significantly contributed to advances in clinical cardiac multi-slice CT.

In general, cardiac CT has two approaches: *first*, non-contrast enhanced CT to detect and quantify coronary calcium, and *second*, contrast-enhanced CT to detect non-obstructive and obstructive coronary atherosclerosis. Coronary calcium is considered a proven marker of the presence of atherosclerosis and the prognostic value of coronary calcium scoring is independent and incremental to the predictive value of traditional risk factors. In fact, an association between visible calcium on CT and the risk of cardiovascular events was

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already demonstrated in the early 1990s [14]. The presence of coronary calcium, as assessed by non-contrast enhanced CT, does not necessarily imply the presence of a significant coronary obstruction [15]. There is a direct relation between the magnitude of the coronary calcium score and the presence of a coronary obstruction, which is located anywhere in the coronary tree and not necessarily at the calcific plaque site. The absence of coronary calcium is associated with a very low risk of adverse coronary events. Whether calcium scoring should be widely used in cardiovascular prevention strategies is still under debate [16]. There are many limitations of applying calcium scoring as a screening tool to broad populations as there is a lack of prospective randomised controlled trials showing that an abnormal calcium score impacts treatment decisions or clinical outcomes. Until these data are available, calcium scoring should be judiciously used by physicians in patients with different risk factors of developing cardiovascular events [17].

The presence of (non)obstructive coronary atherosclerosis is assessed by contrast-enhanced multi-slice CT coronary angiography [18]. In the clinical arena, multi-slice CT coronary angiography demonstrated a very high negative predictive value of more than 95%, indicating that cardiac CT can be used as a reliable technique for excluding patients suspected of CAD [19, 20]. Several meta-analyses of 64-slice CT studies reported sensitivities and specificities ranging from 86% to 99% and 88% to 97%, respectively [21, 22]. These studies indicate that multi-slice cardiac CT, especially with 64 or more slice CT, has a high diagnostic accuracy for detection of CAD and could be used as an effective alternative to invasive coronary angiography in selected patients. Using both conventional coronary angiography and intravascular ultrasound (IVUS), the Leiden group were the first to confirm that the diagnostic performance of multi-slice CT angiography was superior in the evaluation of the presence or the absence of atherosclerosis when compared with the evaluation of significant stenosis [23]. Several studies have suggested that information about atherosclerosis derived from multi-slice CT coronary angiography may provide prognostic information [24, 25]. Interestingly, it was shown that the presence of a substantial non-calcified plaque burden was an independent predictor of events. As a result, CT coronary angiography has been proposed as a gatekeeper for invasive coronary angiography [26].

Currently, cardiac CT is mainly focussed on CT coronary angiography and current guidelines recommend CT angiography only for the exclusion of CAD [27]. The multi-slice CT scanning technique has improved significantly over the last decade, with acquisition of isotropic volume data in patients with high heart rate. Control of high heart rate with the use of beta-blocking agents is still commonly performed in many cardiac multi-slice CT examinations, including scans with the use of 320-slice CT or the dual source high-pitch spiral technique [28, 29]. Further improvements in temporal resolution will contribute to the elimination of the aggressive procedure of heart rate control in patients with a heart rate of more than 70 beats/min. New developments aim to establish a role for CT in the functional imaging of the heart beyond the mere visualisation of anatomy [30]. Technological advances now offer the possibility to assess myocardial perfusion and viability by cardiac CT and initial clinical studies could already show a diagnostic accuracy comparable with the established imaging modalities [31, 32]. Thus, cardiac CT may offer a combined approach of anatomical and functional imaging. Evaluation of the first-pass enhancement of the myocardium and CT-derived fractional flow reserve may have the potential to enhance the application of cardiac CT by providing the means to determine the haemodynamic relevance of coronary artery stenosis [33]. Another primary goal for cardiac CT is a 'snapshot image' of the entire heart in one single cardiac cycle, which can be obtained by using multi-slice CT systems with area detectors or dual-source CT systems with ECG-triggered high-pitch spiral [34]. Techniques to reduce the radiation dose to the patient, such as ECG-controlled dose modulation, ECG-triggered sequential CT, low kV scanning, and iterative reconstruction, have gained considerable attention as a consequence of the ongoing discussion on radiation exposure by CT [35–37].

Hybrid imaging with PET-CT and SPECT-CT integrating both functional and anatomic information yields a better diagnostic performance than stand-alone CT, SPECT or PET [38–41]. Apart from the detection of CAD per se, cardiac CT has shown its value in other patient groups: patients with myocardial bridging, patients with coronary artery stents to assess restenosis, patients with congenital heart disease to evaluate right ventricular volumes and function, patients scheduled for radiofrequency ablation for atrial fibrillation to assess cardiac venous anatomy, and patients with valvular lesions to calculate dimensions of the aortic root or the mitral valve annulus [42–54].

To summarise, multi-slice cardiac CT has revolutionised non-invasive cardiac imaging both by calcium scoring and coronary CT angiography. Cardiac CT allows early detection of coronary atherosclerosis allowing adequate risk stratification and the timely instalment of preventive strategies. Currently, the main asset of cardiac CT is the exclusion of coronary atherosclerosis in patients suspected for CAD. Future directions of multi-slice CT angiography in the diagnosis of CAD lie in three main aspects: improvement of temporal resolution, reduction of radiation dose and judicious use of multi-slice CT. The definite role of multi-slice cardiac CT in the diagnosis and management of patients with stable angina can only be established after the performance of high-quality randomised studies with clinical outcomes as a primary outcome [55, 56]. These studies should provide answers to the pivotal question of which patients benefit most from non-invasive coronary CT angiography and thus help to adequately select the right patients for this imaging procedure.

N.B. This Editor's comment highlights only a specific number of achievements in cardiac CT. For a more detailed description of the achievements by cardiac CT the reader is referred to more in-depth publications [57, 58].

Of note; it has been put forward that thoracic CT scanning was developed in the early 1970s through revenues from selling the Beatles' records by Electric and Musical Industries (EMI). Several individuals have defined this as the Beatles' gift to medicine [59]. *However, some controversies have arisen from analysis of this statement, making its correctness doubtful* [60]. *Whatever the truth, it keeps in public memory the name of the Beatles related to the development of CT scanning.*

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