THE ANATOLIAN JOURNAL OF CARDIOLOGY

Official journal of the TURKISH SOCIETY OF CARDIOLOGY

Arrhythmias Beyond Atrial Fibrillation Detection Using Smartwatches: A Systematic Review

ABSTRACT

Background: Over the past few years, smartwatches have become increasingly popular in the monitoring of arrhythmias. Although the detection of atrial fibrillation with smartwatches has been the subject of various articles, there is no comprehensive research on the detection of arrhythmias other than atrial fibrillation. In this study, we included individual cases from the literature to identify the characteristics of patients with smartwatch-detected arrhythmias other than atrial fibrillation.

Methods: PubMed, Embase, and SCOPUS were searched for case reports, case series, or cohort studies that reported individual participant-level data, until January 6, 2022. The following search string was used for each databases: ("Smart Watch" OR "Apple Watch" OR "Samsung Gear") AND ("Supraventricular Tachycardia" OR "Cardiac Arrhythmia" OR "Ventricular Tachycardia" OR "Atrioventricular Nodal Reentry Tachycardia" OR "Atrioventricular Reentrant Tachycardia" OR "Heart Block" OR "Atrial Flutter" OR "Ectopic Atrial Tachycardia" OR "Bradyarrhythmia").

Results: A total of 52 studies from PubMed, 20 studies from Embase, and 200 studies from SCOPUS were identified. After screening, 18 articles were included. A total of 22 patients were obtained from 14 case reports or case series. Four cohort studies evaluating various arrhythmias were included. Arrhythmias, including ventricular tachycardia, atrial fibrillation, atrial flutter, atrioventricular nodal reentry tachycardia, atrioventricular reentrant tachycardia, second- or third-degree atrioventricular block, and sinus bradycardia, were detected with smartwatches.

Conclusions: Cardiac arrhythmias other than atrial fibrillation are also commonly detected with smartwatches. Smartwatches have an important potential besides traditional methods in the detection of arrhythmias and clinical practice.

Keywords: Apple watch, arrhythmia and antiarrythmics, atrial fibrillation, Smartwatch, supraventricular tachycardias

REVIEW

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Received: November 20, 2022
Accepted: January 3, 2023
Available Online Date: February 24, 2023

Cite this article as: Pay L, Yumurtaş AÇ, Satti DI, et al. Arrhythmias beyond atrial fibrillation detection using smartwatches: A systematic review. *Anatol J Cardiol.* 2023;27(3):126-131.

DOI:10.14744/AnatolJCardiol.2023.2799

INTRODUCTION

Cardiac arrhythmias include a variety of conditions that involve slow, fast, or irregular beats of the heart. Although atrial fibrillation (AF) is the most common of these arrhythmias, other cardiac arrhythmias constitute a significant symptomatic burden for patients.[1] Cardiac arrhythmias are associated with significant mortality, morbidity, and financial burden. The most important limitation of conventional screening tools in the detection of arrhythmia is the transient nature of arrhythmia episodes.

Smartwatches and wearable devices allow access to users' personalized data to be used in the prevention and management of medical conditions. In recent years, watches have evolved from accessories that tell time to computers that allow real-time recording of electrocardiograms (ECGs).[2,3] Heart rhythm monitoring is widely used as a result of developments in mobile health technology and wearable electronic devices.[4] The Apple Heart Study revolutionized the recognition and screening of cardiac arrhythmias with wearable technology.[5] While all Apple Watch series can evaluate heart rate via photoplethysmography (PPG), only series 4 or above can record ECGs. Smartwatches can diagnose patients' heart rhythms within 30 seconds using PPG.[5] Large-scale, app-based studies using the PPG method have shown that it has an important role in screening for AF.[5,6] Although

smartwatches have been widely used to detect AF, these devices may be useful in detecting other cardiac abnormalities.[7] Beyond the diagnosis of AF, clinical information can be obtained with ECG monitoring with the Apple Watch.[8]

In this review, we aimed to systematically review the detectability of other cardiac arrhythmias beyond the distinction of sinus rhythm and AF with single-channel ECG recordings.

METHODS

This was a systematic review of published case reports, followed by pooled analyses of the cohort data. This systematic review was conducted according to the preferred reporting items for systematic reviews and meta-analyses statement.[9] It has also been prospectively submitted to PROSPERO and is awaiting registration.

Search Strategy and Selection Criteria

PubMed, Scopus, and EMBASE were searched electronically to identify all studies concerning smartwatch-detected arrhythmias regardless of publication type or language. All databases were searched from their inception up till January 6, 2022. The search terms used were: ("Smart Watch" OR "Apple Watch" OR "Samsung Gear") AND ("Smart Watch" OR "Apple Watch" OR "Samsung gear") AND ("Supraventricular Tachycardia" OR "Cardiac Arrhythmia" OR "Ventricular Tachycardia" OR "Atrioventricular Nodal Reentry Tachycardia" OR "Atrioventricular Reentrant Tachycardia" OR "Heart Block" OR "Atrial Flutter" OR "Ectopic Atrial Tachycardia" OR "Bradyarrhythmia"). All search terms were combined with Boolean operators and searched as both key words and MeSH terms to maximize sensitivity. Reference lists of papers found in the literature search were manually searched to further identify articles that are eligible for inclusion.

Articles were first screened by at least 2 reviewers (L.P. and G.M.) based on their titles and abstracts. All identified articles were systematically assessed using the inclusion and exclusion criteria for further study. Conflicts over inclusion were resolved by an independent reviewer (DIS). Articles were deemed eligible for inclusion if any type of smartwatch-detected arrhythmia was described except for AF. Conference publications, narrative reviews, systematic reviews, and meta-analyses were excluded.

Risk of Bias (Quality) Assessment

Quality of all case reports or case series was assessed using the methodological quality and synthesis of case series,[10] and case reports and observational studies were assessed using the Newcastle-Ottawa scale.[11]

Data Extraction and Evidence Synthesis

Two reviewers (J.H. and A.C.Y.) independently extracted data from included studies, including country, sample sizes, patients' demographics, type of arrhythmia, smartwatch type, and mean age of the patients. Conflicts were resolved by an independent reviewer (L.P.).

HIGHLIGHTS

- Smartwatches have the potential to detect bradyarrhythmias and tachyarrhythmias other than atrial fibrillation.
- Smartwatches are very useful in the close follow-up of patients at high risk for arrhythmia.
- Smartwatches may be used in the future to replace ILR (implantable loop recorders) or rhythm Holter monitoring in selected patient groups.

RESULTS

A total of 18 studies were included in this review. A total of 22 patients were obtained from 14 case reports or case series. Four cohort studies evaluating various arrhythmias were included (Figure 1).

Case Reports

In case reports, Apple Watch was used in 21 patients, Samsung smartwatch was used in only 1 patient. The ages of the patients ranged from 10 days to 75 years. Complete atrioventricular (AV) block was detected in 4 patients. Permanent pacemaker implantation was performed in 3 patients with complete AV block in the follow-up. Ventricular tachycardia was detected in 3 patients. Catheter ablation was applied to 2 patients with ventricular tachycardia. Atrial flutter (AFL) was detected in 2 patients. In the remaining 13 patients, supraventricular tachycardia consisting of atrioventricular reentrant tachycardia (AVRT) and atrioventricular nodal reentry tachycardia (AVNRT) was detected. Electrophysiological studies were performed on 5 patients with supraventricular tachyarrhythmia (SVT). Case reports and series in which arrhythmias are detected with smartwatches are summarized in Table 1.

Cohort Studies

In the cohort studies, devices consisting primarily of Apple Watch and Fit Bit were used. Detected tachyarrhythmias are sinus tachycardia, AFL, atrial tachycardia (AT), and ventricular tachycardia. Sinus bradycardia and second-or third-degree AV block were detected as bradyarrhythmia. Cohort studies in which arrhythmias other than AF were detected with smartwatches are outlined in Table 2.

In the study by Caillol et al[8] in which they examined 256 patients, standard 12-lead ECG recordings were performed followed by smartwatch ECG recordings. All 40 patients with bradyarrhythmia could be detected using the Apple Watch. Atrioventricular block and sinus bradycardia could be differentiated in 81% of the patients. In addition, all 64 patients with tachyarrhythmia could be detected using the Apple Watch. While the diagnosis of 2 patients with ventricular tachycardia was made correctly, the distinction between AF and AFL/AT was made correctly in 71% of the cases. Accurate diagnosis rates for AFL/AT remained low [sensitivity, 25% (95% CI, 5%-57%) and specificity, 99% (95% CI, 97%-100%)].

Ploux et al[26] evaluated 260 patients who were ECG recorded by wearing an Apple Watch Series 4 after a standard 12-lead ECG. Lead I (AWI) was recorded by keeping the clock on the left arm and the right index finger on the crown. Lead II (AW-II) was recorded by keeping the clock at the left ankle

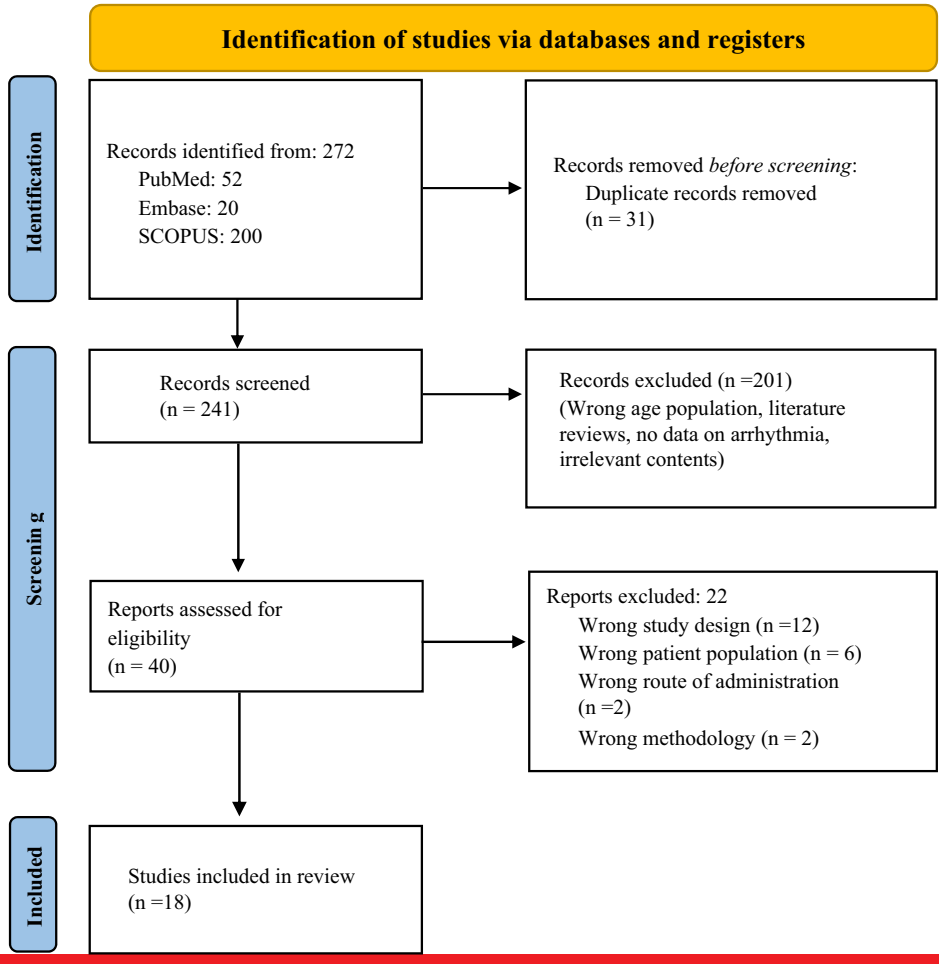

Figure 1. Preferred reporting items for systematic reviews and meta-analyses flow diagram.

and right index finger at the crown. Lead V1 (AW-ANT) was evaluated with the right index finger on the crown and watch at the fourth intercostal level in the right parasternal area. Finally, lead V6 (AW-LAT) was evaluated with the right index finger on crown and the watch at the fifth intercostal level in the left midaxillary line. With AW-I lead, complete AV block was detected in 7/10 cases and second-degree AV block was detected in 0/3 cases. With AW-4, where P waves were evaluated better, all 10 cases of complete AV block and 2/3 cases of second-degree AV block were detected. As a result, AW-4 differentiated AV block and sinus bradycardia more accurately than AW-I. Besides AW-I correctly diagnosing atrial arrhythmia in 57/62 cases (92%), the diagnostic accuracy for AFL/AT was 25% sensitivity, 99% specificity. When an atrial arrhythmia is detected using the AW-I, additional AW-4 analysis has been shown to improve discrimination between AF and AFL/AT (71% to 89% correct; $P = .01$).

Saghir et al[27] enrolled patients with a history of AF or AFL and were scheduled for electrical cardioversion or ablation. In the study, ECG or telemetry strips along with Apple Watch ECGs were taken 1 hour before and after the procedures. Although normal sinus rhythm was detected in 30/31 (96.8%) and sinus tachycardia or bradycardia was detected in 2/2 (100%), AFL was detected in 0/3 (0%).

Koshy et al[28] evaluated 102 patients who were followed by ECG monitoring simultaneously by wearing a smartwatch (Fit Bit, Apple Watch) for 30 minutes. Atrial flutter was detected in 32 patients, and AFL was detected in 20 patients. As a result, both smartwatches were significantly correlated with ECG in atrial arrhythmias, and Apple Watch showed a stronger correlation compared to Fit Bit (Apple Watch $r_S = 0.83$, Fit Bit $r_S = 0.56$, both $P < .01$).

DISCUSSION

To our knowledge, this systematic review is the first to evaluate cardiac arrhythmias other than AF. The fact that smartwatches allow self-recording of ECGs and their evaluation by healthcare providers has facilitated the detection of rare arrhythmias in patients. With the widespread use of smartwatches, it is possible to detect bradycardias, supraventricular tachycardias, and ventricular arrhythmias as well as AF. Another point that should be emphasized is that smartwatches function as event monitors as devices that accurately present ECGs to doctors. Therefore, they have great potential as a noninvasive alternative to implantable loop recorders (ILRs).

The application of electrophysiological study after tachyarrhythmias and the application of permanent pacemaker

Table 1. Summary of General Characteristics of Case Reports/Series Made with Smartwatches

Ref.	Country	Year	Article Type	Arrhythmia Type	No. of Patients	Mean Age ± SD	Type of Smartwatch
Bogossian et al[12]	Germany	2020	Case report	AVNRT	1	65	Apple Watch
Overbeek, DL et al[13]	USA	2019	Case report	Complete heart block	1	60	Apple Watch
Yerasi, C et al[14]	USA	2019	Case Report	High-grade atrioventricular block	1	68	Apple Watch
Kasai, Y et al[15]	Japan	2021	Case report	AVNRT and AVRT	1	52	Apple Watch
Siddeek, H et al[16]	USA	2019	Case report	AVNRT	1	16	Apple Watch
Mun, E et al[17]	South Korea	2021	Case report	Wolff-Parkinson-White	1	26	Samsung Galaxy Fit
Leroux, J et al[18]	France	2021	Case series	Sinus tachycardia, atrial tachycardia, and complete atrioventricular block	3	16 months old, 4 months old, 10 days old	Apple Watch
Kassam N, et al[19]	Tanzania	2021	Case report	AVRT	1	45	Apple Watch
Burke J, et al[20]	USA	2020	Case series	Ventricular tachycardia	2	60,63	Apple Watch
Ringwald M, et al[21]	Switzerland	2020	Case report	Ventricular tachycardia	1	45	Apple Watch
Goldstein LN, et al[22]	South Africa	2019	Case report	AFL	1	56	Apple Watch
Ahmed AS, et al[23]	USA	2020	Case report	AFL	1	54	Apple Watch
Yeo C, et al[24]	Singapore	2021	Image challenge	Supraventricular tachycardia (SVT) with aberrancy	1		Apple Watch
Leroux J, et al[25]	France	2022	Case series	Supraventricular tachycardia, Wolff-Parkinson-White Syndrome and complete atrioventricular block	6	5, 6, 7, 9, 11, 13	Apple Watch

AFL, atrial flutter; AVNRT, atrioventricular nodal reentry tachycardia; AVRT, atrioventricular reentrant tachycardia.

after complete heart block detected with smartwatches in the current case reports reveal the effect of smartwatches on daily practice. As a result of the spread of interventions and medical treatments for arrhythmias detected with smartwatches, it is inevitable that they will take their place in current guidelines. On the other hand, this new examination entering clinical practice will require clinicians to learn to evaluate these data efficiently.

Photoplethysmography, an optical technique, recognizes the cardiac cycle by detecting the change in blood volume in the microvascular bed.[29,30] The peak-to-peak distance of the waves formed by each pulse can be interpreted as the R wave-R wave interval in the cardiac cycle.[31] A single-lead ECG can be recorded by the circuit between the 2 electrodes, one located on the back of the watch in contact with skin and the other on the digital crown.[32] The recording is automatically analyzed by an algorithm, providing a diagnosis of heart rate, arrhythmia, and AF. The most important limitation of the recordings obtained with smartwatches is that they provide a limited view of cardiac activity over a single electrode and cannot detect some abnormalities as a result. Obtaining AW-ECG recordings from the left ankle and left

Table 2. Summary of General Characteristics of Cohort Studies with Smartwatches

Ref.	Country	Year	Article Type	Arrhythmia Type	No. of Patient	Mean Age ± SD	Type of Smartwatch
Caillol, T et al[8]	France	2021	Cohort	Second- or third-degree atrioventricular block, sinus bradycardia, AF Atrial flutter/tachycardia, ventricular tachycardia	256 patients (104 had arrhythmia)	66 ± 6	Apple Watch
Ploux, Sylvain et al[26]	France	2022	Cohort	Sinus bradycardia, third-degree AV block, second-degree AV block, AF, AFL/AT	260	66 ± 6	Apple Watch
Saghir, N et al[27]	USA	2021	Cohort	AF, sinus tachycardia, sinus bradycardia	236		Apple Watch
Koshy, AN et al[28]	Australia	2018	Cohort	Atrial arrhythmias	102	65	Apple Watch and Fit Bit

AF, atrial fibrillation; AFL, atrial flutter; AT, atrial tachycardia; AV, atrioventricular.

chest regions may improve the accuracy of the diagnosis.[33] However, a recent systematic review has shown that smartwatches detect cardiac arrhythmias with high accuracy.[34] The Apple Heart study showed consistent detection of AF by analyzing pulse irregularity obtained with the smartwatch.[35] In this study, the positive predictive value for AF detection with Apple Watch was 0.84 (95% CI, 0.76-0.92). In the Apple Heart Study, an arrhythmia, particularly atrial and ventricular ectopy, was detected, in 40% of participants with an irregular pulse notification and the absence of AF.[36] However, AF is relatively easier to detect than other arrhythmias, as it is done by detecting the R-R irregularity. Therefore, we aimed to show the detectability of other arrhythmias with smartwatches.

Besides all these positive features, ECG recording with smartwatches has certain limitations. First, in order for smartwatches to record ECG, the user must start the recording and keep his index finger on the crown. In addition, at least 30 seconds must pass for the recording to occur. It should be kept in mind that smartwatches may be ineffective in arrhythmias that cause hemodynamic instability or in arrhythmias lasting less than 1 minute, and other alternatives should be preferred. Second, false positive results due to noise and artifact, especially during physical exercise, will lead to overdiagnosis and overtreatment. Third, these devices provide lead 1 recording where the P wave cannot be evaluated ideally. However, recordings from alternative positions such as the precordium or ankle may improve P wave evaluation. Finally, the fact that these devices need to be charged almost daily can lead to unrecognized arrhythmias during charging.

Considering these results, 24-hour rhythm Holter recording should be preferred in patients with more frequent arrhythmias; ILR and smartwatches should be preferred in less frequent arrhythmias.

Although all these technological developments provide significant convenience in the recognition of cardiac arrhythmias, there is no guide for the management of arrhythmias detected by smartwatches. Widespread use of smartwatches will lead to overdiagnosis and serious cost burden. In addition, false positive arrhythmias detected by smartwatches can lead to unnecessary use of health resources.[37] On the other hand, these screening methods can produce many false positive and negative results, which can lead to user anxiety.

FUTURE ASPECT

Today, ILRs are considered the gold standard method for detecting rare arrhythmias. However, the ability of smartwatches to detect various arrhythmias with high accuracy suggests that they may replace ILRs in the near future. In order to use the full potential of this technology, its integration into existing telemedicine applications can be expanded. Although the correct management of the large data density that may occur is seen as a great challenge, this difficulty can be overcome with the applications of artificial intelligence. With additional patches or accessories to be used, it will be possible to record from more than one lead. As a result, the accuracy of arrhythmia diagnoses can be increased. According to the study by Ploux et al.[26] when atrial arrhythmia is detected, evaluating with additional leads improved the results in AF/AFL discrimination.[26] QT measurements, accurate MI diagnoses, and even localizations of the accessory pathway or early ventricular extrasystoles can be detected. Recordings from more than one leads will reduce the interference problem and also reduce false positive results.

In the near future, algorithms that can alert when heart rates are detected above or below a certain level may be added to the devices. In addition, by using a software that can detect the width of the QRS, transient branch blocks or wide QRS tachycardias may be recognized. Finally, with the change in smartwatch designs, more accurate records can be obtained, perhaps more than one derivation record can be taken. For example, in the future, it may be possible to create a derivation and obtain continuous ECG recordings with a smartwatch to be worn on the left wrist and a wristband on the right.

With the development of technology, it can be considered to overcome this problem and increase the accuracy rates in tachyarrhythmias. As a result of arrhythmia detections through smartwatches in the future, there may be potential in reducing cardiovascular mortality and morbidity in diagnosis and treatment. It can also be effective in reducing costs. Smartwatches are promising in recognizing challenging patient groups such as cardio-inhibitory vasovagal syncope and sick sinus syndrome. Finally, drug titration can be applied reliably with smartwatch applications that contain drug information of patients and closely monitor the effects and side effects of these drugs.

CONCLUSIONS

This review highlights the ability of smartwatch technology to detect other cardiac arrhythmias besides AF. This systematic review also reveals the increasing role of digital health applications in healthcare today. The widespread use of mobile technological tools offers great potential in the cardiovascular field as well as in all areas of health. Smartwatches and other wearable devices have significant potential for heart rhythm monitoring in patients at high risk of arrhythmia.

Ethics Committee Approval: Not applicable.

Informed Consent: Not applicable.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – G.Ç.; Design, Supervision – G.T., J.S.K.C.; Resources – J.M.H.H., G.M., Y.H.A.L.; Materials – O.B.; Data Collection and/or Processing – L.P., D.I.S., A.Ç.Y.; Analysis and/or Interpretation – O.T., O.B.; Literature Search – D.İ., E.Ö.; Writing Manuscript – L.P., D.I.S.; Critical Review – G.Ç., G.T.

Declaration of Interests: None.

Funding: There was no funding.

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