Classification of wearables use cases in the mirror of JCAHO patient safety goals for Hospitals

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Research Article

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Abstract

Background

Patient safety can be improved by using wearable devices in hospitals. Wearable technology has the potential to provide enormous advantages to healthcare providers and patients. This study aims to explore the use cases of wearable technology in patient safety in hospitals and classify them based on the healthcare wearable taxonomy, focusing on the JCAHO patient safety goals for hospitals.

Materials and Methods

The search strategy was performed in Medline (PubMed), Scopus, and Google Scholar using keywords related to wearable technology and patient safety on September 4, 2021. English papers that presented the applications of wearable technology on patient safety of inpatients were included. A qualitative synthesis was performed by applying the taxonomy of wearables in healthcare and the JCAHO (Joint Commission on Accreditation of Healthcare Organizations) goals for hospital patient safety.

Results

Of the 345 papers retrieved, ten were included in this study. The results demonstrated the usefulness of wearable devices in patient safety in hospitals. Monitoring, prevention, and assistive technology were three applications of wearables that had been more commonly reported in the studies. This research showed that the two goals of the JCAHO are the most frequently addressed through the application of wearables in hospitals. These goals include 1) identifying patient safety risks in the hospital by measuring various parameters such as vital signs and 2) reducing patient harm associated with the clinical alarm.

Conclusion

This study provides evidence for the potential applications of wearable technology for improving patient safety in hospitals. Considering the multiple functionalities of the wearables and their potential applications, hospitals could put wearables on their agenda for improving patient safety and quality of care.

Background

The notion of patient safety has emerged with the evolving complexity of healthcare systems and the consequent rise of patient harm in healthcare facilities. It aims to prevent and reduce risks, errors and harms that occur to patients while providing health care [1]. Patient safety is crucial for delivering effective, high-quality healthcare [2] and is defined by the World Alliance for Patient Safety of WHO as ‘the reduction of risk of unnecessary harm associated with healthcare to an acceptable minimum’ [3]. WHO has recognized patient safety as a global problem and positioned it as a worldwide endeavour to benefit patients in developed and developing countries [4]. It is estimated that each year millions of patients worldwide suffer disabilities, injuries or death due to unsafe medical care and that around 50% of these harmful outcomes are preventable [5]. The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) recently released seven goals for improving patient safety in hospitals to focus on in 2021 [6]. To achieve these goals, health information technology, such as wearable technology, can play a critical role in facilitating decision-making and reducing errors due to human factors [7, 8].

Wearable technology is a category of electronic devices that can be worn as an accessory, integrated into clothing, implantable in the body, or even directly on the skin. [9]. This technology has been used in various fields of healthcare, including (1) health and patient safety monitoring, (2) management of chronic disease, (3) diagnosis and treatment, and (4) rehabilitation [10]. Additionally, healthcare settings have already benefited from the potential of this technology [11–13]. For example, Tajian et al. have reported using wearable devices to improve patient safety through continuous postoperative monitoring of health metrics [11]. Martínez Pérez et al. indicated that using RFID could play a valuable role in patient safety by managing the care process of ICU patients [14]. Slade Shantz showed that wearable technology as a patient assessment tool for healthcare providers enables more accurate decisions by showing patient-related measurements [6].

Various types of sensors can improve patient safety [15]. It is essential to monitor patient observations in hospitals [15]. The benefits of wearable sensors in high-risk patients and patients with severe acute illness are significant [15]. By more accurately predicting patient deterioration by wearable sensors, patient safety improves [15].

Recently, with the dramatic progress in technology [16–18], miniature sensors have been developed. These sensors have a higher sampling frequency and transmit data wirelessly. As such, patients’ movement is not restricted, and therefore the level of acceptance and cooperation among them is improved [15]. Also, with the production of low-consumption devices, the patient can be monitored continuously in the hospital at a meagre cost [19].

To the best of our knowledge, there is no study of wearable technology applications for patient safety of inpatients in hospitals. Also, to date, studies have yet to apply a combination of the JCAHO goals for patient safety and healthcare wearable taxonomy to analyze wearable use cases in hospitals. This paper aimed to investigate the applications of wearable technology solutions for patient safety and map them to the healthcare wearable taxonomy, focusing on the JCAHO patient safety goals for hospitals.

Materials And Methods

This study was conducted in three phases: In the first phase, the review was carried out to examine use cases of wearable technology for hospitalized patients, reported in the literature. The focus of this stage was merely to explore essential characteristics, technical aspects and clinical features of the
wearables reported in the studies.

In the second phase, we applied dimensional taxonomy of wearable technology in healthcare to classify the wearables based on their technological aspects.

In the third phase, we also mapped the reported use cases of the wearables into the 2021 JCAHO patient safety goals for hospitals for the qualitative synthesis of the findings. Finally, we synthesized the results from the three phases.

**Phase 1: Use Cases Of The Wearable Technology In Hospital**

**Databases and Search Strategy**

To retrieve related papers, the researchers searched databases including Medline (PubMed), Scopus, and Google Scholar on September 4, 2021. Table 1 shows the search strategy deployed for finding papers published on the use cases of wearable technology for patient safety in hospitals. The search strategy was confirmed by librarian experts (n = 3).

<table>
<thead>
<tr>
<th>ID</th>
<th>Search Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>(((((Patient Safeties[MeSH Terms]) OR (Patient Safeties[Title/Abstract])) OR (Patient Safeties[Title/Abstract])) OR (Safeties, Patient[Title/Abstract])) OR (Safety, Patient[Title/Abstract]))</td>
</tr>
<tr>
<td>#2</td>
<td>((((((((((Wearable Electronic Devices[MeSH Terms]) OR (Wearable Electronic Devices[Title/Abstract])) OR (Device, Wearable Electronic[Title/Abstract])) OR (Electronic Device, Wearable[Title/Abstract])) OR (Wearable Electronic Device[Title/Abstract])) OR (Wearable Technology[Title/Abstract])) OR (Technologies, Wearable[Title/Abstract])) OR (Technology, Wearable[Title/Abstract])) OR (Wearable Devices[Title/Abstract])) OR (Device, Wearable[Title/Abstract])) OR (Devices, Wearable[Title/Abstract])) OR (Electronic Skin[Title/Abstract])) OR (Skin, Electronic[Title/Abstract]))</td>
</tr>
<tr>
<td>#3</td>
<td>#1 AND #2</td>
</tr>
</tbody>
</table>

Limited to humans and English languages

**Eligibility Criteria**

Studies were included if they met the following criteria:

1. The intervention was wearable technology.
2. Conducted in hospitals.
3. Reported the use cases of wearable technology for targeting patient safety issues.
4. Peer-reviewed studies.
5. English papers.

The exclusion criteria included a) protocols, b) review papers, c) letters to the editor, and d) not available full text.

**Data Extraction**

Endnote X8 software is used for organizing and removing duplicate studies. Four authors (M.A, L.R.K, A.A, K.Y.R) conducted study selection and data extraction. The authors discussed and resolved disagreements, and the final papers were included. The researchers extracted the following data elements from each study:

1. Basic characteristics of the selected studies (e.g. authors, published year, country of origin, the aim of the study, type of study, the name of wearable technology, experiment duration, population, sample size, and setting).
2. Technical aspects of wearable technology (e.g. wearable device, body location of the wearable, data transmission protocol, wearable working interval, integration / interoperability of the wearable device with local systems, and captured data).
3. Clinical aspects of studies (e.g. detected risks, actions against the detected risk, users involved, outcomes, clinical action applied, and challenges/limitations).

**Phase 2. Mapping the reported wearables into the healthcare wearable taxonomy and the JCAHO patient safety goals**

In the second phase of the study, first, the researchers applied the taxonomy of wearable technologies in health care (introduced by Alrige and Chatterjee) to findings obtained from phase 1. According to Alrige and Chatterjee[20], wearable electronic devices can be classified based on three aspects: form, functionality, and application. These aspects were employed by the two researchers (MA, AA and KY) to analyze and classify the wearables reported in the studies. In the case of any disagreement, the principal investigator (LRK) was involved.
This mapping aimed to investigate the gap between the wearable technologies’ potential in terms of form, functionality and application and their actual reported form, functionality and applications in the real world.

Then the researchers (MA, AA and KY) applied the JCAHO patient safety goals for hospitals to findings from phase 1 [21]. In the case of disagreement, the principal investigator (LRK) was consulted. This mapping aimed to investigate the gap between the patient safety goals and the actual use of wearables reported in the real world for these goals. The researchers aimed to investigate which wearable technologies have addressed patient safety goals in the studies.

The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) has released the updated version of hospital patient safety goals in 2021 based on the emerging patient safety issues reported by widely recognized field experts. JCAHO has set 7 patient safety goals for hospitals as follows:

1. improve the accuracy of patient identification
2. improve staff communication
3. improve the safety of medication administration
4. reduce patient harm associated with clinical alarm systems,
5. reduce the risk of healthcare-associated infections,
6. better identify patient safety risks in the hospital,
7. better prevent surgical mistakes [16].

Finally, the researchers synthesized the results qualitatively by combining the findings from the two phases of the study to reach an overall picture of the current and potential status of the wearables in hospitals for patient safety as well as the opportunities that should be taken into account by wearable designers in the future.

Results

The initial search yielded 345 papers from different databases. A total number of 304 studies were remained after removing duplicate titles. In the screening process based on titles and abstracts, 260 papers were excluded. Finally, 44 papers were eligible to be included in the full-text review, of which 34 did not meet the inclusion criteria. Finally, ten studies were included in the final review (Fig. 1).

Table 2 presents the basic characteristics of the studies that reported wearable technologies for patient safety in hospitals.

As can be seen from Table 2, a variety of wearable devices have been used for different purposes of patient safety. The purpose of using wearable technology for patient safety in hospitals ranges from measuring and monitoring patient vital signs to monitoring the performance of the medical equipment and identifying patients, healthcare personnel, and medicines. The studies have been conducted in hospitals in different countries, including the UK, the US, Spain, Australia, Taiwan, and South Korea. Wearable devices have been used in different hospital wards, including pulmonary, surgery, neuro-surgery, ICU, Acute care unit, and hemodialysis wards.

Table 2. Basic characteristics of the studies reporting wearable technologies for patient safety in hospitals
<table>
<thead>
<tr>
<th>Author / Year</th>
<th>Aim of study</th>
<th>Type of study</th>
<th>Sensor / Device name</th>
<th>Experiment duration</th>
<th>hospital ward</th>
<th>Sample size</th>
<th>Country</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lee, J. H. et al./2018 [22]</td>
<td>· To explore the suitability of wearable devices integrated with mobile applications for recognizing risk during patient transfer.  · To examine the reliability of the risk signal transmission over the network</td>
<td>Single-center observational validation study</td>
<td>· Prince-100 wrist oximeter  · Nonin WristOX2 model 3150 (FDA approved)  · Both devices check oxygen saturation and heart rate in real-time</td>
<td>15 days</td>
<td>Pulmonology ward</td>
<td>23 patients</td>
<td>South Korea</td>
<td>Asan Medical Center</td>
</tr>
<tr>
<td>Ou, Y. K. et al./2019 [23]</td>
<td>· To provide an additional layer of protection for patients undergoing HD  · To alleviate the clinical work pressure on nursing staff  · To facilitate positive nurse-patient interactions  · To develop a blood leakage detection device</td>
<td>Clinical trial</td>
<td>Blood leakage detection device (Array of sensors combined with a mapping circuit and a Wi-Fi module)</td>
<td>5 months</td>
<td>Hemodialysis ward</td>
<td>11 patients: 9 male 2 female</td>
<td>Taiwan</td>
<td>Kaohsiung Veterans General Hospital</td>
</tr>
<tr>
<td>Downey, C. et al./2018 [24]</td>
<td>· To evaluate whether continuous remote vital signs monitoring is a practical way of monitoring surgical patients outside the critical care setting.  · To evaluate whether continuous remote monitoring of vital signs is acceptable to patients.</td>
<td>A pilot cluster-randomized, prospective, parallel-group, controlled single-center pilot study</td>
<td>SensiumVitals (A device that is worn on the chest of a patient, which continuously monitors heart rate, respiratory rate, and temperature)</td>
<td>7 months</td>
<td>Surgical wards</td>
<td>140 patients</td>
<td>UK</td>
<td>Hospital (a single tertiary center in Leeds, United Kingdom)</td>
</tr>
<tr>
<td>Weller, R. S. et al./2018 [25]</td>
<td>· Using an automated VSAS monitoring, multiple VS would allow us to “titrate” the VS settings (VS parameter and time) that triggered alarms and alerted the nursing staff  · To reduce RRT calls and transfers to the ICU.</td>
<td>Prospective, observational pilot study</td>
<td>VSAS (ViSi Mobile System, Sotera Wireless, Inc., San Diego, CA) (This system continually provided all VS measurements [BP, HR, RR, SpO2] required for patient care)</td>
<td>5 months</td>
<td>Neurological/neurosurgical unit (non ICU)</td>
<td>736 patients</td>
<td>USA</td>
<td>Hospital (a academic medical center)</td>
</tr>
<tr>
<td>Study</td>
<td>Authors</td>
<td>Year</td>
<td>Study Design</td>
<td>Technology</td>
<td>Area</td>
<td>Location/Country</td>
<td>Participants/Setting</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Martínez Pérez, M et al. / 2018 [14]</td>
<td>RFID technology integration into the tasks carried out by health professionals in a hospital intensive care unit.</td>
<td>Clinical trial</td>
<td>NFC</td>
<td>not mentioned</td>
<td>ICU ward</td>
<td>not mentioned</td>
<td>Spain</td>
<td></td>
</tr>
<tr>
<td>McFarlane et al. / 2018 [26]</td>
<td>To address the current patient safety crisis related to alarms/alerts.</td>
<td>A randomized within-subjects single-factor clinical experiment</td>
<td>Sensors: · Bedside physiological monitor · IV pumps · Call light system</td>
<td>Actuator: · HAIL-CAT smartwatch implemented on Samsung Gear 2 smartwatches: o Recognize essential changes in patients' status; o Respond to significant changes in patients' status; o Use alarms to improve patient safety; o Manage bedside alarm audio; o Understand and triage alarm occurrences</td>
<td>Acute care unit</td>
<td>20 acute care patients</td>
<td>USA University of Utah, College of Nursing 20 bed patient simulation facility that replicates a full-scale acute care hospital unit</td>
<td></td>
</tr>
<tr>
<td>Pascale, M. T. et al. / 2019 [27]</td>
<td>To test whether displaying continuous patient information on an HWD improves participants' ability to prioritize alarms and maintain greater awareness of patient status.</td>
<td>Clinical trial</td>
<td>Head-Worn Display: (Displays a continuous stream of vital signs from patients) · Experiment 1: Google Glass (Google Inc., Mountain View, CA), which uses monocular optical see-through display, · Experiment 2: Vuzix M100 (Vuzix, Rochester, NY, USA), with a monocular opaque LCD.</td>
<td>Head-Worn Display: (Displays a continuous stream of vital signs from patients)</td>
<td>Nursing students at The University of Queensland General ward</td>
<td>Australia A simulate hospital micro-world</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaz et al. / 2017 [28]</td>
<td>To provide an Android-based platform to warn healthcare providers of the appearance of allergic reactions during allergy provocation tests.</td>
<td>Clinical trial</td>
<td>A SHIMMER device: Portable device for acquiring the ECG signal</td>
<td>not mentioned</td>
<td>Patients undergoing allergy provocation tests.</td>
<td>Spain Guadalajara University Hospital</td>
<td>147 subjects: 28 Children 117 Adults</td>
<td></td>
</tr>
</tbody>
</table>
To determine the safety and feasibility of capturing and streaming neuronavigation images onto a head-up display during spine instrumentation.

Table 3 shows the technical aspects of wearable technologies reported in the studies. Depending on their aim, wearables reported in the studies have been used in different body locations of patients or personnel, including wrist, arm, chest, abdomen, head, or a combination of them and in some cases as a tag on patient medication or bedside.

Various connectivity ranges have been used for communicating the signals or information collected by the wearables, including Wi-Fi, Bluetooth, LTE, and RFID. Both continuous and continual usage of wearables has been reported in the studies. The data captured by the wearables include heart rate, oxygen saturation, respiratory rate, temperature, blood pressure, identification code, allergic reaction, and some neuronavigation images.

Table 3. Technical aspects of wearable technologies reported in the studies
<table>
<thead>
<tr>
<th>Author / Year</th>
<th>Wearable device</th>
<th>Location of the sensor</th>
<th>Connections</th>
<th>Sensor working interval</th>
<th>Integration/Interoperability of the sensor with local systems</th>
<th>Data captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lee, J. H. et al. / 2018 [22]</td>
<td>• Prince-100H wrist oximeter • Nonin WristOX2 model 3150</td>
<td>Patient's wrist</td>
<td>• Bluetooth • Wi-Fi • LTE</td>
<td>Prince-100H: every 1 second • Nonin: every 4 seconds</td>
<td>Not mentioned</td>
<td>• Heart rate • Oxygen saturation</td>
</tr>
<tr>
<td>Ou, Y. K. et al. / 2019 [23]</td>
<td>Blood leakage detection device</td>
<td>Patient's arm</td>
<td>Wi-Fi</td>
<td>Not mentioned</td>
<td></td>
<td>Blood leakage</td>
</tr>
<tr>
<td>Downey, C. et al. / 2018 [24]</td>
<td>SensiumVitals</td>
<td>Patient's chest</td>
<td>Wi-Fi</td>
<td>2 minutes</td>
<td>The monitoring software was integrated with the hospital admissions data system so patients could easily be added to the remote monitoring system. • All data were stored and retained on the hospital network, alleviating initial concerns about data security by inheriting all hospital security procedures and data backup policies.</td>
<td>• Heart rate • Respiratory rate • Body Temperature</td>
</tr>
<tr>
<td>Weller, R. S. et al. / 2018 [25]</td>
<td>VSAS</td>
<td>Body worn (several points) • Wrist • Chest • Arm • Abdomen</td>
<td>Wi-Fi</td>
<td>Not mentioned</td>
<td>The system was connected to the hospital's existing wireless network to distribute VS information and alarms to a central station and to the nurses' hospital-supplied phones.</td>
<td>• Heart rate • Respiratory rate • Blood pressure • SpO2</td>
</tr>
<tr>
<td>Martinez Pérez, M et al. / 2018 [14]</td>
<td>NFC</td>
<td>• Health personnel's wrist • Patient's wrist • Medication</td>
<td>RFID</td>
<td>Real time</td>
<td>It is possible to integrate this system into other existing tracking systems and be compatible with other identification technologies.</td>
<td>Identification code</td>
</tr>
<tr>
<td>McFarlane et al. / 2018 [26]</td>
<td>HAIL-CAT smartwatch implemented on Samsung Gear 2 smartwatches</td>
<td>• Bedside • Health personnel's wrist</td>
<td>• LAN with Wi-Fi • Bluetooth</td>
<td>Every second</td>
<td>Integrated with Bedside physiological monitor)</td>
<td>• Heart rate • Respiratory rate • Blood pressure • SpO2</td>
</tr>
<tr>
<td>Pascale, M. T. et al. / 2019 [27]</td>
<td>Head-Worn Display: • Google Glass • Vuzix M100</td>
<td>Nurse's head</td>
<td>Wi-Fi</td>
<td>2 seconds</td>
<td>Integrate d with Bedside physiological sensors.</td>
<td>Data sensed by physiological sensors: • Heart rate • Blood pressure • Oxygen saturation</td>
</tr>
<tr>
<td>Diaz et al. / 2017 [28]</td>
<td>A Shimmer device</td>
<td>The patient's chest</td>
<td>Bluetooth</td>
<td>Real time</td>
<td>Not mentioned</td>
<td>Differential measurement of the ECG signal: • Heart Rate Variability (HRV) measurement • Allergic reaction detection by a custom algorithm</td>
</tr>
<tr>
<td>Yoon et al. / 2017 [29]</td>
<td>Head-up display device: Google Glass</td>
<td>Surgeon's head</td>
<td>Wi-Fi</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Stream of images from the neuronavigation device directly onto a head-up display</td>
</tr>
</tbody>
</table>
Table 4 shows the clinical aspects of wearable technologies reported in the studies. As it is evident, most of the reported wearables perform based on defining the thresholds for parameters subject to the measurement. For example, while a heart rate higher than 140 or lower than 60 may be defined for detecting the risks for a group of patients by one wearable, mean arterial pressure less than 58 may be defined as a threshold for another group of patients by another wearable.

As it can be observed from the table, wearable technology's risk detection is followed by visual alerts, alarming, messaging, warning audibly, sending reminders, calling the rapid response team, or suspending the administration of the medications. Most of these are followed by relevant clinical actions. The outcomes of such actions reported in the studies are as follows:

1. Recognizing risks endangering patients during transmission
2. Informing health care professionals about patient status in real-time
3. Improving patient experience
4. Alleviating the mental stress of the patient during the procedure
5. Faster receiving the required antibiotics by the patients
6. Shortening patient length of stay in hospitals
7. Lowering the risk of hospital readmission
8. Quicker responding at the patient bedside
9. Decreasing the time duration of the procedure
10. Increasing safety of procedures.

Table 4. Clinical aspects of wearable technologies reported in the studies
<table>
<thead>
<tr>
<th>Author / Year</th>
<th>Detected risks</th>
<th>Actions on risk detection</th>
<th>Users involved</th>
<th>Clinical action applied</th>
<th>Outcome</th>
<th>Challenges/Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lee, J. H. et al. / 2018 [22]</td>
<td>• Heart rate above 140 blood pressure</td>
<td>• Display alarm on the monitor</td>
<td>• Clinicians</td>
<td>When an alarm is raised, staff immediately (within 1 minute) identify and respond to the risk (for example for patients with hypoxemia, clinicians applied oxygen therapy until the patients stabilized without hypoxemia)</td>
<td>• A wearable device and mobile app can detect risk signals effectively during the transport or rehabilitation of a patient within the hospital.</td>
<td>• There was a possibility of security problems regarding patients' medical information</td>
</tr>
<tr>
<td></td>
<td>• Heart rate below 60</td>
<td>• Messaging to clinician via SMS</td>
<td>• Pulmonology ward staff</td>
<td></td>
<td>• A real-time risk signal was sent to the healthcare provider to ensure patient safety.</td>
<td>• Instability of Wi-Fi</td>
</tr>
<tr>
<td></td>
<td>• Oxygen saturation below 90%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Missing values</td>
</tr>
<tr>
<td></td>
<td>• Network error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Network errors</td>
</tr>
<tr>
<td>Ou, Y. K. et al. / 2019 [23]</td>
<td>• Blood leakage above 0.1, 0.2, 0.3, 0.5 mL at angles of 0°, 360°, 720°, 1080°, 1440°, 1800°, 2160°, 2520°, 2880°, and 3240° in relation to the needle</td>
<td>Alarm was triggered:</td>
<td>HD patients</td>
<td>The care staff is notified to attend to the patient.</td>
<td>• A suitable device was designed to improve the HD experience for the patient.</td>
<td>Experimental results showed that the device microcontroller has higher power consumption in continuous Wi-Fi transmission. However, the power consumption is acceptable (9h without continuous Wi-Fi transmission and 70 min with continuous Wi-Fi transmission).</td>
</tr>
<tr>
<td></td>
<td>• Blood flow velocity above 200 mL/min</td>
<td>• Visually on the device built-in screen</td>
<td>• Nursing staff</td>
<td></td>
<td>• The device alleviates patients' mental stress on HD, allowing them to undergo the treatment in a relatively calm, relaxed, and stable state.</td>
<td>• From a medical quality perspective, the device benefits patient safety, nurse-patient relationships, and quality of care.</td>
</tr>
<tr>
<td>Downey, C. et al. / 2018 [24]</td>
<td>• Temperature &gt; 38.3°C or &lt; 36.0°C</td>
<td>Alerts sent to nursing staff</td>
<td>Surgical wards patients</td>
<td>Prescribing antibiotics by a junior doctor</td>
<td>• Surgical patients with evidence of sepsis received antibiotics faster if they received continuous vital signs monitoring than those receiving intermittent monitoring alone.</td>
<td>• A formal sample size calculation was impossible, given the lack of data surrounding the primary outcome measure, so the findings were limited to descriptive statistics.</td>
</tr>
<tr>
<td></td>
<td>• Tachycardia &gt; 90 beats/minute</td>
<td>Reminders were sent every 14 minutes until acknowledgment</td>
<td>• Nursing staff</td>
<td></td>
<td>• Patients receiving continuous vital signs monitoring had a shorter average hospital stay and were less likely to require readmission within 30 days of discharge.</td>
<td>• No formal statistical comparison was possible.</td>
</tr>
<tr>
<td></td>
<td>• Tachypnea &gt; 20 breaths/minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• The relatively small number of sepsis cases means there is likely to be an imbalance in pre-randomization variables, which would require an adjustment in a formal analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• The limitations of the randomization technique must also be considered.</td>
</tr>
<tr>
<td>Author / Year</td>
<td>Detected risks</td>
<td>Actions on risk detection</td>
<td>Users involved</td>
<td>Clinical action applied</td>
<td>Outcome</td>
<td>Challenges/Limitations</td>
</tr>
<tr>
<td>---------------</td>
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<td>---------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Weller, R. S. et al. / 2018 [25]</td>
<td>• SpO2 &lt; 85% • Heart rate &lt; 39 and &gt; 150 beats per minute • Respiratory rate &lt; 4 and &gt; 35 breaths per minute • Systolic blood pressure &gt; 200 mm Hg • Mean arterial pressure &lt; 58</td>
<td>• The nursing assistants would contact the staff RN • The rapid response team (RRT) would be called to evaluate and treat the patient</td>
<td>• Neurological/neurosurgical patients • Nursing staff • Nursing assistants</td>
<td>Evaluating and treating the patient</td>
<td>Continuous patient surveillance can detect alterations in VS while maintaining a low rate of alarms and keep patient outcomes at least as safe, if not safer, compared to standard intermittent vital signs monitoring in a neurological/neurosurgical ward setting.</td>
<td>• Lack of granularity concerning the exact causes of the RRT calls and deaths</td>
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<tr>
<td>Martinez Pérez, M et al. / 2018 [14]</td>
<td>• Wrong medication • Wrong patient • Wrong health staff • Wrong administration</td>
<td>By reading the NFC tag of the patient and the NFC tag of the medication, the system can confirm whether the medication has been prescribed by the doctor and is pending for administration in this shift or, on the contrary, should not be administered by the nursing personnel because it has not been prescribed or is not scheduled for this particular shift.</td>
<td>• Patient • Doctor • Nurse • Auxiliary nurse</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
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<tr>
<td>McFarlane et al. / 2018 [26]</td>
<td>• SpO2 &lt; 90% • Heart rate &lt; 50 and &gt; 120 beats per minute • Respiratory rate &lt; 10 and &gt; 30 breaths per minute • Systolic blood pressure &lt; 90 and &gt; 160 mm Hg • Diastolic blood pressure &lt; 50 and &gt; 90 mmHg</td>
<td>Generate the alarm/alert on • SpO2 &lt; 90% • Heart rate &lt; 50 and &gt; 120 beats per minute • Respiratory rate &lt; 10 and &gt; 30 breaths per minute • Systolic blood pressure &lt; 90 and &gt; 160 mm Hg • Diastolic blood pressure &lt; 50 and &gt; 90 mmHg</td>
<td>• Nurse • Nursing assistant</td>
<td>Triaging alarm/alert signals</td>
<td>A wearable metacognitive attention aid empowered RNs to respond at the bedside 148% faster on average to important clinically-actionable alarms. Evidence confirms the possibility that patient safety can be dramatically improved.</td>
<td>• To further improve external validity, future research is needed for: multi-day testing; clinical trials with actual patients; testing in other hospital environments; and additional exploration of infection control issues.</td>
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<tr>
<td>Author / Year</td>
<td>Detected risks</td>
<td>Actions on risk detection</td>
<td>Users involved</td>
<td>Clinical action applied</td>
<td>Outcome</td>
<td>Challenges/Limitations</td>
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| Pascale, M. T. et al./2019 [27] | “Sensor” alarm: was triggered if a physiological sensor become disconnected or failed  
• “Clinical” alarm: was triggered if the value of a vital sign trended into a high priority range, indicating the start of a clinically relevant problem. | • Raise an alarm in station and on HWD  
• Show notification rather than alarm on HWD  
• Show patient’s vital signs on HWD | Nurse | • Fixing sensor  
• Treating patient | • The results suggest that continuous information on an HWD does give the user the potential to immediately disambiguate a patient alarm, supporting rapid and informed decision-making without having to move to a patient's room or a centralized nursing station.  
• Adding the HWD to alarms makes the alarm sounds seem significantly less annoying to participants.  
• Results support an increase in situation awareness resulting from a more informative multimodal display. | • A first limitation is that the results are insufficient to conclude that continuous information displays, specifically HWDs, will support clinicians adequately in health care settings.  
• A second potential limitation arises from the ongoing tasks used in each experiment. Neither task could simulate the high-stress levels and the necessity for precision that accompanies work in a hospital environment. |
| Diaz et al. / 2017 [28] | A possible allergy reaction according to the algorithm:  
MGB = mean(MRR01);  
NMRR = MRR(t)-MGB;  
When NMRR > 0 Mean Peak = mean(NMRR);  
If Mean Peak > Th Allergic patient;  
** MRR is the mean of HRV in the last 60 seconds;  
**MGB is the mean MRR in the last period;  
**NMRR is the subtraction of MRR and MGB;  
**Mean Peak is the NMRR mean for values greater than zero; It is the alert threshold. | The smartphone application shows an alarm | • Medical staff  
• Patients | Not mentioned | • Reaching a success rate close to 90%, 92.85% (of 28 subjects) in the case of children, and 88.23% (of 119 subjects) in the case of adults)  
• Test time was reduced for the allergic subjects from a mean length of 76 minutes to only 48 minutes and the number of doses from 3.93 to 1.61. | Not mentioned |
<table>
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<tr>
<th>Author / Year</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Yoon et al. /2017 [29]</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Surgeons</td>
<td>Not mentioned</td>
<td>• Safety and feasibility of the proposed system was assessed. • An overall average of 15.05% less time per pedicle screw placement when Google Glass and the streaming device were used while performing spine instrumentation.</td>
<td>Limitations: • The study was not designed to determine the efficacy of comparing a wearable head-up display with standard techniques during spine instrumentation (i.e., at this time, no conclusions can be drawn about the efficacy of this system for saving operative time based on our results and methodology). • Their methodology was not designed to prove or disprove the efficacy of wearable computing device during spine instrumentation. • No proper control group was present for every case, and the screw placement time was reported only as a descriptive observation. • The operator’s experience could have affected pedicle screw placement and significantly impacted the overall pedicle screw placement time, regardless of whether the surgeon used Google Glass and the streaming device. • The binary questionnaire that we used to assess each surgeon’s experience using the device. • There are potential limitations to using Google Glass (e.g., battery life).</td>
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OA: Osteoarthritis

**Synthesing Findings From The Studies With The JCAHO Patient Safety Goals, The Wearable Taxonomy**

Based on dimensions of the wearable taxonomy (functionality, form, and application), the wearable devices reported in the studies were classified into single or multiple sensor/s in terms of functionality. From the perspective of the wearable form, only portable and accessory forms of wearable have been reported in the studies. None of the studies has reported implantable or garment forms of wearable technology. From the application perspective, a range of applications, including prevention, monitoring, assistive technology, and communication, were found for the wearable reported in the studies. However, some applications (e.g., monitoring) were more dominant than others (e.g., communication).

Mapping the use cases of the wearable devices in the hospital into patient safety goals of JCAHO revealed that wearables have contributed to all seven patient safety goals of JCAHO set in 2021. However, the distribution of the wearables in some of the goals is much higher than in others.

**Discussion**

The applications of wearable technology in healthcare settings have increased recently. In this study, we investigated the applications of wearable technology on patient safety in hospitals. The findings revealed that most wearable devices were used in hospitals to measure standard parameters such as vital signs. Additionally, patient safety improvement by using wearables in hospitals was concluded in this paper.
Arlige and Chatterjee revealed that the “Monitoring” application, among others, has predominated wearable technologies’ applications [20]. According to our findings, three subdomains of the application’s dimensions, including: “Monitoring” [1-3, 6, 8, 9], “Prevention” [4, 5, 7, 8], and “Assistive technology” [1-10] have been utilized more than others in the hospitals. However, the “Communication” dimension has only been used in two studies to share information among healthcare personnel [5, 6]. It should be noted communication among health staff can help the treatment of patients in hospitals; therefore, it needs to be taken into account much more in future research toward developing and using wearables in this domain. Chan et al. (2012) highlighted that accessory form is the most commonly used wearable technology. This is in line with the results of the current study [1-10]. According to Chan et al. (2012) study, this wearable form has more subdomains than other forms [30]. It seems that there is a need to conduct examinations for developing and applying different forms of wearable (i.e., implantable, garment, and portable) in the healthcare context.

In hospitals, wearable technology, as a beneficial approach, can play a positive role in patient safety. It can improve processes such as diagnosis, monitoring, and prevention. For example, wearable technology can be used in cardiopulmonary monitoring, detecting cerebrospinal shunt malfunction, improving the precise identification of health personnel, or continuous monitoring of vital signs) [13, 14, 22-29]. Accordingly, Bonacaro et al. (2019) illustrated that there is increasing interest in using wearable devices to monitor the health of patients with long-term conditions and prevent falls [31]. Amin et al. (2021) concluded that wearable devices could provide accurate data capture in the early postoperative phase to remotely monitor patients using various metrics, including temperature, cardiac parameters, and physical activity [8]. As described in Figure 2, two out of the seven goals of JCAHO (i.e., (1) better-identifying patient safety risks by measuring multiple or single parameters [13, 14, 22-29] and (2) reducing harm associated with clinical alarm systems [14, 22-28]) are highlighted in the included studies, but a limited number of papers have focused on the other goals. Therefore, the JCAHO goals for patient safety should be used as a guide for developing wearable technology and deploying them in hospitals. In addition, for meaningful use of wearable technology in hospitals, some aspects should be considered, including 1) patient safety goals developed by the relevant organization in this field (e.g., JCAHO), 2) wearable functionality, 3) wearable applications, 4) wearable forms, and 5) wearable limitations/challenges.

Some challenges have been reported for wearable technology in included studies. [13, 14, 22-29]. For example, wearables have issues related to network connections, such as network failure, instability of Wi-Fi, and missing values [22, 27]. Data privacy, security, and confidentiality in healthcare settings are other significant concerns mentioned in the studies [14, 22, 24, 29]. Being miniature, narrow, and lightweight are the main specification of wearables and why battery life is a common and ongoing issue with wearables requiring to be addressed in future works [29]. Therefore, researchers should consider all challenges and plan to overcome them in developing such technology.

Limitations

Inadequate information about the technical aspects of wearable devices was one of the main limitations of this study.

Conclusion

Through its various capabilities, we concluded that wearable technology played a positive role in hospital patient safety. Wearable technology has dominantly targeted the monitoring, prevention, and assistive applications in various objectives such as recognizing risk during patient transfer, blood leakage monitoring, vital signs monitoring, managing the care process of patients admitted to an ICU, and so on in healthcare settings. This technology appears as an appropriate tool that can help healthcare providers manage patient safety. Therefore, planning for the utilization of their potential should be considered by researchers, healthcare providers, policymakers, and software developers. Additionally, it is required to conduct various studies to show the applications and effects of wearable technology on patient safety in hospitals by focusing on the seven goals of JCAHO.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that there are no competing interests.

Availability of data and material

The data that supported the findings of this study are available from the corresponding author on request

Acknowledgments

Not applicable

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References


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**Figures**

- Records identified through databases searching (n = 344)
- Records after duplicates removed (n = 304)
- Records screened (n = 304)
- Records excluded (n = 260)
- Full-text article assessed for eligibility (n = 44)
- Studies included (n = 10)
- Records identified through manual searching (n = 1)
- Full-text article excluded (n = 34)
  - Intervention was other technology (n=6)
  - Setting was not hospital (n=9)
  - Intervention not related to patient safety (n=19)

*Figure 1*

Flow chart of the process for screening studies reported wearable technologies for patient safety in hospitals
Figure 2

Classification for wearable technology in hospitals according to the health care wearable taxonomy with focusing on the JCAHO patient safety goals