European Journal of Radiology 82 (2013) e58–e63

Contents lists available at SciVerse ScienceDirect

European Journal of Radiology

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

Calcium score of small coronary calcifications on multidetector computed tomography: Results from a static phantom study

J.M. Groen[a], K.F. Kofoed[b], M. Zacho[b], R. Vliegenthart[a], T.P. Willems[a], M.J.W. Greuter[a,*]

[a] Department of Radiology, University of Groningen, University Medical Center Groningen, The Netherlands
[b] Department of Cardiology and Radiology, Rigshospitalet, University of Copenhagen, Denmark

ARTICLE INFO

Article history:
Received 22 July 2012
Received in revised form
24 September 2012
Accepted 30 September 2012

Keywords:
Computed tomography
Coronary calcium
Calcium score

ABSTRACT

Introduction: Multi detector computed tomography (MDCT) underestimates the coronary calcium score as compared to electron beam tomography (EBT). Therefore clinical risk stratification based on MDCT calcium scoring may be inaccurate. The aim of this study was to assess the feasibility of a new phantom which enables establishment of a calcium scoring protocol for MDCT that yields a calcium score comparable to the EBT values and to the physical mass.
Materials and methods: A phantom containing 100 small calcifications ranging from 0.5 to 2.0 mm was scanned on EBT using a standard coronary calcium protocol. In addition, the phantom was scanned on a 320-row MDCT scanner using different scanning, reconstruction and scoring parameters (tube voltage 80–135 kV, slice thickness 0.5–3.0 mm, reconstruction kernel FC11–FC15 and threshold 110–150 HU). The Agatston and mass score of both modalities was compared and the influence of the parameters was assessed.
Results: On EBT the Agatston and mass scores were between 0 and 20, and 0 and 3 mg, respectively. On MDCT the Agatston and mass scores were between 0 and 20, and 0 and 4 mg, respectively. All parameters showed an influence on the calcium score. The Agatston score on MDCT differed 52% between the 80 and 135 kV, 65% between 0.5 and 3.0 mm and 48% between FC11 and FC15. More calcifications were detected with a lower tube voltage, a smaller slice thickness, a sharper kernel and a lower threshold. Based on these observations an acquisition protocol with a tube voltage of 100 kV and two reconstructions protocols were defined with a FC12 reconstruction kernel; one with a slice thickness of 3.0 mm and a one with a slice thickness of 0.5 mm. This protocol yielded an Agatston score as close to the EBT as possible, but also a mass score as close to the physical phantom value as possible, respectively.
Conclusion: With the new phantom one acquisition protocol and two reconstruction protocols can be defined which produces Agatston scores comparable to EBT values and to the physical mass.

1. Introduction

Coronary calcium deposit is a powerful marker in screening studies for coronary artery disease (CAD) [1,2]. Therefore, the amount of coronary calcium is used as a risk stratification for a main cardiac event within the next 5 years [3]. However, a calcium score of zero cannot be interpreted as a reassurance of the absence of CAD [4–6]. Although the prognostic value of zero calcium is under debate, it is still related to a low cardiac risk event. Because small coronary calcifications can contribute significantly to a higher risk on a major adverse cardiac event, detection and a precise score of these small calcifications is therefore important.

Coronary calcifications were originally quantified by the Agatston score (AS) for patients who underwent electron beam computed tomography (EBT) [7]. Later, mass scoring (MS) was proposed as an alternative method because of a better reproducibility compared to the AS [8]. The majority of coronary artery disease studies used EBT as imaging modality because of its high temporal resolution [9–14]. However, the presence of EBT scanners has strongly diminished in recent years and patients are generally scanned on multi-detector computed tomography (MDCT) systems. Although EBT has almost become obsolete, clinical risk stratification is mostly still based upon EBT-acquired AS. Also, the recommendations from expert groups to substitute AS with MS has not yet let to the general acceptance of MS [15].

* Corresponding author at: University of Groningen, University Medical Center Groningen, Department of Radiology EB44, PO Box 30.001, 9700 RB Groningen, The Netherlands. Tel.: +31 50 3614712.
E-mail addresses: jaap.groen@slaz.nl (J.M. Groen), kkofoed@dadlnet.dk (K.F. Kofoed), dls332089@vip.cybercity.dk (M. Zacho), r.vliegenthart@umcg.nl (R. Vliegenthart), t.p.willems@umcg.nl (T.P. Willems), m.j.w.greuter@umcg.nl (M.J.W. Greuter).

0720-048X/$ – see front matter
http://dx.doi.org/10.1016/j.ejrad.2012.09.018

Table 1
Scanning, reconstruction and scoring parameters used on the EBT and MDCT system. FBP = filtered back projection.

EBT	
Scan parameters	
Tube voltage (kV)	130
Tube current (mA s)	~600
Acquisition time (ms)	50
Reconstruction parameters	
Slice thickness (mm)[a]	3.0
Increment (mm)[a]	3.0
Reconstruction kernel	Sharp
Reconstruction method	FBP
MDCT	
Scan parameters	
Tube voltage (kV)[b]	80, 100, 120, 135
Tube current (mA s)	200
Rotation time (ms)	350
Collimation (mm)	320 × 0.625
Reconstruction parameters	
Slice thickness (mm)[b]	0.5, 1.0, 1.5, 2.0, 2.5, 3.0
Increment (mm)[b]	0.5, 1.0, 1.5, 2.0, 2.5, 3.0[a]
Reconstruction kernel[b]	FC11, FC12, FC13, FC14, FC15
Reconstruction method	FBP
Scoring parameter	
Threshold (HU)[b]	110, 120, 130, 140, 150

[a] The increment was equal to the slice thickness.
[b] Parameters that were varied in a systematic way.

Whereas the temporal resolution of MDCT is lower than EBT, the spatial resolution is higher [16]. Although the two techniques seem very similar, standard MDCT calcium scoring protocols do not give the same results as EBT [17–25]. In general, MDCT is associated with a 2–10% underestimation of the AS compared to EBT [17]. For large, high density coronary calcifications this underestimation may have minor clinical implications. However, for small, low density coronary calcifications this underestimation can have a significant clinical implication, e.g. an impact on the estimated cardiovascular risk of the patient [26]. Therefore especially small amounts of coronary calcium should be measured accurately when using MDCT and with outcome similar to measures performed with EBT system in the individual patient. The aim of this study was to assess the feasibility of a new phantom which enables establishment of a calcium scoring protocol for MDCT that yields a calcium score comparable to the EBT values and to the physical mass.

2. Materials and methods

2.1. Phantom

A dedicated phantom was developed which contained 100 small cylindrical calcifications varying in size and density (Fig. 1a). The diameter and length of the calcifications was equal and ranged from 0.5 to 2.0 mm. The density of the calcifications ranged from 90 to 540 mg hydroxyapatite (HA) per cm^3. The phantom was inserted into a thorax phantom (QRM Thorax, QRM, Germany), which comprised of artificial lungs and a spine (Fig. 1b).

2.2. EBT, MDCT scanners

To establish a reference standard in terms of calcium scoring, the phantom was scanned on three EBT scanners (Imatron C300, GE, Milwaukee, USA). Data was acquired at a tube voltage of 130 kV, a tube current of approximately 600 mA s and a collimation of 3.0 mm. The data was reconstructed using a sharp kernel at a slice thickness of 3.0 mm and an increment of 3.0 mm, a standard calcium scoring protocol for EBT scanners (Table 1). Each scan was repeated five times with a small translation (2 mm) and/or rotation (2°) between each scan.

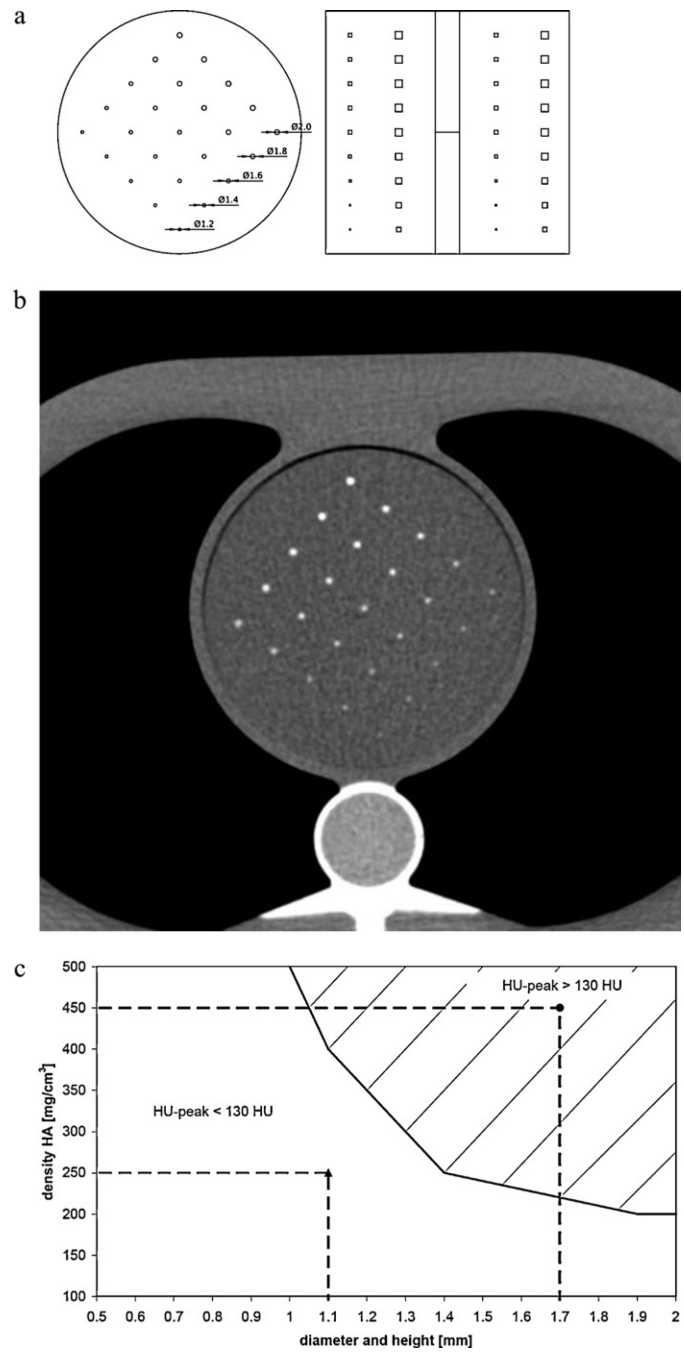

Fig. 1. (a) Schematic axial view of the phantom at one of the four planes containing 25 calcifications each (left), and schematic side view of the phantom showing the all four planes with calcifications (right). (b) Radiologic axial view of the phantom, the different calcifications are clearly visible. (c) Schematic drawing of the analysis method used. The border between detected and undetected calcification as determined by the reference method EBT is given by the visibility curve (isocurve for HU-peak = 130 HU). Two calcifications are given as example, one with a size of 1.1 mm and density of 250 mg HA (triangle) which is not detected and thus below the visibility curve, the other with a size of 1.7 mm and a density of 450 mg HA (circle) which is detected and thus above the visibility curve.

Next, the phantom was scanned with a 320-row MDCT scanner (Toshiba Aquilion ONE, Toshiba Medical Systems, Japan). Data was acquired in a single rotation with an axial scan field of view of 50 cm encompassing the whole phantom. The scan was performed sequentially at different tube voltages (Table 1). Each scan was