A Survey on Technologies Used During out of Hospital Cardiac Arrest

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Abstract: Out of hospital cardiac arrest (OHCA) causes close to 400,000 deaths every year in North America, and it is also a leading cause of death among young athletes. OHCA is a treatable medical condition, and the patient's survival chances can be increased if immediate treatment is provided to the patient. However, non-treatment of the patient leads to a dramatic decline in survival chances at 10% per minute. Currently, various technologies are being used, and many more are being researched to reduce the time to provide early treatment to the patient. This survey focuses on summarizing various available technologies for use during OHCA. This survey focuses on evaluating technologies used in each step of the OHCA process. In this survey, articles were searched using the term "ohca" on Google Scholar and more than 18,000 articles were found. The articles were further filtered using keywords for each stage of the OHCA process, finally, 112 articles were used in this survey. The technologies that exist today work independently and are not linked with the other steps of the OHCA process. Integration between these technologies could help in reducing time and increase the survival chances of the patient.

1 INTRODUCTION

Sudden Cardiac Arrest (SCA) is a medical condition in which a patient's heart either stops or beats irregularly with little or no cardiac perfusion (Medlineplus.gov, 2021). Every year more than 350,000 deaths occur in the U.S. due to out of hospital cardiac arrest (OHCA), and more than 40,000 deaths in Canada (Heart.org, 2021a; Research, 2019). OHCA is the leading cause of death among young athletes, which means that SCA can occur to anyone irrespective of their health or age (Landry et al., 2017). During OHCA, the patient collapses and the blood circulation to organs either stops or is insufficient to prevent damage to organs (Medlineplus.gov, 2021). In this condition, the patient's survival rate decreases at a significant rate of 10% per minute (Heart.org, 2014; Valenzuela et al., 1997). With the rapid decline in survival after each minute, early identification and response by both bystanders and emergency medical services (EMS) is required. The recommended treatment with the greatest evidence for improving survival in OHCA is performing cardiopulmonary resuscitation (CPR) and the application of the automated external defibrillator (AED) (Heart.org, 2014; Nord et al., 2017; Folke et al., 2021). Studies confirm that the survival rate of the patient increases if the recommended treatment is started within the first few minutes of the OHCA occurrence (Sanko et al., 2020; Pijls et al., 2016).

During an OHCA, several steps are performed prior to the arrival of the EMS and if executed swiftly, the survival chances of the patient increases. Figure 1 shows the workflow followed during the emergency. The OHCA workflow includes steps taken by either the bystanders or the dispatcher to assist the patient until the emergency medical services arrive at the patient's location. Figure 1, shows a graphical representation of the workflow. The first step of the OHCA workflow is when a patient collapses or losses of consciousness. This step can be observed by a bystander or an intelligent device such as a smartphone, smartwatch, or camera. The witnessing of the patient's collapse is essential as a delay in identifying the patient suffering an OHCA delays the workflow and rapidly

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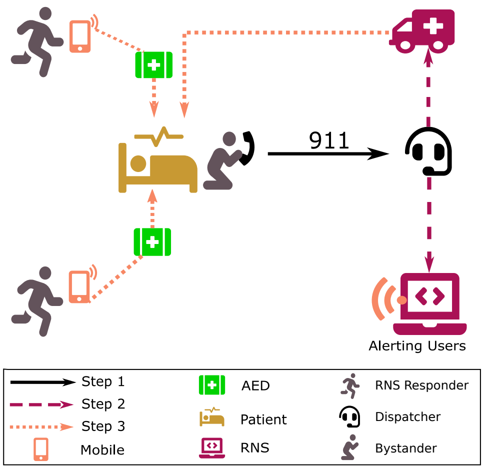

Figure 1: Emergency workflow.

decreases the patient's survival chances (Chan et al., 2019; Rea et al., 2021; Lu et al., 2019). The second step in the OHCA workflow is to alert the emergency services, the bystander can perform this by calling the emergency services through a telephone. Depending on the smart device, this step can be performed in various ways: 1) Send an alert to the patient's emergency contact and then they call the emergency services. 2) The smart device sends an alert to its service provider and then the service provider calls the emergency services (Rao et al., 2020; Berglund et al., 2018). 3) The smart device itself sends an alert to the emergency services. The workflow's third step includes dispatching the emergency resources to the patient's location, the dispatcher performs this action. The emergency resources activated for the patient depend on the services available at the emergency center. The services include: 1) dispatching emergency medical services, 2) dispatching fire and police units, and 3) activating a Responder Network System (RNS) (Stieglis et al., 2020; Rao et al., 2020). The fourth step is to resuscitate the patient by performing CPR. This step is performed by either a bystander who witnessed the OHCA or by a bystander who is responding after receiving the alert from RNS. At this step, the bystander can be assisted by a feedback device or the dispatcher to perform high-quality CPR (White et al., 2017; Plata et al., 2019).

This survey is structured based on the steps followed in the OHCA workflow and the technologies used within each step of the workflow. Section 2 describes the search criteria used to select articles for the survey. Section 3 explains the technologies used for identifying a patient experiencing an OHCA. The techniques used to confirm cardiac arrest in the patient are discussed in Section 4. Section 5 details technologies used to assist a bystander to perform high-quality CPR. In Section 6 technologies related to AED assistance are discussed. Section 7 provides a summary and discussion of all the technologies used during the OHCA.

2 METHODOLOGY

OHCA is a broad topic for research as it includes topics such as: 1) the training of the general public and medical professionals in the use of technologies for the management of cardiac arrest patients; 2) protocols, procedures and technologies used by bystanders, emergency dispatch centres, and emergency medical services during cardiac arrest; 3) the treatment and protocols used by the doctors and nurses at the hospital after the arrival of the patient. The focus of this survey is to summarize the technologies used by bystanders or dispatch centres during an OHCA event. The OHCA event can be divided into four steps: 1) witness OHCA, 2) confirm OHCA, 3) CPR assistance, and 4) AED assistance. The search strategy for article selection for each of these steps is discussed below and also shown in Figure 2.

To obtain the articles for this survey, a search was performed with the term “OHCA” on Google Scholar and PubMed, the query resulted in 8,950 and 1,937 matches, respectively (LLC, 2021; NIH, 2022). A further comparison was performed on the results and it was found that the Google Scholar results covered more than 90% of the articles found on Pubmed. Therefore, all search queries for this survey were performed on Google Scholar. For each step of the OHCA workflow, a more comprehensive search query was generated using a publication date filter set to find articles from 2017 onward to review the latest technologies. The results from these queries were filtered using a semi-automated filtering process to select only the relevant article for each step.

Witness OHCA: To select articles for this section, three different searches were aggregated, which are: a) “OHCA detection smart watch”, b) “OHCA agonal breathing identification”, and c) “OHCA fall detection”. The filter of publishing date since 2017 was also applied, and these queries resulted in 93, 276, and 367 articles, respectively. The number of duplicate articles in each of these queries were 8, 7, 10, respectively, and were removed from further analysis. The next step for filtration was performed using a python script called “QuickSearcher” or “QS”, pesudocode is presented in Algorithm 1. The authors developed QS to search for keywords with logical operations (AND, OR) in the title or abstract of the article. For each of the three queries, the following filtering query was

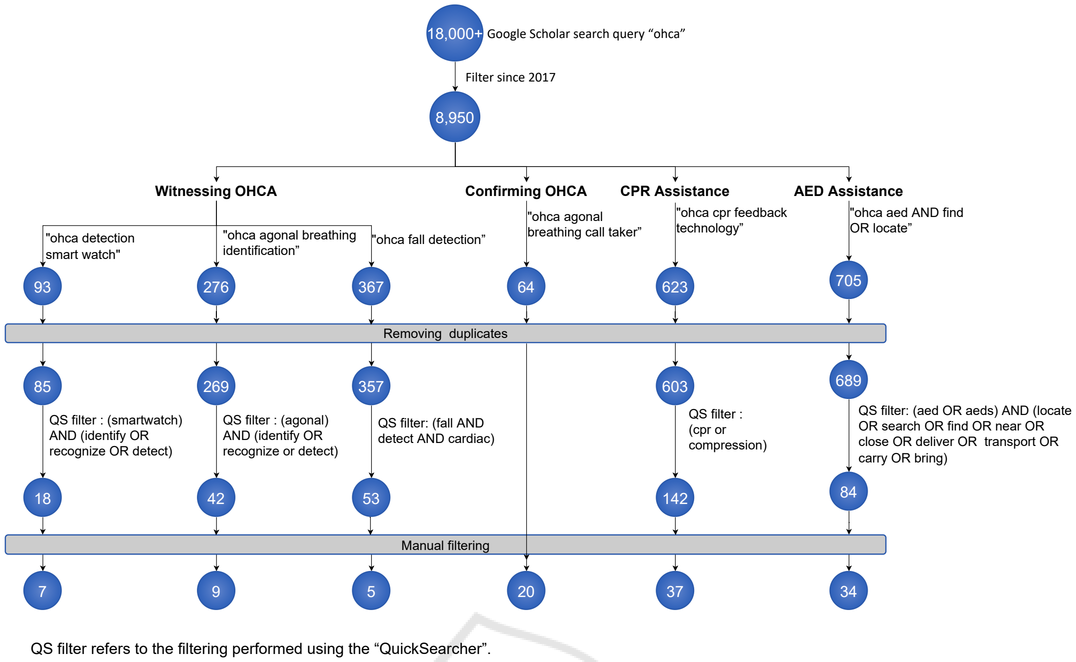

Figure 2: The method of selection and filtering of articles used in this survey, along with the count of articles selected at each step.

made to QS, respectively: 1) *smartwatch* AND (*identify* OR *recognize* OR *detect*) 2) *agonal* AND (*identify* OR *recognize* OR *detect*) 3) *fall* AND *detect* AND *cardiac*. A manual review was performed on the QS results to identify articles relevant to this survey. The authors performed the manual review and identified a total of 21 articles from all three queries performed in this section.

Algorithm 1: Pseudocode for Quick Searcher.

Input:

AllData = List of titles and abstract of the articles
AllSearch =List of combinations to search

Output:

List of articles matching search criteria

Process:

```
for data IN AllData do
    AllMatchFound = True
    newText = Join title and abstract in data
    for search IN AllSearch do
        if search Does Not match newText then
            SET AllMatchFound = False
        end if
    end for
    if AllMatchFound is True then
        ADD article to output
    end if
end for
```

Confirm OHCA: The initial query performed in Google Scholar for this section was "ohca agonal breathing call taker", and articles published since 2017, resulting in 64 articles. Due to a small number of articles found, the authors performed a manual review of the articles' abstracts and selected 20 most relevant articles.

CPR Assistance: In order to find articles for this section, a Google Scholar search was performed using the terms "ohca cpr feedback technology" for articles published since 2017, which resulted in 623 articles out of which 20 were duplicates. QS was used to filter the results further by using the query "compression OR cpr", which narrowed the results to 142. The authors then performed a manual review of the title and abstracts and selected 37 articles.

AED Assistance: The query was performed using Google Scholar for this section using the terms "ohca aed AND find OR locate", for articles published since 2017. The query resulted in 705 articles which included 16 duplicates. The results were further filtered using the QS query "(aed OR aeds) AND (locate OR search OR find OR near OR close OR deliver OR transport OR carry OR bring)". The QS algorithm further reduced the number of articles to 84. A manual review by authors resulted in a selection of 34 articles for this section.

Exclusions: This survey discusses technologies currently being used during OHCA events, along with the technologies under development for future use. However, other technologies are being used during OHCA workflow, such as mechanical CPR initiated by first responders and healthcare professionals, advanced traffic light controls that allow ambulances an unobstructed path to the emergency location, advanced AED algorithms for early detection of a shockable rhythm, and the use of audio and video feedback in CPR training (Nguyen, 2019). These technologies have been excluded as this survey focuses on technologies that directly affect the OHCA workflow before the arrival of the emergency medical services.

3 WITNESSING OHCA

A crucial part of the OHCA process is to witness the occurence of OHCA event, which implies that there should be a bystander nearby the patient who observes the patient experience OHCA symptoms and reports the event to the emergency services. There are a significant number of OHCA events that remain unwitnessed as they occur in private dwellings or in less crowded public places such as parking lots (Chan et al., 2019). Patients who experience an unwitnessed OHCA, experience a delayed response and treatment, and with each minute delay, their survival chances are reduced by 10% per minute (Ko et al., 2018; Heart.org, 2021c). Multiple studies have confirmed that early detection of the OHCA event increases the survival chances of the patient (Chan et al., 2019; Kiyohara et al., 2021). Thus, it is crucial to detect the OHCA in the first few minutes of its occurrence, such that the patient can be treated immediately. Various technologies are being developed for the early detection of the OHCA event, including smartwatches, smart wristbands, radar detection, and fall detection. These technologies are explained in detail below.

Body Sensors: Smartwatches and wristbands are playing an important role in the health monitoring industry (Plata et al., 2019; Lu et al., 2019). These devices are small and can be worn continuously without interrupting day-to-day activities. Depending on the device, they are equipped with sensors to capture the user's physical activity, ECG data, blood oxygen levels, heart rate, and are capable of detecting falls (Jesus, 2018; Chan et al., 2019). The information collected on the device can synchronize with other devices such as smartphones and tablets or even to the cloud server via a cellular or Wi-Fi connection. Some of these devices can detect medical conditions such as irregular heart rhythms and low oxygen levels. These devices can be programmed to send an emergency alert to emergency services or to a designated user specified in the emergency contacts upon detecting an emergency (Fakhrulddin et al., 2019; Tanaka et al., 2017).

Fall Detection: The patients collapse is the first observed sign that a sudden cardiac arrest is occuring. It is not always possible to have bystanders witness and assist the patient; therefore, researchers have proposed solutions to detect falls using smart devices. Fall detection is a highly researched topic, a Google Scholar search found over 233,000 articles using the term "fall detection system" since 2017. A majority of these proposed technologies use smartphones, smartwatches, cameras, radar, and other IoT devices to detect the fall (Bhattacharya and Vaughan, 2020; King and Sarrafzadeh, 2018). Most of these systems can send an alert when the user collapses to the registered emergency contact. Some of these devices may use another device to send the alert, such as a smartwatch using the paired smartphone to send the alert. Additionally, security cameras are widely used in offices, warehouses, parking lots, and especially in isolated parts of a building, to address security concerns. Artificial intelligence (AI) and machine learning (ML) algorithms can use the video from security cameras to detect a person collapsing. For instance, Scquizzato proposed an algorithm that can detect OHCA from a security camera feed (Scquizzato, 2018).

Agonal Breathing Agonal breathing is a type of "gasping" commonly seen in approximately half of patients experiencing cardiac arrest (Chan et al., 2019; Riou et al., 2018b). A recent study confirms that if a patient experiences agonal breathing during CPR, then the patient's survival chances are 17% higher than a cardiac arrest patient without agonal breathing (Adams et al., 2017). A bystander can quickly identify agonal breathing in a patient; in cases when a bystander is not present, researchers have proposed solutions that can detect agonal breathing using microphones built-in smart devices such as mobile phones and smart speakers (Jesus, 2018; Rea et al., 2021). Studies confirm that a significant number of SCA occur in the home environment (Chan et al., 2019; Tsukigase et al., 2019). Agonal breathing detection solutions work optimally in quiet environments, as these solutions require minimal background noise so that the device can record the agonal breathing.

4 CONFIRMATION OF CARDIAC ARREST

Once the emergency dispatcher receives a call about an emergency, they need to determine if the patient is experiencing cardiac arrest or not. If the OHCA is confirmed, the dispatcher then advises the bystander to perform CPR and communicate the confirmation information to the dispatched ambulance. The time taken by the dispatcher to confirm cardiac arrest may cause a substantial delay in the patient's treatment (Ko et al., 2018; Fukushima and Bolstad, 2020). Studies confirm that if the time taken by the dispatchers to confirm OHCA is reduced, then the survival chances of the patient increases (Adams et al., 2017; Sanko et al., 2021). The early confirmation is also beneficial as the dispatcher can dispatch other emergency services (e.g., police and fire services) who can arrive prior to the ambulance (Heart.org, 2021b). This issue has been recognized in the literature and multiple solutions have been proposed which are discussed in this section (Riou et al., 2018b; Breckwoldt et al., 2020).

When OHCA incidents occur in residential locations, the caller is generally known to the patient and is emotionally distressed. In such situations, the dispatcher has to spend time calming the caller first before they can ask the caller to provide the patient's information (Fukushima and Bolstad, 2020). When an OHCA occurs in a public location, the caller sometimes steps away from the patient to call the emergency services. The stepping away from the patient may be due to overcrowding near the patient, cellular reception or environmental noise (Case et al., 2018). In such situations, when the dispatcher requests the caller to check and provide the medical information of the patient, the caller needs to go back to the patient and then analyze the condition, causing the delay in assessment (Fukushima and Bolstad, 2020).

Two significant recommendations from various studies related to agonal breathing and OHCA are 1) overcoming the language and linguistic issues between the caller and dispatcher will improve outcomes (Riou et al., 2017; Fukushima and Bolstad, 2020) and 2) if the dispatcher has confusion in detecting agonal breathing, then CPR should be advised (Adams et al., 2017; Leong et al., 2020). Overall, early confirmation of cardiac arrest can help in reducing the time to resuscitate the patient.

5 ASSISTED CPR

After the dispatcher confirms that the patient is experiencing cardiac arrest, the next step is to guide the caller to perform CPR. CPR performed by bystanders plays a vital role in increasing the patient's survival chances (White et al., 2018; Ng et al., 2021). Bystander CPR is necessary because the ambulance dispatched to the patient's location takes approximately 8-10 minutes, depending on the site of dispatch vehicles (Van de Voorde et al., 2017; Chien et al., 2020). The estimated time from the start of the emergency to the arrival of the emergency services is estimated to be between 8 and 15 minutes, leading to almost 100% mortality for patients who do not receive chest compressions (Ko et al., 2018; Heart.org, 2021c; Andelius et al., 2019). Figure 3, shows an estimate of the time required at each step of the SCA workflow.

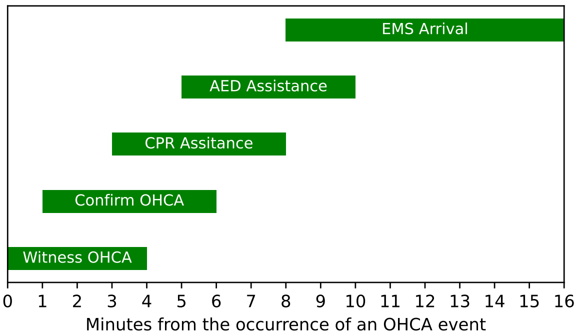

Figure 3: Figure showing an estimated timeline graph of the steps performed during an OHCA.

The CPR quality directly affects the patient's survival chances; high quality CPR increases a patients chances of survival (Ng et al., 2021; Estabrooks, 2018). Medical agencies have defined CPR performance metrics; for instance, the American Heart Association (AHA) defines that high-quality CPR should have a chest compression depth between 2 and 2.4 inches at a rate of 100-120 compressions per minute (Heart.org, 2015). The European Resuscitation Council recommends that chest compressions should have a depth of 5–6 cm with a rate of 100–120 compressions per minute (Perkins et al., 2015). These standards are likely unknown to bystanders unless they are trained in CPR. Also, it is not easy for the bystander to measure the compression depth and the frequency during a stressful emergency scenario. Researchers have proposed various solutions to overcome this issue, such as guiding the bystander over the phone, real-time CPR feedback devices to improve performance, and mechanical devices to perform CPR automatically (Riou et al., 2018a; Case et al., 2018). These technologies are discussed in the following subsections.

Telephone Assisted CPR: Telephone assisted CPR is also known as "Tele CPR", "TCPR", or "DA-CPR" (Dispatcher Assisted CPR) (Hardeland et al., 2017; Al Hasan et al., 2019). In this CPR assistance method, the dispatcher advises the caller to perform CPR and guides them on performing high-quality CPR (Sanko et al., 2021; Al Hasan et al., 2019). This type of assisted CPR is the most commonly used since it does not require any additional hardware or software.

Also, the dispatcher can modify their instructions as per the caller to help them understand and perform high-quality CPR (Riou et al., 2018a). Assisted CPR can encounter challenges caused by the communication between the two parties. One significant concern is the refusal by the caller to perform CPR either due to their physical ability, emotional barriers, or legal concerns. The patient needs to be placed on a hard flat surface such as a floor for performing CPR. The physical movement of the patient might be challenging for the caller due to their own physical ability. Another concern is the refusal by the caller to perform CPR, which may be due to their low confidence level, emotional anxiety, or legal concern that they might hurt the patient (Fukushima and Bolstad, 2020; Takahashi et al., 2018). Linguistic differences between the dispatcher and the caller are also a concern as they may affect the delivery of the instruction and their feedback (Sanko et al., 2021; Case et al., 2018). Researchers have also proposed training the dispatcher to improve communication with the caller (Al Hasan et al., 2019; Michiels et al., 2020). Studies have shown that the dispatchers were able to convince 38% more callers to perform CPR after receiving the specialized training (Riou et al., 2018b). Tele CPR is dependent on the communication between the dispatcher and the caller. There will be situations where the dispatcher's instructions are not accurately heard and understood by the caller due to the surrounding noise or linguistic challenges, ultimately affecting the CPR quality and patient's survival chances (Leong et al., 2020; Gram et al., 2021).

Video-Assisted CPR: Video-assisted CPR (V-CPR) technology allows the dispatcher to view the CPR performed by the caller over video and provide real-time feedback to the CPR provider (Lee et al., 2021a; Meinich-Bache et al., 2018). This technology is one of the latest methods proposed for dispatchers but it has not been implemented widely. Once the dispatcher confirms that the patient is experiencing cardiac arrest and another bystander can hold the phone, the dispatcher switches the audio call to a video call (Lee et al., 2021a). The second bystander holds the device such that the dispatcher can view the CPR being performed and provides real-time feedback to the bystander to perform high-quality CPR (Kim et al., 2020). Studies confirm that CPR quality improved when video feedback was provided (Ali et al., 2019; Lee et al., 2021b). Studies have also confirmed that the time spent explaining hand placement on the chest was reduced during V-CPR with subsequent feedback able to make quick corrections to improve CPR quality. (Lin et al., 2018; Ecker et al., 2020). V-CPR technology has some limitations, implementing this system in existing dispatch centres will require significant cost. The cost will include adding a high-speed, secure network for streaming videos, and a software upgrade to switch audio calls to video calls. Also, another uncontrollable factor is that the bystander should have a cellphone that allows video calling. These requirements may be fulfilled in major cities, but the overhead cost may be too high for rural areas (Hambly and Rajabiun, 2021; Durish, 2020).

CPR Feedback Devices: CPR feedback devices are designed to provide real-time feedback to the CPR performer to provide high-quality CPR. CPR feedback devices are external hardware devices encapsulated with various sensors to analyze current CPR performance and compare it with high-quality CPR standards (i.e., compression depth of 5-6 cm and compression rate from 100-120 per minute). After comparing actual CPR performing metrics with high-quality CPR standards, these devices provide audio, visual, or both feedback to the user for achieving high-quality CPR.

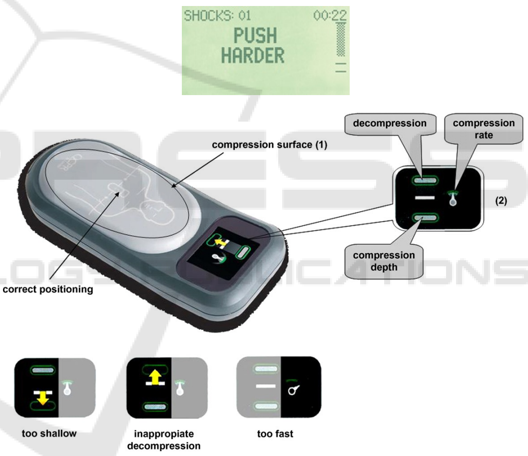

Figure 4: Image showing Visual Feedback indications on CPR feedback devices. Top image: Zoll Real CPR Help, Source: https://www.zoll.com/. Bottom image: Laerdal feedback device, Source: Skorning et al., Resuscitation (2010).

Many CPR feedback devices are available on the market, such as Real CPR Help and CPRmeter 2 (Zoll, 2021; Laerdal, 2021). These devices are placed on the patient's chest and the CPR performer places their hands on the device and performs CPR. Most of these devices consist of two sensors, one measuring acceleration and another measuring force. Based on the data collected from these sensors, the device analyzes the CPR performance and provides feedback. Depending on the device, the feedback can be visual, showing if the parameter is in optimal range or not, shown in Figure 4. However, these devices are ex-

Table 1: A comparison of technologies used to perform CPR during an OHCA.

Technologies	Availability during OHCA	Additional person required	Ease of use	Time to setup	Hardware requirement	Cost	Can cause harm	Market availability
Tele CPR	Easy	No	Hard	None	None	None	Yes	Yes
Camera	Easy	Yes	Easy	Little	Camera phone	None	Minor	Yes
Smart watch	Easy	No	Easy	None	Smartwatch	None	None	Yes
Feedback devices	Hard	No	Hard	Hard	Special device	High	None	Yes
AR	Hard	No	No	Little	Special device	High	None	No
VR	Hard	No	No	Little	Special device	High	None	No

pensive and are not publicly available for help during OHCA incidents. Some researchers are proposing smaller devices similar to the size of a credit card, which will help portability but still limit the use of these devices in an actual incident (White et al., 2018). Another type of CPR feedback device on the market are contained in smartphone and smartwatch devices (Sevil et al., 2021; Plata et al., 2019). As the degree of portability increases, the probability of these devices being used during an emergency also increases. These devices use the built-in sensors like accelerometer and gyroscope to evaluate the performance of the CPR and can provide audio, visual and haptic feedback for improving CPR performance in real-time (Jeon et al., 2021). With technology continually improving, the number of CPR feedback devices continues to expand with the latest technologies being Virtual Reality (VR) and Augmented Reality (AR) (Vaughan et al., 2019; Higashi et al., 2017). At the time of writing this review, the authors are not aware of any application of these technologies in actual OHCA. Overall, many CPR feedback devices are available for OHCA usage and studies confirm that these devices improve CPR performance. However, due to their high cost and limited availability, these devices are often used for CPR training but not during OHCA. Table 1 compares the different CPR assistance technologies used during OHCA and highlights the drawbacks of each technology.

6 AED ASSISTANCE

The American Heart Association and the European Resuscitation Council recommend that in addition to providing high quality CPR, the patient should also be defibrillated using an AED device if they have the appropriate heart rhythm (Sondergaard et al., 2018; Heart.org, 2021b). Multiple studies have confirmed an increased rate of survival for patients when AEDs were used during an OHCA (Heart.org, 2014). AEDs are an electronic device consisting of a central unit and two electrode pads. For portable AEDs used during OHCA, the central unit consists of a battery and a mini-computer to capture and interpret the ECG and other information needed by the AED. The electrode pads are placed on the patient's body to collect the ECG information and delivers an electric shock if needed. When a bystander calls the emergency services during a SCA emergency, the dispatcher sends an ambulance and provides instructions to the caller to perform CPR on the patient. At this stage of the SCA workflow, it becomes vital to apply an AED to the patient to increase their chances of survival. Finding an AED nearby and bringing it to the patient are the two biggest challenges faced at this stage of SCA workflow. These challenges are recognized and have been investigated by several researchers (Murata et al., 2021; Telec et al., 2018). The following subsections detail the various technological solutions proposed by researchers for finding and getting the AED to the patient during OHCA.

Finding AED: AEDs are small devices, generally placed in corridors, on shelves, in cabinets and other places. Studies show that the existing AEDs are underutilized because bystanders are unable to find them during an emergency since many are placed in areas with restricted access or in unmarked locations (Fredman, 2018; Cunningham et al., 2019). Another significant issue found in the studies is that the AEDs are not optimally placed compared to the OHCA occurrence, which results in low availability of AEDs in high OHCA prone geographical locations (Srinivasan et al., 2017; Leung et al., 2021). The following solutions proposed in the literature to find AEDs are: 1) Mobile-based Applications, 2) Dispatcher Assisted, and 3) RNS. There are currently many free mobile applications available on the Google Play Store and the Apple App Store that can help the user to find a nearby AED, such as AED Quebec, Staying Alive, and PulsePoint AED (Champlain, 2021; Association RMC-BFM and AEDMAP, 2021; Foundation, 2021). These mobile applications generally use crowdsourcing techniques to collect AED informa-

Table 2: A comparison between the technologies used to find nearby AED devices during an OHCA event.

	Finding AED using Mobile Application	Finding AED using Dispatcher Assisted	Finding AED using RNS
Action by	Bystander	Dispatcher	RNS system
Requirements	Mobile App	911 system with AED listing	911 RNS integration
Advantage	Can be used when 911 or RNS is not available	Bystander can focus on CPR, dispatcher helps finding AED	Fully automatic and consider various situations
Disadvantage	Pre-installed mobile application. Latest AED information on app.	May distract dispatcher in helping the bystander perform CPR.	RNS responder should agree carrying the AED
Data Reliability	Low	High	High

tion (Neves Briard et al., 2019; Chua et al., 2020). In a dispatcher assisted AED location system, the dispatcher has access to a particular platform integrated within the existing emergency services system to find the available AEDs near the patient's location (Perera et al., 2020; Tsukigase et al., 2019). This system offloads the work of finding an AED from the bystander to the dispatcher. The RNS system can help in finding AEDs during an emergency and is controlled and activated by the dispatcher (Berglund et al., 2018; Stieglis et al., 2020). RNS are automated systems that find and alert registered users near the emergency to assist the patient by finding an AED or performing CPR. RNS have access to the AED location information and can find the nearest AEDs to the emergency (Rao et al., 2019; Smith et al., 2020; Rao et al., 2020). Table 2 summarizes various technologies used in finding the nearby AEDs during an OHCA emergency.

Delivering the AED: Once the nearest AED is found by the methods described above, the next challenge is to quickly bring the AED to the patient. The delivery mechanisms are linked to the technology used to find an AED. For example, if a mobile application is used to find the AED, then another bystander must bring the AED to the patient (Neves Briard et al., 2019; Chua et al., 2020). In this scenario, another bystander is required because the first bystander should not stop performing CPR to get an AED according to the AHA guidelines (Heart.org, 2014; Heart.org, 2021c). Therefore, this technique may not work in situations when another bystander is not available. The second way of AED delivery is dispatcher assisted, and this method is very similar to the mobile application method of delivery discussed above (Perera et al., 2020; Tsukigase et al., 2019). The critical difference between the two methods is that the dispatcher provides the location of the nearest AED in this method. In this situation, there is a high probability that the location of the AED is correct. However, this method shares the identical drawback: one bystander must make a round trip to attain the AED while another bystander performs CPR. The third method of AED delivery discussed is via RNS. In this method, the dispatcher activates the RNS system, which then finds AEDs and responders in close proximity to the patient and provides instructions to either carry an AED or reach the emergency to assist the patient depending on their locations (Stieglis et al., 2020; Smith et al., 2020). These systems have been implemented in limited geographical locations in the world due to their significant cost of setup (Stieglis et al., 2020; Berglund et al., 2018). Another innovative and advanced technology proposed by researchers for the delivery of the AED is by drones (Fredman, 2018; Shirane, 2020). These devices have been tested in simulated OHCA incidents, with multiple studies confirming that they can be used during OHCA and can deliver AEDs faster than any existing method of delivery (Sanfridsson et al., 2019; Nguyen, 2019). Table 3 summarizes various technologies used in delivering the AEDs to the patient. Yet another way to deliver an AED faster is to optimize their placement such that AEDs can be accessed more quickly in locations that cover a larger geographical area. This issue and its solutions are discussed in the following subsection.

AED Placement: Existing AEDs have been underused during OHCA incidents and one significant reason for their under utilization is the distance between the emergency and the AED (Deakin et al., 2018; Sondergaard et al., 2018; Cunningham et al., 2019). Multiple studies show that if the placement of the AEDs is optimized, then their use will increase and ultimately the patient's chances of survival will improve (Cunningham et al., 2019; Srinivasan et al., 2017). Researchers have proposed mathematical models to determine the optimized locations of the AEDs (Leung et al., 2021; Derevitskii et al., 2020). These models include a mathematical formulation to identify high-risk OHCA zones, positioning based on historical OHCA incidents, and equally distributing the units across levels of socioeconomic deprivation.

Table 3: A comparison between the technologies used to deliver AED devices to the emergency location during an OHCA event.

	Mobile Application	Dispatcher Assisted	RNS	Drone
Time to delivery	Two way trip, going and getting it	Two way trip, going and getting it	One way trip, getting the AED enroute	One way trip, getting the AED enroute via air
Constraints	Requries another bystander	Requries another bystander	Requires RNS responder to bring the AED	Requires a nearby drone station.
Advantage	Bystander can search for AED	Bystander focuses on getting AED	Multiple responders get different AEDs	Time to delivery is lowest
Cost	Low	Low	Low	High
Currently Used	Yes	Yes	Yes	In trial

7 DISCUSSION AND CONCLUSION

SCA patient's survival chances depended on the bystander, their CPR knowledge, past CPR training, and CPR performance. We are in a new era, various technologies have been developed to assist the patient in receiving early resuscitation and increasing their survival chances.

Currently, technologies assist bystanders in providing early resuscitation to the patient. One of the primary reasons for delays in response to OHCA or no assistance being provided to the patient relates to the location of the cardiac arrest. A large number of OHCAs occur at home, in parking lots, or other private locations, where bystanders are not available to assist the patient. Researchers have proposed fall detection, agonal breathing and camera monitoring as solutions for detecting OHCA occurrence in these places. The fall detection method uses sensors such as an accelerometer, gyroscope, heart rate sensor, or ECG sensor that are available on smartwatches, smart bands, and smartphones. Furthermore, these devices can also monitor heart rhythm to confirm cardiac arrest using advanced algorithms depending on the device. This method of OHCA detection can be used in the community and is effective since many of the smart devices are now part of people's day-to-day life.

The technological solutions described in this review have the potential to improve mortality for those patients experiencing an OHCA. The feasibility of these proposed solutions depends on the technologies adopted either by the bystander or the dispatch center. The use of smart devices such as smartphones and smartwatches is one of the most practical solutions as they are widely used and have become part of the day-to-day life of people. There are indirect ways that can help to increase the survival chances of the SCA patient, such as better AED placement and better CPR training. Researchers have proposed solutions for these issues as well. This survey provides an overview of the current and future technologies that can be used during an OHCA event. This survey provides a good foundation for researchers who intend to develop or advance technologies used during OHCA, it will also help them integrate their own solutions within the OHCA workflow.

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