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ORIGINAL RESEARCH

Accuracy of Apple Watch in Measuring 30-Second Resting Electrocardiography in Patients with Cardiac Diseases and Comorbidity: An Observational Cross-Sectional Study

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Background: Electrocardiography (ECG) is a standard method for studying the heart rate and heart electricity. The Apple Watch has recently been used to measure heart electricity via 30 seconds of ECG monitoring, but its validity is not known.

Methods: A cross-sectional study included a sample of 112 patients with chronic disorders, including cardiac patients with sinus rhythm, cardiac patients with irregular heart rhythm, and patients with diabetes, hypertension, and dyslipidemia; their cardiac activity was investigated using the Apple Watch and ECG.

Results: The correlations were strong between the Apple Watch and the 12-lead ECG in the heart rate, PR intervals, QT intervals, QRS complex, and RR intervals in all patients' subcategories (cardiac, hypertension, diabetic, and dyslipidemia patients).

Conclusion: The Apple Watch is valid for carrying out ECG in measuring the heart rate, PR intervals, QT intervals, QRS complex, and RR intervals of patients with cardiac and chronic diseases at rest; this may help in initial diagnosis for patients with cardiac diseases or those who are at risk of developing cardiac disease in the future.

Keywords: Apple Watch, electrocardiography, cardiac diseases, chronic diseases

Introduction

Electrocardiography (ECG) has become a routine tool for evaluating cardiovascular health in recent years. Utilization of the 12-lead electrocardiogram is considered the most objective heart rate (HR) assessment procedure and the gold standard for monitoring HR.[1–4] However, in practice, using the ECG can be uncomfortable for some people, particularly older people; hence, wrist-worn watches may be used as an alternative, using the Bluetooth connection to monitor heart rate.[4,5] Wearable devices are acceptable tools to measure HR and conduct ECG in the practice of detecting and diagnosing cardiovascular health in patients with cardiac and chronic diseases and can lead to enhanced patient care.[6,7]

Recent advancements in wearable technology have introduced devices such as the Apple Watch, which offers features including HR monitoring and single-lead ECG recording. These devices provide an accessible and cost-effective solution for continuous monitoring, particularly for individuals who may face barriers to using traditional healthcare systems. Their portability and ease of use make them an attractive alternative for both patients and clinicians. However, questions remain about their accuracy, particularly for individuals with complex cardiac and non-cardiac comorbidities. Previous studies have established the utility of the Apple Watch in general populations;[8] however, its performance in clinical populations, such as those with cardiac and chronic diseases, requires further investigation.

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The Apple Watch Series 1 to 3 gives notifications for atrial fibrillation (AF); however, the Apple Watch Series 4 and above provide 30 seconds of ECG monitoring only at rest; thus, the Apple Watch cannot offer ECG during exercise.[9] A previous Apple Watch heart study showed that 34% of subjects who received an arrhythmia notification were found to have AF.[10,11] Furthermore, a study investigated the Apple Watch's accuracy in detecting AF through a single-electrode ECG downloaded as a PDF file; 50 cardiac patients with only AF and sinus rhythm were assessed six times over two days for each participant, but there were no AF or other cardiac disease patients with abnormal rhythm included in the previous study. The results of a PDF wave from the Apple Watch, compared to telemetry, showed the former's 96% sensitivity in measuring the rhythm of the ECG.[12] However, the available data cannot support the validity of using the Apple Watch with a single-electrode ECG downloaded as a PDF file. Hence, more studies are needed to investigate the Apple Watch's effectiveness in adult cardiac patients, and those with other chronic diseases, such as diabetes, hypertension, and dyslipidemia, because these chronic diseases are comorbid[13] and risk factors for developing cardiac diseases.[14]

A recent study measured the accuracy of the Apple Watch in measuring the HR and SpO2 in chronic patients; it was found to be accurate in these measurements,[8] but the study did not record the Apple Watch's ECG test performance in patients with cardiac and chronic diseases; this is a point of investigation for future research. Hence, the present study is novel because it is the first to measure the validity of the Apple Watch in 30-second resting ECG measurement in patients with cardiac sinus rhythm, irregular heart rhythm, and chronic diseases, such as diabetes, hypertension, and dyslipidemia, who are at risk of developing cardiac disease in the future. This method may provide more detailed data for the ECG records, such as RR intervals, QRS complex, QT intervals, and PR intervals.

Methods

Study Design

An observational, single-center, cross-sectional study was conducted at Umm Al-Qura Medical Center.

Ethical Approval

This study followed the Declaration of Helsinki 1975 principles, revised in 2000 (World Medical Association, 2013).[15] Each participant signed a written consent form approving their voluntary participation in this study and agreeing to the publication of its results. The study was approved by the biomedical research ethics committee at Umm Al-Qura University (HAPO-O2-K-012-2023-02-1433). Twenty-two patients in this study had white skin, and thirty-four had brown skin, and no patients had black skin.

Sample Size

Sample size was calculated following the previously reported guidelines.[16] Using one-way ANOVA (F-test), a required sample size was computed with a 0.05 significance level, a 95% power value, an effect size of 0.43, and allowed allocation into five groups. This gave a total sample size of 110 participants to provide reliable results. Sample size was computed using the online G-Power tool (https://download.cnet.com/G-Power/3000-2054_4-10647044.html).

Subjects' Recruitment and Groups' Allocation

One hundred and seventy patients were initially recruited, of whom 58 were excluded at the beginning of the study. Initially, 18 patients had uncontrolled hypertension, 8 patients had S-T segment depression of more than 2 mm, 10 patients had unstable arrhythmias, 10 patients had unstable angina, 6 patients encountered distance barriers, and 6 patients refused to sign their informed consent.

A sample of 112 (mean [SD]; age 50 [11] y) were enrolled in this study, after checking the inclusion and exclusion criteria with the cardiologist. Patients with cardiac disorders, including 34 cardiac patients with sinus rhythm, and 14 cardiac patients with irregular HR rhythm. Patients with chronic diseases, including 14 diabetics, 34 hypertension patients, and 16 dyslipidemia patients, who are at risk of developing cardiac diseases, participated in this study. There was no control group. The study followed the Guidelines for Reporting Reliability and Agreement Studies (GRRAS).[17]

Inclusion Criteria

Eligible participants within the five study groups were patients with chronic diseases: cardiac patients with sinus rhythm and cardiac patients with irregular heart rate (sub-groups 1 and 2), diabetes type 1 and 2 (sub-group 3), controlled hypertension (sub-group 4), and dyslipidemia (sub-group 5). Cardiac patients with myocardial infarction (6 weeks post-insult), coronary bypass graft surgery (CABG), cardiac patients with valve diseases, stable atrial fibrillation (AF), heart failure (HF)-I, II, and III, and resting ejection fraction (EF) greater than 50% were also invited to participate in this observational, cross-sectional evaluative study.

Exclusion Criteria

Cardiac patients with unstable angina, uncontrolled high blood pressure, unstable arrhythmia, the presence of complex ventricular arrhythmia, ST-segment depression ≥2mm from baseline during exercise testing or recovery, pacemaker patients, and patients with diseases other than those described in the inclusion criteria were excluded from the study.

The choice of the Apple Watch

The Apple Watch was chosen for investigation because it can provide ECG measurement for 30 seconds at rest, which is the main aim of this study.

Evaluation Procedures

Each participant underwent the 12-lead ECG (ECG300G, Contec Medical Systems Co., Ltd., China) evaluation according to the traditional procedure, and also wore the Apple Watch (Series 8, watchOS 9.0, Apple Inc., California, USA) on the left hand, connected to the iPhone (iPhone 11, iPhoneOS 16.1, Apple Inc., California, USA), over a 30-second resting period at the same time duration. The Apple Watch was fitted on the left wrist during the test, and the patient was completely at rest. As recommended by the manufacturer, the Apple Watch was not too tight or too loose. Then, the ECG app was opened in the Apple Watch. The participants rested their arms on a table, and then held their finger on the digital crown for 30 seconds. The results appeared on the watch and were then stored in the health app on the iPhone.[8]

The patients were instructed to compress the crown with a finger of their right hand for 30 seconds, and the Apple Watch reading was recorded. The PDF file from the Apple Watch showed the 30-second resting ECG compared to the ECG rhythm strip, including heart rate, PR intervals, QRS complex, QT interval, and RR intervals. All measurements were conducted with the supervision of all researchers.

Data Analysis

Results were presented as means and standard deviations using descriptive statistical procedures. All data were entered into the statistical JASP program, version 18.1. A one-way ANOVA was used to test the mean difference (MD) between subgroups and to determine the normal distribution of the data. The intraclass correlation tests were used with a 95% confidence interval (CI) to test the associations between variables such as heart rate, PR intervals, QRS complex, QT intervals, and RR intervals evaluated within each subgroup. The correlation was intercepted based on the following definitions: ICC = (>0.90) was excellent, (0.75 to 0.90) was good, (0.60 to 0.75) was moderate, and ICC = (<0.60) was low.[18]

The Bayesian correlation pairwise plots and Bland–Altman plot with confidence intervals were used by the JASP program to measure the bias and the level of agreement between devices. The MD and standard deviation of the mean difference (SDD) were calculated to construct the Bland–Altman plots. The P value was set at 0.05 for significant results.

Results

The heart rate measured by the Apple Watch for 30 seconds, and by the 12-lead ECG, showed an excellent positive correlation in cardiac patients with sinus rhythm, irregular heart rhythm, and patients with chronic diseases, including hypertension, diabetes, and dyslipidemia (Table 1). The correlations between the Apple Watch and the 12-lead ECG in

Table 1 Correlation Between the Apple Watch and 12-Lead ECG in Patients With Cardiac Diseases and Comorbidities for 30 seconds

Outcomes	Mean (SD) of Practical (Apple Watch)	Mean (SD) of Criterion (12 Lead ECG)	ICC (p value)
HR for Hypertension patients	70.47(6.61)	70(6.89)	0.99(<0.001)
HR for diabetic patients	75.42(10.31)	75.57(11.29)	0.99(<0.001)
HR for dyslipidemia patients	69.25(11.80)	68.75(11.41)	0.99(<0.001)
HR for cardiac patients with sinus rhythm	72.70(11.49)	72.17(11.63)	0.99(<0.001)
HR for cardiac patients with irregular rhythm	78.71(12.48)	78.28(13.05)	0.99(<0.001)
HR for all patients	72.62(10.51)	72.21(10.87)	0.99(<0.001)
PR intervals for Hypertension patients	175.52(28.90)	175.88(29.77)	0.99(<0.001)
PR intervals for diabetic patients	165.28(14.18)	165.28(14.18)	1.00(<0.001)
PR intervals for dyslipidemia patients	169.87(18.95)	169.87(18.95)	1.00(<0.001)
PR intervals for cardiac patients with sinus rhythm	170(29.76)	169.94(29.78)	1.00(<0.001)
PR intervals for cardiac patients with irregular heart rhythm	162.71(18.02)	162.71(18.02)	1.00(<0.001)
PR intervals for all patients	170.16(25.31)	170.25(25.64)	1.00(<0.001)
QRS for Hypertension patients	95.47(12.03)	95.52(11.97)	0.99(<0.001)
QRS for diabetic patients	101.42(9.62)	102(9.79)	0.99(<0.001)
QRS for dyslipidemia patients	98(8.79)	98.37(8.71)	0.99(<0.001)
QRS for cardiac patients with sinus rhythm	101.23(10.85)	101.17(10.61)	0.99(<0.001)
QRS for cardiac patients with irregular heart rhythm	90.85(11.18)	91.42(12.15)	0.99(<0.001)
QRS for all patients	97.75(11.27)	97.94(11.28)	0.99(<0.001)
QT interval for Hypertension patients	399.11(27.53)	399.52(27.70)	0.99(<0.001)
QT interval for diabetic patients	414.85(50.40)	415.28(50.76)	1.00(<0.001)
QT interval for dyslipidemia patients	404.37(48.68)	404.5(48.99)	1.00(<0.001)
QT interval for cardiac patients with sinus rhythm	410.29(40.95)	410.82(41.13)	0.99(<0.001)
QT interval for cardiac patients with irregular rhythm	386.28(29.03)	386.28(29.03)	1.00(<0.001)
QT interval for all patients	403.62(38.91)	403.98(39.14)	0.99(<0.001)
RR intervals for Hypertension patients	869.11(136.71)	869.11(136.71)	1.00(<0.001)
RR intervals for diabetic patients	890(163.33)	890(163.33)	1.00(<0.001)
RR intervals for dyslipidemia patients	816.25(104.55)	816.25(104.55)	1.00(<0.001)
RR intervals for cardiac patients with sinus rhythm	885.58(171.03)	885.58(171.03)	1.00(<0.001)
RR intervals for cardiac patients with irregular rhythm	777.14(69.66)	777.14(69.66)	1.00(<0.001)
RR intervals for all patients	857.67(144.56)	857.67(144.56)	1.00(<0.001)

Abbreviations: R, Pearson correlation coefficient; HR, Heart rate; SD, Standard deviation; ICC, Intraclass correlation coefficient.

the PR intervals, QT intervals, QRS complex, and RR intervals were excellent in all cardiac and chronic disease patients (Table 1).

Table 1 presents the mean and SD in the Apple Watch and the 12 lead ECG, regarding the HR, PR intervals, QRS complex, OT intervals, and RR intervals in each group (hypertension, diabetes, dyslipidemia, and cardiac patients with sinus rhythm and irregular heart rhythm).

Heart Rate Data

The correlations between the Apple Watch and the 12-lead ECG in heart rate are presented in Figure 1. The upper and lower limits of agreement in HR for all patients are 2.34 and −1.54, respectively, while the mean difference is 0.41 (Figure 2).

PR Intervals Data

The correlations between the Apple Watch and the 12-lead ECG in PR intervals are presented in Figure 3. The upper and lower limits of agreement in PR intervals are 1.32 and −1.54, with the mean difference of −0.107 (Figure 4).

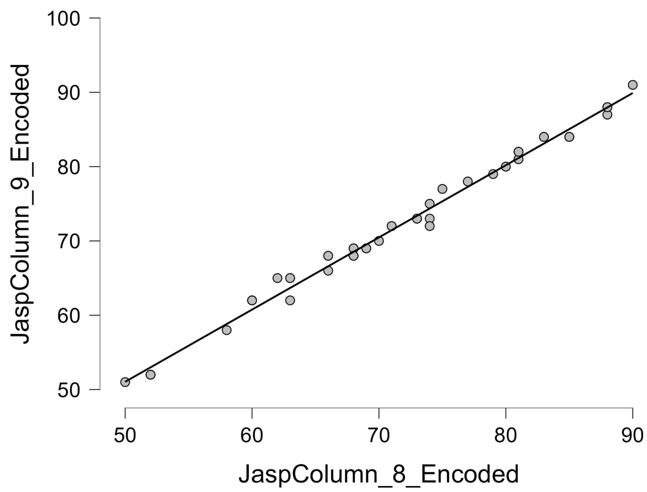

Figure 1 Heart rate correlation for all patients.

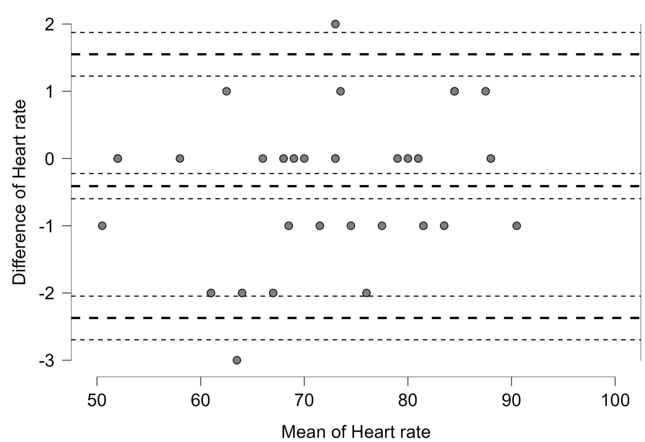

Figure 2 Heart rate for all patients.

 https://doi.org/10.2147/JMDH.S507504

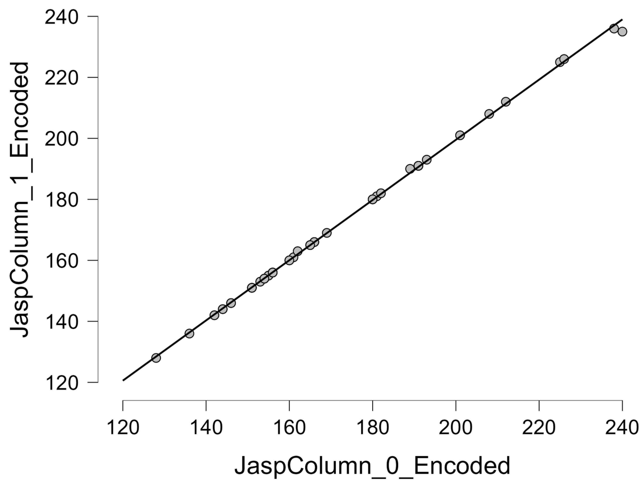

Figure 3 PR intervals correlation for all patients.

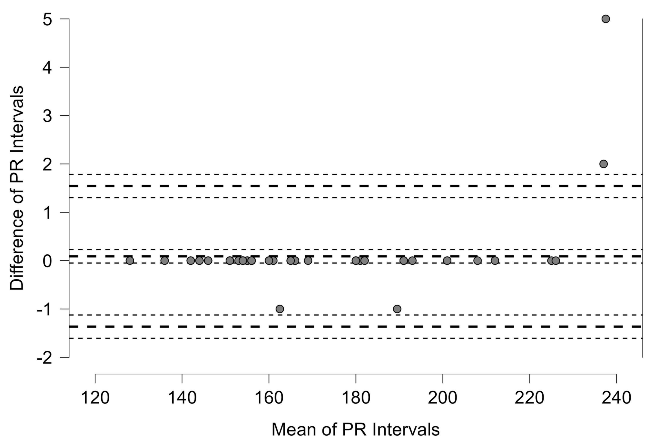

Figure 4 PR intervals for all patients.

QT Intervals Data

The correlations between the Apple Watch and the 12-lead ECG in QT intervals are presented in Figure 5; QT intervals are 1.63, −2.34, with the mean difference −0.35 (Figure 6).

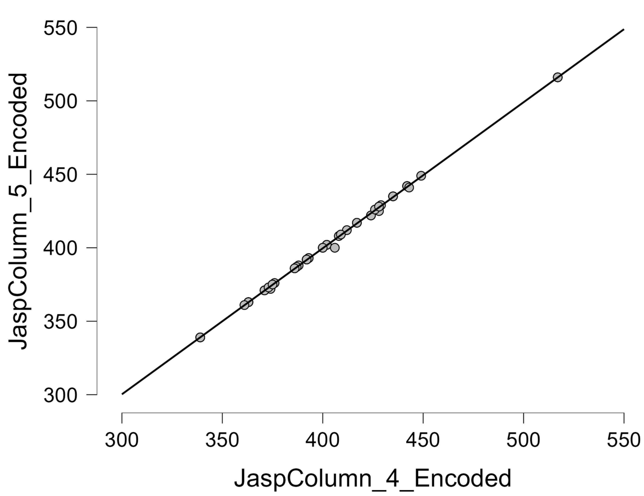

Figure 5 QT intervals correlation for all patients.

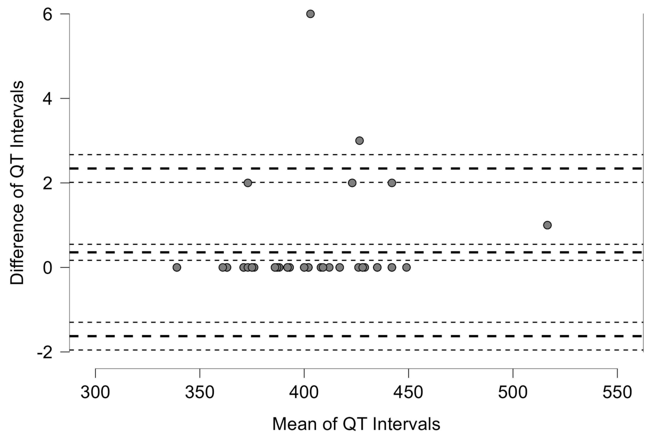

Figure 6 QT intervals for all patients.

QRS Complex Data

The correlations between the Apple Watch and the 12-lead ECG in the QRS complex are presented in Figure 7. QRS complex values are 1.92 and −2.31, with the mean difference −0.19 (Figure 8).

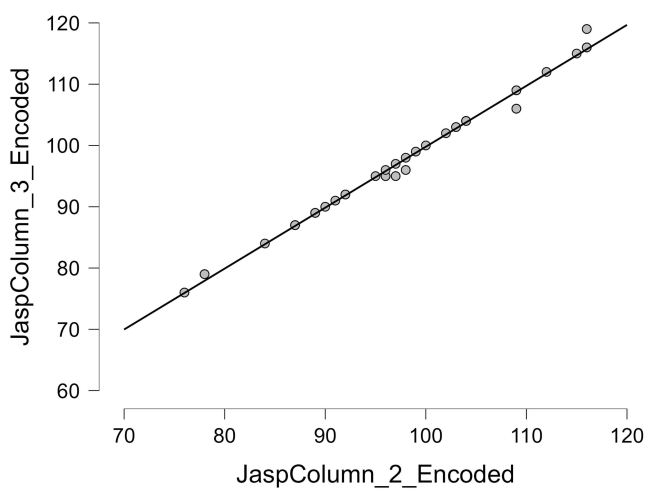

Figure 7 QRS complex correlation for all patients.

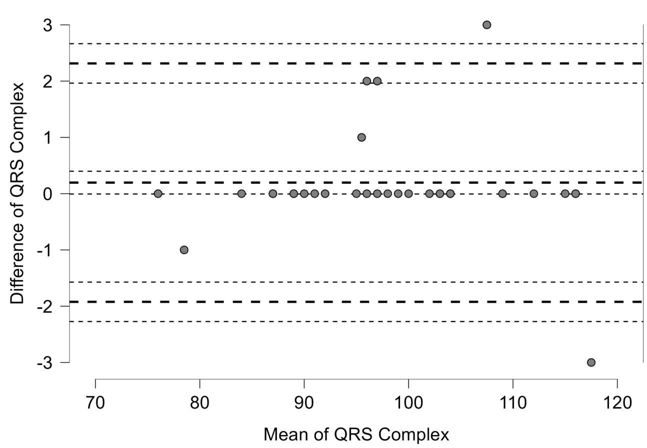

Figure 8 QRS complex for all patients.

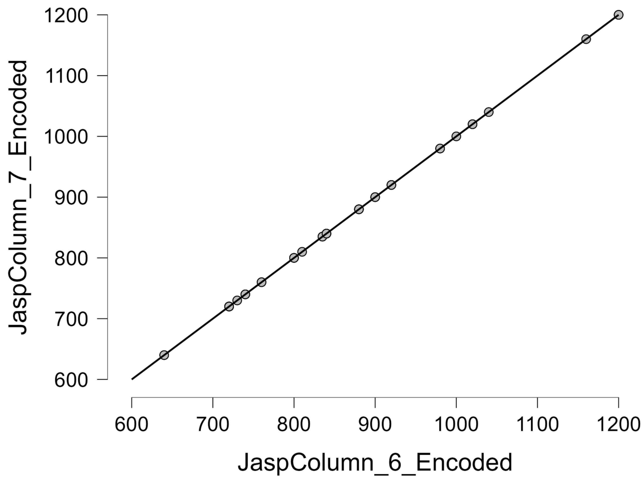

Figure 9 RR intervals correlation for all patients.

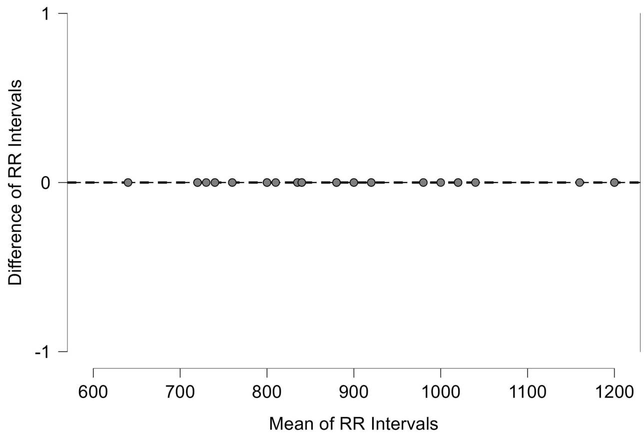

Figure 10 RR intervals for all patients.

RR Intervals Data

The correlations between the Apple Watch and the 12-lead ECG in RR intervals are presented in Figure 9, with RR intervals of 0.0 and the mean difference 0 (Figure 10), in all cardiac and chronic disease patients.

Discussion

The opportunity to provide continuous HR and cardiac activity monitoring without restricting patients' mobility opens the field to the widespread utilization of smart devices. Smartwatches are now commercially available worldwide as an integral part of everyday life.[19] The increased use of smartwatches in the medical field necessitates studying their efficacy in evaluating cardiac health in patients with cardiac as well as other chronic disorders, for health promotion.[20] In particular, the Apple Watch is a smartwatch with FDA-approved photoplethysmography and electrocardiography software.[21]

The accuracy of smart monitoring devices during training is controversial; a number of reports concluded that the wrist-worn devices had the highest accuracy during rest or slow locomotion, while others reported stable, good accuracy during vigorous activities.[22–24] However, various potential challenges are encountered during the monitoring of cardiovascular variables in patients with cardiovascular diseases. Class I (low-risk devices according to the FDA reports) can be safely used for monitoring, but it is important to first assess the accuracy of these devices before relying on their readings for clinical decision-making.[16] Regarding the monitoring of cardiac activity, the Apple Watch operates as basically a single-lead instrument, with the ability to consecutively record the six ECG leads with good diagnostic signal quality, which are highly comparable to the standard ECG 6-lead.[25]

To our knowledge, this is the first study to conduct ECG testing for 30 seconds using the Apple Watch, compared with 12-lead ECG, in adults with cardiac diseases, with sinus rhythm and irregular rhythm; and with chronic diseases, which are comorbid and increase the risk of adults developing the cardiac diseases. The Apple Watch was chosen to evaluate the cardiac health parameters in this study due to its previously reported higher accuracy than other evaluative devices, and because it is ranked as the best method of evaluating HR, compared to other wearable devices.[26]

The high correlation between the Apple Watch and 12-lead ECG in measuring HR for different patient sub-groups is significant, and suggests that the Apple Watch can be a reliable tool for monitoring HR in patients with cardiac and chronic diseases. This is particularly important because patients with chronic diseases often need to monitor their HR regularly, to manage their condition effectively.[6] Our results also showed that HR measured from the Apple Watch for 30 seconds, and by 12-lead ECG, had a strongly positive correlation in cardiac patients with sinus rhythm and irregular rhythm, and chronic patients with hypertension, diabetes, and dyslipidemia.

A previous study conducted ECG testing in 50 neonate cardiac patients using the Apple Watch; the results were of good to excellent validity in neonate cardiac patients and correctly classified the rhythm,[27] which is in line with our results for adult cardiac and chronic disease patients. The high correlation also suggests that the Apple Watch can be a useful tool for healthcare providers to remotely monitor their patients' HR. This can be especially beneficial for patients who live in remote areas or have limited access to healthcare facilities.

The high correlation between the Apple Watch and 12-lead ECG in measuring HR suggests that the Apple Watch can be a valuable tool for monitoring heart health in patients with chronic diseases. However, it is important to note that the Apple Watch should not be used as a substitute for medical advice or treatment. Patients should always consult with their healthcare provider before making any changes to their treatment plan.

Strick et al reported the accuracy of the Apple Watch in measuring the QT-interval in COVID-19 patients with sinus rhythm, and it found excellent agreement between the Apple Watch and the 12-lead ECG (IC = 0.92).[28] This finding supports our results; however, the previous researchers did not test the Apple Watch and 12-lead ECG simultaneously, which could increase the accuracy of 30-second ECG measurement. Furthermore, they did not assess cardiac patients with irregular heart rhythms.

Littell et al study measured oxygen saturation with ECG electrodes using an Apple Watch compared to the 12-lead ECG, in a healthy pediatric population; they found strong agreement in RR intervals and moderate agreement in PR, QRS, and QT-interval,[29] which is in line with our results. However, they had some missed data, which might have caused the reduced agreement in PR, QRS, and QT intervals, while our results did not have any missing data. A possible reason is that it is hard to keep children in a resting position for a long time, whereas this can be done in adults.

Another recent study, by Pash et al, tested the Apple Watch against the 12-lead ECG in 721 cardiac patients[30] in an emergency department; they support our results that the Apple Watch can differentiate between sinus rhythm and irregular rhythm, but they did not measure the ECG performance in details such as QRS complex, QT intervals, PR intervals, and RR intervals, unlike our study.

In line with previous studies on wearable devices, such as the work by Patil et al, which found that wearable ECG devices provide valuable monitoring for patients with cardiovascular diseases,[31] our findings underscore the potential of the Apple Watch to serve as a complementary tool for remote monitoring of HR and ECG. While Patil et al concluded that wearables are particularly beneficial for patients with high-risk cardiovascular conditions, our study builds on this by not only validating the Apple Watch's ability to monitor ECG, but also expanding the focus to patients with a variety of chronic comorbidities. This further supports the claim that wearables, particularly the Apple Watch, could play an essential role in managing patients with chronic health conditions by providing continuous, real-time monitoring.

Patients with cardiac and chronic diseases can benefit from using their Apple Watch to monitor their heart health in several ways. Firstly, the Apple Watch can provide patients with real-time HR monitoring, which can help them identify any HR irregularities or changes, and offer guidance on diagnosis for cardiac patients. This can be particularly important for patients with chronic diseases such as hypertension, diabetes, and dyslipidemia, who need to monitor their HR regularly to manage their condition effectively. Secondly, the Apple Watch can provide patients with alerts if their HR exceeds or falls below a certain threshold. This can help patients to take action if their HR is outside an acceptable range, such as by contacting their healthcare provider or seeking emergency medical attention. Thirdly, the Apple Watch can give patients a record of their HR over time, which can be useful for tracking changes in their heart health and identifying any patterns or trends.[8,9] This can be particularly important for patients with chronic diseases who need to monitor their HR regularly, to manage their condition effectively. Thus, using an Apple Watch to monitor heart health can provide patients with a convenient and accessible way to track their HR and identify any irregularities or changes.

Limitations

There are a few limitations to using the Apple Watch as a substitute for the 12-lead ECG for measuring heart health. HR was assessed in patients with known cardiac diseases; this group was, however, heterogeneous, with the majority of patients having ischemic or valvular heart disease. No subgroup with known AF was included. We therefore cannot state that the accuracy of HR monitoring is good for all types of patients with known heart diseases. Further studies are needed in patient groups with different types of cardiovascular disease, to fully assess the validity of the Apple Watch in these subgroups. Secondly, the Apple Watch only provides a single-lead ECG, which means that it may not be as accurate as a 12-lead ECG for detecting certain heart conditions. For example, the latter can identify more complex arrhythmias and abnormalities in the heart's electrical activity, which a single-lead ECG may miss.

Overall, while the Apple Watch can be a useful tool for monitoring heart health, it should not be used as a substitute for medical advice or treatment. Patients should always consult with their healthcare provider before making any changes to their treatment plan. Caution should be applied when using the current study's results, since it did not include patients with all known cardiac diseases. Thus, a future study may focus on conducting ECG testing for 30 seconds with regard to PR intervals, QT intervals, QRS complex, and RR intervals in patients with other cardiac disorders such as AF.

Conclusion

This study demonstrates that the Apple Watch is a valid and clinically acceptable tool for monitoring cardiac parameters, including heart rate, PR intervals, QT intervals, QRS complex, and RR intervals, for a 30-second duration only at rest in patients with cardiac diseases, including both sinus rhythm and irregular heart rhythms, along with comorbid conditions. The results show an excellent correlation and accuracy when compared to the traditional 12-lead ECG; this confirms the potential of the Apple Watch as a reliable method for continuous, non-invasive cardiac monitoring.

The findings suggest that the Apple Watch can be effectively utilized in both clinical and remote healthcare settings, by offering a convenient and accessible means for patients to track their cardiac health. It may also help in initial diagnosis for cardiac and chronic patients only at rest by using the ECG from the Apple Watch. The Apple Watch could be incorporated into HR-guided interventions, such as cardiac rehabilitation programs, to provide real-time monitoring that may enhance patient outcomes, improve disease management, and potentially reduce the burden on healthcare services.

Data Sharing Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors report there are no competing interests to declare.

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