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Spotting myocardial ischemia on a smartwatch

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A 55-year-old woman with a history of metabolic syndrome presented to the Emergency Department (ED) with chest discomfort, nausea, diaphoresis, and dizziness. The patient had no prior cardiovascular symptoms, was current on routine health screenings and not prescribed any regular medications. At the time of presentation, her metabolic markers included BMI 28 (≥ 25 overweight); HbA1C 5.7% (≤5.6%); Cholesterol 194 (≤239 mg/dL), Triglyceride 158 (≤499 mg/dL), HDL 41 (≥50 mg/dL), LDL calculated 121 (≤159 mg/dL). The patient exercised daily, running several miles without symptoms the previous day. On the day of presentation, she developed severe dizziness after running less than a half-mile. Approximately two minutes after the onset of dizziness, the patient received a bradycardia alert from her smartwatch indicating a heart rate of 48 beats per minute (bpm). The patient then recorded a smartwatch single-lead electrocardiogram (ECG) (15:25 Fig. 1a, Apple Watch® 25 mm/s, 10 mm/mV, Lead I, 512 Hz, iOS 16.1.1, WatchOS 9.3.1, Watch6,2, Algorithm Version 2).

During the next 10 min, the dizziness progressed, and the patient sat on the sidewalk. A new smartwatch alert indicating atrial fibrillation (AF) with rapid heart rate. Her smartwatch single-lead ECG showed AF with rapid ventricular response, average 117 bpm (15:34, Fig. 1b). She called her spouse who drove her to the nearest ED.

Enroute to the ED, 45 min after initial onset of severe dizziness, the patient developed mild, diffuse chest pain radiating down both arms. A 12-lead ECG upon ED arrival revealed an inferior ST segment elevation myocardial infarction (STEMI) and AF (16:20, Fig. 1c). The patient received aspirin, ticagrelor, and heparin and was emergently taken to the catheterization lab.

Coronary angiography revealed a large, dominant right coronary artery (RCA) with plaque rupture at the crux, 100% occlusion and Thrombolysis In Myocardial Infarction (TIMI) 0 flow distally (Fig. 2a). Intravascular ultrasound-guided percutaneous coronary intervention (PCI) was performed and TIMI 3 flow was restored (Fig. 2b). Door to Balloon time was 52 min. Symptom to balloon time was rapid at 107 min due predominantly to heart rate smartwatch alerts (which prompted immediate medical attention). Echocardiogram 15 h after PCI showed normal left and right ventricular size, wall thickness, and systolic function. Ejection Fraction by 2D Simpson biplane was 56%; no significant valvular abnormalities were identified. The patient remained in atrial fibrillation during the echocardiogram, converting to sinus rhythm shortly thereafter. An ECG was recorded at this time (Fig. 1d). Subsequent 14-day event monitor revealed sinus rhythm with no evidence of further atrial fibrillation / flutter.

During recovery, the patient – an emergency physician – reviewed her own initial smartwatch single-lead ECG which revealed 1 to 3 mm horizontal ST segment depression recorded within minutes of symptom onset and 45 min prior to development of chest pain.

Abbreviations: ACS, Acute Coronary Syndrome; AF, Atrial Fibrillation; BBB, Bundle branch block; BMI, Body Mass Index; ECG, Electrocardiogram; ED, Emergency Department; H1AC, Hemoglobin A1C; HDL, High Density Lipoprotein; LAD, Left anterior descending artery; LDL, Low Density Lipoprotein; NSTEMI, non-ST-segment Elevation MI; PCI, percutaneous coronary intervention; STEMI, ST-segment Elevation MI.

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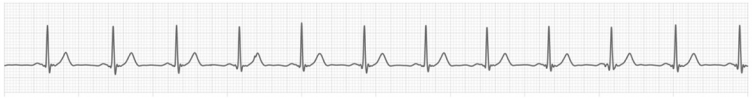
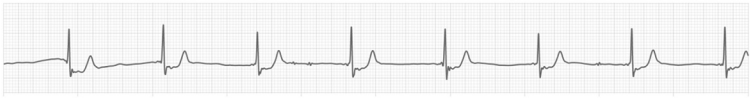
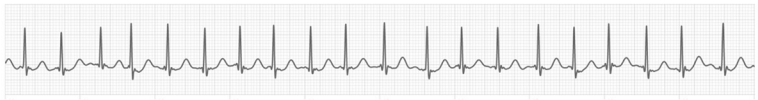
Baseline:
Single-lead ECG recorded one month prior to presentation. Sinus rhythm at 69 beats per minute (bpm). Recorded on Feb 3, 2023 at 12:01 PM.



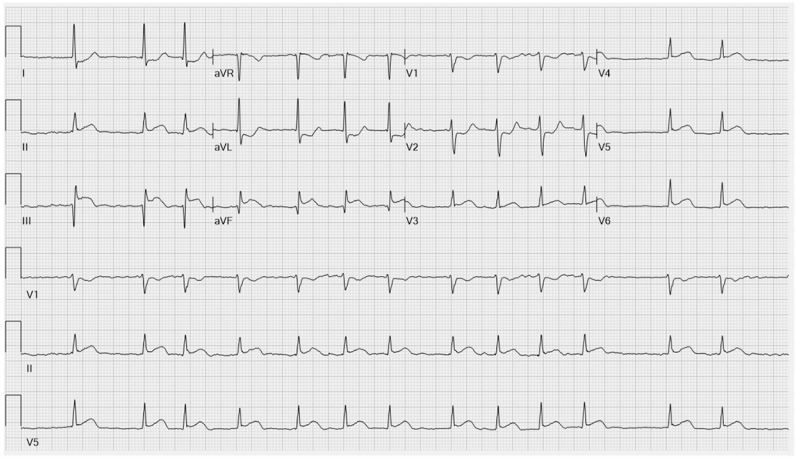
1a 15:25
Single-lead ECG recorded approximately 2 minutes after the onset of dizziness. The rhythm is junctional at 48bpm. 1 to3mm ST depression is visible.
Recorded on Mar 2, 2023 at 3:25 PM



1b 15:34
Single-lead ECG recorded approximately 7 minutes after the onset of dizziness. Smartwatch alerted patient to atrial fibrillation, average 117 bpm.
Recorded on Mar 2, 2023 at 3:34 PM



1c 16:20 12-lead ECG recorded at triage on arrival to the Emergency Department. Atrial fibrillation at 85bpm is present. ST elevation in leads II, III, aVF and ST depression in leads I, aVL, and V1 and V2 suggesting inferoposterior MI.



1d 11:13 (19h after ED Arrival) Post PCI ECG. Sinus rhythm at 62bpm. 1mm ST elevation and T wave inversion present in leads III, aVF.

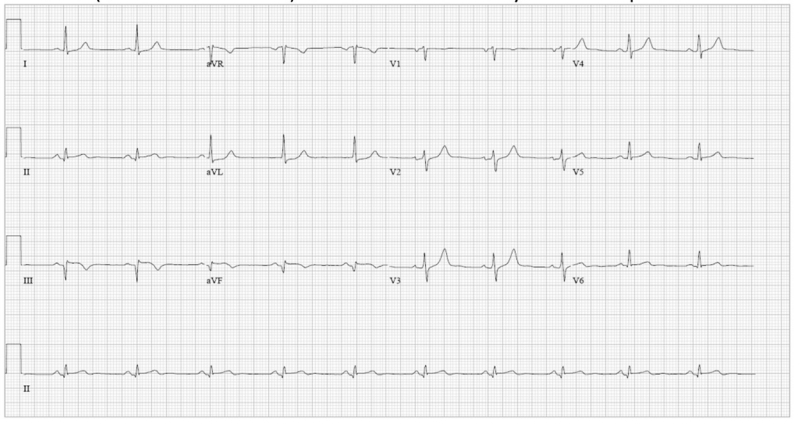


Fig. 1. Single-lead electrocardiogram (ECG) from Apple Watch® and standard 12-lead ECG.
All single-lead ECG recorded on Apple Watch® 25 mm/s, 10 mm/mV, Lead I, 512 Hz, iOS 16.1.1, WatchOS 9.3.1, Watch6,2, Algorithm Version 2.

Discussion

In this case report of a 55-year-old female patient with confirmed STEMI (Fig. 1a-c), the smartwatch single-lead ECG demonstrated 1 to 3 mm horizontal ST-segment depression within two minutes of symptom onset and 45 min prior to the development of chest pain, illustrating the potential opportunity for early identification of acute coronary syndrome (ACS) by widely available wearable technology.

Although initially symptomatic with dizziness the patient had no chest pain or shortness of breath. Dizziness is a common and non-specific symptom with etiologies ranging from innocuous to life-threatening; many patients with acute dizziness do not seek, or require, immediate medical attention. Apple Watch® has default alerts for heart rates under 50 bpm and AF with heart rates over 100 bpm. This

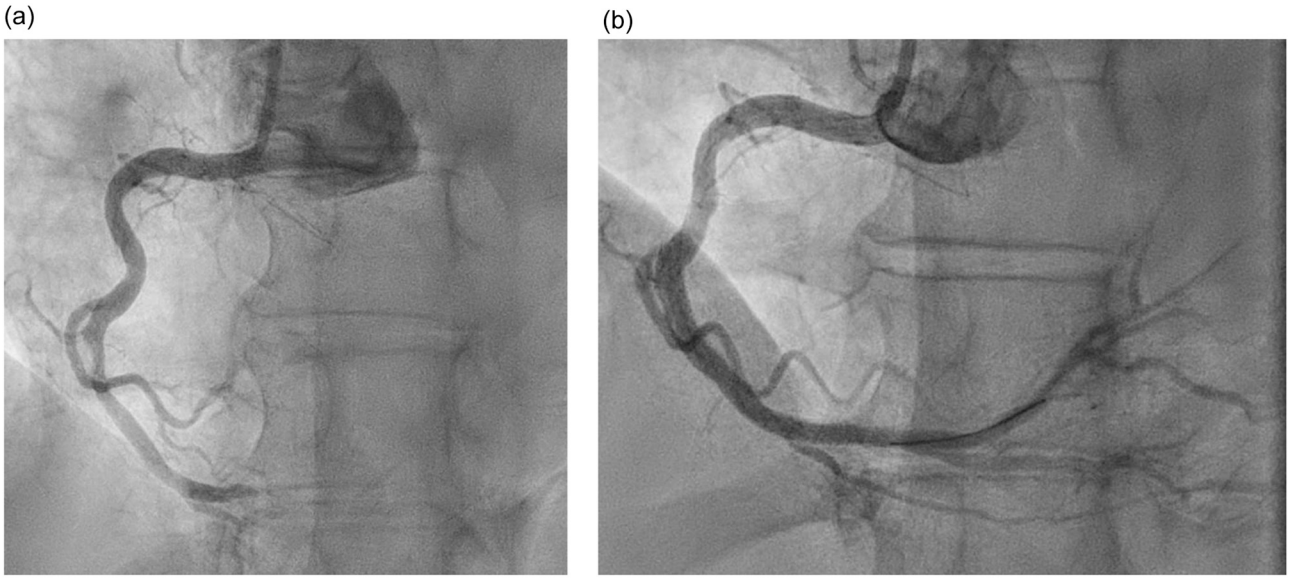


Fig. 2. Coronary angiogram images before and after percutaneous coronary intervention (PCI). a. The right coronary artery was found to have distal plaque rupture at the crux and with 100% occlusion and Thrombolysis In Myocardial Infarction (TIMI) 0 flow distally. There was a 70–80% mid right coronary artery lesion (minimum lumen area by intravascular ultrasound [IVUS] $< 4.5\ mm^2$) proximal to the 100% thrombotic occlusion. b. IVUS guided PCI was performed using non-overlapping 2.5×18 mm and 3.0×18 mm Onyx drug eluting stents, post dilated to 3.5 distally and 4.5 mm proximally, converting 100% stenosis TIMI 0 flow to 0% with TIMI 3 flow guided by IVUS. Following PCI, a coronary angiogram showed TIMI 3 flow into the posterior descending and posterolateral arteries.

Table 1
Smartwatch single-lead ECG and acute coronary syndrome.

	Year published	Number of patients	Patients with known ACS	Acute ischemia identified on smartwatch ECG	Smartwatch single-lead ECG contributed to clinical decision making
Buelga Suárez et al [15]	2023	25	Yes (clinic or ED)	Yes	No
Karelas et al [4]	2023	1	No	Yes	Yes – Chest pain for over 2 h. Patient shared smartwatch ECG with cardiologist. STEMI confirmed in catheterization lab. PCI to LAD
van der Zande et al [13]	2023	200 (67% with ECG anomalies: 54 patients with chest pain including 23 STEMI, 13 NSTEMI, 5 pericarditis, and 13 of other etiology, 56 patients with known abnormalities associated with sudden cardiac arrest (SCA) were included, 30 patients with AF/atrial flutter, and 18 patients with BBB).	Yes (clinic or ED)	Yes	No
Glöckner et al [6]	2022	1	No	Yes	Yes. Smartwatch ECG demonstrated ischemia and non-sustained ventricular tachycardia in patient with nocturnal palpitations. Patient underwent PCI. Two weeks later, patient had recurrent symptoms and smartwatch ECG demonstrated ST-segment deviation and wide QRS tachycardia, Reassessments with coronary angiography and magnetic resonance imaging revealed no relevant ischemia, diagnosed with vasospastic angina.
Caillol et al. [14]	2021	256 (81 with ischemia)	Yes (clinic or ED)	Yes	No
Drexler et al. [7]	2020	1	Yes (clinic or ED)	Yes	Yes. Initial ED ECG and troponin normal. Recurrent symptoms and review of smartwatch ECG showed marked ST-segment depression. Coronary angiography revealed left main stem stenosis and a left anterior descending/diagonal bifurcation lesion. PCI to L Main, LAD.
Spaccarotella et al. [11]	2020	100 (54 known STEMI, 27 NSTEMI, 19 heathy patients)	Yes (clinic or ED)	Yes	No
Stark et al. [5]	2020	1	No	Yes	Yes. Patient presented to physician on day 3 of mild chest pain and after noticing ST-segment changes on smartwatch ECG. Subacute STEMI. PCI to LAD.
Avila [8].	2019	2 (known STEMI)	Yes (clinic or ED)	Yes	No

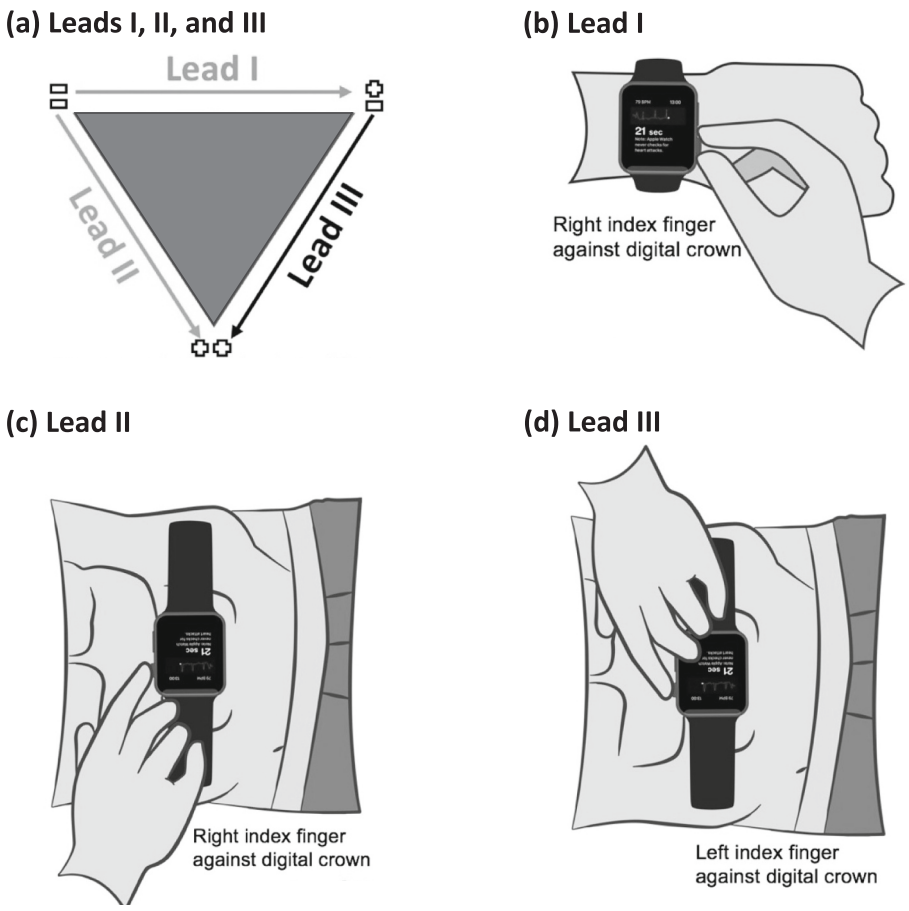


Fig. 3. Used with permission from Novel Use of Apple Watch 4 to Obtain 3-Lead Electrocardiogram and Detect Cardiac Ischemia. C. O. Avila.

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patient experienced both junctional bradycardia and AF with rapid ventricular response during the initial symptoms associated with the STEMI. The smartwatch alerted the patient for both rhythms, prompting immediate medical evaluation. The ST-segment depression suggesting ischemia recorded by the smartwatch did not trigger a smartwatch alert; commercial smartwatches do not currently provide alerts for acute ST-segment changes.

The median time from symptom onset to hospital arrival with ACS ranges from 1.5 to 6 h in the United States [1]. The time interval from symptom onset to seeking medical care for ACS has not changed in decades despite public awareness campaigns and widely available reperfusion technologies [1]. Wearable alerts may be particularly important for patients who lack classic cardiac symptoms such as chest pain, jaw and arm pain, and shortness of breath. Patients with ACS without cardiac symptoms have worse outcomes, and therefore attention should be directed at differences in treatment delay across ischemic pain presentations [2]. An early alert from a smartwatch ECG identifying acute ST-segment changes and possible ACS should provide an alert for immediate medical evaluation.

In this case, a smartwatch single-lead ECG recorded ST-segment depression within two minutes of symptom onset, 45 min prior to the development of chest pain. In a porcine model, Li and colleagues showed smartwatch single-lead ECG ST-segment changes within minutes of coronary artery occlusion and proposed developing an algorithm to alert patients at the onset of ACS [3]. Two previous case reports have identified single patients where a smartwatch contributed to early recognition of ACS within hours or days [4,5]. Several case reports have identified ST-segment changes on smartwatches during recurrent symptom evaluation [6,7]. Multiple case studies and several case series have described the ability of commercially available smartwatches to complete a single-, three-, and nine-lead ECGs in healthy volunteers, patients at rest, and in those with known cardiac ischemia [7–13]. Table 1 describes published reports of smartwatch ECG studies in patients with cardiac ischemia. Caillol and colleagues found smartwatch ECGs have low sensitivity (34%) in detecting ST changes although when present they are highly specific (100%) [14].

Right hand dominant people usually wear watches on the left wrist. The Apple Watch® (Series 4 and above) can record a 30-s single-lead ECG. Currently, a person must actively record an ECG from their smartwatch. This differs from the heart rate and rhythm recording technology which operates in the background of the watch function. Wearing the watch on the left wrist and placing the right index finger on the digital crown corresponds to lead I of a 12-lead ECG (Fig. 3a-b) using the current direction. Leads II and III can be recorded by moving the watch to the skin of the lower abdomen with right or left index fingers on the crown, respectively (Fig. 3c-d) [4,8,11]. Alternatively, Leads II and III can be recorded from the right or left leg [10]. Capturing the precordial leads using a smartwatch would not be practical for a single patient during acute symptoms [7]. Current smartwatches can only record leads sequentially, whereas a 12-lead ECG records all leads synchronously.

The accuracy and predictive values of ischemic ECG changes obtained from smartwatch technology are unknown. ECGs recorded from Apple Watch® had similar durations and waveform amplitudes compared to 12-lead ECG including patients with STEMIs and NSTEMIs [10]. Distinguishing between the rate-related ST-segment changes in response to tachycardia and those caused by ACS can be challenging on 12-lead ECGs and is unknown on smartwatch single-lead ECGs. Apple®

has a clear consumer warning that an Apple Watch® never checks for heart attacks and currently only alerts for arrhythmias. A direct link to calling emergency services is provided as part of the Apple Watch® ECG application for persons living in the United States.

In this patient with a confirmed STEMI, the smartwatch single-lead ECG recorded horizontal ST segment depression consistent with ischemia within two minutes of the onset of dizziness, and 45 min prior to the onset of chest pain. The ST segment changes from the smartwatch was not appreciated by the physician-patient until after PCI had been performed and was never part of the medical decision making.

Mortality and survival from acute cardiovascular disease are strongly linked to early diagnosis, and for STEMI, prompt revascularization. In the current patient with a STEMI, the development of bradycardia and then AF alerted the patient to a new cardiac event, in the absence of chest pain. Review of the smartwatch ECG identified ischemic changes that were present within two minutes of symptom onset. Alerts to patients could prompt immediate ED evaluation and expedite care for critical, time-sensitive processes. This case illustrates a potential opportunity for a smartwatch ECG to alert patients to possible ischemia and seek immediate medical attention for confirmatory 12-lead ECG. Patients who lack classic cardiac symptoms are particularly at risk for delays in presentation. In this patient with a confirmed STEMI, within minutes of symptoms, and well in advance of any localizing chest pain, there were easily recognizable ST-segment changes on a smartwatch ECG. An alert within minutes provides an opportunity for early intervention. Widely available wearable technology such as smartwatches may provide opportunities to alert patients to myocardial ischemia, especially if accompanied by any acute symptomatology such as dizziness or nausea. Arrhythmia alerts from commercially available smartwatches are already incorporated into clinical decision making. Commercially available smartwatches are widely available. While we lack current evidence supporting the standalone use of smartwatch data, it can serve as a crucial alert for individuals to promptly seek medical evaluation, where indications of ischemia can be confirmed through 12-lead ECGs. Smartwatch ECG alerts provide the opportunity to notify patients of critical cardiac events such as acute myocardial ischemia.

Consent

The first author is the described patient and provides written permission for publication.

Authorship

All authors have made substantial contributions to all the following: (1) the conception and design of the paper, (2) drafting the article or revising it critically, (3) final approval of the version to be submitted.

Credit authorship contribution statement

Katren R. Tyler: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Bryn E. Mumma:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **David R. Anderson:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Nora Goldschlager:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization.

Declaration of competing interest

None.

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