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Diagnostic performance of coronary CTA versus exercise electrocardiography in acute chest pain: A propensity score-matched study in the emergency department

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ABSTRACT

Purpose: To compare the clinical impact and operational efficiency of exercise electrocardiography (ex-ECG) and coronary CT angiography (CCTA) in the diagnostic-therapeutic care pathway of patients presenting to the Emergency Department (ED) with acute chest pain (ACP) and suspected non-ST-elevation acute coronary syndrome (NSTE-ACS).

Methods: This single-center retrospective cohort study enrolled 428 consecutive patients presenting with ACP between January 2022 and December 2023. After propensity score matching (PSM) for age, sex, Heart Score, and triage code, two balanced groups of 214 patients each underwent either -ex-ECG or CCTA. Primary outcomes included diagnostic test positivity, hospital admission rate, and ED length-stay. Secondary outcomes included need for invasive coronary angiography (ICA) and revascularization rates.

Results: No statistically significant differences were found in test positivity (42 vs 31 patients, $p = 0.157$) or hospital admission rates (42 vs 30 patients, $p = 0.121$) between ex-ECG and CCTA groups. The ICA rates were similar (36 vs 32 patients, $p = 0.597$), as were revascularization rates (13 patients each, $p = 1.000$). However, discharged patients undergoing CCTA had significantly shorter total ED length-stay compared to ex-ECG (1710 vs 1841 min, $p < 0.001$), representing a 7.12 % reduction.

Conclusion: Both ex-ECG and CCTA demonstrate comparable clinical impact and operational efficiency in patients with ACP and suspected NSTE-ACS. CCTA offers effective advantages with significantly reduced ED length-stay for a safe discharge of the patients, improving resource management without compromising diagnostic quality. These findings support the increasing adoption of CCTA in the diagnostic pathway for ACP and suspected NSTE-ACS in the ED setting.

1. Introduction

The acute chest pain (ACP) represents one of the most frequent reasons for Emergency Departments (ED) access worldwide, accounting for approximately 5–10 % of all ED visits and placing a significant burden on healthcare systems [1, 2]. The clinical challenge in the initial triage and management of these patients lies in the need to quickly and accurately identify those with acute coronary syndrome (ACS) and those

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at very low risk for coronary artery disease (CAD), avoiding unnecessary hospital admissions for patients with non-cardiac chest pain [3]. On the other hand, the consequences of ED inappropriate discharge can be detrimental, given that missed diagnosis of ACS carries significantly increased morbidity/mortality, representing the largest single source of ED malpractice lawsuits [4, 5]. The old paradigm of hospital admission for days to "rule out" ACS is no longer acceptable in an age of spiraling health care costs.

The evaluation of patients with ACP and suspected non-ST-elevation ACS (NSTE-ACS) requires a systematic approach combining clinical assessment, ECG findings, and serum biomarker analysis, primarily high-sensitivity cardiac troponin I (hs-cTnI) [6]. Current guidelines from the American Heart Association (AHA)/American College of Cardiology (ACC) and the European Society of Cardiology (ESC) recommend non-invasive testing for risk stratification in symptomatic patients with suspected ACS who present with negative or non-significant initial troponin levels and uncertain or non-diagnostic ECG [7–9]. The exercise-ECG (ex-ECG) has traditionally served as the primary functional test for evaluating patients with chest pain in the ED setting. However, its diagnostic accuracy is limited by several factors, including the patient's inability to exercise, baseline ECG changes, and moderate sensitivity and specificity for detecting significant CAD. In recent years, coronary CT angiography (CCTA) has emerged as a promising alternative, offering direct visualization of coronary anatomy with high sensitivity and negative predictive value (NPV) [10–14]. Recent guidelines, including those from the National Institute for Health and Care Excellence (NICE) [15] and ESC [8] or consensus documents [16, 17] increasingly recommend CCTA as a first-line investigation for patients with stable chest pain, chronic coronary syndrome (CCS), and in low- to intermediate-risk patients presenting with ACP and non-conclusive ECG and serum biomarkers. Several randomized controlled trials [18–23], including the PROMISE [24] and SCOT-HEART [25] trials and meta-analyses [26–29], have demonstrated that CCTA can safely reduce hospital admissions and expedite discharge of low- intermediate-risk patients compared to functional testing. However, questions remain regarding its impact on rates of invasive coronary angiography (ICA) and revascularization procedures, as well as its effect on ED working efficiency.

1.1. Study aim

The primary objective of this study was to compare the clinical impact and operational efficiency of ex-ECG and CCTA in the diagnostic-therapeutic care pathway (DTCP) of ED patients with ACP and suspected NSTE-ACS assessing the diagnostic test positivity rate, hospital admission rate for further investigations or treatments, and ED length of stay for discharged patients.

Secondary objectives included the rate of ICA following the diagnostic test, and revascularization rates (percutaneous coronary intervention – PCI or coronary artery bypass graft - CABG).

2. Methods

2.1. Study design and population

This single-center retrospective cohort study was conducted at the ED of our large tertiary care hospital. The study protocol was approved by the institutional ethics committee, and the requirement for informed consent was waived, given the retrospective nature of the study.

Consecutive patients presenting at the ED with ACP between January 2022 and December 2023 were screened for eligibility. Prior to 2022, the DTCP didn't include the CCTA. The choice between CCTA and ex-ECG was made based on clinical evaluation by the ED consultant cardiologists, considering patient characteristics and logistical availability. The ex-ECG was available only during morning hours from Monday to Friday, while CCTA could be performed Monday to Friday from 8:00 AM to 6:00 PM and Saturday from 8:00 AM to 1:00 PM, depending on the availability of dedicated cardioradiologists, with a maximum capacity of 2–3 CCTA examinations per day.

2.2. Inclusion and exclusion criteria

Inclusion criteria were age $>$ 18 years, presentation with ACP requiring non-invasive evaluation, non-conclusive ECG, and negative or non-significant hs-cTnI levels both on admission and after 3 h in the ED. Exclusion criteria included known CAD, hemodynamic instability, elevated serum troponin levels, ST-elevation myocardial infarction (STEMI), other known causes of ACP (acute aortic dissection, pulmonary embolism, acute pericarditis), and specific contraindications to either diagnostic modality. Contraindications for CCTA included contrast material allergy, pregnancy, glomerular filtration rate $<$ 30 mL/min, and arrhythmias potentially affecting the image quality. Contraindications for ex-ECG included inability to perform a treadmill exercise, severe valvular disease, severe hypertension, and recent beta-blocker therapy.

2.3. Diagnostic protocols

Ex-ECG was performed on a treadmill using the standard Bruce protocol and interpreted by experienced cardiologists, with positive results defined as horizontal or down-sloping ST-segment depression $\geq$ 1 mm at 80 ms after the J point, ST-segment elevation, or typical anginal symptoms during exercise.

A preliminary unenhanced CT scan for the assessment of calcium score was not performed, given the low- to intermediate-risk enrolled patients. CCTA examination followed the institutional scan protocol including sublingual 5 mg dose of isosorbide dinitrate at least 10 min before the scan for optimal coronary artery dilation [30], intravenous (iv) administration of beta-blockers when necessary to achieve optimal heart-rate (HR) control ($<$75bpm), and iv iodinated contrast material (Iomeron400; Bracco, Milan, Italy) injection at adequate flow-rate (5 mL/sec) for coronary artery visualization through an 18-G peripheral venous access, preferably at the right antecubital vein. All CCTA scans were acquired using a second-generation Dual-Source-CT (DSCT) scanner (Definition-Flash; Siemens Healthcare, Forchheim, Germany), with standardized/optimized prospectively ECG-gating sequential scan protocols and control of the radiation dose. In younger patients and in particular females with low and stable HR ($<$65 bpm), the prospective ECG-triggered high-pitch (FLASH) spiral-scan technique was applied to reduce the radiation dose. With both scanner technologies, in case of thin patients, the kV was maintained lower (80 or 100). All CT data sets were transferred to a dedicated off-line workstation (TeraRecon Inc., Aquarius iNtuition, Durham, NC, USA) for the coronary imaging post-processing to obtain both 2-dimensional (curved and stretched multi-planar reformation, and maximum intensity projection) and 3-dimensional (volume rendering) reconstructions. Radiologists on staff, with at least $>$ 7 years of experience in cardiac CT, evaluated the CT scans during their shifts and compiled the corresponding CT reports. Images were interpreted according to the Society of Cardiovascular Computed Tomography (SCCT) guidelines [31] and the Coronary Artery Disease - Reporting and Data System (CAD-RADS 2.0) [32]. Positive CCTA was defined in the presence of at least a moderate stenosis ($\geq$50 %; CAD-RADS $\geq$3).

2.4. Propensity score matching

To reduce selection bias and ensure comparability between groups, propensity score matching (PSM) was performed using the following variables: age, sex, Heart Score (cardiovascular risk score ranging from 0 to 10), and triage code on ED arrival (red, yellow, or green). Nearest-neighbor matching with a 1:1 ratio and caliper width of 0.2 standard deviations was employed. The final matched cohort consisted of 214 patients in each group. High Heart Score (>6) have been included because, during the study period, clinical management in our institution did not mandate immediate admission or invasive evaluation solely based on Heart Score, particularly in hemodynamically stable patients with negative serial hs-cTnI and non-diagnostic ECG findings. In a small subset of high-Heart Score patients, non-invasive testing was still pursued to clarify coronary status and support disposition decisions when clinical judgment deemed it appropriate. Given the retrospective, real-world nature of the study, we elected to include these patients to reflect actual ED practice.

2.5. Study outcomes

Primary outcomes included diagnostic test positivity rate, defined as detection of myocardial ischemia (ex-ECG) or significant CAD (CCTA), hospital admission rate for further investigations or treatments, and ED length of stay for discharged patients. Secondary outcomes included the rate of ICA following the diagnostic test, and revascularization rates (percutaneous coronary intervention – PCI or coronary artery bypass graft - CABG).

2.6. Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 27.0 and R statistical software. The effectiveness of PSM was verified using chi-square tests for categorical variables and Student's *t*-test or Mann-Whitney *U* test for continuous variables, depending on data distribution. Continuous variables are presented as mean ± standard deviation for normally distributed data or median with interquartile range for non-normally distributed data. Categorical variables are expressed as frequencies and percentages. Comparisons between groups were performed using the chi-square test or Fisher's exact test for categorical variables and Student's *t*-test or Mann-Whitney *U* test for continuous variables. Multivariate logistic regression analysis was performed to evaluate the effect of diagnostic test type on primary and secondary outcomes, adjusting for age, sex, Heart Score, and triage code. Results are reported as odds ratios (OR) with 95 % confidence intervals (CI). A p-value < 0.05 was considered statistically significant. The Fig. 1 summarizes the study flow diagram.

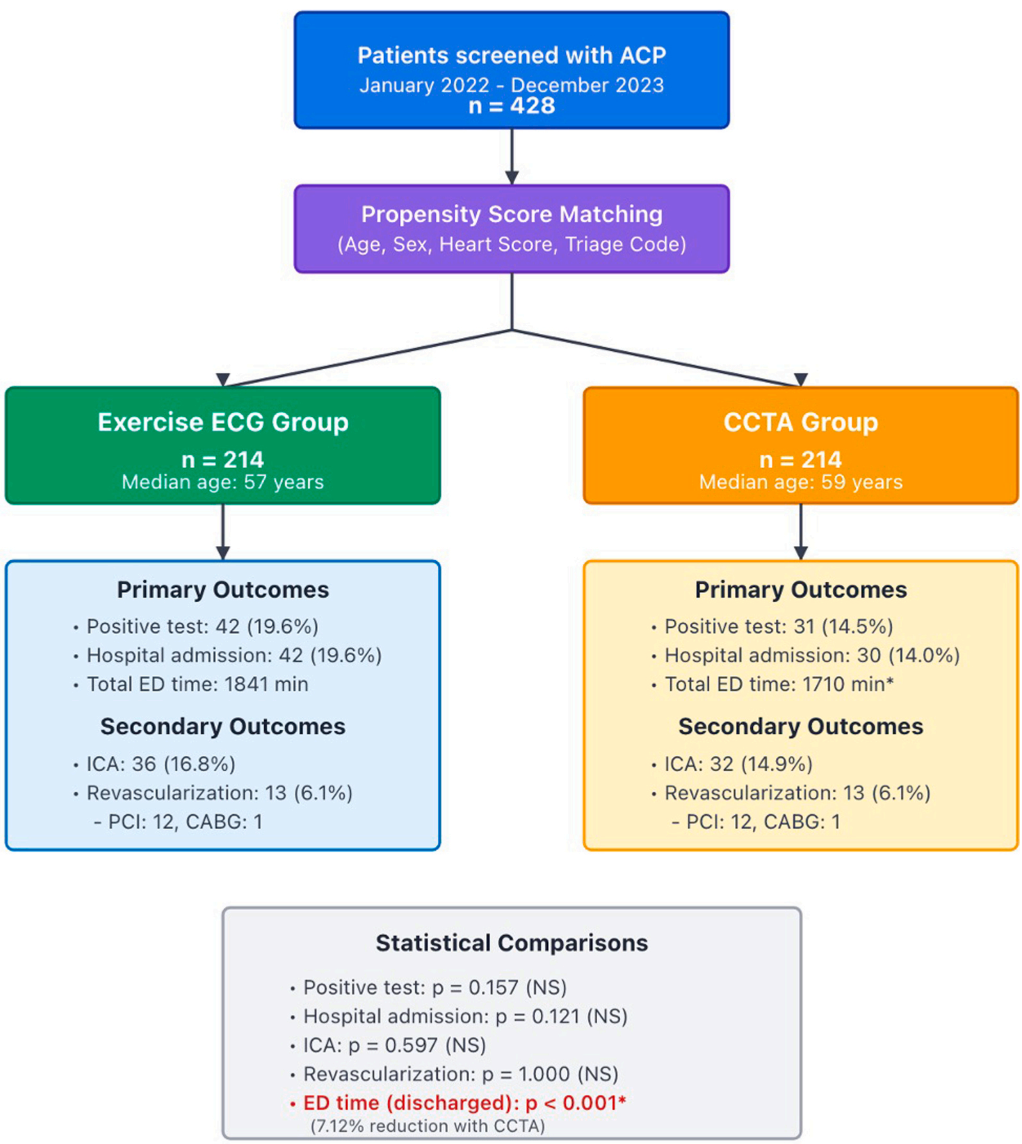

Fig. 1. Study flow diagram showing patient selection, propensity score matching, and outcomes for the ex-ECG and CCTA groups. *NS, not significant; *, statistically significant ($p < 0.001$); ACP, acute chest pain; ICA, invasive coronary angiography; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft.*

3. Results

3.1. Patient characteristics

A total of 428 patients were enrolled and divided into two groups of 214 patients each after PSM. Baseline characteristics demonstrated excellent balance between groups (Table 1). The median age was 57 years in the ex-ECG group and 59 years in the CCTA group ($p = 0.483$). Male patients accounted for 58.4 % of the group undergoing ex-ECG and 54.7 % of the CCTA group ($p = 0.435$). The distribution of triage codes was similar between groups ($p = 0.666$).

The Heart Score distribution showed no significant differences between groups ($p = 0.937$). In the ex-ECG group, 76 patients had low scores (1–3), 134 had intermediate scores (4–6), and 4 had high scores (>6). In the CCTA group, 73 patients had low scores, 133 had intermediate scores, and 8 had high scores.

3.2. Diagnostic test results

All CT scans were of diagnostic quality. Positive diagnostic tests were observed in 42 patients (19.6 %) in the ex-ECG group and 31 patients (14.5 %) in the CCTA group, with no statistically significant difference ($p = 0.157$). Analysis of diagnostic test results stratified by Heart Score categories revealed an increasing percentage of positive tests with higher risk scores (Fig. 2). In the low Heart Score group (1–3), 6.0 % of patients had positive tests (9/149), in the intermediate group (4–6), 22.1 % had positive tests (59/267), and in the high-risk group (>6), 41.7 % had positive tests (5/12).

Table 1
Baseline Characteristics and Outcomes After Propensity Score Matching (PSM).

	Exercise-ECG (n = 214)	CCTA (n = 214)	P-value
Median age, years	57	59	0.483
Male sex, n (%)	125 (58.4)	117 (54.7)	0.435
Triage Code, n (%)			0.666
- Red	15 (7.0)	19 (8.9)	
- Yellow	192 (89.7)	190 (88.8)	
- Green	7 (3.3)	5 (2.3)	
Heart Score, n (%)			0.937
- Low (1–3)	76 (35.5)	73 (34.1)	
- Intermediate (4–6)	134 (62.6)	133 (62.1)	
- High (>6)	4 (1.9)	8 (3.7)	
Median Heart Score	4	4	0.425
Timing of Presentation			
- Night-time arrival (8PM-7AM), n (%)	61 (28.5)	76 (35.5)	0.120
- Weekend arrival, n (%)	46 (21.5)	37 (17.3)	0.271
Primary Outcomes			
- Positive diagnostic test, n (%)	42 (19.6)	31 (14.5)	0.157
- Hospital admission, n (%)	42 (19.6)	30 (14.0)	0.121
Secondary Outcomes			
- ICA, n (%)	36 (16.8)	32 (14.9)	0.597
- Revascularization (PCI or CABG), n (%)	13 (6.1)	13 (6.1)	1.000
- PCI, n (%)	12 (5.6)	12 (5.6)	1.000
- CABG, n (%)	1 (0.5)	1 (0.5)	1.000
- In-hospital death, n (%)	0 (0)	1 (0.5)	0.317
Emergency Department Times			
- Median wait for visit, minutes	16	26	< 0.001
- Median total ED time (all patients), minutes	1841	1802	0.078
- Median total ED time (discharged patients), minutes	1841	1710	< 0.001

CCTA, coronary computed tomography angiography; CABG, coronary artery bypass graft; ECG, electrocardiography; ED, emergency department; ICA, invasive coronary angiography, PCI, percutaneous coronary intervention

3.3. Hospital admissions and invasive procedures

Hospital admission rates were similar between the two groups, with 42 patients (19.6 %) in the ex-ECG group and 30 patients (14.0 %) in the CCTA group ($p = 0.121$). Among admitted patients, the vast majority had positive diagnostic tests, with only one patient in the CCTA group with a positive test not enrolled due to death from non-cardiovascular causes (sepsis in cancer) without affecting the analysis of the results.

The rate of ICA was comparable between the two groups, with 36 patients (16.8 %) in the ex-ECG group versus 32 patients (14.9 %) in the CCTA group ($p = 0.597$). Among the 73 patients with positive diagnostic tests, 68 (93.2 %) subsequently underwent ICA.

Revascularization procedures were performed in 13 patients in each group ($p = 1.000$), with 12 PCI and 1 CABG in each group.

All patients who underwent revascularization had positive diagnostic tests. Among non-admitted patients, only 2.0 % (7/356) subsequently required ICA, and none required revascularization procedures.

3.4. Emergency department time metrics

The median length of stay for initial ED visit was significantly shorter in the ex-ECG group (16 min) compared to the CCTA group (26 min, $p < 0.001$). However, when analyzing only discharged patients, the total ED length-stay was significantly shorter in the CCTA group (median 1710 min) compared to the exercise ECG group (median 1841 min, $p < 0.001$), representing a 7.12 % reduction in ED length-stay. The Fig. 3 compares the ED time metrics for the two different strategies. For all patients regardless of disposition, the median total ED length-stay showed a trend toward shorter duration in the CCTA group (1802 vs 1841 min; $p = 0.078$). Patient distribution during night-time hours (8:00 PM to 7:00 AM) and weekends showed no significant differences between the two groups ($p = 0.120$ and $p = 0.271$, respectively). The Table 1 summarizes the baseline characteristics and outcomes after PSM.

4. Discussion

This single-center retrospective cohort study comparing ex-ECG and CCTA in ED patients with ACP and suspected NSTE-ACS demonstrated comparable clinical impact and operational efficiency between the two modalities, with CCTA offering significant advantages in terms of ED efficiency, allowing a faster, safer discharge of the patients.

4.1. Test yield and risk stratification

The finding of similar test positivity rates between ex-ECG and CCTA (19.6 % vs 14.5 %, $p = 0.157$) was unexpected, given that CCTA generally demonstrates higher sensitivity and specificity for detecting CAD compared to ex-ECG [26–29]. This similarity may reflect several factors, including the specific patient population studied, the prevalence of disease in our cohort, and potential differences in how positive results are defined and acted upon for each modality.

The Heart Score proved to be an effective risk stratification tool, with positive test rates increasing progressively from 6.0 % in low-risk patients to 41.7 % in high-risk patients. The balanced distribution of Heart Scores between the two groups ($p = 0.937$) confirms the effectiveness of our PSM approach and ensures that comparisons between diagnostic modalities were not confounded by differences in baseline cardiovascular risk.

4.2. Hospital admissions and invasive procedures

Contrary to findings from several landmark trials, including PROMISE and SCOT-HEART, which reported reduced hospital admissions with CCTA [24–29], our study found no significant difference in admission rates between groups (19.6 % vs 14.0 %, $p = 0.121$). This

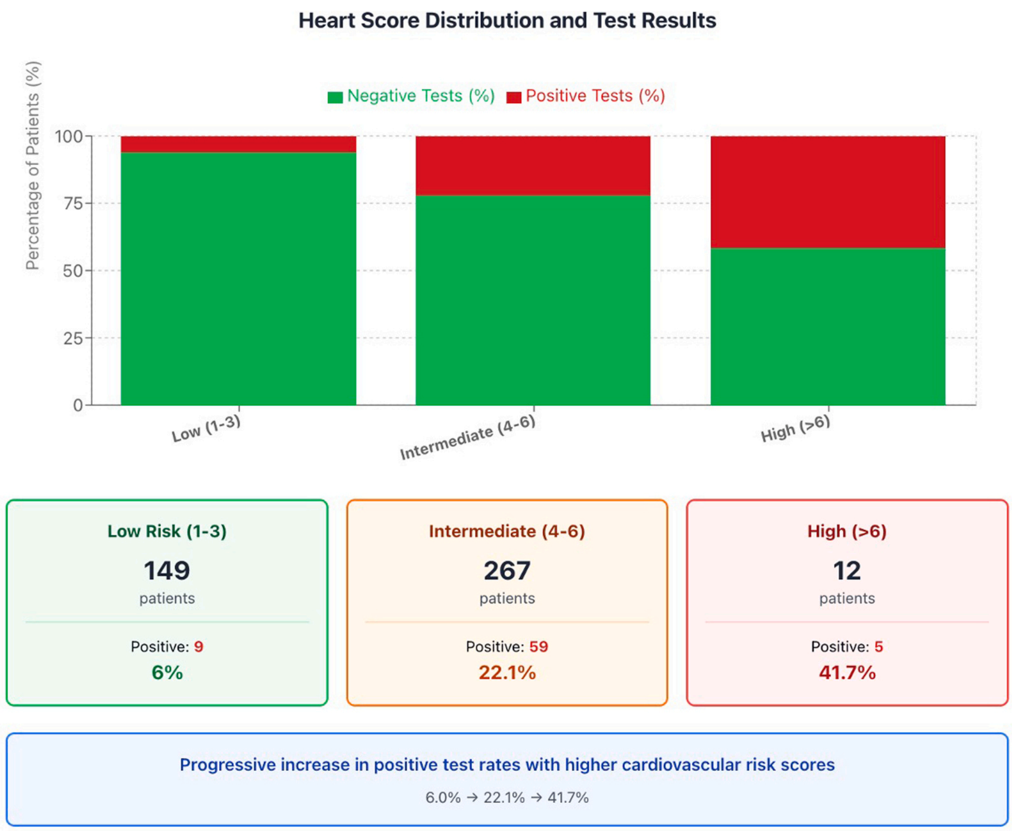

Fig. 2. Distribution of Heart Score categories and corresponding positive test rates in both diagnostic groups, demonstrating progressive increase in positive tests with higher cardiovascular risk scores.

discrepancy may be attributable to differences in study design, patient populations, or institutional practice patterns. In our cohort, the decision to admit was closely tied to test positivity, with nearly all patients with positive tests being admitted regardless of the diagnostic modality used.

The similar rates of ICA (16.8 % vs 14.9 %, $p = 0.597$) and revascularization (6.1 % each) between the two groups contrast with some literature suggesting that CCTA may lead to increased downstream testing and procedures [26]. This finding likely reflects our institution's conservative, multidisciplinary approach to interpreting CCTA findings and making decisions about invasive procedures. The integrated collaboration between cardiologists and radiologists may have contributed to more selective use of ICA, particularly for borderline lesions that might trigger intervention at other centers. The high rate of ICA among patients with positive tests (93.2 %) confirms appropriate patient selection for non-invasive testing and suggests that both modalities effectively identify patients requiring further evaluation. Importantly, among discharged patients with negative tests, only 2.0 % subsequently required ICA and none required revascularization, supporting the safety of both diagnostic strategies. Given the low prevalence of revascularization-requiring CAD in this carefully selected cohort, it is not unexpected that exercise-ECG and CCTA performed similarly in excluding ACS. Accordingly, the principal advantage of CCTA in this setting appears to be operational, streamlining the DTCP and reducing ED length-of-stay, rather than superior identification of patients requiring coronary intervention. The Table 2 summarizes the outcomes stratified by the hospital admission status.

4.3. Emergency department efficiency

A key finding of our study was the significantly shorter total ED length-stay for discharged patients undergoing CCTA compared to ex-ECG (1710 vs 1841 min, $p < 0.001$) (Fig. 3). This 7.12 % reduction in ED time has important implications for operational efficiency and resource management.

Anyway, the absolute ED length-stay values (>28 h) observed in both groups reflect the organization of the ACP pathway in our institution, where low- to intermediate-risk patients are frequently managed within an ED observation-based DTCP. This includes serial hs-cTnI testing, repeated clinical reassessments, deferred non-invasive testing, and disposition planning under limited inpatient bed availability, rather than rapid discharge or short-stay unit models adopted in other ED systems. Thus, the ∼130-minute reduction is operationally relevant within an observation-based ED model, and the prolonged ED length-stay reflects system-level organizational factors, not delayed care.

Although CCTA required slightly longer initial length-stay (26 vs 16 min, $p < 0.001$), presumably due to scheduling requirements, slot availability, and preparation, the overall time savings for most patients (83 % who were discharged) represents a significant improvement.

The reduction in ED length of stay for discharged patients likely reflects several factors. CCTA provides comprehensive anatomical information in a single examination that can definitively exclude significant CAD, facilitating confident discharge decisions. In contrast, ex-ECG may require additional observation time for interpretation and clinical correlation, particularly for equivocal results. The time savings achieved with CCTA can have a significant impact on overall ED productivity, potentially reducing overcrowding and improving patient satisfaction.

These operational benefits were not influenced by time of presentation, as the distribution of patients presenting during night-time hours or weekends was similar between the groups. This suggests that the efficiency advantages of CCTA are consistent across different operational scenarios.

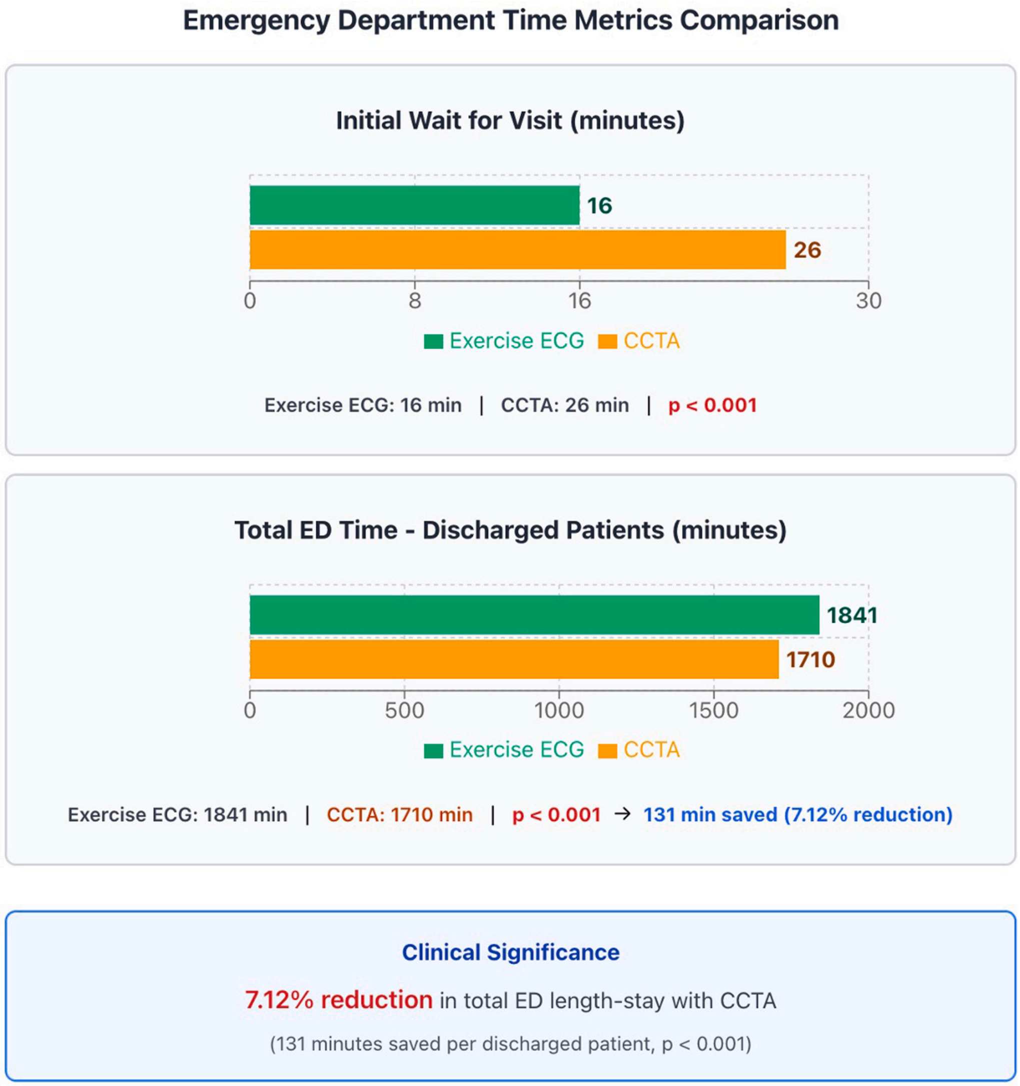

Fig. 3. Comparison of Emergency Department time metrics between ex-ECG and CCTA groups, showing median length-stay for visit and total ED stay time for discharged patients.

Table 2
Outcomes Stratified by Hospital Admission Status.

	Admitted Patients (n = 72)	Non-Admitted Patients (n = 356)	P-value
Diagnostic Modality, n (%)			0.121
- Ex-ECG, n (%)	42 (58.3)	172 (48.3)	
- CCTA, n (%)	30 (41.7)	184 (51.7)	
Invasive Procedures			
- ICA, n (%)	61 (84.7)	7 (2.0)	< 0.001
- CABG, n (%)	2 (2.8)	0 (0)	0.002
- PCI, n (%)	24 (33.3)	0 (0)	< 0.001
- Death, n (%)	1 (1.4)	0 (0)	0.026

CCTA, coronary computed tomography angiography; ex-ECG, exercise electrocardiography; CABG, coronary artery bypass grafting; ICA, invasive coronary angiography; PCI, percutaneous coronary intervention.

4.4. *Clinical implications and guidelines*

Our findings align with current ESC guidelines recommending CCTA as a first-line investigation for patients with suspected CCS, particularly those with low to intermediate pre-test probability [8, 9]. The combination of comparable diagnostic accuracy, similar rates of invasive procedures, and improved ED efficiency supports the expanding role of CCTA in the acute chest pain diagnostic pathway. However, it is important to emphasize that ex-ECG remains a reasonable and reliable alternative, especially for low- to intermediate-risk patients who can exercise and have interpretable baseline ECGs, and particularly in resource-limited settings, when dedicated cardiac radiologists or adequate CT scanner are unavailable, or in patients who cannot undergo CCTA due to contraindications. A tailored diagnostic strategy should depend on patient characteristics, institutional capabilities, test feasibility, and local expertise. Where high-quality CCTA is available and efficiently integrated into ED workflows, it may offer operational advantages; however, functional testing remains an appropriate and sometimes preferable option where CT performance is constrained.

4.5. *Limitations*

In addition to the small number of patients enrolled, several limitations of this study warrant consideration. First, the retrospective design introduces potential for unmeasured confounding despite PSM. Second, the non-randomized allocation of diagnostic tests during the study period may have introduced selection bias, although PSM was employed to mitigate this and strongly influenced by time of day/weekday test availability, scanner capacity (2–3 CCTA/day), and finally the cardiologist preference. Third, the study was conducted at a single tertiary care center, which may limit generalizability to other settings with different patient populations or practice patterns. Fourth, long-term outcomes and follow-up data beyond the initial ED encounter were not systematically collected. Finally, a cost-effectiveness analysis was not performed, which would be important for informing resource allocation decisions.

5. Conclusion

This study demonstrates that CCTA and ex-ECG provide comparable clinical impact and operational efficiency in the evaluation of ED patients with ACP and suspected NSTE-ACS. While no significant differences were observed in test positivity, hospital admission rates, or rates of invasive procedures, CCTA offered substantial operational advantages with significantly reduced ED length of stay for discharged patients. These findings support the increasing adoption of CCTA in the diagnostic pathway for ACP, particularly in settings where ED efficiency and resource optimization are priorities. The conservative approach to invasive procedures observed at our institution, facilitated by multidisciplinary collaboration, suggests that concerns about CCTA leading to excessive downstream testing may be mitigated through careful case selection and interpretation. Further prospective studies with larger sample sizes, longer follow-up, and cost-effectiveness analyses are needed to fully establish the optimal role of CCTA in the ACP diagnostic algorithm.

Abbreviations

ACS, acute coronary syndrome; CABG, coronary artery bypass graft; CAD, coronary artery disease, CCTA, coronary computed tomography angiography; CCS chronic coronary syndrome; ECG, electrocardiography; ED, emergency department; ex-ECG, exercise electrocardiography; DTCP, diagnostic-therapeutic care pathway; HR, heart-rate; ICA, invasive coronary angiography; NSTE-ACS, non-ST elevation ACS; PCI, percutaneous coronary intervention.

CRediT authorship contribution statement

Riccardo Marano: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonio De Vita:** Methodology, Data curation. **Luigi Natale:** Writing – review & editing, Supervision, Methodology, Investigation. **Domenico Amatulli:** Formal analysis, Data curation. **Francesco Lauriero:** Investigation. **Gaetano Antonio Lanza:** Investigation, Supervision, Writing – review & editing. **Massimo Muciaccia:** Investigation. **Anna Rita Larici:** Writing – review & editing, Supervision. **Giancarlo Savino:** Investigation. **Marcello Covino:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Biagio Merlino:** Writing – review & editing, Supervision, Investigation. **Alessandro Marchetti:** Investigation, Formal analysis, Data curation. **Giovanna Liuzzo:** Supervision. **Giuseppe Rovere:** Investigation, Formal analysis, Data curation. **Eleonora Moliterno:** Investigation, Formal analysis, Data curation. **Francesco Burzotta:** Supervision. **Alessio Perazzolo:** Investigation, Formal analysis, Data curation. **Francesco Franceschi:** Supervision. **Lorenzo Giarletta:** Investigation, Formal analysis, Data curation.

Ethics approval and consent to participate

This study was approved by the Institutional Ethics Committee of Fondazione Policlinico Universitario Agostino Gemelli IRCCS (Protocol number: [0025817/22]. The requirement for informed consent was waived due to the retrospective nature of the study and use of anonymized data.

Declaration of Generative AI and AI-Assisted technologies in the writing process

During the preparation of this work, the authors did not use any AI-assisted tools or services. The authors take full responsibility for the content of the publication.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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