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Diagnostic value of nocturnal trend changes in a dynamic electrocardiogram for coronary heart disease

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Abstract

Objective To explore the diagnostic value of intermittent changes in the nocturnal ST segment trend graph in a dynamic electrocardiogram (ECG) for coronary heart disease (CHD).

Methods A total of 205 patients who underwent coronary angiography were included in this retrospective study. The study sample was determined through a power analysis aimed at achieving power of 80% with a significance level of 0.05. The participants were divided into the CHD ($n = 101$) and the non-CHD ($n = 104$) group, based on the degree of coronary artery diameter stenosis. The morphological changes in the ST segment trend graph were observed and divided into two categories: 'wall-shaped' and 'peak-shaped' changes.

Results Among the 205 patients, 94 had nocturnal ST segment dynamic changes and 111 did not. The detection rate of CHD without nocturnal ST segment dynamic changes was 21.59%, significantly lower than the detection rate of 93.18% in those with nocturnal ST segment changes, reflecting a statistically significant difference ($P < 0.05$). The positive rate of ST segment in patients with single-vessel disease (71.88%) was lower than in patients with multi-vessel disease (78.57%), and both differences were statistically significant ($P < 0.05$). The duration of ST segment trend graph changes in 94 cases in the CHD group with intermittent changes in the nocturnal ST segment trend graph was higher than in the non-CHD group, but no significant difference was observed ($P > 0.05$). The detection rate of CHD in the peak-shaped dynamic change group of the nocturnal ST segment trend graph was significantly higher (76/82) than in the wall-shaped (6/82) dynamic change group ($P < 0.05$).

Conclusion Peak-shaped changes in the nocturnal ST segment trend graph indicate coronary artery lesions. Nocturnal ST segment changes observed through dynamic ECG monitoring can serve as a valuable non-invasive predictor for CHD, providing a feasible method for early diagnosis and intervention in clinical practice.

Keywords Dynamic electrocardiogram, Coronary heart disease, ST segment trend, Coronary angiography

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Introduction

Coronary heart disease (CHD) is a significant health threat, particularly in middle-aged and elderly individuals, and an incidence that increases with age [1]. Arrhythmias can result from myocardial ischaemia due to insufficient blood supply, complicating CHD diagnosis and treatment [2]. While coronary angiography remains the gold standard for diagnosing CHD, providing precise information on coronary artery stenosis, it is invasive, poorly tolerated by some patients, and costly, limiting its widespread use [3].

Electrocardiography (ECG) is a common, non-invasive, cost-effective, and safe diagnostic tool for cardiovascular disease [4]. Changes in ECG waveforms, including P waves, QRS complexes, T waves, and ST segments, are crucial for predicting CHD severity [5, 6]. Additionally, ECG is vital for arrhythmia diagnosis, with advanced integrated methods like Shifted 1-Dimensional Local Binary Pattern and Long Short-Term Memory networks enhancing rapid diagnosis [7]. Key ECG parameters such as ST-segment elevation, ST-segment depression, T wave inversion, and Q waves indicate coronary artery disease (CAD) and potential myocardial ischaemia or infarction [8, 9].

Intermittent nocturnal ST segment changes, typically due to coronary artery spasms, often represent transient myocardial ischaemia. These spasms can be triggered by autonomic nervous system imbalances, particularly a heightened vagal tone during sleep [10]. The vagus nerve, when overstimulated, increases myocardial oxygen demand while simultaneously reducing coronary blood flow, leading to ischaemia and resultant ST segment deviations on an ECG [10], which has predictive value for the early diagnosis of CHD [11]. Previous studies have underscored the diagnostic value of continuous ECG monitoring for detecting myocardial ischaemia [12, 13]. These studies all suggest a correlation between nocturnal ST segment changes and an underlying coronary pathology. The clinical significance of these changes lies in their potential to serve as early indicators of CHD to predict adverse cardiac events. Additionally, recognising these patterns can lead to the improved management of nocturnal symptoms and potentially reduce the incidence of nocturnal angina and myocardial infarction [14].

Despite these insights, several gaps remain in clinical practice. Due to its limited duration, conventional ECG monitoring often fails to capture intermittent ischaemic events. Dynamic ECG, with its extended monitoring capabilities, can detect these transient changes but is underutilised in routine practice [15]. Furthermore, while some scoring systems for ischaemic heart disease exist, there is a lack of standardised protocols for assessing nocturnal ST segment changes. This leads to missed opportunities for early intervention and tailored treatment strategies [16].

To enhance the diagnostic accuracy and management of CHD, this study aims to compare coronary angiography results to evaluate the diagnostic value of changes in ST trend graph features for CHD.

Materials and methods

General information

A retrospective study was conducted on the clinical data of patients who underwent dynamic ECG examinations and exhibited intermittent changes in the nocturnal ST segment trend graph in our hospital between January 2021 and June 2023. A total of 205 cases were included in the study, including 119 men and 86 women, aged 37–79 years with an average age of 62.5 ± 13.9 years.

Inclusion criteria: (1) clinical symptoms of precordial pain or referred pain in the left shoulder, suggesting the possibility of CAD requiring further confirmation, as well as patients with an irregular heartbeat, palpitations, or other arrhythmias requiring dynamic ECG monitoring; (2) good compliance and the ability to cooperate with the examination; (3) clear consciousness and a normal mental state; (4) undergoing coronary angiography; (5) provided signed informed consent for inclusion in the study.

Exclusion criteria: (1) patients with myocardial disease, acute myocardial infarction, left ventricular hypertrophy, and heart failure. These patients may exhibit significant structural or functional cardiac abnormalities that can potentially confound interpretation of the dynamic ECG; (2) patients with impaired liver or kidney function, as they may be incapable of effectively metabolising medications, which could impact the efficacy and safety of cardiac medications, subsequently affecting the results of the dynamic ECG; (3) patients with hypertension, diabetes, as these chronic conditions may interact with coronary artery disease, complicating interpretation of the study results; (4) patients with electrolyte disorders. Electrolyte imbalances, such as abnormalities in potassium, calcium, or magnesium, can directly affect the electrophysiological properties of the heart, leading to alterations in the ECG. This study was approved by the Ethics Committee of Shanxi Provincial People's Hospital.

The sample size for this study was determined using a power analysis, based on the expected effect size of nocturnal ST segment changes for predicting CHD. We aimed for a power of 0.80 (80%) with a significance level of 0.05 (two-tailed). The formula for sample-size calculation aimed at comparing two proportions was used, based on prior studies and preliminary data [17, 18], and the sample size required was calculated to be approximately 200 patients. To account for potential dropouts and incomplete data, we increased the sample size to 205 patients.

Methods

Dynamic electrocardiogram examination

The Shenzhen Bo Ying Dynamic ECG Analysis System (http://www.bi-biomed.com/ProductsStd_247.html) was used to replay the 24-hour dynamic ECG data of each group. The system automatically analysed ST segment deviations after the J wave for 80 ms. The time range of ST segment changes occurring between 22:00 and 6:00 the next day was defined as nocturnal ST changes.

The criteria for judging ST segment changes were as follows: ST segment depression, appearing horizontal or showing down-sloping greater than 0.1 mv, or ST-segment elevation ≥ 0.2 mv. The duration of ST segment changes needed to be at least 1 min, with an interval of more than 1 min between two episodes, and the ST segment within the interval had to be normal.

Based on the morphological changes in the ST segment trend graph, we divided these into two categories: changes resembling '∪' or '∩' were referred to as 'wall-shaped' changes, while changes resembling '∨' or '∧' were referred to as 'peak-shaped' changes. Wall-shaped changes were changes in the ST segment trend graph that resembled ∪ (a U-shaped curve) or ∩ (an inverted U-shaped curve) shapes. The ST segment in these patterns typically demonstrated a gradual decline and then a return to baseline in the case of ∪-shaped changes, or a gradual rise followed by a return to baseline in the case of ∩-shaped changes. Wall-shaped changes are often indicative of specific cardiac conditions such as ischaemic episodes or ventricular repolarisation abnormalities. Peak-shaped changes resembled a ∨ (an upward-pointing V-shaped curve) or ∧ (a downward-pointing V-shaped curve) shape in the ST segment trend graph. The ST segment in these patterns typically showed a sharp ascent followed by a peak, and then a rapid descent in the case of ∨-shaped changes, or a sharp descent followed by a peak and then a rapid ascent in the case of ∧-shaped changes. Peak-shaped changes are often associated with acute myocardial infarction or other sudden changes in cardiac ischaemia.

Coronary angiography

The diagnostic criteria for CAD were as follows: confirmation that the diameter representing the degree of stenosis in the main branch of coronary artery or at least one major coronary artery was no less than 50%, based on coronary angiography. All patients underwent coronary angiography using the Innova 3100 cardiovascular-specific digital subtraction angiography machine (General Electric Company, OH, USA). The Seldinger technique was used for puncturing, with puncture sites being the right femoral or radial arteries [19]. Coronary angiography was performed using the Judkins technique. The CAD diagnosis was as follows: stenosis exceeding 1/2 in the left main trunk, left circumflex branch, left anterior descending branch, right coronary artery, or any combination thereof. 'Single-vessel disease' referred to the involvement of one coronary artery, while 'multi-vessel disease' referred to the involvement of two or more coronary arteries.

Grouping

According to coronary angiography, the degree of stenosis was expressed in diameter, and if the degree of stenosis in the main branch or one of the main coronary arteries was greater than 50%, a diagnosis of CHD was confirmed [20]. Based on the diagnostic results, the participants were divided into the CHD and non-CHD groups. Coronary artery diameter stenosis was less than 50% in 101(non-CHD group) cases and greater than 50% in 104 (CHD group) cases. None of the patients in the non-CHD group had a history of myocardial infarction, documented silent ischaemia, typical angina symptoms, or atypical chest discomfort. In the CHD group, there were 32 cases with single-vessel disease and 56 cases with multi-vessel disease.

Based on the presence or absence of nocturnal ST segment changes, the participants were divided into the nocturnal ST segment dynamic change group and the non-dynamic change group. Based on changes in the nocturnal ST segment trend graph in the dynamic ECG, patients were divided into the ST segment elevation group and the ST segment depression group. To investigate whether the morphological changes in the ST segment trend graph had diagnostic significance for CAD, the ST segment trend graph was further divided into peak-shaped and wall-shaped changes.

Evaluation criteria

To evaluate ST-T segment changes, the following criteria were used.

(1) Analysis of the diagnostic value of ST-T segment changes using coronary angiography as the reference standard; (2) analysis of the ST-T segment changes in patients with single and multi-vessel disease; (3) analysis of the ST-T segment changes in patients with stenosis ≤ 50% and > 50%.

Statistical methods

Statistical analysis was performed using the SPSS 26.0 software. Measurement data were presented as mean ± standard deviation ($\bar{x} \pm s$), and the t-test was used for group comparisons. Count data were presented as cases (percentages; [n (%)]), and the chi-square test was used for group comparisons. A significance level of 0.05 was used, with $P < 0.05$ indicating a statistically significant difference.

Table 1 Comparison of detection rates of coronary heart disease with and without nocturnal ST segment dynamic changes

Nocturnal ST segment dynamic changes	*n*	Coronary heart disease group (101)	Non-coronary heart disease group (104)	χ^2	*P*
Positive	94	82 (93.18%)	12 (10.26%)	49.184	0.012
Negative	111	19 (21.59%)	92 (78.63%)		

Table 2 Analysis of diagnosis in different vessels of coronary artery lesion

Nocturnal ST segment dynamic changes	Single-vessel disease (32)	Multi-vessel disease (56)	χ^2	*P*
Positive	23 (71.88%)	44 (78.57%)	31.631	0.024
Negative	9 (28.13%)	12 (21.43%)		

Results

Comparison of the coronary heart disease detection rate based on nocturnal ST segment dynamic changes

Among the 205 participants, 94 cases showed nocturnal ST segment dynamic changes, while 111 cases did not. Using coronary angiography results as the gold standard, the detection rate of CHD in patients without nocturnal ST segment dynamic changes was 21.59%, significantly lower than the detection rate of 93.18% in those with nocturnal ST segment changes, with a statistically significant difference (χ^2=49.184, P<0.05) as shown in Table 1.

Comparison of the number of coronary heart disease lesions based on nocturnal ST segment dynamic changes

Following diagnosis by coronary angiography, 32 cases were identified with single-vessel disease and 56 cases with multi-vessel disease. Analysing the nocturnal ST segment dynamic changes, the ST segment positivity rate in patients with single-vessel disease (71.88%) was observed to be lower than in patients with multi-vessel disease (78.57%), and both differences were statistically significant (χ^2=31.631, P<0.05) as shown in Table 2.

Research results of intermittent changes in nocturnal ST segment trend graph

Among the 94 cases with intermittent changes in the nocturnal ST segment trend graph, the duration of ST segment trend graph changes in the CHD group (13.52±1.63 min) was higher than that in the non-CHD group (10.13±5.79 min), but no significant difference was observed (P>0.05). The detection rate of CHD was significantly higher in the group with a peak-shaped dynamic change in the nocturnal ST segment trend graph (76/82) compared with the group reflecting wall-shaped dynamic changes (5/82), with a statistically significant difference (χ^2=37.106, P<0.05) as shown in Table 3. Typical intermittent nocturnal ST segment trend charts are shown in Figs. 1 and 2. Figure 1 shows the ECG data of a 58-year-old female from 04:07 to 04:35. During this period, there was a sudden depression of the ST segment curve in leads II, III, and aVF, presenting a 'sawtooth' pattern change (Fig. 1A). Additionally, the 12-lead ECG during myocardial ischaemic attack and recovery is shown in Fig. 1B. Coronary angiography of the patient revealed sclerosis and approximately 40% stenosis in the mid-to-distal segment of the left circumflex artery (LCX), with no significant stenosis observed elsewhere. Figure 2 shows the ECG data of a 67-year-old female from 00:42 to 0:58. During this time, there was a sudden depression of the ST segment curve in leads I, II, III, aVF, and V2–V6, presenting a 'peak' pattern change (Fig. 2A). Additionally, the 12-lead ECG of this patient during myocardial ischaemic attack and recovery is shown in Fig. 2B. Coronary angiography of the patient revealed approximately 60% stenosis in the left anterior descending artery, approximately 60% sclerosis and stenosis in the mid-to-proximal segment of the LCX, and approximately 95% localised stenosis in the proximal-to-mid segment of the right coronary artery, indicating three-vessel coronary heart disease.

Discussion

Research has shown that intermittent changes in the nocturnal ST segment have a high diagnostic value for CHD [12]. However, conventional ECG has a short detection time and may not capture ischaemic events. Conversely, dynamic ECG has a longer detection time. In the overall analysis of arrhythmia, myocardial ischaemia and other conditions, by combining the ST segment trend graph, doctors can shorten the analysis time and improve its accuracy, enabling the visualisation of myocardial ischaemic events [21]. Our findings suggest that peak-shaped changes could act as a preliminary filter for patients who may benefit from more invasive diagnostic procedures, such as coronary angiography. This could help in the rational allocation of healthcare resources by prioritising those who exhibit these changes for further investigation.

Table 3 Comparison of changes in nocturnal ST segment trend graph between coronary heart disease group and non-coronary heart disease group

Group	Cases	ST segment elevation		ST segment depression		Duration
		Peak-shaped	Wall-shaped	Peak-shaped	Wall-shaped	
Non-coronary heart disease group	12	2	0	3	7	10.13±5.79
Coronary heart disease group	82	10	1	66	5	13.52±1.63
Total	94	12	1	69	12	

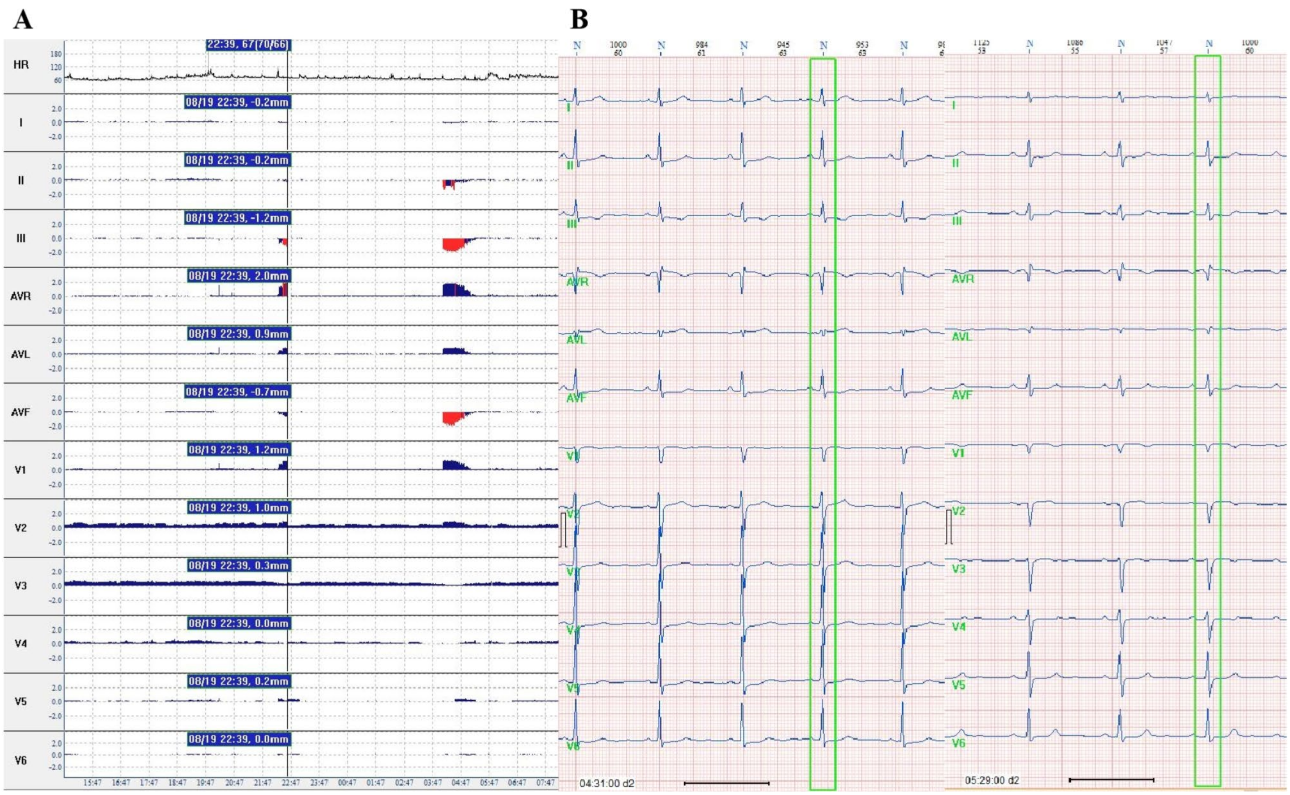

Fig. 1 shows the ST segment trend chart changes in a patient from 04:07 to 04:35

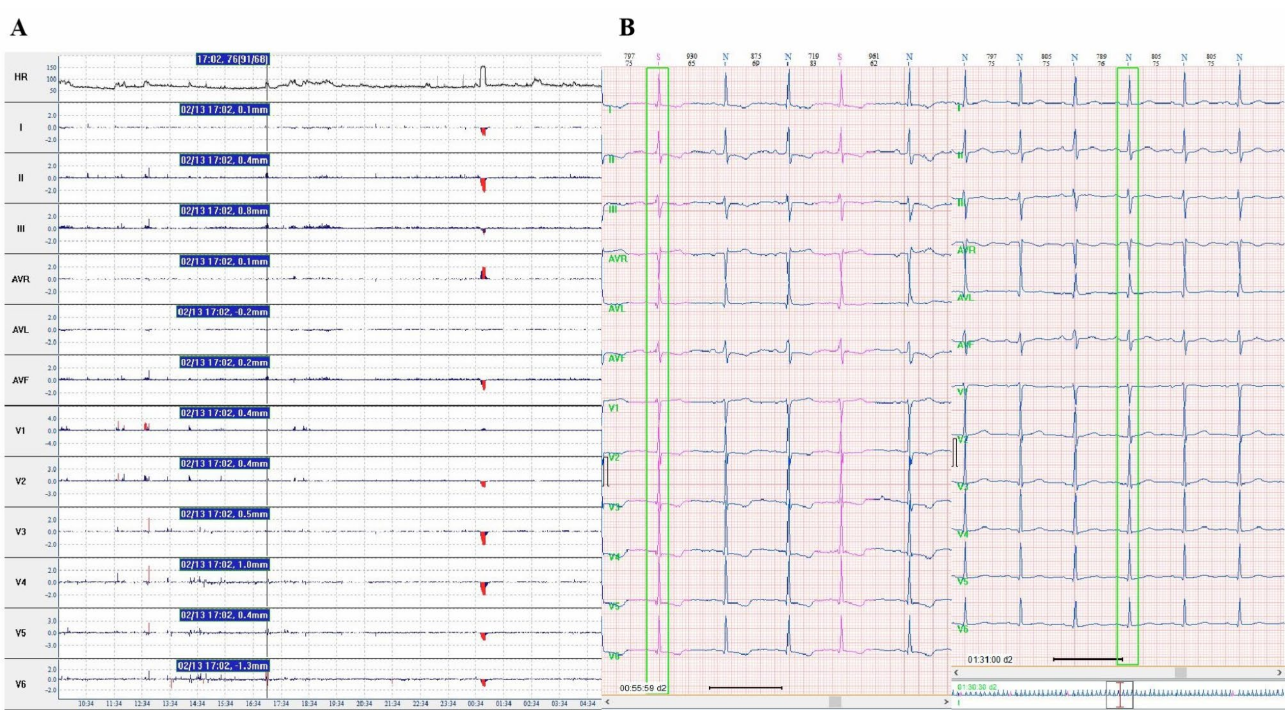

Fig. 2 shows the ST segment trend chart changes in a patient from 00:42 to 0:58

A study by Shimizu et al. [22] indicate that chest pain in patients with vasospastic angina frequently occurs during rest, especially during nighttime sleep, with the peak occurrence between midnight and 08:00. These patients often also experience effort angina in addition to rest pain, with coronary angiography confirming significant fixed stenosis in the coronary arteries. Research by Jo SH et al. [16] also indicates that, compared with patients with non-spastic coronary arteries, patients who experience any coronary artery spasms are more likely to have atherosclerotic plaques, even in non-spastic arteries. Several precise scoring systems for ischaemic heart disease have been established, and collecting the results of these scoring systems can lead to more accurate medical treatments. This suggests that optimising the scoring of dynamic ECG graphic changes may have potential assessment value in future evaluations [23, 24].

In this study, among 94 patients with changes in the nocturnal ST segment trend graph, 82 patients were confirmed to have CHD through coronary angiography, with a positive rate of 93.18%. This suggests that patients with atherosclerotic heart disease are prone to undergoing dynamic ECG ischaemic changes at night. These types of transient ischaemic ST changes in a dynamic ECG often indicate coronary artery spasms, which may be related to autonomic nervous system dysfunction [25]. When the vagus nerve is stimulated at night, it causes increased myocardial spasming, leading to coronary artery spasms and resulting in myocardial ischaemia, which manifests as ST segment changes in the corresponding ECG leads. This suggests that nocturnal ST changes may indicate ischaemic changes in the myocardium itself, while the coronary artery spasms exacerbate the preexisting coronary artery stenosis. During the day, when sympathetic nervous system activity increases, heart rate accelerates, cardiac tension decreases, and coronary artery spasm is relieved, the myocardial ischaemic phenomenon migrates, and ST segment changes are gradually restored to normal [26]. Coronary artery spasms exacerbate existing coronary artery stenosis, leading to myocardial ischaemia and ST segment changes on the ECG; this suggests that nocturnal ST segment changes may occur due to stenosis in the coronary arteries.

In this study, the detection rate of the peak-shaped nocturnal ST trend graph was 92.68% compared with coronary angiography. This suggests that peak-shaped changes in the nocturnal ST segment trend graph can improve the CHD detection rate. The generation of peak-shaped changes in the ST segment trend graph could be attributed to a gradual reduction, or even blocking, of coronary artery blood supply due to coronary spasm, based on coronary artery stenosis, leading to ischaemic changes in corresponding myocardial cells [27]. When coronary spasms are resolved, the coronary artery gradually opens, relieving myocardial ischaemia. This is reflected in the ECG as a gradual worsening and subsequent recovery of ST segment deviation [28]. Conversely, wall-shaped changes in the ST segment trend graph may occur due to a lack of specificity regarding ST segment changes in the ECG, as factors such as technical issues, body position, electrolyte imbalances, and psychological and neural factors can also cause changes in the ST segment of the ECG [29], thereby affecting acquisition of the cardiac signal. The presence of peak-shaped changes can serve as a non-invasive indicator of transient myocardial ischaemia, potentially allowing for earlier identification of patients at risk of CAD. By incorporating this parameter into routine ECG analysis, clinicians can enhance their ability to stratify patients, based on the likelihood of coronary artery lesions.

This study has some limitations. More patients with nocturnal ST segment dynamic changes must be included in future studies to explore the false negative rate of dynamic ECG monitoring. Additionally, the study's sample size was small, and multiple factors may have interfered with changes in the ST segment of the dynamic ECG. Therefore, a direct diagnosis of CHD cannot be made at present, and further research is needed regarding the use of a nocturnal ST segment trend graph for the diagnosis of CHD. Future research should be conducted with a larger patient population to further validate our preliminary findings and enhance the statistical significance and clinical applicability of the results.

Conclusion

Our research found that a peak-shaped change in the nocturnal ST segment trend graph indicated the presence of CAD. The duration of changes in the nocturnal ST segment trend graph is not significantly correlated with the degree of coronary artery stenosis. This suggests that observing changes in dynamic ECGs may provide new evidence for the diagnosis of CHD.

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Author contributions

YB and JZY conceived and designed research. YB and JZY conducted experiments. YB and JZY contributed new reagents or analytical tools. YB and JZY analyzed data. YB and JZY wrote the manuscript. All authors read and approved the manuscript.

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Data availability

All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Shanxi Provincial People's Hospital and informed consent was obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Dibben GO, Faulkner J, Oldridge N, Rees K, Thompson DR, Zwisler AD, Taylor RS. Exercise-based cardiac rehabilitation for coronary heart disease: a meta-analysis. Eur Heart J. 2023;44(6):452–69. https://doi.org/10.1093/eurheartj/ehac747. PMID: 36746187; PMCID: PMC9902155.
2. Kreska Z, Mátrai P, Nemeth B, Ajtay B, Kiss I, Hejjel L, Ajtay Z. Physical Vascular Therapy (BEMER) Affects Heart Rate Asymmetry in Patients With Coronary Heart Disease. In Vivo. 2022 May-Jun;36(3):1408–1415. https://doi.org/10.21873/invivo.12845. PMID: 35478109; PMCID: PMC9087094.
3. Ngam PI, Ong CC, Chai P, Wong SS, Liang CR, Teo LLS. Computed tomography coronary angiography - past, present and future. Singap Med J. 2020;61(3):109–15. https://doi.org/10.11622/smedj.2020028. PMID: 32488269; PMCID: PMC7905109.
4. Liu Junqing. Research on the clinical value of dynamic electrocardiogram in detecting myocardial ischemia and arrhythmia in elderly patients with coronary heart disease. Heilongjiang Med J. 2023;36(03):712–4. https://doi.org/10.14035/j.cnki.hljyy.2023.03.073.
5. Lee YH, Tsai TH, Chen JH, et al. Machine learning of treadmill exercise test to improve selection for testing for coronary artery disease. Atherosclerosis. 2022;340:23–7. https://doi.org/10.1016/j.atherosclerosis.2021.11.028.
6. Uchiyama R, Okada Y, Kakizaki R, Tomioka S. End-to-end convolutional neural network model to detect and localize myocardial infarction using 12-Lead ECG images without preprocessing. Bioeng (Basel). 2022;9(9):430. https://doi.org/10.3390/bioengineering9090430.
7. ÇALIŞKAN A. A New Ensemble Approach for Congestive Heart failure and arrhythmia classification using shifted one-dimensional local binary patterns with long short-term memory [J]. Comput J. 2022;65(9):2535–46.
8. Hayıroğlu Mİ, Lakhani I, Tse G, Çınar T, Çinier G, Tekkeşin Aİ. In-Hospital Prognostic Value of Electrocardiographic Parameters Other Than ST-Segment changes in Acute myocardial infarction: literature review and future perspectives. Heart Lung Circ. 2020;29(11):1603–12.
9. Yilmaz A, Hayıroğlu Mİ, Salturk S, et al. Machine Learning Approach on High Risk Treadmill Exercise Test to predict obstructive coronary artery disease by using P, QRS, and T waves' features. Curr Probl Cardiol. 2023;48(2):101482.
10. Mou Fangjun D, Hongyu. Analysis of the diagnostic effect of ST-T changes in electrocardiogram for coronary heart disease [J]. J Imaging Res Med Appl. 2021;5(11):228–9.
11. Xie Xijuan. Discussion on the value and clinical significance of nocturnal ST-T changes in 24-hour dynamic electrocardiogram for the diagnosis of coronary heart disease. Guizhou Med J. 2019;43(09):1471–3.
12. Himmelreich JC, Lucassen WA, Coutinho JM, Harskamp RE, de Groot JR, van Cpm H. 14-day Holter monitoring for atrial fibrillation after ischemic stroke: the yield of guideline-recommended monitoring duration. Eur Stroke J. 2023;8(1):157–67.
13. Ahmmed P, Reynolds J, Bozkurt A, Regmi P. Continuous heart rate variability monitoring of freely moving chicken through a wearable electrocardiography recording system. Poult Sci. 2023;102(2):102375.
14. Dominguez-Rodriguez A, Abreu-Gonzalez P, Garcia-Gonzalez MJ, Samimi-Fard S, Kaski JC, Reiter RJ. Light/dark patterns of soluble vascular cell adhesion molecule-1 in relation to melatonin in patients with ST-segment elevation myocardial infarction. J Pineal Res. 2008;44(1):65–9.
15. Taqueti VR. Coronary microvascular dysfunction in Vasospastic Angina: provocative role for the Microcirculation in Macrovessel Disease Prognosis. J Am Coll Cardiol. 2019;74(19):2361–4.
16. Jo SH, Sim JH, Baek SH. Coronary plaque characteristics and cut-off stenosis for developing spasm in patients with Vasospastic Angina. Sci Rep. 2020;10(1):5707.
17. Deng L, Hsu CY, Shyr Y. Power and sample sizes estimation in clinical trials with treatment switching in intention-to-treat analysis: a simulation study. BMC Med Res Methodol. 2023;23(1):49.
18. Clark T, Berger U, Mansmann U. Sample size determinations in original research protocols for randomised clinical trials submitted to UK research ethics committees: review. BMJ. 2013;346:f1135.
19. Nishijima S, Nakamura Y, Yoshiyama D, et al. Single direct right axillary artery cannulation using a modified seldinger technique in minimally invasive cardiac surgery. Gen Thorac Cardiovasc Surg. 2022;70(11):954–61.
20. Ma Fangwei Z, Lei C, Shouming, et al. Diagnostic value of 64-layer CCTA for coronary artery stenosis in patients with coronary heart disease [J]. Med J West China. 2023;35(07):1079–82.
21. Liu Hongyan S, Yafen P, Jingyan, et al. Analysis of ST segment change trend graph and scatter plot in variant angina pectoris [J]. J Clin Eletrocardiology. 2020;29(01):22–5.
22. Shimizu T, Uzui H, Sato Y, Miyoshi M, Shiomi Y, Hasegawa K, Ikeda H, Tama N, Fukuoka Y, Morishita T, Ishida K, Miyazaki S, Tada H. Association between changes in the systolic blood pressure from Evening to the Next morning and night glucose variability in Heart Disease patients. Intern Med. 2021;60(22):3543–9. https://doi.org/10.2169/internalmedicine.6784-20. Epub 2021 Jun 5. PMID: 34092728; PMCID: PMC8666227.
23. Hayıroğlu Mİ, Altay S. The role of Artificial Intelligence in Coronary Artery Disease and Atrial Fibrillation. Balkan Med J. 2023;40(3):151–2.
24. Hayıroğlu Mİ, Çınar T, Çiçek V, et al. A simple formula to predict echocardiographic diastolic dysfunction-electrocardiographic diastolic index. Eine Einfache Formel Zur Vorhersage Der Echokardiographischen Diastolischen Dysfunktion – Elektrokardiographischer Diastolischer Index. Herz. 2021;46(Suppl 2):159–65.
25. Yuan Dongmei. Analysis of the value of ST-T changes in electrocardiogram for the clinical diagnosis of patients with coronary heart disease [J]. China Medical Device Information. 2021, 27(16): 132 + 174. https://doi.org/10.15971/j.cnki.cmdi.2021.16.063
26. Nafakhi H, Al-Mosawi AA, Hassan MB, Hameed F, Alareedh M, Al-Shokry W. ECG changes and markers of increased risk of arrhythmia in patients with myocardial bridge. J Electrocardiol 2019 Sep-Oct;56:90–3. doi: 10.1016/j.jelectrocard.2019.07.007. Epub 2019 Jul 17. PMID: 31349132.
27. Bugiardini R, Cenko E. A Short History of Vasospastic Angina. J Am Coll Cardiol. 2017;70(19):2359–2362. https://doi.org/10.1016/j.jacc.2017.09.034. PMID: 29096806.
28. Bergström G, Persson M, Adiels M, Björnson E, Bonander C, Ahlström H, Alfredsson J, Angerås O, Berglund G, Blomberg A, Brandberg J, Börjesson M, Cederlund K, de Faire U, Duvernoy O, Ekblom Ö, Engström G, Engvall JE, Fagman E, Eriksson M, Erlinge D, Fagerberg B, Flinck A, Gonçalves I, Hagström E, Hjelmgren O, Lind L, Lindberg E, Lindqvist P, Ljungberg J, Magnusson M, Mannila M, Markstad H, Mohammad MA, Nystrom FH, Ostenfeld E, Persson A, Rosengren A, Sandström A, Själander A, Sköld MC, Sundström J, Swahn E, Söderberg S, Torén K, Östgren CJ, Jernberg T. Prevalence of subclinical coronary artery atherosclerosis in the General Population. Circulation. 2021;144(12):916–29. https://doi.org/10.1161/CIRCULATIONAHA.121.055340. Epub 2021 Sep 20. PMID: 34543072; PMCID: PMC8448414.
29. Zhang Y. Application value of ST-T changes in electrocardiogram in the diagnosis of coronary heart disease. J Imaging Res Med Appl. 2020;4(06):148–9.

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