A Review of Wearable Sensor Patches for Patient Monitoring

Sónia Santos[1], Maria Pedro Guarino[2], Sandra Neves[3], and Nuno Vieira Lopes[4](✉)

[1] ciTechCare - Center for Innovative Care and Health Technology, Polytechnic University of Leiria, Leiria, Portugal
[2] ciTechCare, School of Health Sciences, Polytechnic University of Leiria, Leiria, Portugal
[3] LIDA - Research Laboratory in Design and Arts, School of Arts and Design, Polytechnic University of Leiria, Caldas da Rainha, Portugal
[4] ciTechCare, School of Technology and Management, Polytechnic University of Leiria, Leiria, Portugal
nuno.lopes@ipleiria.pt

Abstract. Wearable sensor patches are potent tools for patient monitoring in hospital care, with a particular focus on the Emergency Department waiting areas. They can enhance patient safety by alerting healthcare professionals to abnormal changes in vital physiological signals. Wearable sensors have been shown to be useful in monitoring patients' vital signs continuously and in real-time in emergency rooms. However, there are still some challenges that need to be addressed before they can be widely adopted in emergency rooms. Some of these challenges include sensor stability with minimized signal drift, on-body sensor reusability, and long-term continuous health monitoring. This paper reviews wearable sensor patches that have the potential for use in hospital patient monitoring, considering the key variables monitored in emergency rooms. Eligible patches must be wearable, present at least one approval (CE or FDA), and measure more than one physiological parameter.

Keywords: Vital signals · monitoring · wearable · patch

1 Introduction

Healthcare professionals are the most important and critical part of a hospital. They are assigned to perform a wide range of functions such as diagnosis, supervision, cooperation, training, or conflict resolution, always seeking to respond to all needs, even if unforeseen [1].

An emergency room (ER) in a public hospital must always be prepared to provide medical, surgical, or psychiatric care to any patient. It includes an initial evaluation, diagnosis, and subsequent treatment that requires higher active cooperation between these health professionals, compared to others assigned to a different hospital service [2].

P. J. Coelho et al. (Eds.): GOODTECHS 2023, LNICST 556, pp. 136–148, 2024.
https://doi.org/10.1007/978-3-031-52524-7_10

The number of patients who are admitted to the ER can be very high, and the workload on these healthcare professionals, who try to act quickly and effectively, becomes difficult to calculate, however easy to imagine [3].

At the hospital level, the continuous monitoring of patients is critical and allows health professionals to verify and evaluate the physiological condition of the patients more quickly, check the evolution of the clinical status, validate the results of the applied therapies, and prevent and detect critical situations that may endanger the patient. On the other hand, patients with monitoring devices feel safer and more confident when they are in the ER. However, due to the limitations of human and physical resources in hospitals, it is only possible to monitor some patients. With electronic miniaturization, advances in data processing, battery technology, and wireless protocols, several small and light wearable monitoring devices have emerged, which can be placed on patients without causing movement restrictions.

Different types of wearable devices are available in the market, such as watches, wristbands, and patches. Watches are convenient, they are often multifunctional and can perform various tasks, such as monitoring heart rate, blood oxygenation, sleep quality, and physical activity. Also, they can provide notifications for calls, messages, and emails. However, they have limited battery life, and, in general, they are expensive and not waterproof. Wristbands are thin, comfortable, and often more affordable than watches. Typically they have longer battery life than watches, and many wristbands are water-resistant, which makes them suitable for hospital sterilization. Wearable devices like wristbands may have limited features and perform fewer tasks than watches.

Watches and wristbands are readily available in the market, and there are many brands and models to choose from, making them accessible. Several research studies involving the use of watches and wristbands for healthcare can be found in the literature [4–7]. According to these studies, these devices should only be used as a self-control tool and rigorous research on their use in clinical settings is still needed. Also, from the health professionals' point of view, the wrist should be kept free as it provides rapid and easy vascular access.

In [7] six medical patches were reviewed, however three of them were discontinued. Wearable devices like skin patches are discreet and can be worn under clothing. They are comfortable to wear and do not cause discomfort or movement restrictions. Typically they are often more affordable than wristbands. Also, they could be placed in several body locations to continuously monitor health parameters, leaving the wrists and arms free. Some patch devices are fully disposable, but in some cases, the core hub can be detached, sterilized, and reusable. For these reasons, using skin patch monitoring devices to verify and evaluate the physiological condition of ER patients could be a valuable help for patients and health professionals. Patches have become increasingly popular, and many companies are developing novel products. SAFETRACK is a multidisciplinary project that involves academia experts in health, informatics, electronic engineering and design, and companies dedicated to medical devices development and commercialization to explore how emergency departments in hospital can better respond to patient safety during hospitalization and deliver a prototype solution [8].

Within this scope this paper aims to review the wearable sensor patches, already available in the market, that could be used for patient monitoring in a hospital emergency room.

2 Wearable Sensor Patches

In this section, vital signs monitoring devices with adhesive surfaces commonly defined as patches will be described. Devices were excluded if they measure just one vital sign, if they are not wearable and wireless and if they had no formal approval as a medical device through the Conformité Européenne (CE) mark or Food and Drug Administration (FDA) clearance or both.

2.1 Biobeat Chest Monitor

The Biobeat chest monitor is both CE and FDA certified (Fig. 1) [9]. According to the manufacturer, one of the main features of the Biobeat chest monitor is its ability to continuously monitor a wide range of vital signs, including heart rate (HR), respiratory rate (RR), blood oxygen saturation (SpO_2), heart rate variability (HRV), blood pressure (BP), stroke volume (SV), cardiac output (CO), cardiac index (CI), pulse pressure (PP), one lead electrocardiogram (ECG), sweat level, and skin temperature (ST). A non rechargeable battery lasts for up to 7 days, at the end of which the sensor is disposed of. It also features a simple smartphone app, that collects data via Bluetooth, and allows users to track their vital signs, set personalized alerts, and view detailed health reports over time [10].

Recent peer reviewed publications can be found in the literature. This patch was used to evaluate continuous BP measurements in 10 patients after a cardiac surgery [11]. Results were compared with an arterial line transducer, and this device has shown high accuracy. In [12] it was used to evaluate the influence of sex, skin tone, or Body Mass Index (BMI) in PPG-based BP measurements. 1057 participants were used in the experiment and the device have provided valid results. This device was also used in 160 participants to identify physiological changes following COVID-19 vaccine administration [13]. According to this study, almost all vital parameters exhibited significant changes following vaccine administration in both symptomatic and asymptomatic participants. These changes were more pronounced at night, especially in younger participants and those who had received the second vaccine dose. In [14], a continuous monitoring of ECG, respiratory rate, systolic and diastolic blood pressure, pulse rate, cardiac output, and cardiac index was performed on 15 patients (median age of 52.8 years) after a coronary intervention. The patch have showed high satisfaction rates among the nursing staff. The Biobeat chest monitor was also used in a study with 521 participants to perform multi-parameter measurements to assess clinical deterioration [15]. High correlation RR values were obtained in a validation study presented in [16]. A patient deterioration detection tool was implemented in [17] and [18] with encouraging results.

Fig. 1. Biobeat Chest Monitor.

2.2 Sensium Patch

Sensium Patch (Fig. 2) is also CE and FDA certified. It utilises radio frequency (RF) technology to wirelessly communicate physiological information such as HR, RR and axillary temperature, providing data every two minutes. It is easy to apply and remove, and can be worn comfortably on the skin for up to 6 days. The patch transmits the information to a bridge module that allows seamless transition of patch data to nursing stations, desktop or mobile apps. Healthcare professionals can quickly and accurately assess a patient's condition and make informed treatment decisions [19].

In [23] a validation study measuring RR, HR and temperature on 51 patients recovering from a major surgery is presented. In this study the differences between manual and patch measurements for all three measurements were outside of acceptable limits. Authors justify such differences due to artefacts in the continuous signal, errors during manual measurement and concerning the temperature, the skin temperature measured by the patch not accurately reflect the tympanic temperature measured by the nursing staff. This wearable device was successfully used in several studies to evaluate the feasibility, patient and surgical stuff acceptability, and clinical outcomes of using continuous remote monitoring [20–22]. An economical analysis is presented in [24]. The study involved monitoring post-operative patients in two hospital wards for 30 days. The authors concluded that the use of this patch could be a cost-saving strategy, as it has the potential to reduce the length of post-operative hospital stays, readmission rates, and associated costs in post-operative patients.

Fig. 2. Sensium Patch.

2.3 VitalPatch RTM

The VitalPatch Real-Time Monitoring (RTM) is a fully disposable wireless wearable device that allows continuous real-time monitoring of ECG, HR, RR, ST, HRV, activity (including step count), posture and fall detection (Fig. 3). It is manufactured by VitalConnect, a company based in California and it is both CE and FDA certified. Bluetooth Low Energy connectivity allows for continuous data transmission to a central monitoring station or a mobile device. According to the manufacturer, the patch weights 13g and is powered by a non-rechargeable battery that lasts up to 7 days. Also, a proprietary third-party artificial intelligence software continuously analyzes the transmitted data to detect 21 unique cardiac arrhythmias [25].

Validation studies concerning the accuracy of HR, RR and temperature measurements can be found in [26–28]. Another validation study, considering 29 participants performing different movements and controlled hypoxia [29], the VitalPatch has demonstrated to be safely used and accurate throughout both the movement and hypoxia phases, except for RR during the sit-to-stand and turning page movements.

In a comparative study [30], the patch performance was assessed against 2 other weareable sensors (Everion and Fitbit Charge 3) and 2 reference devices (Oxycon Mobile and iButton). Using a total of 20 volunteers performing various daily life activities, authors have conclude the accuracy of all sensors decreased with physical activity, however, the VitalPatch was found to be the most accurate.

2.4 Philips Biosensor BX100

The BX100 is a dual-certified wireless wearable device that can be attached to a patient's chest using an adhesive patch (Fig. 4). The device is equipped with sensors that measure the patient's HR, RR, activity level and posture.

Fig. 3. VitalPatch RTM.

The device sends data over Bluetooth Low Energy (BLE), is also lightweight and comfortable to wear, making it an ideal solution for patients who require long-term monitoring. It is designed to work with the IntelliVue Guardian Software to assist in the early identification of clinical deterioration, leading to early intervention [31].

[32] presents a respiratory rate validation study against values derived from capnography via nasal cannula that suggests the Philips Biosensor can provide comparable respiratory rates. Comparing the data from the Biosensor with a reference monitor, (General Electric Carescape B650), in severely obese patients during and after bariatric surgery, it was concluded the sensor had performed accordingly for HR monitoring, but not for RR [33]. 44 adult patients receiving care in an ER have wore the patch and they reported that it was comfortable and no serious adverse reactions were observed [35]. A remote ECG monitoring system with real time diagnosis was implemented in [34].

Fig. 4. Philips Biosensor BX100.

2.5 BodyGuardian Heart

The BodyGuardian Heart sensor, illustrated in Fig. 5 is a wearable wireless device that continuous monitors patients' vital signs such as ECG, HR, RR and physical activity. Preventice Solutions manufacture it with CE and FDA approval. It is a small, discreet device that can be placed in the user's chest via a disposable strip with medical-grade adhesive and electrode gel. Bluetooth connectivity allows continuous data transmission to a mobile phone which acts as a gateway to a remote station. The company also offers a service that provides remote cardiac diagnostic monitoring. Patients' results are then sent and interpreted by doctors [36].

A pilot study assessing ECG quality in remote monitoring is presented in [37]. The patch is capable of acquiring and transmitting high quality diagnostic ECG data. It is relevant to note that some authors may have a financial interest in the technology.In [38] the BodyGuardian Heart sensor was successfully used to detect HR changes after amphetamine administration, and in [39], the patch was used to describe and validate a platform for ECG interpretation named BeatLogic developed by the same company.

Fig. 5. BodyGuardian Heart.

2.6 1AX Biosensor

The 1AX biosensor, manufactured by LifeSignals, is a wearable wireless device with both FDA and CE marking approvals (Fig. 6). This single-use patch can continuously acquire ECG, HR, RR, skin temperature, and posture status. The company also offers another patch called the 1AXe Biosensor solely for ECG and HR measurements. The wireless connectivity allows continuous data transmission to a mobile device or a central monitoring station. When the wireless connection is lost or unavailable, it has an internal memory cache that supports up to 16 h of recordings. It is also equipped with a Lithium-Manganese dioxide (Li-MnO_2) battery that can last up to 5 days [40]. The company has announced an upgraded version of this patch that includes SpO_2 measurement but has yet to be available in the market. No validation studies with comparison to gold-standard methodologies or peer reviewed publications were found in the literature.

2.7 Multi-vital ECG

The Multi-Vital ECG patch developed by Vivalink can capture ECG, HR, RR, ST, step count and posture status on a single device and stream data to a mobile or the cloud (Fig. 7). The device is FDA cleared for ECG and HR, and CE cleared for ECG, HR and RR. According to the manufacturer, using a rechargeable battery, it transmits data over BLE and can work continuously up to 14 days. In network failure, it can record data up to 30 days in its internal memory and then

Fig. 6. 1AX Biosensor.

automatically synchronize it once network connection is established [41]. It has a fully disposable adhesive band, but the hub can be reusable, safely sanitized, and recharged using the provided charger. No peer reviewed studies concerning this sensor were found in the scientific literature.

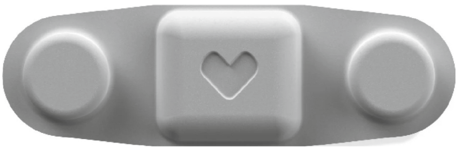

Fig. 7. Multi-Vital ECG.

3 Discussion

Wearable sensor patches are small, unnoticeable devices that can be attached directly to a person's skin. They can be used for monitoring health conditions such as heart rate and blood pressure. First generation wearable patches were lightweight and flexible and consisted of several coatings, including an electronic circuitry, a protective cover and an attaching system. Some first-generation patches use microscopic needles as minimally invasive techniques to support biosensors or to deliver medications. Regarding the presented patches, it is possible to observe that, compared to the previous generation of patches, they are smaller, lighter, and can be worn under clothing. They are placed on the patient's chest and do not introduce movement restrictions. The chest positioning allows better heart electrical activity and thoracic impedance measurements.

Analysing the technical specifications, all the presented patches can provide two significant clinical parameters: HR and RR. Some are equipped with a temperature sensor to measure superficial skin temperature and an accelerometer or an inertial measurement unit to measure activity level, body posture, or steps.

The BioBeat Chest Monitor, the VitalPatch RTM and the Multi-Vital ECG can provide a wide range of parameters.

Due to energy limitations, the preferred wireless technology is Bluetooth except the 1AX Biosensor that uses Wi-Fi and the Sensium Patch that uses a proprietary RF protocol. Two devices (BodyGuardian Heart and Multi-Vital ECG) are partially reusable since their core can be detached from the disposable adhesive strip. They can be adequately cleaned and have a proper charger to recharge their batteries. The remaining patches are fully disposable.

Concerning battery life no information was found about the BodyGuardian Heart but the Multi-Vital ECG announces a lifespan of 14 days, a significantly longer duration compared to the other patches. Based on this, it is reasonable to assume that all patches can be adopted in emergency rooms.

Sensium Patch, Biosensor BX100, 1AX Biosensor, and Multi-Vital ECG patches have internal memory to save data when the wireless connection between the companion device is lost. Once again, the Multi-Vital ECG states a significantly higher cache capacity, but no further information was found about how they achieve it. Table 1 presents a summary of the devices' main characteristics.

Finally, it is important to note that the BodyGuardian Heart, VitalPatch RTM, and Multi-Vital ECG were designed to monitor heart activity continuously, and they have a support analysis platform with advanced algorithms to process the sensor data and detect risk situations such as cardiac arrhythmias or sudden cardiac arrest.

In scientific publications, numerous cases evaluating the use of the BioBeat Chest Monitor and the Sensium Patch in various clinical scenarios, including validation tests, clinical trials, patient outcomes, and perspectives from both patients and healthcare professionals can be found. Multiple validation studies are also available concerning the VitalPatch RTM and the Philips Biosensor BX100. However, it should be noted that a significant number of these papers were written and published by individuals related to the companies that produce such devices.

On the other hand, no peer-reviewed publications were found for both the 1AX Biosensor and Multi-Vital ECG, which may be explained by their recent introduction to the market, lack of knowledge on the part of the scientific community or company strategy.

Since it is an emergent technology, it faces several challenges. These challenges are critical to address for the successful integration and adoption of these devices in clinical practice. Some of these challenges are:

- Informed Consent and Ethical Considerations: Patients must be informed about the purpose of monitoring, the data collected, and how it will be used. Ethical considerations also involve ensuring that patients' rights, autonomy, and privacy are respected throughout the monitoring process.
- Patient Engagement: Engaging patients in their own care and encouraging compliance with biosensor patch usage is a challenge. Healthcare providers should educate patients about the benefits of continuous monitoring and help them understand the importance of adhering to monitoring protocols.

- Health Professionals' Acceptance: Healthcare professionals, including doctors, nurses, and technicians, must be willing to incorporate biosensor patch data into their clinical practice. Proper training and education are necessary to ensure that healthcare providers understand the values and limitations of the technology.
- Definition of New Hospital Staff Workflows: The introduction of biosensor patches may require the development of new workflows within healthcare facilities. This includes protocols for data monitoring, response to alerts, and coordination among healthcare teams.
- Data Privacy and Security: As biosensor patches collect sensitive health data, maintaining privacy and data security is mandatory. Robust encryption, secure data transmission, and strict access controls are necessary to protect patient information from unauthorized access or breaches.
- Integration with the Hospital Information System (HIS): Integrating biosensor patch data with the hospital's existing information systems can be complex. Seamless integration allows healthcare providers to access and utilize the data efficiently.
- Cost and Reimbursement: The cost of implementing biosensor patch technology, including device acquisition, maintenance, and data management, may pose financial challenges for healthcare institutions. Ensuring appropriate reimbursement models is crucial to support the adoption of these technologies.

Table 1. Device main characteristics.

Device Name	Vital Signs	Other Parameters	Wireless Technology	Internal Memory	Battery Life	Weight	Reusable
BioBeat Chest Monitor	HR, RR, SpO_2, BP, ECG	HRV, SV, CO, CI PP sweat level	Bluetooth	No	5 days	23g	No
Sensium Patch	HR, RR, ST	None	RF	3h (max)	6 days	15g	No
VitalPatch RTM	HR, RR, ECG, ST	HRV, steps, posture fall detection activity	Bluetooth	No	7 days	13g	No
Biosensor BX100	HR, RR, ST	Activity, posture	Bluetooth	4h (max)	5 days	10g	No
BodyGuardian Heart	HR, RR	Activity	Bluetooth	No	N/D	35g	Partial
1AX Biosensor	HR, RR, ST	Posture	Wi-Fi	16h (max)	5 days	28g	No
Multi-Vital ECG	HR, RR, ECG, ST	HRV, steps activity	Bluetooth	30 days (up to)	14 days	7.5g	Partial

4 Conclusions

Wearable sensor patches have revolutionized healthcare by providing continuous monitoring of vital signs through a small and discreet device, without introducing movement restrictions to the patients and alerting healthcare professionals if any physiological abnormality is detected. Like all medical devices it is mandatory that healthcare professionals carefully understand their clinical procedures, applications, limitations and challenges when using a wearable sensor patch on their patients.

Despite their benefits, wearable sensor patches present some limitations and challenges. They lack autonomy since they require wireless connectivity to a companion device or a remote station to receive, monitor and process the data. In general, the devices that are entirely disposable have a life period of about one week, after that, they are useless or require periodic battery recharging. For patients with certain skin conditions, the adhesive band can cause skin irritation, particularly for long time monitoring.

In the literature, there is also an observed lack of unbiased peer-reviewed publications, as some studies are performed in close collaboration with the manufacturers. This emphasizes the need for more independent research in the field.

Also, there are some challenges to be addressed such as ethical considerations, data privacy and security, patients and professionals' acceptance, HIS integration and economic viability. Addressing these challenges is essential for the successful integration of biosensor patches into healthcare providers.

This work aimed to present technical information, relevant research studies, limitations, and challenges about multi-parameter biosensor patches. However, as technology continues to advance, it is expected to see even more innovative wearable sensor patches in the near future.

Acknowledgements. Funded by SafeTrack - CENTRO-01-0247-FEDER-070111. Supported by Fundação para a Ciência e a Tecnologia (FCT) (UIDB/05468/2020), Laboratório de Investigação em Design e Artes (LIDA), (UI/05704/2020), Center for Innovative Care and Health Technology (ciTechCare).

References

1. Brazão, M. da Luz, Nóbrega, S., Bebiano, G., Carvalho, E.: Atividade dos Serviços de Urgência Hospitalares. Medicina Interna **23**(3), 8–14 (2016)
2. Definition of Emergency Medicine: Ann. Emerg. Med. **52**(2), 189–190 (2008)
3. Gedmintas, A., Bost, N., Keijzers, G., Green, D., Lind, J.: Emergency care workload units: a novel tool to compare emergency department activity. EMA - Emerg. Med. Australas. **22**(5), 442–448 (2010)
4. Lu, T.C., Fu, C.M., Ma, M.H., Fang, C.C., Turner, A.M.: Healthcare applications of smart watches. A Syst. Rev. Appl. Clin. Inf. **7**(3), 850–869 (2016)
5. Reeder, B., David, A.: Health at hand: a systematic review of smart watch uses for health and wellness. J. Biomed. Inform. **63**, 269–276 (2016)
6. Jachymek, M., et al.: Wristbands in home-based rehabilitation-validation of heart rate measurement. Sensors **22**(1) (2021)

7. Soon, S., Svavarsdottir, H., Downey, C., Jayne, D.: Wearable devices for remote vital signs monitoring in the outpatient setting: an overview of the field. BMJ Innov. **6**, 55–71 (2020)
8. Neves, S., Oliveira, V., Guarino, M.: Using co-design methods to develop a patient monitoring system in hospital emergency care to support patient safety. In: 13th International Conference on Applied Human Factors and Ergonomics (AHFE 2022). AHFE International, New York (2022)
9. BioBeat Product Homepage. https://www.bio-beat.com/products. Accessed 1 Apr 2023
10. BioBeat Platform User Guide. https://www.mindtecstore.com/mediafiles/Sonstiges/Shop/Biobeat/Biobeat_User_Manual_July2020.pdf. Accessed 1 Apr 2023
11. Kachel, E., et al.: A pilot study of blood pressure monitoring after cardiac surgery using a wearable, non-invasive sensor. Front. Med. **8**, 693926 (2021)
12. Nachman, D., et al.: Influence of sex, BMI, and skin color on the accuracy of non-invasive cuffless photoplethysmography-based blood pressure measurements. Front. Physiol. **13**, 911544 (2022)
13. Gepner, Y., et al.: Utilizing wearable sensors for continuous and highly-sensitive monitoring of reactions to the BNT162b2 mRNA COVID-19 vaccine. Commun. Med. **2**, 27 (2022)
14. Sharabi, I., et al.: Assessing the use of a noninvasive monitoring system providing multiple cardio-pulmonary parameters following revascularization in STEMI patients. Digit. Health **9** (2023)
15. Eisenkraft, A., et al.: Developing a real-time detection tool and an early warning score using a continuous wearable multi-parameter monitor. Front. Physiol. **14**, 519 (2023)
16. Eisenkraft, A., et al.: Clinical validation of a wearable respiratory rate device: a brief report. Chronic Respir. Disease **20** (2023)
17. Eisenkraft, A., et al.: Developing a real-time detection tool and an early warning score using a continuous wearable multi-parameter monitor. Front. Physiol. **14** (2023)
18. Itelman, E., et al.: Assessing the usability of a novel wearable remote patient monitoring device for the early detection of in-hospital patient deterioration: observational study. JMIR Formative Res. **6**(6), e36066 (2022)
19. Sensium System Webpage. https://www.tsc-group.com/connected-care/products/sensium/. Accessed 1 Apr 2023
20. Downey, C.L., et al.: Trial of remote continuous versus intermittent NEWS monitoring after major surgery (TRaCINg): a feasibility randomised controlled trial. Pilot Feasibility Stud. **6**(1), 183 (2020)
21. Joshi, M., et al.: Perceptions on the use of wearable sensors and continuous monitoring in surgical patients: interview study among surgical staff. JMIR Formative Res. **6**(2), e27866 (2022)
22. Joshi, M., et al.: Short-term wearable sensors for in-hospital medical and surgical patients: mixed methods analysis of patient perspectives. JMIR Perioperative Med. **4**(1), e18836 (2021)
23. Downey, C., Ng, S., Jayne, D., Wong, D.: Reliability of a wearable wireless patch for continuous remote monitoring of vital signs in patients recovering from major surgery: a clinical validation study from the TRaCINg trial. BMJ Open **9**(8), e031150 (2019)

24. Javanbakht, M., et al.: Cost utility analysis of continuous and intermittent versus intermittent vital signs monitoring in patients admitted to surgical wards. J. Med. Econ. **23**(7), 728–736 (2020)
25. VitalConnect Homepage. https://vitalconnect.com/. Accessed 1 Apr 2023
26. Selvaraj, N., Nallathambi, G., Moghadam, R., Aga, A.: Disposable wireless patch sensor for continuous remote patient monitoring. In: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society, pp. 1632–1635 (2018)
27. Rajbhandary, P. L., Nallathambi, G.: Feasibility of continuous monitoring of core body temperature using chest-worn patch sensor. In: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society, pp. 4652–4655 (2020)
28. Selvaraj, N., Nallathambi, G., Kettle, P.: A novel synthetic simulation platform for validation of breathing rate measurement. In: 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Honolulu, pp. 1177–1180 (2018)
29. Morgado Areia, C., et al.: A chest patch for continuous vital sign monitoring: clinical validation study during movement and controlled hypoxia. J. Med. Internet Res. **23**(9), e27547 (2021)
30. Haveman, M.E., et al.: Continuous monitoring of vital signs with wearable sensors during daily life activities: validation study. JMIR Formative Res. **6**(1), e30863 (2022)
31. Biosensor BX100 Product Page. https://www.philips.ca/healthcare/product/HC989803203011/biosensor-bx100-wearable-remote-measurement-device. Accessed 1 Apr 2023
32. Li, T., Divatia, S., McKittrick, J., Moss, J., Hijnen, N.M., Becker, L.B.: A pilot study of respiratory rate derived from a wearable biosensor compared with capnography in emergency department patients. Open Access Emer. Med. **11**, 103–108 (2019)
33. Kant, N., et al.: Continuous vital sign monitoring using a wearable patch sensor in obese patients: a validation study in a clinical setting. J. Clin. Monit. Comput. **36**(5), 1449–1459 (2022)
34. Bhattarai, A., Peng, D., Payne, J., Sharif, H.: Adaptive partition of ECG diagnosis between cloud and wearable sensor net using open-loop and closed-loop switch mode. IEEE Access **10**, 63684–63697 (2022)
35. Miller, K., et al.: Deployment of a wearable biosensor system in the emergency department: a technical feasibility study. In: Proceedings of the Annual Hawaii International Conference on System Sciences, pp. 3567–3572 (2021)
36. Preventice Solutions Home Page. https://www.preventicesolutions.com/us/en/home.html. Accessed 10 Apr 2023
37. Bruce, C.J., et al.: Remote electrocardiograph monitoring using a novel adhesive strip sensor: a pilot study. World J. Cardiol. **8**(10), 559–565 (2016)
38. Izmailova, E.S., et al.: Continuous monitoring using a wearable device detects activity-induced heart rate changes after administration of amphetamine. Clin. Transl. Sci. **12**(6), 677–686 (2019)
39. Teplitzky, B.A., McRoberts, M., Ghanbari, H.: Deep learning for comprehensive ECG annotation. Heart Rhythm **17**(5 Pt B), 881–888 (2020)
40. 1AX Biosensor Product Page. https://lifesignals.com/wearable-biosensors/1ax-biosensor/. Accessed 10 Apr 2023
41. Multi-Vital ECG Sensor Product Page. https://www.vivalink.com/wearable-ecg-monitor. Accessed 10 Apr 2023