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Research article

# Diagnostic performance of coronary CT angiography with ultra-high-resolution CT: Comparison with invasive coronary angiography☆

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ABSTRACT

*Purpose:* Recently, ultra-high-resolution computed tomography (U-HRCT) with a 0.25 mm × 128-row detector was introduced. The purpose of this study was to evaluate the diagnostic performance of coronary CT angiography (CCTA) using U-HRCT.

*Methods:* This retrospective study included 38 consecutive patients with suspected coronary artery disease (CAD) who underwent CCTA with U-HRCT followed by invasive coronary angiography (ICA). Per-segment diameter stenosis was calculated. Diagnostic performance of CCTA relative to ICA as the reference standard was determined. For segments with > 30% diameter stenosis, the correlation and agreement of percent diameter stenosis between CCTA and ICA were calculated.

*Results:* Obstructive CAD was observed in 65 segments (12%) of 51 vessels (45%) in 32 patients (84%) during ICA. The per-patient, vessel, and segment analyses showed a sensitivity of 100% (95% confidence interval [CI], 95%–100%), 96% (95% CI: 89%–99%) and 95% (95% CI: 89%–98%), respectively, and a specificity of 67% (95% CI: 38%–67%), 81% (95% CI: 75%–83%) and 96% (95% CI: 96%–97%), respectively. The percentage of diameter stenosis, as determined by CCTA, demonstrated an excellent correlation with ICA (R = 0.90; 95% CI: 0.83–0.95) and a slight significant overestimation (mean: 4% ± 7%, $p < .01$), with the agreed range of limits being ± 16%. The median effective radiation dose for CCTA was 5.4 mSv (range: 2.9–18.0 mSv).

*Conclusions:* CCTA with U-HRCT demonstrated an excellent correlation and agreement with ICA in the quantification of coronary artery stenosis.

## 1. Introduction

Coronary computed tomography angiography (CCTA) has progressed substantially since the introduction of 64-row detector CT scanners. Previous multicenter trials and meta-analyses have demonstrated that CCTA has a high sensitivity and negative predictive value (NPV) to detect obstructive coronary artery disease (CAD) compared to invasive coronary angiography (ICA) as the reference standard [1–6]. In addition, wide-coverage detector CT beyond 64 detector rows, such as 320-row detector CT, has enabled volumetric whole-heart CCTA scanning with a lower radiation exposure and dose of an iodine contrast medium [7]. Furthermore, recent prospective multicenter trials have demonstrated that CCTA is clinically useful in patients with stable CAD as an alternative or in addition to functional testing [8,9]. However, in the last decade, the detector element of clinical CT scanners was 0.5–0.6 mm wide, and there has been no change in the minimum detector-element width to date. A recently developed ultra-high-resolution CT (U-HRCT, TSX-304R, Toshiba Medical Systems, Otawara, Japan) has 0.25 mm × 128-row detectors with 1792 channels [10]. Its X-ray tube has a focus size of 0.6 × 0.6 mm and a maximum output of 450 mA at 120 kV. Combined with 1024 × 1024 matrix image reconstruction, this U-HRCT scanner can obtain CT images with higher spatial resolution than conventional CT scanners. Using this new technology, we hypothesized that CCTA with U-HRCT would demonstrate a higher ability to diagnose CAD. The purpose of this study was to evaluate the performance of CCTA with U-HRCT for the diagnosis of

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obstructive CAD relative to ICA as the standard reference test.

## 2. Materials and methods

### 2.1. Patients

This retrospective, observational, single-center study was approved by an institutional review board. Informed consent for this retrospective analysis was waived by the institutional review board. The cohort included consecutive patients with suspected CAD who underwent CCTA with U-HRCT between November 2015 and August 2016, followed by ICA within 3 months after CCTA. The exclusion criteria were as follows: known CAD, history of ICA, history of coronary artery bypass grafting or stenting, suspected acute coronary syndrome, or young age (< 30 years). Moreover, patients with severe renal dysfunction (estimated glomerular filtration rate [eGFR] < 30 ml/min/1.73 $mm^2$), severe coronary artery calcification (Agatston score [11] > 2000) at the coronary calcium scoring, history of an allergic reaction to iodine contrast media, or suspected pregnancy were not referred for CCTA at our institution.

### 2.2. CT scanning protocol

All patients underwent two coronary CT examinations (coronary calcium scoring [11] and angiography), using a clinical prototype U-HRCT scanner (TSX-304R, Toshiba Medical Systems). Patient preparation and coronary CT scanning were performed based on the Society of Cardiovascular Computed Tomography (SCCT) guidelines [12,13]. All patients with moderate renal dysfunction (eGFR of 30–60 ml//min/1.73 $mm^2$) received 6 h of saline hydration before CT examination to prevent contrast-induced nephropathy. Coronary calcium scoring was performed with prospective electrocardiographic (ECG) gating axial scan at 75% of the RR interval, with 120 kV tube voltage and a 300-mA tube current. All patients were administered nitroglycerin to increase the diameter of the coronary arteries. Patients with a heart rate > 65 beats/min (bpm) received intravenous beta-blockers (landiolol hydrochloride of 0.125 mg/kg × body weight [kg]), and CCTA scanning was performed 5–7 min after the intravenous administration. The CCTA scans were performed at 120 kV (or 100 kV in 2 patients with a body mass index < 22 $kg/m^2$ and Agatston score [11] < 400) with a collimation of 128 × 0.25 mm. A gantry rotation time at which temporal resolution was high was used based on a pitch. The tube current was determined based on the targeted image noise of 28 HU (i.e., the standard deviation [SD] of attenuation values in the region of interest [ROI] in the ascending aorta). A prospective ECG gating helical scan with an acquisition window of 35%–80% or 65%–80% of the RR interval was used for patients with a heart rate of > 65 or ≤65 bpm, respectively. A retrospective ECG gating helical scan was used for patients with arrhythmia or those who could not sufficiently hold their breath.

Contrast medium containing 370 mg/ml of iodine (Iopamiron 370: Bayer, Osaka, Japan) was administered at 0.070 ml/s/kg × body weight (kg), followed by a 35 ml saline flush that was delivered via a 20-gauge intravenous catheter placed in the right antecubital vein using a double-headed power injector (Dual Shot-Type GX7; Nemoto-Kyorindo, Tokyo, Japan). The injection time of the contrast medium was calculated as the scan time of CCTA + 5 s. Scanning delay was determined using a computer-assisted bolus tracking system (SureStart, Toshiba Medical Systems, Otawara, Japan). We identified a ROI within the ascending aorta at the level of bifurcation of the pulmonary artery, and established the trigger threshold in the ROI at 150 HU. Subsequent to triggering, image acquisition began automatically at 5 s.

We recorded all adverse events associated with the CT examination and reviewed the patients' medical records. Both the volumetric CT dose index ($CTDI_{vol}$) and dose-length product (DLP) were recorded for each patient. The corresponding effective radiation dose was calculated using a standard conversion factor of 0.014 mSv/mGy cm for chest CT [14].

### 2.3. CT image reconstruction

An experienced cardiovascular CT technician determined the optimal stationary cardiac phase from the available scanning data. All helical CT data were reconstructed with a smooth kernel (FC13) using the hybrid iterative reconstruction (IR) technique (Adaptive Iterative Dose Reduction 3D; AIDR 3D, Toshiba Medical Systems) at a thickness of 0.25 mm with 0.25 mm increments in the axial plane. An axial field of view of 200 × 200 $mm^2$ with an imaging matrix of 1024 × 1024 pixels was used. Thus, we acquired three-dimensional volume data sets of 0.20 × 0.20 × 0.25 $mm^3$. To objectively evaluate the quality of CCTA images, we measured attenuation values (HU) of the ascending aorta at the level of pulmonary bifurcation. Image noise was defined as SD of the attenuation values at the ROI located in the ascending aorta.

### 2.4. Invasive coronary angiography

Experienced cardiovascular physicians with more than 8 years of experience performed all selective ICA scanning using the standard Judkins technique, with a radial approach on a biplane angiography system (AlluraClarity FD10/10, Philips Electronics Japan, Tokyo Japan). Contrast medium was administered using an automated injection system (ACIST Cvi, ACIST Japan, Tokyo, Japan). The injection volume of contrast medium was 6.2 ml for the left coronary angiography, and 5.4 ml for the right coronary angiography. We recorded the total amount of contrast medium and all adverse events associated with the ICA procedure. The dose-area product (DAP, Gy $cm^2$) was recorded for all ICA procedures, and the corresponding effective radiation dose was calculated using a conversion factor of 0.185 mSv/Gy $cm^2$, as previously described [15].

### 2.5. Assessment of coronary artery stenosis

Two independent and blinded observers (RT with more than 20 years of experience and HT with 8 years of experience) evaluated the CCTA images and calculated the per-segment percent diameter stenosis based on the 18-segment SCCT model [16]. A dedicated CCTA application that allowed automatic creation of angiographic-view images (maximum intensity projection) and curved planar reformation along the coronary arteries on a prototype workstation compatible with the analysis of the 1024 × 1024 matrix images (ZIOSTATION 2, Ziosoft, Tokyo, Japan) was used. For each coronary segment, proximal and distal reference sites were manually selected to be the most adjacent points to the maximal stenosis in which there was minimal or no plaque. The reference diameter was automatically calculated using a linear regression fit on the lumen diameter. Minimal lumen diameter was manually selected and calculated as the average of the short and long diameter at the site of the maximal stenosis. From these geometric variables, percent diameter stenosis was automatically calculated as: (1 − minimal lumen diameter/corresponding reference diameter) × 100%.

The ICA images were evaluated by another blinded observer (KN with 6 years of experience) and HT independently using image quantification software (Medis Medical Imaging Systems, Leiden, the Netherlands) based on 18-segment SCCT model as follows [16]. Image calibration was performed in an end-diastolic frame with a catheter diameter of 4 or 5F. The semi-automated edge-detection software then traced the lesion contours and determined the reference vessel diameter and luminal diameter at maximal obstruction. The proximal and distal limits of the lesion corresponding to the sites of minimal luminal encroachment were automatically defined as the reference. The reference diameter was obtained from a linear regression fit on the lumen diameter similar to the CCTA analysis (Fig. 1). At the site of the minimal