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Review

Sensor technologies to detect out-of-hospital cardiac arrest: A systematic review of diagnostic test performance

Jacob Hutton[a,b,c,*], Saud Lingawi[a,c,d,f], Joseph H. Puyat[c,g], Calvin Kuo[c,d], Babak Shadgan[c,d,e,f], Jim Christenson[c,g,h], Brian Grunau[b,c,g,h]

Abstract

Aim: Cardiac arrest (CA) is the cessation of circulation to vital organs that can only be reversed with rapid and appropriate interventions. Sensor technologies for early detection and activation of the emergency medical system could enable rapid response to CA and increase the probability of survival. We conducted a systematic review to summarize the literature surrounding the performance of sensor technologies in detecting OHCA.

Methods: We searched the academic and grey literature using keywords related to cardiac arrest, sensor technologies, and recognition/detection. We included English articles published up until June 6, 2022, including investigations and patent filings that reported the sensitivity and specificity of sensor technologies to detect cardiac arrest on human or animal subjects. (Prospero# CRD42021267797).

Results: We screened 1666 articles and included four publications examining sensor technologies. One tested the performance of a physical sensor on human participants in simulated CA, one tested performance on audio recordings of patients in cardiac arrest, and two utilized a hybrid design for testing including human participants and ECG databases. Three of the devices were wearable and one was an audio detection algorithm utilizing household smart technologies. Real-world testing was limited in all studies. Sensitivity and specificity for the sensors ranged from 97.2 to 100% and 90.3 to 99.9%, respectively. All included studies had a medium/high risk of bias, with 2/4 having a high risk of bias.

Conclusions: Sensor technologies show promise for cardiac arrest detection. However, current evidence is sparse and of high risk of bias. Small sample sizes and databases with low external validity limit the generalizability of findings.

Keywords: Cardiac Arrest, OHCA, Arrythmia, 9-1-1, Emergency Medical System, Wearables, Health technology, Sensors, Implantable sensor

Introduction

Out-of-hospital cardiac arrest (OHCA) is a major population health issue in the US and Canada, resulting in the death of 430,000 per year.[1–2] Survival to hospital discharge in North America ranges from 5 to 7 % for Emergency Medical Services (EMS)-attended OHCA, and an estimated 18 % of discharged patients experience moderate to severe long-term functional impairment.2 OHCA is highly time-sensitive and requires immediate intervention to maximize chances for survival to hospital discharge and recovery.[3–4] One of the major barriers to increasing survival from this condition is that approximately-one-half of OHCAs are “unwitnessed”: cases where no bystanders are present to activate the emergency medical system and provide immediate life-saving interventions.[5]

Unwitnessed OHCA occurs in isolation, preventing the prompt administration of critical interventions through bystander recognition and action. While survival to hospital discharge from witnessed OHCA has been estimated to be approximately 10.5 %, survival to hospital discharge from treated but unwitnessed OHCA is even lower at approximately 4.4 %.[6] Further, approximately half of unwitnessed cardiac arrests are not treated at all by EMS due to delays in recognition and subsequent EMS arrival, resulting in an assessment of futility.[7–8] One intervention that has been proposed to address the problem of unwitnessed OHCA is to integrate the use of health sensors (technologies that measure physiological parameters for moni-

* Corresponding author at: BC Resuscitation Research Collaborative, 4th Flr-1190 Hornby St, Vancouver, BC V6Z 2K5, Canada.
E-mail address: Jacob.hutton@ubc.ca (J. Hutton).

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toring, diagnosis, or assessment of health conditions) into the emergency response system, such that the cessation of circulation experienced in cardiac arrest would trigger activation of the emergency response system.[10] While there have been reports of such technologies, no systematic reviews have summarized the applicable literature and reported the performance of these technologies.[11] For this reason, we performed a systematic search of the literature to identify investigations of sensor technologies to detect OHCA, and the sensitivity and specificity of these devices.

Methods

Design & search strategy

This systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols extension for Diagnostic Test Accuracy studies (PRISMA-DTA) checklist and was registered with PROSPERO (CRD42021267797).[12]

We conducted a literature search of PubMed, MEDLINE, Web of Science, COMPENDEX, Science Direct, and EMBASE, to identify studies that investigated recognition and/or detection of cardiac arrhythmias or cardiac arrest, and at least one of the following factors: wearable sensors; non-wearable sensors; health technologies; implantable sensors. The keywords used were Medical Subject Headings (MeSH) related to the parameters of interest and were combined using *AND* and *OR* logistic operators. The full search strategies used for all databases are shown in Appendix A, Table A1.

In addition, we conducted a search of grey literature to identify any commercial technologies or patent descriptions for sensors that detect cardiac arrest. We searched the internet for company websites and press release articles using the Google search engine, as well as registered patents using Google Patents. For both searches, the terms "cardiac arrest", "device", and "continuous monitoring and detection" were combined with the AND logistic operator.

Inclusion criteria

We included studies that: (1) were conducted with mammalian participants; (2) evaluated the performance of sensor technologies to detect cardiac arrest (or ventricular tachycardia/fibrillation), either through direct circulatory monitoring or monitoring of associated parameters (such as tissue temperature, arterial oxygen saturation, movement, respiratory rate, abnormal respirations, etc., or any combination); (3) have feasible utility in the out-of-hospital consumer setting. Sensor technologies include wearable technologies (e.g., watch, patch, textiles), non-wearable technologies (e.g., computer vision, audio monitoring, movement sensor, etc.), as well as implantable devices. To satisfy our inclusion criteria for evaluating sensor performance, studies must have reported sensitivity (the ability of the sensor to correctly identify cases of cardiac arrest) and/or specificity (the ability of the sensor to correctly identify cases that do not have cardiac arrest) to detect cardiac arrest.

Full-text case reports, observational studies, clinical trials, and meta-analyses investigating the performance of sensor technologies to detect cardiac arrest from January 1, 1950 to June 6th, 2022 were included in the search. Mixed methods studies were only included if data from the quantitative component could be clearly extracted. Although review articles that did not include meta-analyses were not eligible for this review, the reference lists of relevant review articles were searched for additional eligible studies.

Study selection

All identified citations were loaded into the online Joanna Briggs Institute (JBI) System for the Unified Management of the Assessment and Review of Information (SUMARI) system.[13] After the removal of duplicates, titles and abstracts were screened by two independent reviewers (JH and SL) for assessment against the inclusion criteria. Potentially relevant studies progressed to full-text screening. Reasons for exclusion of full text reviewed studies that do not meet the inclusion criteria were recorded and included in Fig. 1. At this step, the reference lists of all excluded review articles were uploaded into the review software for a second round of title and abstract screening followed by full-text screening. Any disagreements that arose between the reviewers at each stage of the study selection process were resolved through discussion in reference to the inclusion/exclusion criteria.

Risk of bias assessment and data extraction

Studies selected for inclusion were appraised by two independent reviewers (JH and SL) for methodological validity using the University of Bristol Quality Assessment of Diagnostic Accuracy Studies-2 tool (QUADAS-2).[14] Any disagreements that arose between the reviewers were resolved through discussion in reference to the QUADAS-2 checklist.

Data were extracted from the appraised studies by two independent reviewers (JH and SL) using a data extraction instrument for evaluating studies for diagnostic test accuracy in Joanna Briggs Institute (JBI) SUMARI.[15] Extracted data include details about the population (participant demographics and sample size), context (period that study was carried out, geographical location, setting, persons executing and interpreting reference/index tests, etc.), technology tested (index and reference tests), study methods, and reported accuracy of the technology (sensitivity, specificity, false positives/negatives). The extracted parameters are summarized in **Appendix B**. Any disagreements that arose between the reviewers were resolved through discussion in reference to the digital data extraction instrument. Due to the heterogeneity of evaluated technologies and methodologies, we did not conduct a meta-analysis and report results following the Synthesis Without Meta-analyses (SWiM) guidelines.[16].

Results

Results of published literature search

Our search of the published literature retrieved 1307 citations. Results of the search are detailed in a PRISMA flow diagram (Fig. 1). We identified an additional 681 citations for screening from the reference lists of review articles in the initial search. Together, this produced 1666 citations after duplicates were removed. All titles and abstracts were assessed according to our inclusion criteria for initial screening, followed by more detailed full-text screening. One study which described an implantable cardiac arrest sensor, but in testing utilized an alternate electrode, was excluded but described in Appendix D. Four studies met our criteria to be included in this review. The full results of the risk of bias assessment can be found in **Appendix C**.

Results of grey literature search

The search of company websites and press release articles as well as registered patents on the Google search and Google patent engines was conducted on the 6th of June, 2022, and produced approximately 9,600,000 and 18,700 results, respectively. For both searches, screening was limited to the first 20 pages of results (a total of 400 search results) due to results on later pages losing relevancy with regards to the search terms. There were four results from these searches that were selected for further screening. One of the four selected technologies, The Heart Sentinel App by Gaibazzi et al., also appeared in our search of published literature and was included in our review as one of the five selected published literature studies.[17] The remaining three grey literature technologies were excluded, as no data on sensor performance was available but are described in **Appendix D**.

Characteristics of included studies

The study characteristics are summarized in Table 1. All included studies were published in English in full-text research articles published between 2006–2022, reporting the results of primary research efforts. All included studies utilized a quasi-experimental design and reported at least one of sensitivity or specificity to detect cardiac arrest or an associated parameter. Of the four included studies, two were at "High" risk of bias, and the remaining two were at "Medium" risk of bias. We found no randomized control trials on this topic. Sensor test performance is summarized in Table 2.

Rickard et al. (2011) tested a wearable watch-based device (the Wriskwatch) for recognition of pulselessness.[17] Pulselessness was achieved by two methods: (1) applying a blood pressure cuff to occlude the brachial artery (pulselessness confirmed with human palpation), and (2) inducing ventricular fibrillation (VF) during implantable cardioverter defibrillator (ICD) implantation surgery (VF was confirmed by a cardiologist). The study enrolled 34 patients; however, excluded several participants prior to analysis primarily due to poor signal. Among the 21 participants analyzed in the blood pressure occlusion group (17 cases, and 4 controls), the device identified pulselessness in 16/17 (sensitivity = 94 %) and correctly identified no loss of pulse in 3/4 (specificity = 75 %). Among the 8 participants analyzed in the ICD VF group, pulselessness was correctly identified by the device at the time of VF in 7/8 (sensitivity 89 %). Investigators also calculated the sensitivity and specificity of the device to detect pulselessness in individual 15-s time intervals, using observation data from all patients combined.

Sugano et al. (2011) introduced an integrated remote healthcare system composed of a wireless vital signs monitoring sensor, multiple receivers, and a triage engine installed in a personal computer.[18] The study team described the physical sensor as a commercially available wearable patch in Japan which can continuously measure ECG, body surface temperature, and 3D acceleration for 48 hours, but did not specify the exact sensor used. The objective was to demonstrate sensor classification accuracy for the recognition of daily activities (e.g. walking, running, lying, etc.), as well as lethal

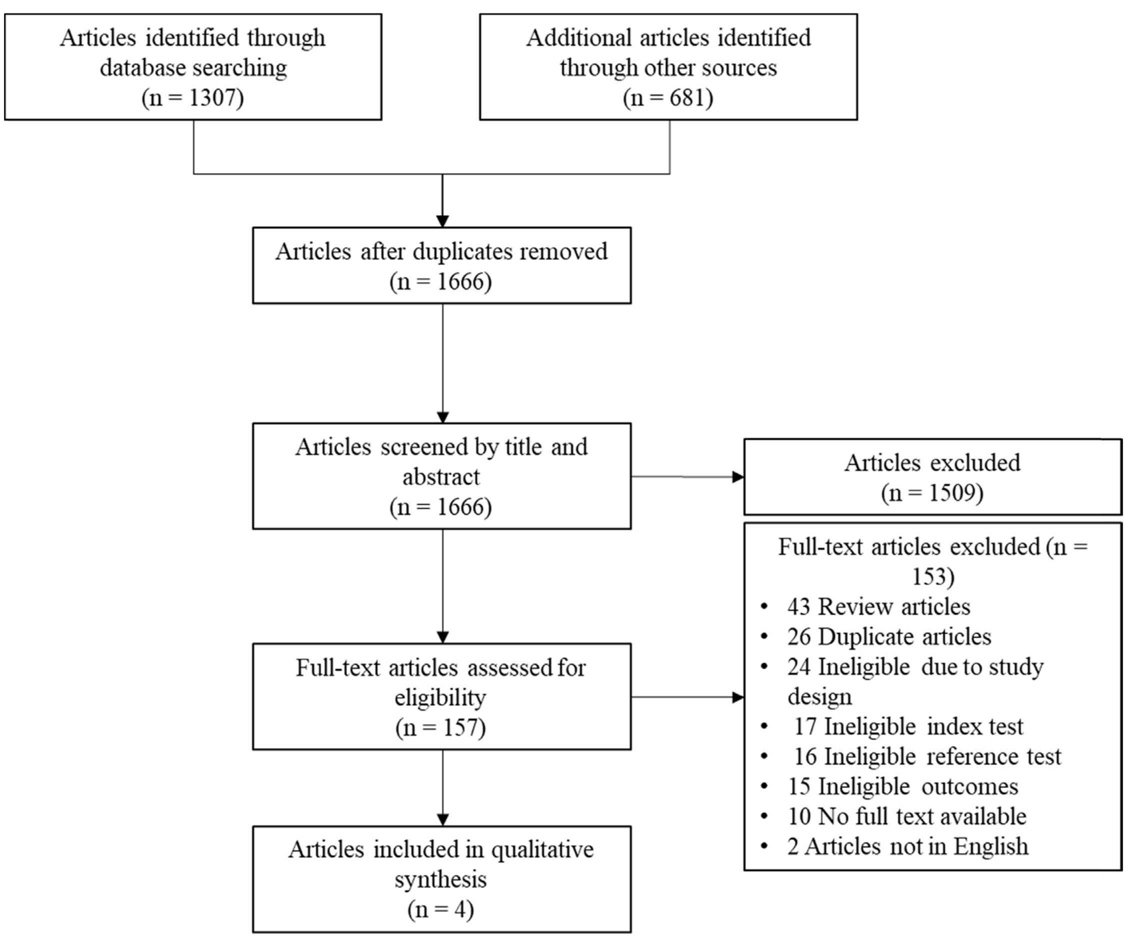

Fig. 1 – Article selection process (PRISMA Flow-Chart) and exclusion tags.

Table 1 – A summary of the included papers and study characteristics after full-text screening.

Article	Setting	No. of Samples	Outcome
Rickard et al., 2011	1. Clinical 2. Clinical	1. Blood Pressure Occlusion Arm (n = 21) used to calculate sensitivity and specificity 2. ICD Implantation arm(n = 8) used to calculate specificity	Detection of pulselessness
Sugano et al., 2011	1. Clinical 2. Database	1. Subjects Performing Daily Activities (n = 7): used to calculate specificity 2. Database data (n = 19): used to calculate sensitivity	Detection of lethal arrhythmia
Gaibazzi et al., 2018	1. Clinical 2. Sensor connected to ECG simulator with Database Data	1. Subjects Performing Physical Activity (n = 30 over 829 hours): used to calculate specificity 2. Database data (n = 140 sequences): used to calculate sensitivity	Detection of cardiac arrest (motionless and ventricular fibrillation)
Chan et al., 2019	1. Real-world recordings 2. Real-world recordings	1. 162 9–1-1 calls with agonal breathing: used to calculate sensitivity 2. Audio from sleeping patients not in cardiac arrest (n = 12 over 83 hours): used to calculate specificity	Detection of agonal respiration

Table 2 – A summary of diagnostic test accuracy results for sensor technologies to detect cardiac arrest.

Article	Index Test & (Parameter)	Sensor Technology	Reference Standard	Physically Tested on Humans?		Sensitivity	Specificity	Risk of Bias
				Sensitivity	Specificity			
Rickard et al., 2011	Wristwatch (Radial Pulse)	Mechanical plethysmography (piezoelectric)	Clinician confirmed	Yes	Yes	99.9 %	90.3 %	Medium
Sugano et al., 2011	Commercially available wireless vital sensor	ECG, accelerometer, temperature	Annotated ECG data	No	No	100 %	99.99 %	High
Gaibazzi et al., 2018	Wahoo Tickr and T-Shirt (Sensoria Inc.) and smart phone accelerometers	ECG & Accelerometer	Simulated ECG for arrythmias	No	Yes	99.8 %	100 %	High
Chan et al., 2019	Smart device (Amazon Echo and Apple iPhone 5 s)	Audio classifier	Annotated audio database	No	No	97.24 % (96.86–97.61 %)*	99.51 % (99.35–99.67 %)*	Medium

* Confidence intervals were provided in the study. The remainder of the studies did not include these intervals, nor were the full datasets provided to allow for this calculation.

arrhythmia detection. This was done in two phases. In Phase 1, seven participants were recruited was used to recognize different daily activities, and ECG sensors were monitored for lethal arrhythmias. The researchers reported no lethal arrhythmias detected (specificity 100 %; however, real-time detection was not performed to identify false-positive activations. In Phase 2, the sensor was not used; however, the accuracy of the system's lethal arrhythmia detection algorithm was evaluated, using a sudden cardiac death Holter database, which contained annotated ventricular tachycardia (VT) and VF arrhythmia data from 19 subjects.[19] The data used to calculate specificity was not shared.

Gaibazzi et al. (2018) tested a mobile app system (Heart Sentinel App) for cardiac arrest detection.[20] The Heart Sentinel App (HS-App) uses input data from a commercial ECG chest strap or textile to identify cardiac arrest through the detection of ventricular fibrillation and sudden motionlessness. When the device detects a cardiac arrest, the program is designed to initiate a 15-second countdown period prior to emergency medical system activation, which can be manually deactivated. The researchers designed this app to be used during periods of physical activity (running, cycling, etc.) where the user is required to manually "start" and "pause" the device observation periods. To assess specificity, investigators recruited participants (n = 30; age: 39.1 ± 8.1 years; sex: 17 males, 13 females) who then wore commercial ECG straps or textile-based sensors and used the HS-App, with their smartphones strapped on an armband, while engaging in running and cycling activities at least twice a week for one month for a total of 829 hours. This produced two instances where the 15-second countdown was initiated and manually deactivated by the users. To assess sensitivity, 12-lead ECG arrhythmia simulators were connected to a commercial ECG strap and a standard ECG monitor (reference standard), and the smartphone component was laid stationary on a flat surface to simulate motionlessness. The ECG strap then relayed the simulated arrhythmia, as confirmed by the reference ECG monitor, to the HS-app and the algorithm's ability to detect VF within 1-minute of commencement was evaluated. Overall, 140 simulated sequences were assessed and all were correctly identified.

Chan et al. (2019) tested commercial smart devices (Amazon Echo, Apple iPhone 5 s) deployed in a home and lab sleep setting.[21] The parameter of interest was detection accuracy for agonal breathing, an abnormal breathing audio parameter present in a proportion of cases of cardiac arrest. To assess specificity, audio from 162 9-1-1 calls were provided by Public Heath – Seattle & King County that had evidence of agonal breathing as determined by their medical team. Audio files were streamed at varying volumes with various interfering sounds to simulate real-world conditions and captured on the different devices. To assess specificity, sleep lab data consisting of 83 hours of audio recordings from 12 patients not in cardiac arrest was used.

Discussion

We searched the available published and grey literature to identify all studies investigating the performance of cardiac arrest detection technologies. Overall, we found few studies meeting our inclusion criteria, and none included testing of a sensor on an actual cardiac arrest. For studies that evaluated sensors that detected malignant arrhythmias such as ventricular fibrillation or ventricular tachycardia, the use of a simulation or database approach was common. Across all included studies, testing conditions were frequently idealized, using high-quality data, and often only a specific component of the sensor system was evaluated. Overall, while sensor technologies hold promise for cardiac arrest detection, the available evidence is unable to provide estimates of performance that are generalizable to real-world conditions.

In a majority of the included studies, the researchers assessed specificity through direct sensor deployment on humans but utilized simulated data or annotated databases for the assessment of sensitivity. In such studies, specificity was assessed on real-life raw data, including noise and motion artifacts. Compared to the highly idealized and noise-free database or simulation approach for assessing sensitivity, the applied methods for assessing specificity were more representative of the out-of-hospital setting. When comparing the discrepancies in testing environments in the assessment of sensitivity and specificity, it is possible that the trained algorithms are in fact detecting differences in environment (strength of the signal, amount of noise or motion artifacts, etc.) rather than detecting the actual cardiac arrest or associated parameter. Further, the detection of certain arrhythmias from a database does not equate to detecting cardiac arrest in real people. Previous studies demonstrate that the initial recorded rhythm is ventricular fibrillation in only a minority of cases. In our searches, other than the single study evaluating agonal breathing from historical records (which is present in approximately 50 % of cardiac arrest cases),[22] we did not encounter a single study referencing the evaluation of these technologies in patients in cardiac arrest in the out-of-hospital setting. This approach increases the risk of bias away from the null in the evidence base, as issues such as measurement variability, device contact, data loss, and other entropic factors are artificially controlled for in a way that is not reflective of the true conditions under which these devices are intended to function. As such, the performance of these devices in a real-world setting is unclear.

The discrepancy between lab-based and real-world testing conditions is not the only challenge in assessing the relevance of findings from the evidence base for OHCA detection. Typically, when designing technologies that aim to provide alerts of critical health emergencies, developers will optimize the sensitivity of the detection algorithm to increase the likelihood of detecting a life-threatening change in physiological state (the true-positive rate). While this results in an optimized ability to detect cardiac arrest, it also increases the likelihood of a false-positive activation, where the device indicates that a cardiac arrest has occurred when it has not (the false-positive rate). For developers designing health technologies for use in the public emergency health space, the impact of false-positive device activations on EMS operations should be considered. Currently, EMS systems are overburdened and substantially impacted by surges in demand.

Consideration of this overburdening risk in the context of widespread adoption of such devices should allow developers to contextualize the desirable sensor function as providing a balance between sensitivity and specificity. Devices engineered to detect cardiac arrest should balance specificity and sensitivity in the context of individual level accuracy as well as EMS function. There is a trade-off between these two metrics for sensor accuracy. Sensors can be designed to either detect all cases of OHCA (high sensitivity), and produce high rates of false positives; or sensors can be designed to only detect cases that are very obviously cases of OHCA, thus leaving a portion of OHCA cases undetected. Developers may also consider designing devices that utilize a multi-channel approach to parameter measurement, as a device that triggers an alert using a signal based on two measurements with the same specificity demonstrated above would reduce the daily false positive rate significantly and aid in achieving widespread adoption of these devices.

In addition to algorithmic development, the device form factor also plays a role in the likelihood of adoption. Wearable devices can travel with the user, increasing the chances of detecting an arrest where it occurs. Conversely, audio or camera-based, non-contact devices would only be able to detect an arrest within the physical confines of a room and would require several installed devices to cover a wider range of detection locations. While a multi-channel approach to parameter measurement may address concerns related to false-positive activations, users may prefer a smaller and lighter device with fewer sensor types, illustrating another trade-off between accuracy and implementation.

In addition to considerations at the design stage, integration of sensor technologies into the 911 chain of care will require careful testing and development. This would likely involve the participation of EMS agencies and commercial partners to connect EMS dispatch systems to external alerting software infrastructure. Software platforms capable of connectivity across a range of sensor devices, as well as those that secure the relevant partnerships with EMS agencies will likely be best positioned to assist in the market uptake of such technologies. Opportunities also exist to incorporate sensor technologies into a new wave of technology-assisted EMS system innovations, as introduced as the "Systems Saving Lives" concept by Semeraro, et al. (2021).[23] Connectivity with citizen responder mobile applications as well as AED drone delivery programs will serve to create an integrated technology ecosystem for rapid recognition and response to OHCA, with sensor technologies serving as the foundation. It is essential that developers of these technologies conceptualize this interconnected system of response from the design to the implementation stage, optimizing the potential for integration with other commercial products, as well as the relevant EMS agencies.

Although this review outlined studies that provide evidence of detecting lethal arrhythmias or cardiac arrest conditions, we observed low rates of subsequent publication and further testing of the described devices. Considering that much of the included evidence utilizes a proof-of-concept approach to testing, we expected to find evidence of ongoing evaluation of these technologies prior to clinical implementation. The general lack of uptake of these devices, including the devices observed in the grey literature search (**Appendix D**), alludes to consistent obstacles that prevent the widespread acceptance of such technologies. Such obstacles could be a lack of user interest due to the highly specific nature of the technology, or a lack of reliable methods to test and validate the detection of lethal arrhythmias or cardiac arrest conditions. Commercial forces and market conditions likely play a significant role in the uptake of these technologies, and it is possible that manufacturers are either unaware of the potential impact of these devices or appraise the market for such technologies as currently not viable. Future developers, scientists, and clinicians in this area should consider partnering with EMS stakeholders to focus on developing technologies that are not only highly accurate but also consider the context of device use at the design stage, and are likely to be embraced by end-users that are concerned with such factors as functionality, fashion, and intrusiveness.

Limitations

Throughout the evidence base, sample sizes are small, blinding is varied, and study designs are highly heterogeneous. Studies that utilize arrhythmia databases for evaluation or algorithm training are at risk of selection bias, and data used is often acquired under controlled conditions using clinical-grade equipment. Some studies that included heart rate and accelerometry detection systems only tested their devices on heart rate data, leaving the accelerometry component of their devices untested, due to their static and motionless study settings.[13] Several studies evaluated algorithms, but not the sensor that would collect physiological data for the algorithm, or the infrastructure to relay this data to the computing module. Due to these limitations, we are unable to generalize accuracy rates in the included papers for use in the out-of-hospital setting, and further evaluation of these or similar technologies will need to occur to understand the feasibility of biosensors for OHCA detection.

Conclusion

We performed a systematic review of the literature to summarise the currently available evidence demonstrating the performance of sensor technologies to detect cardiac arrest. While reported metrics for sensitivity and specificity were high, no published experiment has actually tested a sensor on an actual cardiac arrest case. Widespread and reliable sensing technologies with high sensitivity and specificity are needed for real-time and rapid detection of sudden cardiac arrest to increase survival in the out-of-hospital setting.

Author Contributions

SL and JH contributed equally to the design of the research proposal, as well as the execution of the systematic review and manuscript development.

CRediT authorship contribution statement

Jacob Hutton: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Saud Lingawi:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Joseph H. Puyat:** Writing – review & editing. **Calvin Kuo:** Writing – review & editing. **Babak Shadgan:** Writing – review & editing. **Jim Christenson:** Funding acquisition, Resources, Writing – review & editing. **Brian Grunau:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix A:. Search terms and an example of a completed search strategy in MEDLINE

The literature search strategy for the systematic review of diagnostic test accuracy for sensor technologies to detect out-of-hospital cardiac arrest is provided below. The searched databases include PubMed/MEDLINE, Web of Science, COMPENDEX, and EMBASE, and the search was restricted to articles in English within the date range of January 1, 1950 to June 6, 2022. Case reports, clinical trials, and meta-analyses were included in the search.

Search terms

The terms used in this search fit broadly under two classifying categories: terms for cardiac arrest and dangerous cardiac arrhythmias, and terms for continuous monitoring and detection of physiological parameters. As such, the relevant search terms are:

Cardiac Arrest and Dangerous Cardiac Arrhythmias	Continuous Monitoring and Detection of Physiological Parameters
Heart arrest	Physiological monitoring
Sudden cardiac death	Wearable electronic devices
Out-of-hospital cardiac arrest	Detect*
Cardiac arrhythmias	-

When necessary, keywords were shortened and truncated with an asterisk (e.g. detect*) to retrieve unlimited suffix variations (e.g. detect, detecting, detectable, etc.).

MEDLINE example search

The search terms were combined in a way to encompass the most relevant results while limiting the possibility of pre-filtering articles that would otherwise fit the search criteria. An example search is as follows:

((heart arrest OR sudden cardiac death OR out-of-hospital cardiac arrest or cardiac arrhythmias) AND (physiological monitoring OR wearable electronic devices OR detect*)).

On MEDLINE, all of the search terms used, with the exception of detect*, were Medical Subject Headings (MeSH). Broader MeSH were selected to encompass relevant subcategories when necessary. For example, the heart arrest MeSH includes the subheadings sudden cardiac death and out-of-hospital cardiac arrest, both of which were also selected to focus on the search for specific aspects of the arrest. Below is a more detailed representation of this search strategy.

Detailed MEDLINE Search Strategy
#Searches
1heart arrest/ or death, sudden, cardiac/ or out-of-hospital cardiac arrest/ or arrhythmias, cardiac/
2Monitoring, physiologic/ or detect*.mp
31 and 2

Table A1 – An overview of search phrases and databases used during article retrieval. Numbers indicate the number of identified articles during the two literature searches.

Database	Search Phrase	Results
Web of Science Core Collection	TOPIC: (sensor* AND ("cardiac arrest" OR "heart arrest" OR "OHCA" OR "CPR") AND ("recognition" OR "recognize" OR "detect" OR "predict" OR "prediction")) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.	127
MEDLINE	Search 1: (exp Wearable Electronic Devices) AND (heart arrest/ OR death, sudden, cardiac/ OR out-of-hospital cardiac arrest/ OR arrhythmias, cardiac/ OR heart failure/) Search 2: (exp Death, Sudden, Cardiac/ or exp Death, Sudden/ or (exp Heart Arrest/ or exp Out-of-Hospital Cardiac Arrest/)) and Sensor* Search 3: (out-of-hospital cardiac arrest) AND detect*	204 281 217
COMPENDEX	((("cardiac arrest" OR "heart arrest") AND ("sensor*" OR "wearable*" OR "device*")) WN ALL)	180
ScienceDirect	(("cardiac arrest" OR "heart arrest") AND ("sensor" OR "wearable" OR "device")) AND ("detection" OR "prevention" OR "recognition") AND ("911″)	58
EMBASE	(cardiac stress monitoring system/ OR cardiovascular monitoring device/ OR ambulatory monitoring/ OR blood pressure monitoring/ OR electrocardiography monitoring/ OR patient monitoring/ OR biological monitoring/ OR monitoring/ OR physiologic monitoring/) AND ((heart arrest/ OR cardiopulmonary arrest/ OR "out of hospital cardiac arrest"/ OR sudden cardiac death/) AND (detect*))	209
PubMed	Cardiac arrest AND detect* AND physiological monitoring	362

Appendix B:. Characteristics of included studies

See Table B1.

Table B1 – Characteristics of Included Studies - Diagnostic Test Accuracy Form.

Study	Country	Setting/context	Year/timeframe for data collection	Participant characteristics	Reference test descriptions and samples	Index test description and sample	Description of main results (including adverse events from tests)
Chan J, Rea T, Gollakota S, Sunshine JE. 2019.	USA	Prehospital	2017	Labelled audio data of the patient in cardiac arrest	The model was evaluated using audio data known to demonstrate evidence of agonal breathing. Agonal breathing ground truth was evaluated by trained reviewers and overseen by a specialist physician. Data was collected from 9-1-1 calls that demonstrated agonal breathing.	Audio classification algorithm	Classifier model demonstrated overall sensitivity and specificity of 97.24 % (95 % CI: 96.86–97.61 %) and 99.51 % (95 % CI: 99.35–99.67 %). The detection algorithm ran in real-time on a smartphone natively and classified each 2.5 s audio segment within 21 ms. With the smart speaker, the algorithm ran within 58 ms.
Rickard J, Ahmed S, Baruch M, Klocman B, Martin DO, Menon V. 2011.	United States	Cleveland Clinic - in ED and OR	unknown - prior to 2011	In the hospitalized arm: patients wore the watch on their arm and a blood pressure cuff was inflated until the radial pulse was occluded for 10 seconds. This provided the reference of pulselessness.In the ICD arm: patients receiving implantation wore the watch and VF was induced and confirmed with telemetry.	Two study arms: 1) 24 patients who were hospitalized for any reason 2) 10 patients who presented to the electrophysiology laboratory for ICD implantation	A novel mechanical plethysmograph watch that contains a piezoelectric crystal capable of detecting pulse motion and artifact, which is then converted to a voltage, digitized, sent to a microprocessor and filtered algorithmically to produce a pulse detection signal.	The final cohort contained 30 patients: 22 in the hospitalized patient arm and 8 in the ICD testing arm. Overall, the Wriskwatch was worn for a total of 561.2 minutes. Pulselessness was present for 5.8 minutes. The sensitivity of the watch to detect pulse status (based on 15-second time intervals) was 99.9 %, specificity was 90.3 %, and positive and negative predictive values were 99.9 % (95 % confidence interval 99.67 %–99.99 %) and 90.3 % (95 % confidence interval 74.3 %–98.0 %), respectively.
Sugano H, Hara S, Tsujioka T, Inoue T, Nakajima S, Kozaki T, et al. 2011.	Japan	Database and Laboratory	unknown - prior to 2011	The lethal arrhythmia database is annotated by medical specialists and 19 subject data containing Vf signal or VT signal were used as test data.	Tested the arrhythmia detection algorithm using the sudden cardiac death Holter monitor database. Used 19 subject data as the test data.	A commercially available sensor that can continuously measure ECG, body surface temperature and 3D acceleration and send the data by wireless for more than forty-eight	The algorithm is reliable enough for the detection of lethal arrhythmias with sensitivity of 100 % and specificity of 99.99 %.

Table B1 (continued)

Study	Country	Setting/context	Year/timeframe for data collection	Participant characteristics	Reference test descriptions and samples	Index test description and sample	Description of main results (including adverse events from tests)
						hours.	
Gaibazzi N, Siniscalchi C, Reverberi C. 2018.	Italy	Simulated and clinical	2018	Arrhythmia was simulated. False-positives were tested by having the participants exercise at least twice a week for one month.	30 voluntary athletes. 17 males and 13 females. Ran and biked for an overall 829 h during the study. The mean age was 39.1 ± 8.1 y/o. Also used a 12-lead ECG arrhythmia simulator.	The HS-app is a smartphone app running on both iOS and Android operative system smartphones, which continuously monitors HR data transmitted wireless in real-time by commercially-available BLE heart rate monitors, at a frequency of 1 value per second. In the current study both a standard chest-strap BLE HR monitor (Wahoo Tickr) and a t-shirt type (Sensoria Inc) were tested.	The false-positive rate can be described as 2 alert countdowns out of 829 h of outdoor exercise, but 0 emergency SMS sent. The occurrence of false negatives was tested using the 140 overall sequences of VF simulation which resulted in a 100 % VF detection rate (140/140) using all simulators and protocols

Appendix C:. Critical Appraisal results

Risk of bias was ascertaining through the QUADAS-2 tool, which provides guiding questions to arrive at a conclusion on bias. The QUADAS-2 tool questions, along with our reported answers, are provided below. Table C1.Table C2.

Critical Appraisal Questions:

Q1: Was a consecutive or random sample of patients enrolled? (yes, no, unclear, N/A).
Q2: Was a case-control design avoided? (yes, no, unclear, N/A).
Q3: Did the study avoid inappropriate exclusions? (yes, no, unclear, N/A).
Q4: Were the index test results interpreted without knowledge of the results of the reference standard? (yes, no, unclear, N/A).
Q5: If a threshold was used, was it pre-specified? (yes, no, unclear, N/A).
Q6: Is the reference standard likely to correctly classify the target condition? (yes, no, unclear, N/A).
Q7: Were the reference standard results interpreted without knowledge of the results of the index test? (yes, no, unclear, N/A).
Q8: Was there an appropriate interval between index test and reference standard? (yes, no, unclear, N/A).
Q9: Did all patients receive the same reference standard? (yes, no, unclear, N/A).

Table C1 – Risk of Bias Assessment.

Citation	Risk of Bias
Chan J, Rea T, Gollakota S, Sunshine JE. 2019.	Medium
Gaibazzi N, Siniscalchi C, Reverberi C. 2018.	High
Sugano H, Hara S, Tsujioka T, Inoue T, Nakajima S, Kozaki T, et al. 2011.	High
Rickard J, Ahmed S, Baruch M, Klocman B, Martin DO, Menon V. 2011.	Medium

Table C2 – Risk of Bias Assessment Questions.

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Chan J, Rea T, Gollakota S, Sunshine JE. 2019.	N	Y	Y	N	N/A	Y	N	N/A	Y	Y
Gaibazzi N, Siniscalchi C, Reverberi C. 2018.	N	Y	Y	U	U	Y	U	N/A	Y	Y
Sugano H, Hara S, Tsujioka T, Inoue T, Nakajima S, Kozaki T, et al. 2011.	N	N	Y	U	U	Y	U	N/A	Y	Y
Rickard J, Ahmed S, Baruch M, Klocman B, Martin DO, Menon V. 2011.	Y	Y	U	N	U	Y	N	N/A	Y	N

Q10: Were all patients included in the analysis? (yes, no, unclear, N/A).

Appendix D:

Results from grey literature and screened citations that detail cardiac arrest technologies.

Results of grey literature search

Excluding the HeartSentinel App by Gaibazzi et al., which was included in the systematic review, there were three additional results that the search of grey literature uncovered. The two technologies revealed through a Google search of company websites and press release articles are the iBeat Heart Watch (iBeat, San Francisco, USA) and the Wristwatch (CardiacSense, Caesarea, Israel). The registered patent uncovered through the patent search is an implantable cardiac device by Medtronic Inc (European Patent Office, EP2753234A1).

The iBeat Heart Watch received publicity in 2018 for being the first wrist-worn device to detect cardiac arrest and initiate an emergency sequence accordingly, based on heart rate and blood flow analysis. The watch was designed to trigger a message to the user when an emergency is detected to verify whether or not the user is conscious and would then contact emergency services if the user remains unresponsive. Despite the publicity that this technology had gained, there does not appear to be published data on the accuracy or validation of the device. The device has since been abandoned, and the company has ceased operations as well.

The CardiacSense Wristwatch[24] is a device that is still under development. It is meant to be able to detect cardiac arrest and trigger an audible alarm response; however, validation and device accuracy studies are yet to be conducted. Results from such trials are expected to be available in the upcoming years. The implantable cardiac device by Medtronic Inc was first registered in 2011, and is ongoing until 2032. It is designed to detect motions of the cardiac wall to detect OHCA. Despite this device fitting the criteria of OHCA detection and having support from a large biomedical company, we were unable to obtain further information regarding its current state of development outside of the published patent document.

None of the three results outlined in this appendix met the inclusion criteria of our systematic review and were therefore excluded from the review.

Results from peer-reviewed literature

The CardioAlarm subcutaneous sensor is an implantable electrode-based cardiac monitoring device that communicates to an external module via Bluetooth automatically or following user activation. It produces an alert that is relayed to an external telephone module when a potentially dangerous cardiac arrhythmia is detected. In our search, we captured a report by Arzbaecher et al. (2006) detailing testing this system for lethal arrhythmia detection, further examination revealed that the report focused on a purely computational testing design that evaluated the ability of the device algorithm to detect lethal arrhythmias using the MIT-BIH arrhythmia database and did not involve placing the physical sensor on human participants.[25–26] As such, the study did not fit the criteria for inclusion in the systematic review, but is detailed here as the described technology may be a candidate for future evaluation.

Appendix E. Papers excluded at full text screening

Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
2019	Ip James E	Evaluation of Cardiac Rhythm Abnormalities From Wearable Devices.	JAMA	321	11	1099	https://dx.https://doi.org/10.1001/jama.2019.1681	Review article
2018	Cheung Christopher CKrahn Andrew DAndrade Jason G	The Emerging Role of Wearable Technologies in Detection of Arrhythmia.	The Canadian journal of cardiology	34	8	1087	https://dx.https://doi.org/10.1016/j.cjca.2018.05.003	Review article
2018	Ryvlin PhilippeCiumas CarolinaWisniewski IlonaBeniczky Sandor	Wearable devices for sudden unexpected death in epilepsy prevention.	Epilepsia	59 Suppl 1		66	https://dx.https://doi.org/10.1111/epi.14054	Review article
2017	Sadrawi MuammarLin Chien-HungLin Yin-TsongHsieh YitaKuo Chia-ChunChien Jen ChienHaraikawa KoichiAbbod Maysam FShieh Jiann-Shing	Arrhythmia Evaluation in Wearable ECG Devices.	Sensors (Basel, Switzerland)	17	11		https://dx.https://doi.org/10.3390/s17112445	Ineligible study design
2019	Sajeev Jithin KKoshy Anoop NTeh Andrew W	Wearable devices for cardiac arrhythmia detection: a new contender?.	Internal medicine journal	49	5	573	https://dx.https://doi.org/10.1111/imj.14274	Review article
2019	Sajeev Jithin KKoshy Anoop NTeh Andrew W	Wearable devices for cardiac arrhythmia detection: a new contender?.	Internal medicine journal	49	5	573	https://dx.https://doi.org/10.1111/imj.14274	Duplicate study
2019	Samol AlexanderBischof KristinaLuani BlerimPascut DanWiemer MarcusKaese Sven	Single-Lead ECG Recordings Including Einthoven and Wilson Leads by a Smartwatch: A New Era of Patient Directed Early ECG Differential Diagnosis of Cardiac Diseases?.	Sensors (Basel, Switzerland)	19	20		https://dx.https://doi.org/10.3390/s19204377	Ineligible index test
2004	Feldman Arthur MKlein HelmutTchou PatrickMurali SrinivasHall W JacksonMancini DonnaBoehmer JohnHarvey MarkHeilman M StephenSzymkiewicz Steven JMoss Arthur JWEARIT investigators and coordinators nullBIROAD investigators and coordinators null	Use of a wearable defibrillator in terminating tachyarrhythmias in patients at high risk for sudden death: results of the WEARIT/BIROAD.	Pacing and clinical electrophysiology: PACE	27	1	9		Ineligible outcomes
2019	Elola AndoniAramendi ElisabeteIrusta UnaiPicon ArtzaiAlonso ErikIsasi IraiaIdris Ahamed	Convolutional Recurrent Neural Networks to Characterize the Circulation Component in the Thoracic Impedance during Out-of-Hospital Cardiac Arrest.	Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual	2019		1925	https://dx.https://doi.org/10.1109/EMBC.2019.8857758	No full text available

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
			International Conference					
2018	Latimer Andrew JMcCoy Andrew MSayre Michael R	Emerging and Future Technologies in Out-of-Hospital Cardiac Arrest Care.	Cardiology clinics	36	3	441	https://dx.https://doi.org/10.1016/j.ccl.2018.03.010	Review article
2018	Douma Matthew J	Automated video surveillance and machine learning: Leveraging existing infrastructure for cardiac arrest detection and emergency response activation.	Resuscitation	126			https://dx.https://doi.org/10.1016/j.resuscitation.2018.02.010	Ineligible study design
		This Smart Watch Detects Cardiac Arrest, and Summons Help - IEEE Spectrum						Ineligible study design
2019	Elola AndoniAramendi ElisabeteIrusta UnaiDel Ser JavierAlonso ErikDaya Mohamud	ECG-based pulse detection during cardiac arrest using random forest classifier	Med Biol Eng Comput	57	2	462	https://doi.org/10.1007/s11517-018–1892-2	Excluded due to JBI software bug - imported again into full text screening
2019	Lee YoonjeShin HyungooChoi Hyuk JoongKim Changsun	Can pulse check by the photoplethysmography sensor on a smart watch replace carotid artery palpation during cardiopulmonary resuscitation in cardiac arrest patients? a prospective observational diagnostic accuracy study	BMJ Open	9	2		https://doi.org/10.1136/bmjopen-2018–023627	Duplicate study
2015	Fung ErikJÃ¤rvelin Marjo-RiittaDoshi Rahul N.Shinbane Jerold S.Carlson Steven K.Grazette Luanda P.Chang Philip M.Sangha Rajbir S.Huikuri Heikki V.Peters Nicholas S.	Electrocardiographic patch devices and contemporary wireless cardiac monitoring	Front Physiol	6			https://doi.org/10.3389/fphys.2015.00149	Review article
2020	A DaganO.j Mechanic	Use of ultra-low cost fitness trackers as clinical monitors in low resource emergency departments					https://doi.org/10.15441/ceem.19.081	Review article
2018	N GaibazziC SiniscalchiC Reverberi	The Heart SentinelTM app for detection and automatic alerting in cardiac arrest during outdoor sports: Field tests and ventricular fibrillation simulation results					https://doi.org/10.1016/j.ijcard.2018.07.062	Duplicate study
2017	E ChorinA HochstadtR RossoL SchwartzS Viskin	Continuous heart rate monitoring for automatic detection of life-threatening arrhythmias with novel bio-sensing technology						No full text available
2016	C JungenC EickholtJ MuehlsteffK DellimoreV AartsN GosauB.a HoffmannP KuklikS WillemsC Meyer	A simple device for transcutaneous detection of blood pressure and pulse rate changes-initial experience with a sensor located at the carotid artery						No full text available

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
2017	Barai A.R.Rahman M.R.Sarkar A.K.	Comparison of Noninvasive Heart Rate Monitoring System using GSM Module and RF Module				4	https://doi.org/10.1109/CEEE.2017.8412905	Ineligible outcomes
2018	Schellenberger SvenShi KilinSteigleder TobiasMichler FabianLurz FabianWeigel RobertKoelpin Alexander	Support vector machine-based instantaneous presence detection for continuous wave radar systems		2018-November		1467	https://doi.org/10.23919/APMC.2018.8617181	Ineligible study design
2013	Kim Yong-HoonLee Myung-HwanMurakami YuichiInaba HisashiTokuda Kiyohito	Study of heart detection doppler radar development for automotive application						Article not in English
2017	Aarts VincentDellimore Kiran H.Wijshoff RalphDerkx ReneVan De Laar JakobMuehlsteff Jens	Performance of an accelerometer-based pulse presence detection approach compared to a reference sensor				168	https://doi.org/10.1109/BSN.2017.7936033	Ineligible index test
2008	Leijdekkers PeterGay Valerie	A self-test to detect a heart attack using a mobile phone and wearable sensors				98	https://doi.org/10.1109/CBMS.2008.59	Ineligible study design
2020	Malepati NiyathaFatima RubiaGupta SwarnimaRamsali VaishnaviRk Shobha	Portable ECG Device for Remote Monitoring and Detection of Onset of Arrhythmia					https://doi.org/10.1109/CONECCT50063.2020.9198658	Excluded due to JBI software bug - imported again into full text screening
2020	Jayaweera K.N.Kallora K.M.C. Subasinghe N.A.C.K.Rupasinghe LakmalLiyanapathirana C.	An integrated framework for predicting health based on sensor data using machine learning				48	https://doi.org/10.1109/ICAC51239.2020.9357134	Ineligible outcomes
2020	Reddy SashankSeshadri Surabhi B. Sankesh Bothra G.Suhas T.G.Thundiyil Saneesh Cleatus	Detection of Arrhythmia in Real-time using ECG Signal Analysis and Convolutional Neural Networks					https://doi.org/10.1109/CPEE50798.2020.9238743	Excluded due to JBI software bug - imported again into full text screening
2008	Leijdekkers PeterGay Valerie	A self-test to detect a heart attack using a mobile phone and wearable sensors	Proceedings of the 21st Ieee International Symposium on Computer-Based Medical Systems			98	https://doi.org/10.1109/CBMS.2008.59	Duplicate study
2012	Birkholz T.Fernsner S.Irouschek A. Wettach D.Schmidt J.Einhaus F.Bolz A. Jaeger M.	Detection of Cardiac Arrest with an Integrated Sensor System	Notarzt	28	3	113	https://doi.org/10.1055/s-0031–1299000	No full text available
2018	Syvaoja SakariRissanen Tuomas THiltunen PamelaCastren MaaretMantyla PirjoKivela AnttiUusaro AriJantti Helena	Ventricular fibrillation recorded and analysed within an area the size of a mobile phone: could it enable cardiac arrest recognition?.	European journal of emergency medicine: official journal of the European Society for Emergency Medicine	25	6	399	https://dx.https://doi.org/10.1097/MEJ.0000000000000473	Ineligible study design
2019	Lee YoonjeShin HyungooChoi Hyuk JoongKim Changsun	Can pulse check by the photoplethysmography sensor on a	BMJ open	9	2		https://dx.https://doi.org/10.1136/bmjopen-2018–	Duplicate study

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
		smart watch replace carotid artery palpation during cardiopulmonary resuscitation in cardiac arrest patients? a prospective observational diagnostic accuracy study.					023627	
2016	Dellimore KiranWijshoff RalphHaarburger ChristophAarts VincentDerkx Renevan de Laar JakobNammi KrishnakantRussell James KHubner PiaSterz FritzMuehlsteff Jens	Towards an algorithm for automatic accelerometer-based pulse presence detection during cardiopulmonary resuscitation.	Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference	2016		3534	https://dx.https://doi.org/10.1109/EMBC.2016.7591490	Ineligible reference test - associated parameter
2006	Arzbaecher RobertJenkins JaniceBurke MartinSong ZhendongGarrett Michael	Database testing of a subcutaneous monitor with wireless alarm.	Journal of electrocardiology	39	4 Suppl	3		Duplicate study
2017	Trummer StephanieEhrmann AndreaBuesgen Alexander	Development of Underwear with Integrated 12 Channel Ecg for Men and Women	Autex Research Journal	17	4	349	https://doi.org/10.1515/aut-2017–0008	Ineligible reference test
1978	Mirowski MMower M MLanger AHeilman M SSchreibman J	A chronically implanted system for automatic defibrillation in active conscious dogs. Experimental model for treatment of sudden death from ventricular fibrillation.	Circulation	58	1	4		Ineligible outcomes
2012	Vijayalakshmi S.R.Muruganand S.	Real-time monitoring of ubiquitous wireless ECG sensor node for medical care using ZigBee	International Journal of Electronics	99	1	89	https://doi.org/10.1080/00207217.2011.609981	Ineligible study design
2019	Y LeeH ShinH.j ChoiC Kim	Can pulse check by the photoplethysmography sensor on a smart watch replace carotid artery palpation during cardiopulmonary resuscitation in cardiac arrest patients? A prospective observational diagnostic accuracy study					https://doi.org/10.1136/bmjopen-2018–023627	Duplicate study
2020	Zhao YangShang ZhongxiaLian Yong	A 13.34 muW Event-Driven Patient-Specific ANN Cardiac Arrhythmia Classifier for Wearable ECG Sensors.	IEEE transactions on biomedical circuits and systems	14	2	197	https://dx.https://doi.org/10.1109/TBCAS.2019.2954479	Ineligible study design
2020	Singhal ArvindCowie Martin R	The Role of Wearables in Heart Failure.	Current heart failure reports	17	4	132	https://dx.https://doi.org/10.1007/s11897-020–00467-x	Review article
2020	Sana FurrukhIsselbacher Eric MSingh Jagmeet PHeist E KevinPathik BhupeshArmoundas Antonis A	Wearable Devices for Ambulatory Cardiac Monitoring: JACC State-of-the-Art Review.	Journal of the American College of Cardiology	75	13	1592	https://dx.https://doi.org/10.1016/j.jacc.2020.01.046	Review article
2020	Sperzel JohannesHamm Christian WHain Andreas	Over- and undersensing-pitfalls of arrhythmia detection with implantable devices and wearables.	Herzschrittmachertherapie & Elektrophysiologie	31	3	287	https://dx.https://doi.org/10.1007/s00399-020–00710-x	Review article

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
2019	Sanders DavidUngar LeoEskander Michael ASeto Arnold H	Ambulatory ECG monitoring in the age of smartphones.	Cleveland Clinic journal of medicine	86	7	493	https://dx.https://doi.org/10.3949/ccjm.86a.18123	Review article
2019	Almqvist MansMattsson GustavMagnusson Peter	[The wearable cardioverter defibrillator - temporary protection against sudden cardiac death].	Lakartidningen	116				Review article
2019	Hartwell LelandRoss Heather MLa Belle Jeffrey T	Project honeybee: Clinical applications for wearable biosensors.	Biomedical microdevices	21	2		https://dx.https://doi.org/10.1007/s10544-019–0392-y	Ineligible reference test
2019	Ip James E	Wearable Devices for Cardiac Rhythm Diagnosis and Management.	JAMA	321	4	338	https://dx.https://doi.org/10.1001/jama.2018.20437	Review article
2020	Sana FurrukhIsselbacher Eric MSingh Jagmeet PHeist E KevinPathik BhupeshArmoundas Antonis A	Wearable Devices for Ambulatory Cardiac Monitoring: JACC State-of-the-Art Review.	Journal of the American College of Cardiology	75	13	1592	https://dx.https://doi.org/10.1016/j.jacc.2020.01.046	Duplicate study
2019	Sanders DavidUngar LeoEskander Michael ASeto Arnold H	Ambulatory ECG monitoring in the age of smartphones.	Cleveland Clinic journal of medicine	86	7	493	https://dx.https://doi.org/10.3949/ccjm.86a.18123	Duplicate study
2019	Ip James E	Wearable Devices for Cardiac Rhythm Diagnosis and Management.	JAMA	321	4	338	https://dx.https://doi.org/10.1001/jama.2018.20437	Duplicate study
2018	Cheung Christopher CKrahn Andrew DAndrade Jason G	The Emerging Role of Wearable Technologies in Detection of Arrhythmia.	The Canadian journal of cardiology	34	8	1087	https://dx.https://doi.org/10.1016/j.cjca.2018.05.003	Duplicate study
2019	Almqvist MansMattsson GustavMagnusson Peter	[The wearable cardioverter defibrillator - temporary protection against sudden cardiac death].	Lakartidningen	116				Duplicate study
2018	Zylla Maura MHillmann Henrike AKProctor TanjaKieser MeinhardScholz EberhardZitron EdgarKatus Hugo AThomas Dierk	Use of the wearable cardioverter-defibrillator (WCD) and WCD-based remote rhythm monitoring in a real-life patient cohort.	Heart and vessels	33	11	1402	https://dx.https://doi.org/10.1007/s00380-018–1181-x	Ineligible outcomes
2010	Dillon Katie ASzymkiewicz Steven JKaib Thomas E	Evaluation of the effectiveness of a wearable cardioverter defibrillator detection algorithm.	Journal of electrocardiology	43	1	7	https://dx.https://doi.org/10.1016/j.jelectrocard.2009.05.010	Ineligible study design
2018	Zylla Maura MHillmann Henrike AKProctor TanjaKieser MeinhardScholz EberhardZitron EdgarKatus Hugo AThomas Dierk	Use of the wearable cardioverter-defibrillator (WCD) and WCD-based remote rhythm monitoring in a real-life patient cohort.	Heart and vessels	33	11	1402	https://dx.https://doi.org/10.1007/s00380-018–1181-x	Duplicate study
2018	Zylla Maura MHillmann Henrike AKProctor TanjaKieser MeinhardScholz	Use of the wearable cardioverter-defibrillator (WCD) and WCD-based	Heart and vessels	33	11	1402	https://dx.https://doi.org/10.1007/s00380-018–	Ineligible outcomes

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
	EberhardZitron EdgarKatus Hugo AThomas Dierk	remote rhythm monitoring in a real-life patient cohort.					1181-x	
2020	Hubner PiaWijshoff Ralph W C G RMuehlsteff JensWallmuller ChristianWarenits Alexandra MariaMagnet Ingrid Anna MariaNammi KrishnakantRussell James KSterz Fritz	On detection of spontaneous pulse by photoplethysmography in cardiopulmonary resuscitation.	The American journal of emergency medicine	38	3	533	https://dx.https://doi.org/10.1016/j.ajem.2019.05.044	Ineligible outcomes
2018	Zengin SuatGumusboga HasanSabak MustafaEren Sevki HakanAltunbas GokhanAl Behcet	Comparison of manual pulse palpation, cardiac ultrasonography and Doppler ultrasonography to check the pulse in cardiopulmonary arrest patients.	Resuscitation	133		64	https://dx.https://doi.org/10.1016/j.resuscitation.2018.09.018	Ineligible study design
2019	Majumder AKM Jahangir AlamElSaadany Yosuf AmrYoung RogerUcci Donald R.	An Energy Efficient Wearable Smart IoT System to Predict Cardiac Arrest		2019			https://doi.org/10.1155/2019/1507465	Duplicate study
2021	Bayoumy KarimGaber MohammedElshafeey AbdallahMhaimeed OmarDineen Elizabeth H.Marvel Francoise A.Martin Seth S.Muse Evan D.Turakhia Mintu P. Tarakji Khaldoun G.Elshazly Mohamed B.	Smart wearable devices in cardiovascular care: where we are and how to move forward	Nat Rev Cardiol			19	https://doi.org/10.1038/s41569-021–00522-7	Review article
2018	KamiÅ¡aliÄ‡ AidaFister IztokTurkanoviÄ‡ MuhamedKarakatiÄ SaÅ¡o	Sensors and Functionalities of Non-Invasive Wrist-Wearable Devices: A Review		18	6		https://doi.org/10.3390/s18061714	Review article
2020	Hahnen ChristinaFreeman Cecilia G. Haldar NilanjanHamati Jacquelyn N.Bard Dylan M.Murali VigneshMerli Geno J. Joseph Jeffrey I.van Helmond Noud	Accuracy of Vital Signs Measurements by a Smartwatch and a Portable Health Device: Validation Study		8	2		https://doi.org/10.2196/16811	Ineligible reference test
2017	Ahn Hyun JunYou Sung MinCho KyeongwonPark Hoon KiKim In Young	ì‹¬ì •ì§€ ê°ì§€ë¥¼ ìœ„í•œ ë‹¤ìƒì^2´ ì‹ í˜¸ ì¸¡ì • ì›¨ì–´ëŸ¬ë¸” ë””ë°”ì´ìŠ¤ ê°œë°œ		38	6	335	https://doi.org/10.9718/JBER.2017.38.6.330	Article not in English
2021	C MartinsJ Machado da SilvaD GuimaraesL MartinsM Vaz Da Silva	MONITORIA: The start of a new era of ambulatory heart failure monitoring? Part II - Design					https://doi.org/10.1016/j.repc.2020.07.022	Ineligible study design
2012	M JaegerS FernsnerD WettachA IrouschekF EinhausJ SchmidtA BolzT Birkholz	Non-invasive detection of changes in arterial blood pressure with novel nonlinear capacitive resonance circuit technology					https://doi.org/10.1016/j.resuscitation.2012.08.098	Ineligible reference test
2012	T BirkholzS FernsnerA IrouschekD WettachJ SchmidtF EinhausA BolzM	Detection of cardiac arrest with an integrated sensor system. [German]					https://doi.org/10.1055/s-0031–1299000	No full text available

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
	Jaeger							
2011	T BirkholzM PetruninaS FernsnerD WettachA IrouschekF EinhausJ SchmidtM Jaeger	Detection of prehospital cardiac arrest by lays: Validation of aminiaturized sensor system in patients with cardiopulmonary bypass					https://doi.org/10.1016/S0300-9572 %2811 %2970033–8	No full text available
2010	P Bonato	Advances in wearable technology and its medical applications						Review article
1973	David R.M.Portnoy W.M.	A low cost, portable ventricular fibrillation cardiac arrest discriminator	Medical Instrumentation	7	4	239		No full text available
2017	Nishitha Reddy A.Mary Marks A. Prabaharan S.R.S.Muthulakshmi S.	IoT augmented health monitoring system				254	https://doi.org/10.1109/ICNETS2.2017.8067942	Ineligible study design
2017	Ferretti JacopoDi Pietro LiciaDe Maria Carmelo	Open-source automated external defibrillator	HardwareX	2		70	https://doi.org/10.1016/j.ohx.2017.09.001	Ineligible index test
2010	Bonato Paolo	Advances in wearable technology and its medical applications				2024	https://doi.org/10.1109/IEMBS.2010.5628037	Review article
2014	Shivakumar Nair SiddharthSasikala M.	Design of vital sign monitor based on wireless sensor networks and telemedicine technology					https://doi.org/10.1109/ICGCCEE.2014.6922257	Ineligible study design
2019	Mahajan SonaliBirajdar A.M.	IOT based Smart Health Monitoring System for Chronic Diseases					https://doi.org/10.1109/PuneCon46936.2019.9105717	Ineligible study design
2016	Kassem AbdallahHamad MustaphaMoucary Chady ElFayad Elie	A smart device for the detection of heart abnormality using R-R interval		0		296	https://doi.org/10.1109/ICM.2016.7847873	Ineligible study design
2021	Roy Etee KawnaKher Shubhalaxmi	Smart assist system for driver safety		1252 AISC		187	https://doi.org/10.1007/978–3-030–55190-2_14	Ineligible reference test
2020	Kristoffersson AnnicaLinden Maria	Wearable sensors for monitoring and preventing noncommunicable diseases: A systematic review	Information (Switzerland)	11	11	31	https://doi.org/10.3390/info11110521	Review article
2017	Sun FangminYi ChenfuLi WeinanLi Ye	A wearable H-shirt for exercise ECG monitoring and individual lactate threshold computing	Computers in Industry	92–93		11	https://doi.org/10.1016/j.compind.2017.06.004	Ineligible outcomes
2010	Arzbaecher RobertHampton David R. Burke Martin C.Garrett Michael C.	Subcutaneous electrocardiogram monitors and their field of view	Journal of electrocardiology	43	6	605	https://doi.org/10.1016/j.jelectrocard.2010.05.017	Review article
2012	Bose SumantaPrabu K.Kumar D. Sriram	Real-Time Breath Rate Monitor based Health Security System using Non-invasive Biosensor	2012 Third International Conference on Computing Communication & Networking Technologies (Icccnt)					Ineligible study design
2017	Tan Tan-HsuGochoo MunkhjargalChen Yung-FuHu Jin-JiaChiang John Y.Chang	Ubiquitous Emergency Medical Service System Based on Wireless Biosensors,	Sensors	17	1		https://doi.org/10.3390/s17010202	Ineligible study design

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
	Ching-SuLee Ming-HueiHsu Yung-NianHsu Jiin-Chyr	Traffic Information, and Wireless Communication Technologies: Development and Evaluation						
2017	Kim Kwang-ilGollamudi Shreya S. Steinhubl Steven	Digital technology to enable aging in place	Experimental gerontology	88		31	https://doi.org/10.1016/j.exger.2016.11.013	Review article
2017	Sun FangminYi ChenfuLi WeinanLi Ye	A wearable H-shirt for exercise ECG monitoring and individual lactate threshold computing	Computers in Industry	92–93		11	https://doi.org/10.1016/j.compind.2017.06.004	Duplicate study
2017	Wei LiangChen GangYang ZhengfeiYu TaoQuan WeilunLi Yongqin	Detection of spontaneous pulse using the acceleration signals acquired from CPR feedback sensor in a porcine model of cardiac arrest	Plos One	12	12	e0189217	https://doi.org/10.1371/journal.pone.0189217	Ineligible index test
2019	Majumder A. K. M. Jahangir AlamElSaadany Yosuf AmrYoung RogerUcci Donald R.	An Energy Efficient Wearable Smart IoT System to Predict Cardiac Arrest	Advances in Human-Computer Interaction	2019			https://doi.org/10.1155/2019/1507465	Ineligible outcomes
2010	Bonato Paolo	Advances in wearable technology and its medical applications.	Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference	2010		4	https://dx.https://doi.org/10.1109/IEMBS.2010.5628037	Duplicate study
2000	Aly A FAfchine DEsser PJoos MNiewerth H JWiater AMeier MPadeken DPericas ASchwartmann DWeber TWendrix VWirtz M	Telemetry as a new concept in long term monitoring of SIDS-risk infant.	European journal of medical research	5	1	22		Ineligible reference test
1985	Munley A JRailton RFisher JBarclay R P	Infant respiration monitoring--evaluation of a simple home monitor.	Journal of medical engineering & technology	9	6	5		Ineligible outcomes
2019	Elola AndoniAramendi ElisabeteIrusta UnaiDel Ser JavierAlonso ErikDaya Mohamud	ECG-based pulse detection during cardiac arrest using random forest classifier	Medical & Biological Engineering & Computing	57	2	462	https://doi.org/10.1007/s11517-018–1892-2	Ineligible index test
2020	S. Reddy nullS. B. Seshadri nullG. Sankesh Bothra nullT. G. Suhas nullS. C. Thundiyil null	Detection of Arrhythmia in Real-time using ECG Signal Analysis and Convolutional Neural Networks	2020 IEEE 21st International Conference on Computational Problems of Electrical Engineering (CPEE)			4	https://doi.org/10.1109/CPEE50798.2020.9238743	Ineligible index test
		Database testing of a subcutaneous monitor with wireless alarm - PubMed						Duplicate study
2021	Bayoumy KarimGaber MohammedElshafeey AbdallahMhaimeed OmarDineen Elizabeth H.Marvel Francoise A.Martin	Smart wearable devices in cardiovascular care: where we are and how to move forward	Nat Rev Cardiol			19	https://doi.org/10.1038/s41569-021–00522-7	Review article - round 2

Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
(Continued)								
	Seth S.Muse Evan D.Turakhia Mintu P. Tarakji Khaldoun G.Elshazly Mohamed B.							
		Diagnostic utility of a novel leadless arrhythmia monitoring device - PubMed						Ineligible index test
2019	Elola AndoniAramendi ElisabeteIrusta UnaiDel Ser JavierAlonso ErikDaya Mohamud	ECG-based pulse detection during cardiac arrest using random forest classifier	Med Biol Eng Comput	57	2	462	https://doi.org/10.1007/s11517-018–1892-2	Duplicate study
2016	Gjoreski MartinGjoreski HristijanLuÅ¡trek MitjaGams MatjaÅ¾	How Accurately Can Your Wrist Device Recognize Daily Activities and Detect Falls?	Sensors (Basel)	16	6		https://doi.org/10.3390/s16060800	Ineligible reference test
2013	Hsu Yu-PinYoung Darrin J.	Skin-surface-coupled personal health monitoring system				4	https://doi.org/10.1109/ICSENS.2013.6688176	Ineligible reference test
		Robust real-time PPG-based heart rate monitoring | IEEE Conference Publication | IEEE Xplore						Ineligible reference test
2016	Kroll Ryan R.Boyd J. GordonMaslove David M.	Accuracy of a Wrist-Worn Wearable Device for Monitoring Heart Rates in Hospital Inpatients: A Prospective Observational Study	J Med Internet Res	18	9		https://doi.org/10.2196/jmir.6025	Ineligible study design
2017	Kroll Ryan R.McKenzie Erica D.Boyd J. GordonSheth PrameetHowes DanielWood MichaelMaslove David M. WEARable Information Technology for hospital INpatients (WEARIT-IN) study group null	Use of wearable devices for post-discharge monitoring of ICU patients: a feasibility study	J Intensive Care	5			https://doi.org/10.1186/s40560-017–0261-9	Ineligible index test
2017	Lee Chieh-SenWu Chun-YiKuo Yen-Liang	Wearable Bracelet Belt Resonators for Noncontact Wrist Location and Pulse Detection		65	11	4482	https://doi.org/10.1109/TMTT.2017.2684118	Ineligible reference test
2020	Hankey Martha E.Foster James	Care event detection and alerts						Ineligible study design
		Abstract 11586: Pulse-based Arrhythmia Discrimination Using a Novel Smartphone Application | Circulation						No full text available
2014	Appelboom GeoffCamacho ElvisAbraham Mickey E.Bruce Samuel S.Dumont Emmanuel LPZacharia Brad E.Dâ€™Amico RandySlomian JustinReginster Jean YvesBruyÃ¨re	Smart wearable body sensors for patient self-assessment and monitoring	Archives of Public Health	72	1		https://doi.org/10.1186/2049–3258-72–28	Review article - round 2

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
	OlivierConnolly E. Sander							
2018	Narasimha DeepikaHanna NaderBeck HirokoChaskes MichaelGlover RobertGatewood RobertBourji MohamadGudleski Gregory D.Danzer SusanCurtis Anne B.	Validation of a smartphone-based event recorder for arrhythmia detection		41	5	494	https://doi.org/10.1111/pace.13317	Ineligible study design
2019	Sohn KwanghyunMerchant Faisal M. Abohashem ShadyKulkarni KanchanSingh Jagmeet P.Heist E. KevinOwen ChrisJr Jesse D. RobertsIsselbacher Eric M.Sana FurrukhArmoundas Antonis A.	Utility of a smartphone based system (cvrphone) to accurately determine apneic events from electrocardiographic signals	PLOS ONE	14	6		https://doi.org/10.1371/journal.pone.0217217	Ineligible outcomes
2015	Hernandez JavierMcDuff Daniel J.Picard Rosalind W.	Biophone: Physiology monitoring from peripheral smartphone motions				7183	https://doi.org/10.1109/EMBC.2015.7320048	Ineligible outcomes
2015	Hernandez J.Li Y.Rehg J. M.Picard R. W.	Cardiac and Respiratory Parameter Estimation Using Head-mounted Motion-sensitive Sensors		“1”	1			Ineligible reference test
2017	Kiranyaz SerkanInce TurkerGabbouj Moncef	Personalized Monitoring and Advance Warning System for Cardiac Arrhythmias	Sci Rep	7	1		https://doi.org/10.1038/s41598-017–09544-z	Ineligible index test
2014	Barrett Paddy M.Komatireddy RaviHaaser SharonTopol SarahSheard JudithEncinas JackieFought Angela J. Topol Eric J.	Comparison of 24-hour Holter monitoring with 14-day novel adhesive patch electrocardiographic monitoring	Am J Med	127	1	17	https://doi.org/10.1016/j.amjmed.2013.10.003	Duplicate study
2014	Schreiber DonaldSattar AyeshaDrigalla DorianHiggins Steven	Ambulatory Cardiac Monitoring for Discharged Emergency Department Patients with Possible Cardiac Arrhythmias		15	2		https://doi.org/10.5811/westjem.2013.11.18973	Ineligible index test
2018	Narasimha DeepikaHanna NaderBeck HirokoChaskes MichaelGlover RobertGatewood RobertBourji MohamadGudleski Gregory D.Danzer SusanCurtis Anne B.	Validation of a smartphone-based event recorder for arrhythmia detection		41	5	494	https://doi.org/10.1111/pace.13317	Duplicate study
2017	Cadmus-Bertram LisaGangnon RonaldWirkus Emily J.Thraen-Borowski Keith M.Gorzelitz-Liebhauser Jessica	The Accuracy of Heart Rate Monitoring by Some Wrist-Worn Activity Trackers	Ann Intern Med	166	8	612	https://doi.org/10.7326/L16-0353	Ineligible reference test
2017	Paradkar NeerajChowdhury Shubhajit Roy	Cardiac arrhythmia detection using photoplethysmography	Annu Int Conf IEEE Eng Med Biol Soc	2017		116	https://doi.org/10.1109/EMBC.2017.8036775	No full text available
2019	Ip James E.	Wearable Devices for Cardiac Rhythm Diagnosis and Management	JAMA	321	4	338	https://doi.org/10.1001/jama.2018.20437	Review article - round 2
2013	Lobodzinski S. Suave	ECG patch monitors for assessment of	Prog Cardiovasc Dis	56	2	229	https://doi.org/10.1016/j.	Review article -

Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
		cardiac rhythm abnormalities					pcad.2013.08.006	round 2
2019	Majumder AKM Jahangir AlamElSaadany Yosuf AmrYoung RogerUcci Donald R.	An Energy Efficient Wearable Smart IoT System to Predict Cardiac Arrest		2019			https://doi.org/10.1155/2019/1507465	Duplicate study
2021	Krittanawong ChayakritRogers Albert J. Johnson Kipp W.Wang ZhenTurakhia Mintu P.Halperin Jonathan L.Narayan Sanjiv M.	Integration of novel monitoring devices with machine learning technology for scalable cardiovascular management	Nat Rev Cardiol	18	2	91	https://doi.org/10.1038/s41569-020–00445-9	Review article - round 2
2014	Walsh Joseph A.Topol Eric J.Steinhubl Steven R.	Novel Wireless Devices for Cardiac Monitoring		130	7	581	https://doi.org/10.1161/CIRCULATIONAHA.114.009024	Review article - round 2
2017	Wang RobertBlackburn GordonDesai MilindPhelan DermotGillinov LaurenHoughtaling PennyGillinov Marc	Accuracy of Wrist-Worn Heart Rate Monitors	JAMA Cardiology	2	1	106	https://doi.org/10.1001/jamacardio.2016.3340	Ineligible reference test
2013	Winokur Eric S.Delano Maggie K.Sodini Charles G.	A Wearable Cardiac Monitor for Long-Term Data Acquisition and Analysis		60	1	192	https://doi.org/10.1109/TBME.2012.2217958	Ineligible reference test
2019	Chan JustinRea ThomasGollakota ShyamnathSunshine Jacob E.	Contactless cardiac arrest detection using smart devices	npj Digit. Med.	2	1	8	https://doi.org/10.1038/s41746-019–0128-7	Duplicate study
2017	Shcherbina AnnaMattsson C. MikaelWaggott DarylSalisbury HeidiChristle Jeffrey W.Hastie TrevorWheeler Matthew T.Ashley Euan A.	Accuracy in Wrist-Worn, Sensor-Based Measurements of Heart Rate and Energy Expenditure in a Diverse Cohort		7	2		https://doi.org/10.3390/jpm7020003	Duplicate study
2019	Lee YoonjeShin HyungooChoi Hyuk JoongKim Changsun	Can pulse check by the photoplethysmography sensor on a smart watch replace carotid artery palpation during cardiopulmonary resuscitation in cardiac arrest patients? a prospective observational diagnostic accuracy study	BMJ Open	9	2		https://doi.org/10.1136/bmjopen-2018–023627	Ineligible index test
2018	KamiÅ¡aliÄ‡ AidaFister IztokTurkanoviÄ‡ MuhamedKarakatiÄ SaÅ¡o	Sensors and Functionalities of Non-Invasive Wrist-Wearable Devices: A Review		18	6		https://doi.org/10.3390/s18061714	Review article - round 2
2021	Fine JesseBranan Kimberly L.Rodriguez Andres J.Boonya-Ananta TananantAjmal nullRamella-Roman Jessica C.McShane Michael J.Cote Gerard L.	Sources of Inaccuracy in Photoplethysmography for Continuous Cardiovascular Monitoring. [Review]		11	4		https://doi.org/10.3390/bios11040126	Review article - round 2

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
2020	Elayi Claude SErath-Honold Julia WJabbari RezaRoubille FrancoisSilvain JohanneBarra SergioProvidencia RuiNjeim MarioNarayanan KumarDeharo Jean-ClaudeDefaye PascalBoveda SergeLeclercq ChristopheMarijon Eloi	Wearable cardioverter-defibrillator to reduce the transient risk of sudden cardiac death in coronary artery disease.	Europace: European pacing, arrhythmias, and cardiac electrophysiology: journal of the working groups on cardiac pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology	22	10		https://dx.https://doi.org/10.1093/europace/euaa045	
2020	Hahnen ChristinaFreeman Cecilia G. Haldar NilanjanHamati Jacquelyn N.Bard Dylan M.Murali VigneshMerli Geno J. Joseph Jeffrey I.van Helmond Noud	Accuracy of Vital Signs Measurements by a Smartwatch and a Portable Health Device: Validation Study		8	2		https://doi.org/10.2196/16811	Duplicate study
2015	Fung ErikJÃ¤rvelin Marjo-RiittaDoshi Rahul N.Shinbane Jerold S.Carlson Steven K.Grazette Luanda P.Chang Philip M.Sangha Rajbir S.Huikuri Heikki V.Peters Nicholas S.	Electrocardiographic patch devices and contemporary wireless cardiac monitoring	Front Physiol	6			https://doi.org/10.3389/fphys.2015.00149	Duplicate study
2017	Ahn Hyun JunYou Sung MinCho KyeongwonPark Hoon KiKim In Young			38	6	335	https://doi.org/10.9718/JBER.2017.38.6.330	Duplicate study
		Accuracy in Wrist-Worn, Sensor-Based Measurements of Heart Rate and Energy Expenditure in a Diverse Cohort						Ineligible reference test
2012	Ackermans Paul A. J.Solosko Thomas A. Spencer Elise C.Gehman Stacy E. Nammi KrishnakantEngel JanRussell James K.	A user-friendly integrated monitor-adhesive patch for long-term ambulatory electrocardiogram monitoring	J Electrocardiol	45	2	153	https://doi.org/10.1016/j.jelectrocard.2011.10.007	Ineligible outcomes
2014	Barrett Paddy M.Komatireddy RaviHaaser SharonTopol SarahSheard JudithEncinas JackieFought Angela J. Topol Eric J.	Comparison of 24-hour Holter Monitoring with 14-day Novel Adhesive Patch Electrocardiographic Monitoring	Am J Med	127	1		https://doi.org/10.1016/j.amjmed.2013.10.003	Ineligible index test
2015	Bolourchi MeenaBatra Anjan S.	Diagnostic yield of patch ambulatory electrocardiogram monitoring in children (from a national registry)	Am J Cardiol	115	5	634	https://doi.org/10.1016/j.amjcard.2014.12.014	Ineligible index test
		Ambulatory Cardiac Monitoring for Discharged Emergency Department Patients with Possible Cardiac Arrhythmias						Ineligible index test
2010	Zimetbaum PeterGoldman Alena	Ambulatory arrhythmia monitoring: choosing the right device	Circulation	122	16	1636	https://doi.org/10.1161/CIRCULATIONAHA.109.925610	Review article - round 2
2017	An Byeong WanShin Jung HwalKim So-YunKim JooheeJi SangyoonPark JihunLee YoungjinJang JiukPark Young-	Smart Sensor Systems for Wearable Electronic Devices		9	8		https://doi.org/10.3390/polym9080303	Review article - round 2

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
	GeunCho EunjinJo SubinPark Jang-Ung							
2011	Lee Sang-SukSon Il-HoChoi Jong-GuNam Dong-HyunHong You-SikLee Woo-Beom	Estimated Blood Pressure Algorithm for a Wrist-wearable Pulsimeter Using Hall Device		58	2	352	https://doi.org/10.3938/jkps.58.349	Ineligible outcomes
2016	Khan YasserOstfeld Aminy E.Lochner Claire M.Pierre AdrienArias Ana C.	Monitoring of Vital Signs with Flexible and Wearable Medical Devices	Adv Mater	28	22	4395	https://doi.org/10.1002/adma.201504366	Review article - round 2
2015	Bloss Richard	Wearable sensors bring new benefits to continuous medical monitoring, real time physical activity assessment, baby monitoring and industrial applications		35	2	145	https://doi.org/10.1108/SR-10–2014-722	Review article - round 2
		Human health monitoring technology						Review article - round 2
2012	Malhi KarandeepMukhopadhyay Subhas ChandraSchnepper JuliaHaefke MathiasEwald Hartmut	A Zigbee-Based Wearable Physiological Parameters Monitoring System		12	3	430	https://doi.org/10.1109/JSEN.2010.2091719	Ineligible index test
2014	Tamura ToshiyoMaeda YukaSekine MasakiYoshida Masaki	Wearable Photoplethysmographic Sensorsâ€"Past and Present		3	2	302	https://doi.org/10.3390/electronics3020282	Review article - round 2
2018	Koydemir Hatice CeylanOzcan Aydogan	Wearable and Implantable Sensors for Biomedical Applications	Annu Rev Anal Chem (Palo Alto Calif)	11	1	146	https://doi.org/10.1146/annurev-anchem-061417–125956	Review article - round 2
2011	Ding DanCooper Rory A.Pasquina Paul F.Fici-Pasquina Lavinia	Sensor technology for smart homes	Maturitas	69	2	136	https://doi.org/10.1016/j.maturitas.2011.03.016	Review article - round 2
2020	Kristoffersson AnnicaLindÃ©n Maria	A Systematic Review on the Use of Wearable Body Sensors for Health Monitoring: A Qualitative Synthesis	Sensors (Basel)	20	5		https://doi.org/10.3390/s20051502	Review article - round 2
2011	Scholten Annemieke C.van Manen Jeannette G.van der Worp Wim E. IJzerman Maarten J.Doggen Carine J. M.	Early cardiopulmonary resuscitation and use of Automated External Defibrillators by laypersons in out-of-hospital cardiac arrest using an SMS alert service	Resuscitation	82	10	1278	https://doi.org/10.1016/j.resuscitation.2011.05.008	Ineligible outcomes
2018	King Christine E.Sarrafzadeh Majid	A Survey of Smartwatches in Remote Health Monitoring	J Healthc Inform Res	2	1	24	https://doi.org/10.1007/s41666-017–0012-7	Review article - round 2
2021	Zompanti AlessandroSabatini AnnaGrasso SimonePennazza GiorgioFerri GiuseppeBarile GianlucaChello MassimoLusini MarioSantonico Marco	Development and Test of a Portable ECG Device with Dry Capacitive Electrodes and Driven Right Leg Circuit.	Sensors (Basel, Switzerland)	21	8		https://dx.https://doi.org/10.3390/s21082777	
2010	Bonato Paolo	Wearable Sensors and Systems		29	3	36	https://doi.org/10.1109/MEMB.2010.936554	Review article - round 2
2018	Kekade ShwetambaraHseieh Chung-HoIslam Md. MohaimenulAtique	The usefulness and actual use of wearable devices among the elderly	Computer Methods and Programs in Biomedicine	153		159	https://doi.org/10.1016/j.cmpb.2017.10.008	Review article - round 2

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Year	Authors	Title	Journal	Volume	Issue	Page	DOI	Excluded reason
	SulemanMohammed Khalfan AbdulwahedLi Yu-ChuanAbdul Shabbir Syed	population						
2016	Piwek LukaszEllis David A.Andrews SallyJoinson Adam	The Rise of Consumer Health Wearables: Promises and Barriers	PLOS Medicine	13	2		https://doi.org/10.1371/journal.pmed.1001953	Review article - round 2
2017	Vegesna AshokTran MelodyAngelaccio MicheleArcona Steve	Remote Patient Monitoring via Non-Invasive Digital Technologies: A Systematic Review		23	1	17	https://doi.org/10.1089/tmj.2016.0051	Review article - round 2
2020	Vardas PanosCowie MartinDagres NikolaosAsvestas DimitriosTzeis StylianosVardas Emmanuel P.Hindricks GerhardCamm John	The electrocardiogram endeavour: from the Holter single-lead recordings to multilead wearable devices supported by computational machine learning algorithms	Europace	22	1	23	https://doi.org/10.1093/europace/euz249	Review article - round 2
2020	Kurath-Koller StefanSallmon HannesScherr DanielBisping EgbertBurmas AnteKnez IgorKoestenberger Martin	Wearable cardioverter-defibrillator as bridging to ICD in pediatric hypertrophic cardiomyopathy with myocardial bridging - a case report.	BMC pediatrics	20	1		https://dx.https://doi.org/10.1186/s12887-020–02113-w	
2020	Shah Amit JIsakadze NinoLevantsevych OleksiyVest AdrianaClifford GariNemati Shamim	Detecting heart failure using wearables: a pilot study.	Physiological measurement	41	4		https://dx.https://doi.org/10.1088/1361–6579/ab7f93	

Appendix F. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2022.100277.

Author details

[a]Faculty of Medicine, University of British Columbia, British Columbia, Canada [b]British Columbia Emergency Health Services, British Columbia, Canada[c]British Columbia Resuscitation Research Collaborative, British Columbia, Canada [d]School of Biomedical Engineering, University of British Columbia, British Columbia, Canada [e]Department of Orthopedic Surgery, University of British Columbia, British Columbia, Canada [f]International Collaboration on Repair Discoveries, British Columbia, Canada[g]Department of Emergency Medicine, University of British Columbia, British Columbia, Canada [h]Centre for Health Evaluation and Outcome Sciences, University of British Columbia, British Columbia, Canada

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3. Lee S, Park JH, Ro YS, et al. Time to first defibrillation and survival outcomes of out-of-hospital cardiac arrest with refractory ventricular fibrillation. Am J Emerg Med 2021;40:96–102. https://doi.org/10.1016/j.ajem.2020.12.019.
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