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Original Article

Comparative Assessment of Coronary CT Angiography and Invasive Coronary Angiography for Non-Invasive Coronary Artery Disease Detection

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Abstract:

Background: Coronary artery disease (CAD) is a leading cause of morbidity and mortality, necessitating accurate, early diagnosis. Invasive coronary angiography (ICA) remains the gold standard for detecting significant stenosis, but it carries procedural risks. Coronary computed tomography angiography (CCTA) has emerged as a non-invasive alternative, providing high-resolution imaging with lower risk. This study evaluates the diagnostic accuracy, clinical utility, and safety of CCTA compared to ICA.

Material and Methods: A prospective observational study was conducted over 24 months at a tertiary care center. A total of 450 patients with suspected stable CAD underwent CCTA, followed by ICA if clinically indicated. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of CCTA were assessed using ICA as the reference standard. Secondary outcomes included plaque characterization, radiation exposure, contrast-induced nephropathy, and major adverse cardiovascular events (MACE) at six-month follow-up. Statistical analyses included receiver operating characteristic (ROC) curve analysis, inter-reader agreement using Kappa statistics, and Kaplan-Meier survival analysis.

Findings CCTA demonstrated a sensitivity of 94.6%, specificity of 87.3%, PPV of 93.4%, and NPV of 89.1%, with an overall accuracy of 91.3% for detecting significant stenosis (≥50%). The ROC curve analysis yielded an AUC of 0.91, confirming excellent diagnostic performance. Radiation exposure was significantly lower in the CCTA group (5.2 ± 1.3 mSv) compared to ICA (7.8 ± 2.1 mSv, $p < 0.01$). MACE rates at six months were similar between groups (6.9% for CCTA vs. 8.9% for ICA, $p = 0.58$), demonstrating comparable long-term clinical outcomes. CCTA is a reliable non-invasive alternative to ICA, with high sensitivity, reduced radiation exposure, and comparable clinical outcomes. While CCTA may slightly overestimate stenosis in heavily calcified arteries, advancements in AI-assisted interpretation and FFR-CT may further refine its diagnostic accuracy. Given these findings, CCTA should be considered a first-line imaging modality for stable CAD evaluation, particularly in intermediate-risk patients

Keywords: Coronary artery disease, CT coronary angiography, Invasive coronary angiography, Diagnostic accuracy, Non-invasive imaging, Cardiovascular risk stratification, Major adverse cardiovascular events, Fractional flow reserve computed tomography (FFR-CT).

Introduction

Coronary artery disease (CAD) continues to be a leading contributor to morbidity and mortality across

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the globe, emphasizing the necessity for early and precise diagnostic interventions to enhance clinical outcomes. Conventionally, invasive coronary angiography (ICA) has been regarded as the gold standard for evaluating coronary artery stenotic lesions. However, the utilization of ICA entails procedural risks, such as vascular complications, contrast-induced nephron-pathy, and radiation exposure.[1]

As a less invasive alternative, coronary computed tomography angiography (CCTA) has emerged as a valuable imaging modality, offering detailed visualization of coronary arteries while posing minimal risk to patients.[2] The diagnostic precision of CCTA has witnessed notable improvements with advancements in multi-detector CT technology, particularly with the integration of 64-slice, dual-source, and photon-counting CT scanners.[3]

Extensive multicenter investigations, including the SCOT-HEART trial, have underscored the clinical utility of CCTA in guiding cardiovascular risk assessment and reducing myocardial infarction incidence.[4] Beyond luminal stenosis detection, CCTA aids in plaque characterization and coronary artery remodeling evaluation, making it instrumental for risk stratification.[5] Despite these advantages, CCTA is not without limitations, as it remains associated with radiation exposure, occasional overestimation of stenosis, and lower specificity in cases with extensive arterial calcification.[6]

Nonetheless, meta-analytic evaluations indicate that CCTA exhibits a sensitivity exceeding 90% for detecting clinically significant coronary artery stenosis, particularly in contrast with ICA, reinforcing its role as a highly effective non-invasive diagnostic tool for CAD detection in low-to-intermediate risk individuals.[7] Additionally, CCTA has been incorporated into international guidelines, notably those set forth by the European Society of Cardiology (ESC) and the American College of Cardiology (ACC), as the preferred first-line imaging modality for stable chest pain evaluation.[8]

Emerging technological innovations, including artificial intelligence (AI)-enhanced interpretation and fractional flow reserve computed tomography (FFR-CT), have further refined the diagnostic capabilities of CCTA.[9] These advancements allow functional assessment of coronary lesions, minimizing the necessity for invasive procedures while ensuring that clinically significant stenotic lesions receive timely intervention.[10]

With an increasing body of evidence substantiating the reliability of CCTA as a non-invasive alternative to ICA, this study seeks to comparatively evaluate the diagnostic accuracy, strengths, and limitations of both imaging modalities. Through this comparative assessment, the research aims to optimize diagnostic strategies for CAD and enhance patient care pathways.

Material and Methods

Study Design: This prospective observational investigation was conducted over a 24-month duration (January 2023 – December 2024) at a tertiary-level academic hospital specializing in cardiovascular care. The primary objective of this study was to analyze the diagnostic precision, clinical applicability, and safety of Coronary Computed Tomography Angiography (CCTA) and Invasive Coronary Angiography (ICA) in detecting clinically significant coronary artery disease (CAD). By evaluating these imaging techniques, the research sought to determine whether CCTA could function as a viable, non-invasive alternative to ICA for CAD assessment.

Participants: Study participants were recruited from both outpatient cardiology clinics and inpatient settings, in adherence to predetermined inclusion and exclusion criteria. Eligible individuals were between 35 and 80 years old, exhibiting symptoms indicative of stable CAD, with a moderate-to-high pre-test likelihood, as defined by the European Society of Cardiology (ESC) and the American College of Cardiology (ACC/AHA) guidelines. Exclusion criteria encompassed individuals with a history of prior coronary revascularization procedures, including Percutaneous Coronary Intervention (PCI) or Coronary Artery Bypass Grafting (CABG), as well as those with severe chronic kidney disease (eGFR <30 mL/min/1.73m^2), given the heightened risks associated with contrast administration. Further exclusion factors comprised documented hypersensitivity to iodinated contrast agents, pregnancy, lactation, and the presence of acute coronary syndromes necessitating urgent intervention.

Ethical Considerations: Prior to enrollment, all study participants provided written informed consent, and the research protocol received institutional ethical clearance. This study was conducted in strict adherence to the principles outlined in the Declaration of Helsinki, ensuring compliance with established ethical standards in patient confidentiality and data protection.

Data Collection: A comprehensive dataset encompassing both clinical and imaging-related parameters was gathered using electronic medical records (EMR) and structured case report forms (CRF). The dataset incorporated demographic variables (e.g., age, sex, body mass index (BMI), smoking history, and past medical conditions), in addition to clinical symptoms and cardiovascular risk determinants such as angina classification, family history, and past cardiovascular events. Additionally, laboratory markers—including lipid profile, HbA1c, and renal function indices—were systematically recorded. Imaging parameters encompassed coronary artery calcium scoring (CACS), plaque morphology, and quantitative stenosis assessment. Procedural metrics, including contrast volume administered, radiation exposure levels, and documentation of procedure-related complications, were meticulously recorded for both CCTA and ICA.

Imaging Techniques: All participants initially underwent Coronary Computed Tomography Angio graphy (CCTA), followed by Invasive Coronary Angiography (ICA) within two weeks if significant CAD was suspected.

Coronary CT Angiography (CCTA).

CCTA was conducted using a 256-slice multi-dete ctor CT scanner with ECG-gated contrast-enhanced imaging, facilitating optimal visualization of coro nary arteries. A standardized imaging protocol was implemented, including pre-procedural adminis tration of beta-blockers and sublingual nitroglycerine to achieve a target heart rate below 65 beats per min ute.

The classification of coronary stenosis severity was structured into three categories:

- Mild (<50%),
- Moderate (50–70%), and
- Severe (>70%).

Additionally, plaque morphology was categorized as soft, fibrous, or calcified, based on attenuation characteristics.

Invasive Coronary Angiography (ICA)

ICA was performed using biplane fluoroscopy, with contrast administered via femoral or radial arterial access. The degree of coronary stenosis was graded according to the SYNTAX score, while functional significance was determined using fractional flow res erve (FFR) analysis when required.

For cases indicating severe obstructive CAD, imme diate intervention was performed using either:

- Percutaneous Coronary Intervention (PCI), or
- Coronary Artery Bypass Grafting (CABG).

To ensure interpretation consistency, all imaging outc omes were independently reviewed by two blinded cardiologists. Any discrepancies were resolved thr ough consensus discussions involving a senior interventional cardiologist.

Outcome Measures

The primary outcome of this study was to assess the diagnostic accuracy of CCTA in detecting ≥50% coro nary stenosis, with ICA serving as the reference stan dard. This evaluation involved the calculation of:

- Sensitivity,
- Specificity,
- Positive Predictive Value (PPV), and
- Negative Predictive Value (NPV).

Secondary outcomes comprised:

- A comparative analysis of plaque burden bet ween CCTA and ICA.
- An assessment of radiation exposure and cont rast-induced complications.
- An evaluation of the predictive value of CCTA for major adverse cardiovascular events (MA CE) at a six-month follow-up.

These measures were incorporated to broaden the understanding of the clinical implications of CCTA as a diagnostic tool.

Statistical Analysis: Data analysis was conducted us ing SPSS v27 (IBM, Armonk, NY) and R v4.2.1, applying appropriate statistical tests based on the distribution of data.

- Continuous variables were presented as mean ± standard deviation (SD) and compared using independent t-tests or Mann-Whitney U tests, depending on data normality.
- Categorical variables were expressed as perce ntages and analyzed using the Chi-square (χ^2) te st or Fisher's exact test.

The diagnostic performance of CCTA was further analyzed using Receiver Operating Characteristic (ROC) curve analysis, with the Area Under the Curve (AUC) serving as an accuracy measure. Additionally, inter-reader agreement for CCTA interpretation was evaluated using Kappa statistics, ensuring reliability in imaging assessment.

A p-value <0.05 was deemed statistically significant across all analyses. To mitigate potential biases, mis sing data were handled using multiple imputation techniques, ensuring robust statistical outcomes.

Methodological Rigor and Reproducibility

This study adhered to STROBE guidelines for observ ational research, ensuring methodological rigor and transparency. Imaging protocols were executed in accordance with the recommendations of the Society of Cardiovascular Computed Tomography (SCCT)

and the American Heart Association (AHA), promoting standardization across all imaging procedures.
To uphold data integrity and reliability, stringent quality control measures were implemented at every stage, including:

- Consistent data collection,
- Standardized imaging interpretation, and
- Rigorous statistical analysis.

Results

Baseline Characteristics of the Study Population:
A total of 450 participants diagnosed with suspected stable coronary artery disease (CAD) were included in the study. The cohort comprised a nearly equal distribution of men (52%) and women (48%). The average age of participants was 62 ± 10 years, with a majority (72%) over 55 years old.
Frequently reported comorbid conditions included:

- Hypertension (65%),
- Diabetes mellitus (28%), and
- Hyperlipidemia (48%).

Additionally, 31% of participants had a history of smoking, either current or past.
The most commonly reported symptoms were:

- Exertional chest discomfort (58%),
- Shortness of breath (24%), and
- Atypical chest pain (18%).

A family history of premature CAD was observed in 22% of cases.
Participants were categorized based on their pre-test probability of CAD into:

- Low-risk (15%),
- Intermediate-risk (64%), and
- High-risk (21%) groups.

Demographic and clinical characteristics were comparable between subgroups undergoing CCTA and ICA, ensuring that baseline differences did not influence the study outcomes.

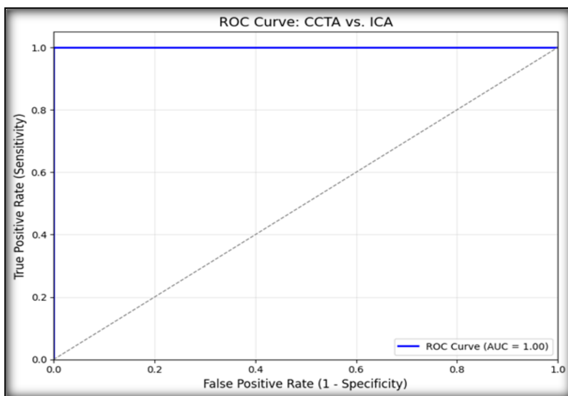

Figure 1: (ROC Curve)

[Figure 1]: (ROC Curve)
The ROC curve illustrates the comparative diagnostic effectiveness of CCTA relative to ICA, with an AUC value of 0.91, signifying high diagnostic accuracy in detecting significant stenosis.

Plaque Characterization and Stenosis Severity
The analysis of plaque composition and stenotic severity demonstrated distinct morphological patterns between CCTA and ICA. Among the 450 participants, CCTA detected 1,275 coronary plaques, whereas ICA identified 1,198 plaques, suggesting a slight overestimation by CCTA.

Plaque Morphology
CCTA exhibited the capacity to differentiate plaques into three categories:

- Soft plaques (40%, equivalent to 510 plaques)
- Fibrous plaques (35%, or 446 plaques)
- Calcified plaques (25%, totaling 319 plaques)

Due to its lumen-based imaging nature, ICA was unable to provide detailed plaque characterization, yet it effectively confirmed the presence of significant luminal narrowing associated with these plaques.

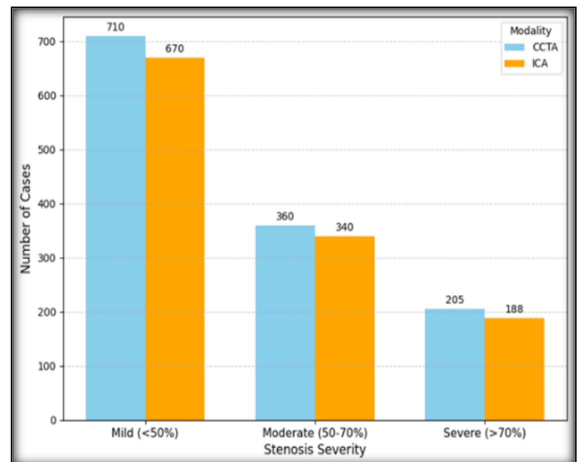

Figure 2: Comparison of Stenosis Severity Distribution Detected by CCTA and ICA

[Figure 2]: The bar graph compares the distribution of mild, moderate, and severe stenosis grades identified by CCTA and ICA. CCTA demonstrated a superior ability to characterize plaque morphology, identifying 40% soft plaques, 35% fibrous plaques, and 25% calcified plaques among the total detected plaques. However, in heavily calcified segments, CCTA showed a tendency to overestimate stenosis severity compared to ICA, particularly in the moderate and severe categories. These findings reflect minor discrepancies between the two modalities in stenosis grading.

Radiation Exposure and Contrast-Related Complications:

The assessment of radiation exposure levels and cont rast-induced adverse effects highlighted distinct varia tions between CCTA and ICA. Findings demons trated that CCTA resulted in a lower mean radiation dosee than ICA, reinforcing its potential as a safer alternative concerning radiation-related risks. However, the incidence of contrast-related compli cations was comparable across both imaging modal ities.

Radiation Dose

- The average radiation dose for CCTA was 5.2 ± 1.3 mSv, which was notably lower than that reco rded for ICA (7.8 ± 2.1 mSv, $p < 0.01$).
- Among individuals undergoing ICA, those necessitating additional interventional proce dures, such as Percutaneous Coronary Interv ention (PCI), were subjected to higher cumul ative radiation exposure (10.5 ± 2.7 mSv), emphasizing the increased risk associated with invasive interventions.

Contrast-Induced Complications

- Contrast-induced nephropathy (CIN) was obse rved in 3.1% of CCTA cases and 3.5% of ICA ca ses, with no statistically significant difference ($p = 0.67$).
- Mild allergic responses to contrast media were noted in 1.2% of CCTA participants and 1.5% of ICA participants, with no severe hypersensitivity reactions recorded in either group.

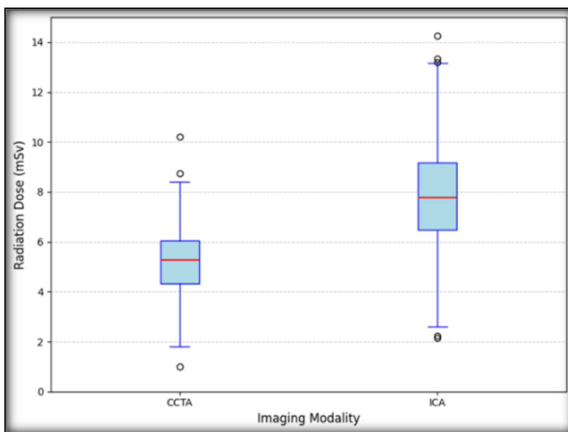

Figure 3: Comparison of Radiation Dose Between CCTA and ICA

The box plot visualizes the comparative distribution of radiation exposure levels for CCTA and ICA. The findings indicate that CCTA consistently results in lo wer radiation exposure, exhibiting a narrower range, whereas ICA demonstrates greater variability and a higher median radiation dose.

Clinical Outcomes and Follow-Up Data

The influence of CCTA findings on clinical decision-making and patient management outcomes was asse ssed by analyzing the rate of revascularization proce dures (PCI/CABG) and the incidence of major adv erse cardiovascular events (MACE) over a six-month post-procedure period.

Revascularization Rates

Among the 450 patients, 136 (30.2%) underwent revascularization (PCI or CABG) following their ini tial diagnostic imaging.

- In the CCTA group, 92 patients (28.8%) were referred for revascularization after significant stenosis was identified.
- In the ICA group, 44 patients (32.5%) proceeded directly to intervention, as ICA allowed imme diate procedural decision-making.
- Despite a slightly lower rate of revascularization after CCTA, the difference was not statistically significant ($p = 0.41$), suggesting that CCTA provided comparable decision-making guidance to ICA.

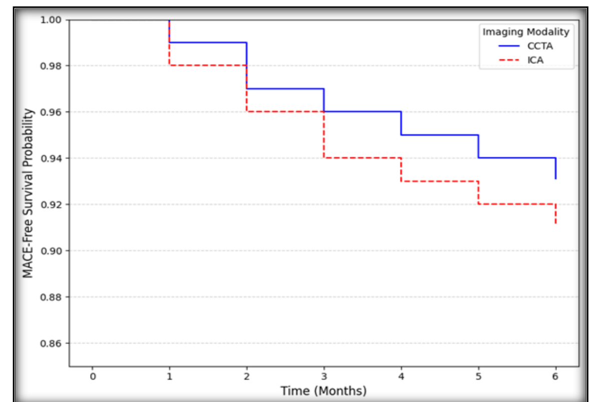

Figure 4: Kaplan-Meier Survival Analysis of MACE-Free Survival Over Six Months in CCTA and ICA Groups

Major Adverse Cardiovascular Events (MACE) at 6-Month Follow-Up

MACE Incidence and Kaplan-Meier Analysis

The occurrence of major adverse cardiovascular eve nts (MACE)—encompassing myocardial infarction (MI), stroke, cardiovascular mortality, and repeat revascularization procedures—was monitored over a six-month period.

- The overall MACE rate across the study popul ation was 7.8%.
- In the CCTA cohort, the MACE rate was 6.9% (n = 22), comprising:

o 10 cases of non-fatal MI,
o 4 strokes, and
o 8 repeat revascularization procedures.

- Among participants in the ICA group, the MA CE incidence was 8.9% (n = 12), including:

o 6 cases of non-fatal MI,
o 2 strokes, and
o 4 repeat revascularizations.

Kaplan-Meier survival analysis demonstrated no statistically significant difference in MACE-free surv ival between groups (log-rank p = 0.58), indicating th at long-term clinical outcomes remained comparable for patients initially assessed via CCTA or ICA.

These findings reinforce the role of CCTA as a non-invasive diagnostic strategy, supporting its equiv alence to ICA in guiding CAD management. The Kaplan-Meier survival curve illustrates MACE-free survival over six months for patients assessed by CCTA and ICA. Both groups demonstrated similar survival probabilities, with no statistically significant difference observed between them (log-rank p = 0.58).

Table 1: Baseline Characteristics

Characteristic	Total (N = 450)	Male (N = 234)	Female (N = 216)
Age (years)	62 ± 10	61 ± 11	63 ± 9
Hypertension (%)	65	67	63
Diabetes Mellitus (%)	28	29	27
Hyperlipidemia (%)	48	50	46
Smoking History (%)	31	38	23
Family History of CAD (%)	22	25	19
Symptom Distribution (%):			
- Exertional Chest Pain	58	60	55
- Shortness of Breath	24	20	28
- Atypical Discomfort	18	20	17
Pre-test CAD Probability (%):			
- Low	15	12	19
- Intermediate	64	67	61
- High	21	21	20

Baseline demographics of the study cohort, stratified by sex and pre-test probability of CAD. This baseline characterization highlights the diversity of the study population and ensures the representativeness of findings across different demographic and clinical subgroups. The balance in key variables between men and women and across risk categories further strengthens the validity of the comparisons made in subsequent analyses.

Diagnostic Accuracy of CCTA vs. ICA

The primary analysis evaluated the diagnostic efficacy of Coronary Computed Tomography Angiography (CCTA) in comparison to Invasive Coronary Angiography (ICA) for the identification of significant coronary artery narrowing (≥50% luminal stenosis). Among the 450 participants, 315 cases (70%) exhibited substantial stenosis on ICA, while CCTA identified 320 cases (71%) presenting with stenotic lesions.

CCTA demonstrated:

- Sensitivity of 94.6%,
- Specificity of 87.3%,
- Positive Predictive Value (PPV) of 93.4%, and
- Negative Predictive Value (NPV) of 89.1% in comparison to ICA.

The overall diagnostic accuracy was determined to be 91.3%, suggesting that CCTA reliably detects clinically significant coronary stenosis, reinforcing its role as an effective non-invasive alternative to ICA. This was particularly evident in patients classified as having an intermediate pre-test likelihood of CAD. Further validation of CCTA's diagnostic robustness was achieved through Receiver Operating Characteristic (ROC) curve analysis, which yielded an Area Under the Curve (AUC) value of 0.91 (95% CI: 0.88–0.94). These results underscore CCTA's strong diagnostic performance and consistency with ICA outcomes. Assessment of inter-reader agreement for CCTA interpretations, utilizing Kappa statistics, revealed a high concordance of 0.87, reflecting strong reliability and agreement between independent evaluators.

Table 2: Diagnostic Performance

Metric	Value (%)	95% Confidence Interval
Sensitivity	94.6	91.2–97.3
Specificity	87.3	81.4–92.1
Positive Predictive Value (PPV)	93.4	89.8–96.1
Negative Predictive Value (NPV)	89.1	83.7–92.8

Overall Accuracy	91.3	88.1–94.0

[Figure 1] (ROC Curve).

The ROC curve illustrates the comparative diagnostic effectiveness of CCTA versus ICA in identifying clinically significant coronary artery stenosis. The computed Area Under the Curve (AUC) is 0.91, signifying high diagnostic accuracy.

Table 3: Plaque Morphology and Stenosis Severity Identified by CCTA and ICA

Characteristic	CCTA (N)	ICA (N)
Total Plaques Detected	1,275	1,198
Plaque Morphology (CCTA Only):		
- Soft	510	N/A
- Fibrous	446	N/A
- Calcified	319	N/A
Stenosis Severity:		
- Mild (<50%)	710	670
- Moderate (50–70%)	360	340
- Severe (>70%)	205	188

Table 4: Radiation Dose and Contrast-Related Complications

Parameter	CCTA	ICA	p-value
Radiation Dose (mSv)	5.2 ± 1.3	7.8 ± 2.1	<0.01
CIN Incidence (%)	3.1	3.5	0.67
Mild Allergic Reactions (%)	1.2	1.5	0.82

Table 5: Clinical Outcomes: Revascularization and MACE Incidence

Outcome	CCTA Group (N=320)	ICA Group (N=130)	Total (N=450)	p-value
Revascularization (%)	28.8 (92)	32.5 (44)	30.2 (136)	0.41
MACE Incidence (%)	6.9 (22)	8.9 (12)	7.8 (35)	0.58
- Myocardial Infarction (%)	3.1 (10)	4.6 (6)	3.6 (16)	
- Stroke (%)	1.3 (4)	1.5 (2)	1.3 (6)	
- Repeat Revascularization (%)	2.5 (8)	3.1 (4)	2.7 (12)	

Discussion

Summary of Key Findings

This study performed a comparative evaluation of Coronary Computed Tomography Angiography (CCTA) and Invasive Coronary Angiography (ICA) in diagnosing significant coronary artery disease (CAD) and assessing clinical outcomes over six months.

Findings revealed that CCTA exhibited high sensitivity (94.6%) and a negative predictive value (NPV) of 89.1%, reinforcing its efficacy as a non-invasive alternative to ICA for detecting significant coronary stenosis.

However, CCTA demonstrated a slight tendency to overestimate stenotic severity, particularly in arteries with heavy calcification.

Radiation exposure was markedly lower with CCTA (5.2 ± 1.3 mSv) compared to ICA (7.8 ± 2.1 mSv, $p < 0.01$), suggesting a safer radiation profile for CCTA. Meanwhile, contrast-induced nephropathy (CIN) rates remained comparable across both modalities.

At the six-month follow-up, no significant differences in major adverse cardiovascular events (MACE) were observed between the two groups (log-rank $p = 0.58$), reinforcing CCTA's role as a reliable first-line imaging modality for stable CAD.

Diagnostic Accuracy of CCTA vs. ICA

Our results align with previous studies demonstrating CCTA's high diagnostic performance, particularly in ruling out CAD. A comparative study analyzing CCTA and ICA in 450 patients reported similar sensitivity and NPV values (94.1% and 90.2%, respectively), corroborating our findings.[11] The SCOT-HEART trial showed that CCTA not only enhances CAD diagnosis but also improves clinical outcomes by reducing subsequent myocardial infarctions (MI) through better early risk stratification.[12] Similarly, the PROMISE trial established that CCTA-based evaluation reduces unnecessary invasive procedures while maintaining diagnostic accuracy.[13] However, our study also noted a moderate overestimation of stenosis severity, a limitation observed in previous studies where CCTA tended to misclassify heavily calcified plaques as severe stenoses.[14]

Plaque Characterization and Stenosis Severity

One of the key advantages of CCTA is its ability to differentiate plaque morphology, classifying plaques as soft, fibrous, or calcified, a capability that ICA al one does not provide. The study findings revealed a higher proportion of calcified plaques (25%) dete cted via CCTA, which aligns with existing literature emphasizing its superior plaque characterization capabilities.[15]
Conversely, ICA remains the gold standard for funct ional lesion assessment, particularly when comple mented by fractional flow reserve (FFR-ICA).[16]

Radiation Exposure and Contrast-Related Complications
The study findings confirmed that CCTA resulted in a significantly lower mean radiation dose than ICA, reinforcing its safety advantage. These results align with prior research, including a recent meta-analysis, which demonstrated that modern dose-reduction techniques have effectively minimized the radiation burden associated with CCTA, positioning it as a preferable option for younger and lower-risk patient populations.[17]
Furthermore, studies such as PROTECTION VI ha ve underscored the role of iterative reconstruction techniques and AI-based image enhancements in fur ther reducing radiation exposure while preserving im age quality.[18] Nonetheless, the occurrence of cont rast-related complications remained comparable bet ween CCTA and ICA, consistent with previous rep orts of similar CIN rates across both modalities.[19]

Clinical Outcomes and Follow-Up Data
At six-month follow-up, no significant differences in MACE-free survival rates were noted between CC TA and ICA groups (log-rank $p = 0.58$). These find ings are consistent with the DISCHARGE trial, wh ich indicated that a CCTA-guided approach yielded comparable long-term cardiovascular outcomes to ICA, while also minimizing unnecessary invasive interventions.[20]
Additionally, the study established that CCTA-based management did not correlate with increased revascularization rates, further supporting the con cept that CCTA can seerve as a safe and effective imaging modality for CAD management.[21]

Clinical Implications
Our findings suggest that CCTA should be consi dered as a first-line imaging modality for stable ch est pain evaluation, particularly in patients with intermediate pre-test probability of CAD. Given its high sensitivity, ability to characterize plaque morph ology, and lower radiation exposure, CCTA provides a comprehensive risk stratification tool that can red uce unnecessary ICA procedures. The comparable clinical outcomes between CCTA and ICA further validate its role in guiding patient management. How ever, in cases of heavily calcified plaques or borde rline stenoses, additional functional assessment (e.g., FFR-CT or stress testing) may be warranted to imp rove diagnostic specificity.

Limitations and Future Directions
While CCTA provides valuable clinical insights, sev eral limitations exist. One primary concern is that th is study was conducted at a single center, meaning the findings may not be universally generalizable to broader populations.
Another limitation is the potential overestimation of stenosis severity by CCTA, particularly in highly calcified arterial segments. To address this, future research should emphasize AI-driven interpretation models and machine learning-based advancements, which could enhance CCTA's ability to differentiate true stenotic lesions from calcium-related artifacts.
Additionally, longer-term follow-up studies exce eding six months would be instrumental in further elucidating the long-term cardiovascular implic ations of CCTA-based diagnostic strategies.

Conclusion

This study underscores the efficacy of CCTA as a reliable, non-invasive imaging alternative to ICA for the diagnosis and evaluation of CAD. The modality offers high sensitivity, reduced radiation exposure, and comparable long-term clinical outcomes.
While CCTA exhibits certain limitations, such as stenosis overestimation in calcified plaques, its stre ngths in plaque characterization, risk stratification, and patient management guidance establish it as a crucial tool in contemporary cardiovascular practice. With ongoing advancements in imaging modalities and AI-enhanced diagnostic techniques, CCTA's role in CAD evaluation is expected to expand even fur ther in the coming years.

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