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RESEARCH ARTICLE

Diagnostic Accuracy of Dual-Energy CT Coronary Angiography for Coronary Stenosis Detection: A Comprehensive Study of Demographics and Comorbidities

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Abstract Dual-energy computed tomography coronary angiography is a non-invasive method for diagnosing coronary artery disease. Few studies have compared this technique with invasive coronary angiography in Malaysia. This study assessed the accuracy of 128-slice, single-source dual-energy computed tomography coronary angiography compared with invasive coronary angiography in detecting coronary artery stenosis and evaluated the demographics and comorbidities of patients undergoing these procedures. Thirty-five participants underwent both procedures at a private Malaysian medical facility. Two independent radiologists evaluated the diagnostic accuracy for sensitivity, specificity, positive and negative predictive values, and area under the curve. Coronary artery disease was most prevalent in males aged 51-60, with hypercholesterolaemia (85.7%) and hypertension (57.1%) as common comorbidities. Dual-energy computed tomography coronary angiography showed high sensitivity (82.61%–87.50%), specificity (75.00%–90.48%), positive predictive value (82.35%–90.48%), and negative predictive value (69.23%–88.89%) for detecting stenoses in major coronary arteries. AUC values (0.79–0.88) indicated strong diagnostic accuracy. This study demonstrated that dual-energy computed tomography coronary angiography is an effective non-invasive technique for diagnosing coronary artery stenosis, comparable to invasive coronary angiography. Future studies should optimise scanning protocols for dual-energy computed tomography coronary angiography or investigate its cost-effectiveness in clinical practice.

Keywords: Coronary artery disease, computed tomography angiography, invasive coronary angiography, dual-energy CT, diagnostic accuracy.

Introduction

Coronary artery disease (CAD) ranks among the principal causes of death worldwide, with an especially elevated incidence in Malaysia. Globally, CAD contributed to 17.9 million deaths worldwide in 2019 [1], whereas in Malaysia it was responsible for 18,557 deaths in 2020 [2], with the most recent reliable statistics available at the time of this study being from 2021. Stenosis is among the most prevalent disorders in CAD and is an important marker of heart attack and other cardiovascular events [3]. The coronary arteries need to be assessed carefully for the accurate diagnosis and management of CAD. Studies have shown that computed tomography coronary angiography (CTCA) can identify coronary structural anomalies and pre-clinical arterial disease in individuals with a normal treadmill stress test but with typical angina chest pain [4, 5].

With the non-invasive nature of CTCA and its ability to provide in-depth information on the coronary arteries, its use has been steadily increasing in Malaysia. Because of this advantage, in recent years, non-invasive imaging methods like Dual-energy computed tomography coronary angiography (DECTCA) to detect coronary plaque have a rise in development. Although invasive coronary angiography (ICA), in most cases, may not easily show plaque composition and extraluminal plaque components, the use of DECTCA has shown the potential to detect these abnormalities [6]. Few studies

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have examined the effectiveness of DECTCA in accurately diagnosing CAD compared with ICA among Malaysian patients. The majority of research has shown that CTCA exhibits high diagnostic precision in patients regardless of prior coronary artery interventions [7]. Another study in 2022 suggested that CTCA exhibited a high degree of sensitivity and specificity for detecting coronary artery stenosis (CAS), including individuals who underwent both ICA and CTCA [8]. All these studies mentioned only general CTCA, regardless of whether they used DECTCA.

CTCA is more than just a stepping stone in the evaluation of CAD and has several benefits compared to ICA as an imaging modality. In addition, recent advances in technology have transformed CTCA, enabling image acquisition with proportionately lower radiation dosages [9, 10]. Age, sex, hypertension, and hypercholesterolaemia are important demographic factors and comorbidities that can have a significant impact on CAD incidence and diagnostic performance of DECTCA and ICA [11]. Research has also demonstrated that some demographic groups have a higher prevalence of CAD, like in older men, for example [12]. In the past, research has emphasised the disparities in accuracy between DECTCA and ICA. DECTCA demonstrated exceptional accuracy in identifying myocardial ischaemia, achieving a sensitivity of 84%, specificity of 94%, and overall accuracy of 92%, proving the viability of the results of a study conducted in 2008 [13]. Another study in 2011 showed the same results, with high sensitivity (90%) and specificity (86%), with an accuracy of 88% for identifying substantial coronary stenosis [14]. Variability in the accuracy of DECTCA might be explained by factors including patient selection and technical aspects.

We designed this study to gauge the precision of 128-slice single-source DECTCA compared with ICA for stenosis detection in patients referred for both examinations. This study hypothesises that, similar to ICA, DECTCA would have high accuracy for diagnosing coronary artery stenosis. Demographic and comorbidity data of patients included in this study were also evaluated. Given that the use of DECTCA for the evaluation of CAD is a novel and trajectory-inducing diagnostic modality, these findings may be important for healthcare providers, including radiologists and cardiologists, who are considering using it. This study follows the DECTCA experience of a single institution, which could enhance the effective care and treatment of patients with suspected CAD, and offers support for the use of DECTCA as an alternative diagnostic option.

Materials and Methods

Study Design and Population

This was a retrospective cohort study design. In this study, we compared the accuracy of DECTCA with that of ICA for detecting CAD. ICA was used as a benchmark to assess the accuracy of DECTCA. The final sample size was set to 35.

Inclusion and Exclusion Criteria

The inclusion requirements were 35 patients diagnosed with symptomatic CAD who underwent both DECTCA and ICA at the study institution in 2020. Patients aged 40-80 years with symptomatic CAD and at least one stenotic vessel were included if both procedures were completed within six months. Patients with comorbid conditions such as hypertension, hypercholesterolaemia, or diabetes were also included, provided they met the other inclusion criteria. Exclusion criteria were a calcium score >600, prior coronary artery bypass graft surgery (CABG), poor image quality due to arrhythmias, or significant renal dysfunction (eGFR <30 ml/min), or any condition that could interfere with the imaging procedures or interpretation of results.

Data Collection

Authorisation was secured from the hospital authorities to access data from the Picture Archiving and Communication System (PACS). The DECTCA procedure used a 64-detector, double-sampling to obtain 128 slices, a Somatom Definition Edge dual-energy helical CT scanner (Siemens Healthineers, Germany), and the triphasic IV contrast infusion method. Images were obtained with ECG-triggered 12-second breath-holds. 3D volume-rendered reconstructions assessed coronary artery architecture and significant narrowing, adhering to the Society of Cardiovascular Computed Tomography (SCCT) 2014 standards. Segments were classified as normal (0% narrowing), minimal (<25%), mild (25%-49%), Moderate (50%-69%), Severe (70%-99%) and occluded [15]. ICA was conducted using a Shimadzu Bransist Alexa single-plane C-arm system (Shimadzu Corporation, Japan), capturing images at 15 frames per second using a routine femoral or radial artery approach. Coronary segments ≥1.5 mm in diameter were evaluated visually and quantitatively using quantitative coronary angiography (QCA) software. We used six months to complete data collection.

The DECTCA and ICA images collected from 35 patients were individually evaluated by a pair of radiologists who were uninformed of the patients' personal information, medical backgrounds, and outcomes of the other imaging techniques. After completing all requisite fields, the radiologists selected the most appropriate response for each item from the following options: 'Normal,' 'Minimal,' 'Mild,' 'Moderate,' 'Severe,' and 'Occluded.' For statistical analysis, only segments classified as moderate, severe and occluded were considered obstructive coronary artery segments. Each radiologist reviewed an identical set of DECTCA and ICA images on three separate occasions, with one-week intervals between each review, to assess intra and inter-observer reliability.

Statistical Analysis

The diagnostic efficacy of DECTCA and ICA in the analysis of diagnostically relevant coronary artery narrowing was evaluated using various statistical measures. These included sensitivity, specificity, positive and negative predictive values, and total diagnostic precision, all accompanied by 95% confidence intervals (CI). The analysis was conducted separately for each vessel and individual patient. The demographic data of the selected patients were analysed descriptively using frequencies and percentages. Statistical significance was set at a p-value less than 0.05 ($p<0.05$), with all p-values being two-sided. The Statistical Package for Social Science (SPSS) software version 26 was employed to perform the statistical analyses.

Ethical Clearance

The study was approved by the KPJUC Research Ethics Committee (KPJUC/RMC/SOHS/EC/2020/298). All patient data were anonymised to ensure confidentiality.

Results and Discussion

Descriptive Analysis

Data on patients admitted to the hospital with CAD were collected for one year. Based on the predefined inclusion and exclusion criteria, data from 35 patients were selected for the study. In this investigation, participants were divided into four distinct age brackets: 30-40 years (group 1), 41-50 years (group 2), 51-60 years (group 3), and 61-70 years (group 4). Most patients fell into group 3, with 13 patients accounting for 37.1% of the total. The age range with the second highest number of patients was group 2, accounting for 11 (31.4%) patients. Group 4 had the lowest number of patients, with four (11.4%). Only seven (20.0%) patients were in the 30-40 age range (n=35). There were 27 (77.1%) male and 8 (22.9%) female patients. The findings indicated that men were more susceptible to developing coronary artery disease (CAD).

The results revealed notable trends in age and sex distribution regarding the occurrence of CAD, as most patients were within the age range of 51 to 60 years and found a significantly higher proportion of male predominance, which aligns with the results of multiple previous studies, such as a comprehensive review study by Mumcu A *et al*. (2023), which revealed a similar age and sex distribution emphasising the prevalence of CAD in older males [16, 17]. The empirical consistency observed in demographic trends across the sample population improves the reliability and generalisability of the research outcomes. Moreover, these results strengthen the existing knowledge about the demographic risk profiles associated with CAD. Sharing these findings with a wider range of medical professionals, such as radiologists and heart specialists, could offer valuable perspectives on the effectiveness of DECTCA in evaluating and managing CAD. Unlike investigations that focus on technical details or precision, this study highlights the utility of DECTCA across various patient populations, shedding light on its diagnostic capabilities among different age groups and genders.

Analysis of patient comorbidities using descriptive statistics revealed that hypercholesterolaemia was the primary cause of CAD, affecting 30 (85.7%) patients, with hypertension being the second most common factor in 20 (57.1%) cases. Only 10 (28.6%) patients had a history of CAD, whereas 15 (42.9%) had diabetes. Referring to our study values, the predominant causes of CAD were hypercholesterolaemia and hypertension, with hypercholesterolaemia being the most prevalent. A previous CAD history and diabetes were not found to be significant contributors to CAD. These results are consistent with those of Tserioti E *et al*. (2023) and Ge *et al*. (2018), who identified hypertension as the main predictor of CAD, especially in patients experiencing chest pain [18, 19]. Additionally, Amerizadeh *et al*. (2022) and Aparicio *et al*. (2023) reported a high occurrence of familial hypercholesterolaemia among patients with early-onset CAD [20, 21].

Intra and Inter-Observer Reliability of DECTCA and ICA for Detecting Major Coronary Artery Obstructions

The intra-observer reliability (ICC) of DECTCA and ICA for detecting major coronary artery obstructions was assessed. The same set of DECTCA and ICA images was independently interpreted by two radiologists three times. For DECTCA images, the first radiologist exhibited excellent reliability, with ICCs of .919 (95% CI [.863, .955]) for single measures and .971 (95% CI [.950, .985]) for average measures. The analysis showed $F(34,68) = 36.000$, $p < .001$, and a standard error of measurement (SEM) of approximately 0.403. The second radiologist also showed good-to-excellent reliability for DECTCA images, with ICCs of .803 (95% CI [.687, .887]) for single measures and .924 (95% CI [.868, .959]) for average measures, $F(34,68)=13.158$, $p<.001$, and an SEM of approximately 0.610. On the other hand, both radiologists demonstrated excellent intra-observer reliability for ICA, with identical ICC values of .959 (95% CI [.931, .978]) for single measures and .986 (95% CI [.976, .993]) for average measures. The SEM was approximately 0.3656 for both radiologists ($F(34,68)=71.941$, $p<.001$).

Inter-observer reliability was assessed by comparing the most frequent observations from the three readings by each radiologist. The DECTCA and ICA results were identical for both radiologists. The calculated ICC for inter-observer reliability was 1.00 for both DECTCA and ICA demonstrated perfect agreement between radiologists in evaluating major coronary artery segments.

Accuracy of DECTCA

The accuracy of DECTCA compared to that of the gold standard ICA was evaluated. Based on the radiology analysis report from the evaluators, the data were arranged according to the occurrence of stenosis in the segments of the right coronary artery (RCA), left anterior descending (LAD), and left circumflex (LCx). The imaging results in Figure 1 show the different coronary artery assessment scenarios.

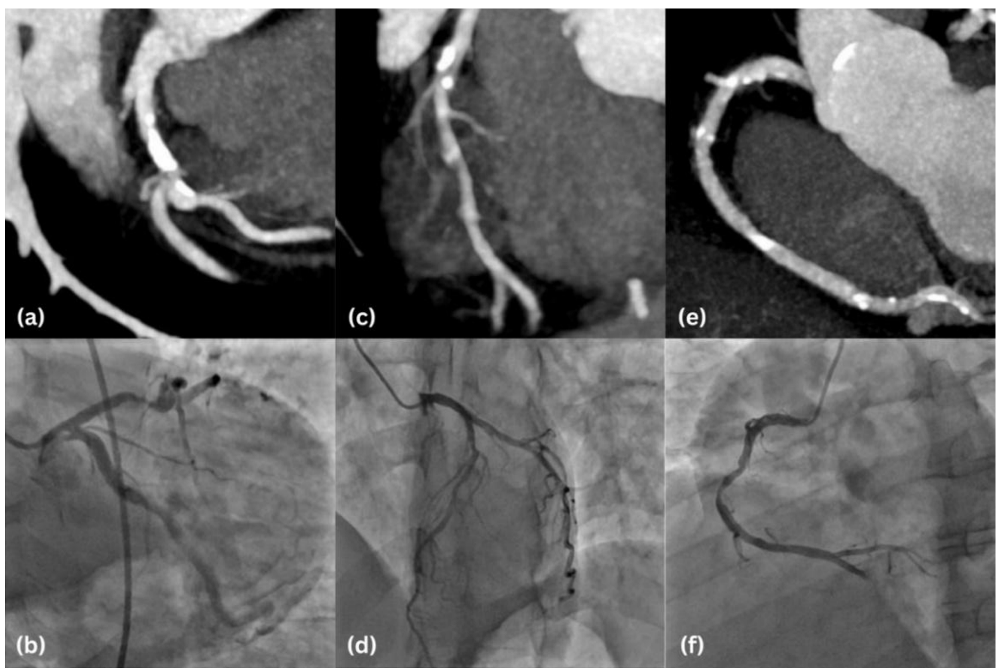

Figure 1. Illustrative cases of coronary artery imaging results. (a) A true-positive situation in which CTA shows severe stenosis in the proximal left circumflex artery, confirmed by ICA (b). (c) Typical case of false-positive angiography, where CTA identifies stenosis in the proximal left anterior descending artery, but (d) ICA shows no significant stenosis. (e) A case of false-negative angiography in which CTA showed no significant stenosis, whereas (f) ICA revealed considerable stenosis in the middle of the right coronary artery

Table 1 summarises the vessel-based analysis of DECTCA compared with ICA, outlining the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), likelihood ratios (LR+ and LR-), accuracy, chi-square values, degrees of freedom, *p*-values, and area under the curve (AUC) for the RCA, LAD, and LCx segments.

Table 1. Vessel-based analysis of DECTCA coronary angiography compared to ICA

Index	RCA	LAD	LCx
Sensitivity (%)	82.61	85.71	87.50
Specificity (%)	75.00	90.48	84.21
PPV (%)	86.36	85.71	82.35
NPV (%)	69.23	90.48	88.89
LR+	3.30	9.00	5.54
LR-	0.23	0.16	0.15
Accuracy (%)	80.00	88.57	85.70
χ^2	11.21	20.32	17.89
df	1	1	1
p	0.000**	0.000**	0.000**
AUC	0.79	0.88	0.86

DECTCA detected 22 obstructive segments of the RCA, whereas ICA detected 23 obstructive segments of the RCA (n=35). DECTCA had a sensitivity of 82.61% (95% CI: 61.2%, 95.1%), specificity of 75.00% (95% CI: 42.8%, 94.5%), positive predictive value (PPV) of 86.36% (95% CI: 70.0%, 94.5%), and negative predictive value (NPV) of 69.23% (95% CI: 46.6%, 85.3%). The positive likelihood ratio (LR+) was 3.30 (95% CI: 1.2, 9.0), and the negative likelihood ratio (LR-) was 0.23 (95% CI: 0.1, 0.6). The chi-square statistic was 11.21 ($p < 0.001$). Overall, DECTCA demonstrated good accuracy (80%).

Both the DECTCA and ICA detected 14 obstructive LAD segments (n=35). The DECTCA had a sensitivity of 85.71% (95% CI: 57.2%, 98.2%), a specificity of 90.48% (95% CI: 69.6%, 98.8%), a PPV of 85.71% (95% CI: 61.2%, 95.8%), and a NPV of 90.48% (95% CI: 72.3%, 97.2%). The LR+ was 9.00 (95% CI: 2.4, 34.2), and the LR- was 0.16 (95% CI: 0.04, 0.6). The chi-square statistic was 20.32 ($p < 0.001$). With all the above measurements, the calculated accuracy of DECTCA was 88.57%.

Seventeen segments of the LCx were obstructed. Our study accurately detected it using DECTCA. But, ICA detected only 16 obstructive segments (n=35). The DECTCA had a sensitivity of 87.50% (95% CI: 61.65%, 98.5%), a specificity of 84.21% (95% CI: 60.4%, 96.6%), a PPV of 82.35% (95% CI: 61.9%, 93.1%), and a NPV of 88.89% (95% CI: 68.3%, 96.7%). The LR+ was 5.54 (95% CI: 1.9, 15.09), and the LR- was 0.15 (95% CI: 0.04, 0.6). The chi-square statistic was 17.89 ($p < 0.001$). The DECTCA demonstrated 85.7% of accuracy.

Figure 2 presents the ROC for the RCA, LAD, and LCx. The curves highlight the accuracy of DECTCA in distinguishing patients with and without significant stenosis. The AUC values further illustrate the diagnostic performance of DECTCA across all three major coronary artery segments.

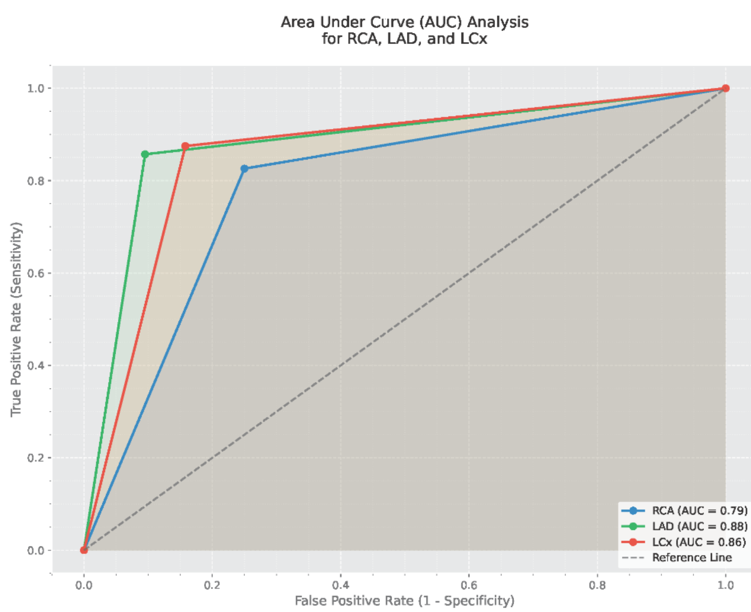

Figure 2. Receiver Operating Characteristic (ROC) curves for DECTCA versus ICA for detecting coronary artery stenosis

In this study, DECTCA demonstrated high performance in detecting obstructive RCA, LAD, and LCx segments. The sensitivity range of 82.61% to 87.50% and a specificity ranging from 75.00% to 90.48% show its effectiveness in accurately detecting obstructed segments. These results align with and even surpass those of a previous study, which reported a segment-wise sensitivity of 70.4% and specificity of 86.4%[22].

It is important to elucidate the remarkable predictive accuracy of DECTCA. The vessel-based analysis in this study demonstrated a PPV between 82.35% and 90.48% and an NPV between 69.23% and 88.89%, with an accuracy ranging from 80% to 88.57%. These remarkable results indicate that DECTCA can be used as a diagnostic method and warrant further research. In addition, the positive and negative likelihood ratios indicated that DECTCA could significantly increase the probability of CAD presence or absence. To the best of our knowledge, very few studies have compared the accuracy of DECTCA specifically with ICA. The majority of available research focuses on comparing general CTCA with ICA. In this study, we specifically compared the dual-energy CTCA. A recent study using 128-slice DECTCA demonstrated its high precision with a high PPV and NPV of 100% and 94.4%, respectively, and an accuracy ranging from 90.9% to 95.6% [22]. Moreover, our findings with AUC values ranged from 0.79 to 0.88. reinforces the accuracy of DECTCA for detecting CAD.

The outcomes of this study will further expand the advancement of knowledge in the medical imaging field by providing additional evidence supporting the clinical efficacy of DECTCA in the assessment of patients with CAD. Furthermore, DECTCA is non-invasive, unlike ICA, which is more invasive. This makes DECTCA essential for the diagnosis of CAD in high-risk patients. Therefore, DECTCA can be used as a primary tool for the early detection of coronary artery disease. However, this study has certain limitations that should be acknowledged. The sample size, though sufficient for preliminary analysis, may limit the generalisability of the findings, and future multi-centre studies with larger cohorts are recommended to validate these results. Additionally, the lack of comparison with single-energy CCTA is another limitation, as such a comparison could have provided further insights into the relative performance of DECTCA. Unfortunately, we did not have access to single-energy CCTA data for all included patients. Future research should focus on refining DECTCA protocols, evaluating its cost-effectiveness in routine clinical practice, and conducting comparative studies with single-energy CCTA to further elucidate its diagnostic advantages and limitations. Additionally, future studies should explore the optimisation of radiation and contrast doses, as these aspects are crucial for enhancing the clinical utility and safety of DECTCA in routine practice.

Conclusions

According to our study, CAD can be accurately detected using DECTCA, which is almost the same as the gold standard ICA method. It showed high sensitivity (82.61% to 87.50%) and specificity (75.00% to 90.48%) compared with ICA for identifying obstructive RCA, LAD, and LCx segments. This study highlights hypercholesterolaemia and hypertension as the most significant CAD risk factors, emphasising the need for targeted prevention and early intervention in populations with higher prevalence. However, this study has certain limitations, including a relatively small sample size, a single-hospital setting, and the use of only one DECTCA machine model, which may affect the generalisability of the findings. Additionally, the lack of comparison with single-energy CCTA and the absence of data on radiation and contrast dose optimisation are notable limitations. Future research should focus on multi-centre studies with larger cohorts, comparative analyses with single-energy CCTA, and the optimisation of radiation and contrast doses to enhance patient safety and cost-effectiveness. These efforts will further refine DECTCA protocols and improve its clinical utility in the diagnosis and management of CAD.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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