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Wearable ECG patch monitoring for 72 h is comparable to conventional Holter monitoring for 24 h to detect cardiogenic vertigo

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We sought to compare the diagnostic efficacy of a 72-hour wearable electrocardiography (ECG) patch monitoring with a conventional 24-hour Holter monitoring for the detection of cardiogenic vertigo. We conducted a prospective multicenter study that recruited 47 patients suspected of cardiogenic vertigo in four referral-based university hospitals between November 2019 and April 2022. Patients received simultaneous ambulatory ECG recordings using a 72-hour wearable ECG patch monitoring and a conventional 24-hour Holter monitor. The primary outcome was the detection rate of arrhythmia events during the entire wearing period. The secondary outcomes included device preference and factors affecting the detection of cardiogenic vertigo. During the 72-hour monitoring period, there was no significant difference in the overall detection rate of arrhythmia events between the wearable patch and conventional Holter monitoring (10 of 47 [21.3%] vs. 8 of 47 [17.0%], $p = .500$) Most patients (46/47) favored a wearable patch over Holter monitoring. The effectiveness of wearable ECG patch monitoring was comparable to conventional Holter monitoring in detecting cardiogenic vertigo. With its extended monitoring capability and patient preference, wearable patch monitoring holds promise as an alternative method for the diagnosis of cardiogenic vertigo. Limitations of this study include small sample size and selection bias.

Cardiogenic vertigo refers to vertigo, dizziness, and lightheadedness that is associated with cardiovascular or heart-related issues. Although early identification of cardiogenic vertigo is crucial to prevent serious complications of cardiovascular diseases, including embolic stroke, sudden cardiac arrest, and syncope-related trauma[1–4], the diagnosis is mostly challenging when it presents atypically with recurrent vertigo/dizziness without syncope. Cardiac tests are not a common practice in patients with vertigo, particularly in cases where syncope is not present. Patients with cardiac problems, predominantly bradyarrhythmia, often seek consultation with neuro-otologists due to the predominant manifestation of vertigo. The ECG monitoring of these patients can pose a challenge, further complicating the diagnostic process. A recent study proposed new diagnostic criteria based on the clinical characteristics of 27 patients with cardiogenic vertigo, and the most common cardiac abnormality during the attacks of vertigo was bradyarrhythmia (89%)[5].

Short monitoring periods, poor patient compliance, and lack of real-time feedback of Holter monitoring can be one of the critical factors in the delayed diagnosis of cardiogenic vertigo. Significant progress has been made in cardiac rhythm monitoring through the use of bespoke medical devices and techniques via mobile systems, enabling extended monitoring of a patient's heart rhythm. This leads to more accurate arrhythmia detection rates compared to the traditional 24-hour Holter monitor. There have been some studies on the diagnosis of arrhythmias with wearable ECG monitoring, but there are no recent studies specifically on the diagnostic method for the detection of cardiogenic vertigo and the diagnostic efficacy of such devices for the diagnosis of cardiogenic vertigo has not been validated. A prospective, cohort study compared with 24-hour Holter monitoring, 72-hour monitoring with the wearable ECG monitoring increased the detection rate of paroxysmal

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atrial fibrillation by 2.2-fold[6]. A recent randomized clinical trial about 2 weeks of wearable ECG monitoring compared to routine clinical follow-up plus a pulse check and heart auscultation among older community-dwelling individuals with hypertension showed that atrial fibrillation screening with a wearable ECG monitor was well tolerated and increased atrial fibrillation detection 10-fold[7]. Another study showed a 7-day wearable patch ECG monitoring is more effective for the detection of supraventricular tachycardia compared to a 24-hour Holter monitoring[8]. These studies have shown that a longer duration of monitoring could detect more patients with arrhythmia[6–8]. , which has not been confirmed in cardiogenic vertigo. In order to document this issue, we extended monitoring time to 72 h in a group of wearable patch devices.

The aim of this study was to compare a 72-hour wearable electrocardiography (ECG) patch monitoring with 24-hour conventional Holter monitoring for the detection of cardiogenic vertigo.

Methods

Participants

We conducted a prospective multicenter study that consecutively recruited patients suspected of cardiogenic vertigo in four referral-based university hospitals between November 2019 and April 2022. Based on the diagnostic criteria of cardiogenic vertigo in a recent study[5], we included patients with (1) recurrent (more than one) attacks of spontaneous spinning or non-spinning vertigo that lasted less than 5 min, and (2) symptoms onset over the age of 60 or at any age with known heart diseases. We excluded patients who were unable to use a smartphone, had accompanying auditory or neurological symptoms/signs, or cognitive dysfunction, abnormal findings in vestibular and autonomic function tests, and declined to participate in the study.

We defined cardiogenic vertigo if the cardiac disease was documented in ECG monitoring when the patient had an attack of vertigo and that vertigo did not recur during the one-year follow-up period among participants.

Procedures

Patients received simultaneous ambulatory ECG recordings using a 72-hour wearable ECG patch monitoring and a conventional 24-hour Holter monitoring. To reduce variability, each hospital used the same wearable patch ECG monitor (Wellysis S-Patch Cardio), and all technicians were trained in its use by one person. The interpretation of the results of both wearable patch ECG monitoring and Holter monitoring was performed by the same cardiologist at each hospital, who were blinded to clinical information. Wellysis S-Patch Cardio is a lightweight (11 g) device containing a bioprocessor that continuously collects ECG data and transmits it in real time via a bluetooth connection to an Android smartphone application. The actual device is easily applied with only two standard ECG electrodes typically placed in the V2-V4 position. Patients kept the phone within 3 m of them throughout the test period. Arrhythmic events as causes of cardiogenic vertigo were defined as supraventricular tachycardia (>4 beats), atrial fibrillation (>4 beats), sinus pause>3 s, atrioventricular block (Mobitz type II or third-degree atrioventricular block), ventricular tachycardia (>4 beats), or polymorphic ventricular tachycardia/ventricular fibrillation.

The primary end point was overall detection rate of arrhythmia events during the entire wearing period. The secondary end points included device preference and factors affecting the detection of cardiogenic vertigo.

Statistical analysis

Based on the data from previously published studies[5,8,9], we estimated that the diagnostic efficacy would be 10% in Holter monitoring group, and approximately 40% in patch monitoring group. By adopting 0.8 power to detect a significant difference and a drop rate of 5%, 50 patients were required.

All analyses were performed using SPSS (version 27.0, SPSS, Chicago, IL, USA). Differences in the detection rates of arrhythmic events between Holter and wearable patch monitoring were evaluated by the McNemar test. Levene's homogeneity of variance and two-sample independent t-test were performed for numeric variables. Between groups with and without documented arrhythmic events, continuous variables were compared using the t test or Mann-Whitney U tests, and nominal variables were compared using the $\chi 2$ or Fisher exact tests. A p-value less than 0.01 was considered statistically significant.

Standard protocol approvals, registrations, and patient consents

All experiments followed the tenets of the Declaration of Helsinki and were approved by the institutional review boards of the Pusan National University Hospital (IRB NO. 2106-030-104), Pusan National University Yangsan Hospital (IRB NO. 05-2021-100), Ulsan University Hospital (IRB NO. 2021-05-024), and Keimyung University Dongsan Hospital (IRB NO. 2021-05-035). Written informed consents were obtained after the nature and possible consequences of this study had been explained to the participants. This study complies with Standards for Reporting Diagnostic accuracy studies guidelines and are registered through International Clinical Trials Registry Platform (https://www.who.int/ictrp; Unique identifiers: KCT0009088).

Results

Initially, 50 patients were assessed for eligibility, of which 3 (6%) were excluded, including those who were unable to use a smartphone ($n=2$) or declined to participate in the study ($n=1$) (Supplementary Fig. 1). Thus, 47 patients were selected for this study. The patients included 22 men (47%) aged from 42 to 85 years (71.2 ± 9.2 years).

There was no significant difference in the detection rate of cardiogenic vertigo between the wearable patch monitoring and Holter monitoring (10 of 47 [21.3%] vs. 8 of 47 [17.0%], $p=.500$) (Fig. 1).

Most patients (46/47) favored a wearable patch over Holter monitoring. Fifteen patients experienced minimal erythema due to Holter monitoring. The frequency of vertigo was lower in the group with documented

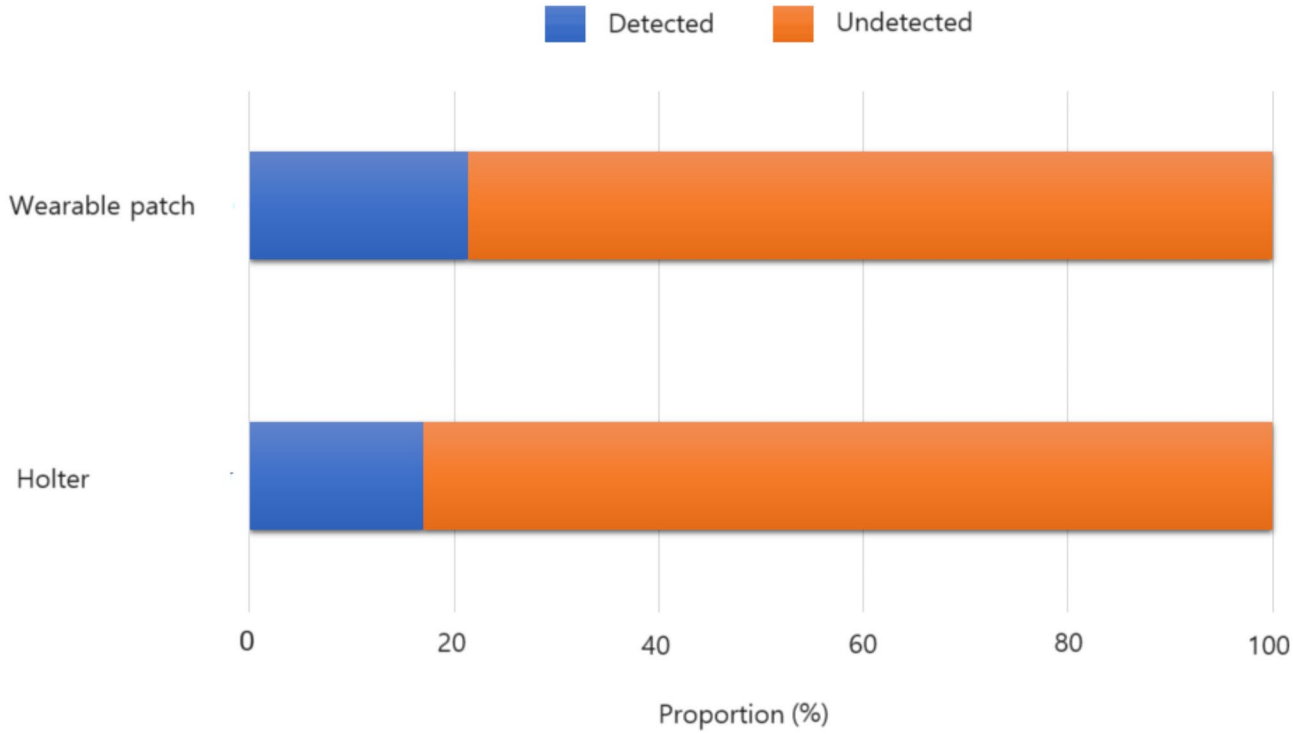

Fig. 1. Detection rates of arrhythmic events of a 72-hour wearable patch monitoring and a 24-hour Holter monitoring. The detection rates are not significantly different between the two devices (the McNemar test: $p > .01$).

	Arrhythmia detected ($n = 10$)	Arrhythmia undetected ($n = 37$)	p-value
Age, y, median (IQR)	75.5 (67.25–80.25)	71 (62.5–79.00)	0.239
Male, n (%)	5 (50)	20 (54)	1.000
Time from symptoms onset to test, days, median (IQR)	45 (12.25–265.00)	330 (60.00-1001.25)	0.151
Vertigo			
Duration, sec., median (IQR)	76.8 (2.75-60.00)	60 (2.25–150.00)	0.731
Frequency, times per week, median (IQR)	1.5 (0.88–5.50)	3 (1.00–21.00)	0.004
Imbalance, n (%)	7 (70)	27 (73)	1.000
Syncope, n (%)	6 (60)	11 (30)	0.136
Accompanying symptoms, n (%)	6 (60)	22 (60)	1.000
History of heart disease, n (%)	8 (80)	17 (46)	0.079

Table 1. Comparison of demographic and clinical characteristics between patients with and without documented arrhythmic events. IQR, interquartile range.

arrhythmic events than in the group without, however, it was not significantly different (median [interquartile range]: 1.5 [0.88–5.50] vs. 3 [1.00–21.00], $p = .004$) (Table 1).

Out of 10 patients with documented arrhythmic events, four (40%) had isolated recurrent vertigo without syncope, while vertigo preceded ($n = 3$) or occurred simultaneously ($n = 3$) with the syncopal attacks in the remaining six. Half of the patients with cardiogenic vertigo had a history of atrial fibrillation. The most common cardiac abnormality during the attacks of vertigo was bradyarrhythmia ($n = 8$, 80%), including tachycardia-bradycardia syndrome ($n = 5$), complete atrioventricular block ($n = 2$), and sick sinus syndrome ($n = 1$). The remaining two patients had paroxysmal atrial fibrillation during the attacks of vertigo. The longest pause ranged from 1.9 to 26.9 s.

Discussion

Our study demonstrated that the effectiveness of wearable ECG patch monitoring was comparable to conventional Holter monitoring in detecting cardiogenic vertigo, with patients finding the patch more preferable. These findings emphasize the potential of wearable ECG patch monitoring as a viable diagnostic tool for cardiogenic

vertigo. In terms of cost-effectiveness, conventional Holter monitoring is better than wearable ECG patch monitoring. However, wearable patch monitoring has other advantages including the patient-centric design, with its lightweight, compact, and adhesive, allowing patients to go about their daily activities without the discomfort or inconvenience of wires and bulky equipment associated with Holter monitoring, offers an added advantage in terms of patient compliance and comfort. This design not only improves patient compliance but also reduces the likelihood of signal artifacts caused by movement, as the patches adhere securely to the skin. All patients except only one favored a wearable patch over Holter monitoring in our study. The integration of modern technology with real-time data transmission capabilities, such as Bluetooth and smartphone applications, enhances the user experience, potentially leading to better adherence to monitoring protocols.

This study discovered that within the first 24 h, detection rates of both devices surpassed the general diagnostic yield of Holter ECG monitoring in assessing syncope, which stands at 8.6%[10]. The discrepancy could be attributed to the limited inclusion criteria of our research, which were based on the recently proposed diagnostic criteria for cardiogenic vertigo[5]. Only patients with symptoms onset over the age of 60 and recurrent episodes of spontaneous vertigo lasting less than 5 min were recruited for this study. Our results emphasize the significance of carefully selecting candidates for cardiovascular monitoring using appropriate diagnostic criteria and advanced methods for prolonged monitoring in order to diagnose cardiogenic vertigo accurately.

Recurrent vertigo without syncope was observed in 40% of our patients with cardiogenic vertigo, while an additional 30% occurred prior to syncope. A previous study similarly revealed a higher incidence of isolated or preceding vertigo in patients with cardiogenic vertigo. These findings underline the importance of timely diagnosis of cardiogenic vertigo, especially prior to the occurrence of syncope, to minimize potential complications, including sudden cardiac arrest and syncope-related injuries. The estimated 1-year mortality rate for cardiac syncope is around 30%[11,12].

Arrhythmias are the most common cause of cardiac vertigo. In our previous study, 41% percent of patients with cardiac vertigo had pre-existing arrhythmias[5]. Similarly, in the present study, half of the patients with cardiogenic vertigo had previous arrhythmias, but the other half did not have arrhythmia before.

Limitations of this study include small sample size and selection bias which limits statistical power. Cardiogenic vertigo is relatively rare condition and we only included patients with recurrent vertigo within 5 minutes without other vestibular or autonomic dysfunction who were able to use a smartphone. In the previous study, the frequency of cardiogenic vertigo was daily in 63% and less than once a week in 30%.[5] Therefore, not only 3 days ECG monitoring but one week ECG monitoring also would not take much advantage than 24 h ECG monitoring according to this data.

We believe that an extended monitoring for 7 to 14 days or more greatly would increase the likelihood of capturing cardiogenic vertigo and further studies are needed. Since the population for this study was limited to recurrent vertigo/dizziness independent of syncope, some patients with other vestibular disorders might be included.

A significant concern pertains to the security of patients' data in the context of wireless transmission, authentication, and cloud storage. The resolution of these issue would entail the establishment and implementation of an internal management plan, designation of a personal information protection officer, establishment and disclosure of personal information processing policy, and storage of key personal information, such as unique identification information, passwords, and biometric information, through safe protection measures such as encryption.

Data availability

Anonymized data not published within this article will be made available from the corresponding author upon reasonable request.

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Author contributions

HA. K.: writing – original draft (lead); Data Curation (lead); formal analysis (equal); writing – review and editing (equal). H. L.: Supervision (equal); writing – review and editing (supporting). H-S. P.: Conceptualization (lead); writing – review and editing (equal). J. A.: Formal analysis (lead); Conceptualization (supporting). S-M. L.: Data Curation (supporting); original draft (equal). S-Y. C.: Conceptualization (supporting); Writing – original draft (equal). EH. O.: Methodology (supporting), Writing – review and editing (equal). J-H. C.: Methodology (supporting); writing – review and editing (equal). J-Y. P.: Conceptualization (supporting); Writing – original draft (equal). K-D. C.: Funding Acquisition; Methodology (lead); Writing – original draft (equal); Writing – review and editing (lead).

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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