Submitted: 26 March, 2024 Accepted: 06 June, 2024 Published: 08 January, 2025 DOI:10.22514/sv.2025.010

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ORIGINAL RESEARCH

Using a mobile application to improve recording during cardiopulmonary resuscitation: a mixed-methods study

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Abstract

Background: Accurate documentation of cardiopulmonary resuscitation (CPR) is essential. However, traditional methods, particularly handwriting, often introduce errors and increase the workload of the medical staff. This study aimed to describe the process of developing a tablet application for documenting CPR and to evaluate its accuracy in comparison with a paper-based method. **Methods**: We organized a multidisciplinary team of medical professionals, developers, and designers. We used a participative human-centered design (HCD) approach that consisted of discovering, defining, developing and delivering solutions. We conducted a simulation study to compare the accuracy of the CPR documentation application with that of the handwriting method, focusing on documentation completeness and temporal fidelity. We evaluated the usability of the application using a System Usability Scale (SUS) and semi-structured interviews. **Results**: We developed the "CPReCoder" in accordance with the HCD process. The study application consists of two screens: a CPR recording screen and a reporting screen. The CPR recording screen is divided into three zones: zone 1 (patient and prehospital area), zone 2 (CPR code button area) and zone 3 (time information and log area). In the simulation study, the documentation completeness of the "CPReCoder" was significantly higher than that of the handwritten record (96.8% *vs.* 88.1%, $p < 0.001$). Both approaches exhibit comparable temporal fidelity. The SUS score of the application was 87.9 points, indicating excellent usability. According to the responses in the interviews, the main benefit of CPReCoder was its ability to reduce workload. **Conclusions**: We described the process of creating a CPR recording application. Use of the application resulted in a more complete documentation than the handwriting method, and its usability was excellent.

Keywords

Cardiac arrest; Cardiopulmonary resuscitation; Documentation; Mobile applications

1. Introduction

Digital technologies are rapidly advancing and healthcare organizations are increasingly utilizing these innovations to meet clinical needs [1–4]. These technologies aid better clinical decision-making, improve communication and potentially enhance patient outcomes [5, 6]. Mobile devices are one of the technologies that have become prevalent in health care, resulting in a significant increase in the production of medical software applications [7, 8]. Numerous mobile applications are available for cardiopulmonary resuscitation (CPR). While many are intended to guide and support CPR efforts, only a few are specifically designed to document CPR [9–11].

The detailed and structured documentation of CPR procedures is the foundation for facilitating clinical research, improving quality, and developing resuscitation strategies for patients with cardiac arrest. Thus, it is critical to accurately document any events, including the exact time it occurred. However, unifying the essential variables for CPR data collection presents major challenges that are complicated by significant variations in the documentation of CPR-related variables at the international level. Nishiyama *et al.* [12] reported in a large-scale retrospective study that even when using the Utstein-style template, which is recognized as a standard for documenting the CPR process, there are substantial international variations in the interpretation or implementation of the template as well as in the extent of missing data. To address these challenges, scientific organizations such as the International Liaison Committee on Resuscitation (ILCOR) have made concerted efforts to standardize and harmonize the definitions, criteria, and metrics for CPR documentation across regions and healthcare systems [13, 14].

CPR has traditionally been documented using either handwriting or computer-based methods. Despite the critical need for accuracy, recurrent errors such as omissions and incorrect timing are prevalent, particularly with handwritten documents [15]. These errors can be attributed to the rapid and complex nature of CPR, large volume of information exchanged, and urgency of interventions that frequently prioritize immediate care over detailed documentation. Additionally, errors can arise during the transfer of written records to hospital information systems, further increasing the workload of medical staff. In response to these challenges, a range of mobile applications has recently been created [15, 16].

Human-centered design (HCD) is a comprehensive strategy that includes identifying user needs, collaborating to address these goals, and validating applications in real-world contexts [17, 18]. It involves iterative cycles of observation, ideation, prototyping and testing to ensure that the end product is functional, intuitive and tailored to the user's context. HCD is crucial in medical situations, especially in high-stake contexts such as CPR. It ensures that the developed tools are technically sound and align with the practical realities and constraints of emergency medical settings. Therefore, the HCD process is not just about technology development but also about deeply understanding the workflow, challenges and needs of medical professionals in critical scenarios [19].

This study aimed to outline the development process of a CPR documentation application using the participatory HCD process, compare the accuracy of mobile-based documentation with conventional paper-based methods, and gather insights from emergency medical professionals regarding the utility and usability of the new approach. The importance of this study lies in its potential to revolutionize CPR documentation, making it more efficient, accurate and user-friendly, thereby contributing to better CPR information and advancing clinical research in emergency medicine.

2. Materials and methods

2.1 Overall study design

This mixed-method study was conducted at a single tertiary referral hospital in Seoul, Korea. We designed and developed an application for a tablet named "CPReCoder" (Version 1.1, Ji Woong Kim, Seoul, Korea). The investigation progresses through three main stages:

(1) Phase I: Application development—discover, define, and design.

(2) Phase II: Simulation study utilizing the application.

(3) Phase III: Data collection from simulation participants.

A Gantt chart to help visualize the different stages of the project, connecting the initial application development with the final evaluation and analysis is provided in **Supplementary Table 1**.

2.2 Phase I: application development—discover, define and design

A multidisciplinary team consisting of three emergency physicians, a software developer, and two user experience and user interface (UX/UI) designers led the project. The CPReCoder application was strategically designed and developed between March 2020 and August 2021, encompassing all stages, from initial planning to finalization. The team first made observations to identify specific challenges and inefficiencies in the current CPR documentation practices. At our institution, designated nurses primarily document events that occur during CPR using traditional paper-based methods. The team leader, usually an emergency medicine specialist, is responsible for ensuring that the final documentation is of the highest quality. Thus, we involved experienced nurses who had been responsible for CPR documentation for over three years, as well as emergency medicine specialists, in every step of the development of this application. We interviewed them to further identify issues with current documentation practices and gather insights for improvements. Their involvement ensured that the application addressed real-world challenges and requirements faced by users. Their contributions were critical for developing a user interface that was both user-friendly and efficient in high-pressure CPR situations.

We conducted a comprehensive review of the previous literature to select essential variables for inclusion in the application, such as CPR guidelines from scientific organizations or Utstein-style recommended guidelines [14, 20, 21]. Based on this review, we identified candidate variables among the key data elements to record during CPR when developing applications. However, given the urgency of CPR, it is crucial to balance the volume of data with the practicality of data entry. Therefore, we consulted frontline emergency medical professionals to prioritize the variables that were most critical for collection during CPR. A wireframe was created based on the selected variables. The application was subsequently refined through multiple rounds of testing and feedback from emergency medical staff, ensuring that the final design not only met clinical needs, but also enhanced user experience during critical interventions.

2.3 Phase II: simulation study utilizing the application developed in Phase I

2.3.1 Study design and setting

This single-center simulation study was conducted from August to October 2021. The study was conducted in a controlled simulation room at the Samsung Medical Center (a tertiary academic hospital located in a metropolitan city in Korea).

2.3.2 Study population

We included emergency medical personnel with prior CPR experience. Individuals who were deemed unsuitable for the rigorous physical requirements of CPR simulations for the following reasons were excluded: physical limitations such as musculoskeletal disorders (*e.g.*, back pain); underlying medical conditions (*e.g.*, heart disease or asthma) that could be worsened by vigorous activity; or pregnancy.

2.3.3 Study protocol

2.3.3.1 Role assignment

Seven team members were assembled for each CPR simulation. The CPR team, comprising a leader, two CPR providers, a nurse, and a respiratory therapist, executed CPR on a man-

nequin (Laerdal Medical, Stavanger, Norway). The other two members were responsible for documenting the procedures. Participants regularly alternated between administering CPR and documenting procedures.

2.3.3.2 Pre-simulation orientation

Before initiating the simulations, the participants received a comprehensive briefing that outlined the study objectives, detailed the simulation protocol and clarified their roles. Additionally, we gathered demographic and professional data through questionnaires that captured information on participants' age, sex, department, occupation, years of clinical experience and CPR certification status. The application was installed on a Samsung Galaxy S6 (Samsung Electronics, Suwon-si, South Korea) tablet. The participants were given detailed instructions on how to use the application and had the opportunity to practice with it before participating in the simulations. We used unstructured plain paper instead of a standard format for the handwriting method because handwriting practices can differ significantly between institutions.

2.3.3.3 Conducting the simulation

The scenarios were meticulously created by three emergency medicine specialists from the application development team, all of whom had extensive experience in managing cardiac arrests and simulation training. To reflect the variety of real-world situations frequently encountered in the emergency department (ED), they created a range of scenarios with varying levels of complexity ranging from straightforward to highly complex. One scenario required a total of 10–15 minutes to complete, and four to five CPR scenarios were performed per day. Under the supervision of the investigator, the participants performed standard CPR on a mannequin in accordance with the given scenarios as well as the 2020 American Heart Association Guidelines and 2021 European Resuscitation Council Guidelines [20, 21]. The two participants responsible for the documentation did not participate in the CPR simulation. They were randomly assigned to either record using an application or handwriting, and they concurrently documented the procedures occurring during the CPR scenarios. One participant used the CPReCoder, whereas the other used a conventional paper-based method.

The accuracy of each documentation method was assessed based on two criteria: documentation completeness, which confirmed that the procedures performed were recorded correctly, and temporal fidelity, which verified that the timing of these procedures was accurately documented. The clock application installed on a Samsung Galaxy S6 tablet was used to measure the time in seconds and was placed beside the bed. Participants who used the paper-based method used this clock to track the time. When using the application, the time was automatically recorded to match the time on the tablet; therefore, the clock and tablet times were corrected before starting each simulation so that they matched. We used an Osmo Pocket 2 (DJI, Shenzhen, China) to film each simulation session and the clock to accurately capture the various procedures performed during the CPR simulations. These videos served as reference standards to verify the documentation completeness and temporal fidelity of the two recording methods. The documentation completeness of the recordings was determined as follows:

$$Documentation\ completeness\ of\ the\ CPR\ recording = \frac{Number\ of\ procedures\ recorded\ by\ the\ recorder}{Total\ number\ of\ procedures\ actually\ performed} \times 100$$

We calculated temporal fidelity using the absolute value of the difference between the reference time and the actual recorded time.

2.3.3.4 Sample size calculation for simulation study

Due to the lack of prior research for use as a reference, we conducted a pilot simulation to determine the sample size. Six CPR cases were simulated, and two volunteers documented the procedures performed on a mannequin using a tablet or by hand. Video recordings were used as the gold standard to accurately document procedures. The mean number of procedures was 19.2. Tablet and handwriting methods had documentation completeness values of 89.6% and 73.0%, respectively. According to Hayes *et al.* [22], the coefficient of variation (CV_M), defined as the within-pair coefficient of variation between clusters in the absence of intervention, is typically <0.25; thus, we examined the CV_M at increments of 0.05 units from 0.05 to 0.25. According to the CV_M, the required number of cases (cluster K) was 8–31. Because the data would be collected using two methods—tablet and handwritten—K will double. In addition, the amount of data (N) obtained may vary based on the number of procedures (cluster size, M) performed (cluster, K). The average number of procedures was 19.17. With M = 19, a minimum of 304 and a maximum of 1178 data points can be collected; when M = 20, a minimum of 320 and a maximum of 1240 data points can be collected. According to the pilot data, the accuracy of handwriting versus tablets was 73.04% versus 89.57%, with a difference of 16.53% between the two approaches. To calculate the sample size, the difference in accuracy between handwriting and the tablet was assumed to be approximately 15% (75% *vs.* 90%). The CV_M was examined in the range of 0.05–0.25 at increments of 0.05 units. The number of required cases (cluster K) ranged from nine to 37. As a result, 37 cases (cluster K) were determined, which was the maximum number assuming $CV_M = 0.25$. Because the data would be captured by hand and using tablets, the total amount of data obtained (N) might vary based on the number of procedures performed in each of the 74 cases.

2.4 Phase III: data collection from simulation participants

2.4.1 System usability scale for the application

After the simulation, we used the System Usability Scale (SUS) to evaluate the application's usability for the participants who completed the recording tasks (see **Supplementary Table 2**). SUS scores were calculated as follows: (1) we added the

total scores for all odd-numbered questions, then subtracted five points from the total to obtain (X); (2) we added the total scores for all even-numbered questions, then subtracted 25 points from the total to obtain (Y); and (3) we added the total scores for the new values (X + Y) and multiplied by 2.5.

The SUS is a quick and user-friendly questionnaire that provides a global view of subjective usability assessments. John Brooke developed it in 1986 and it has since become an industry standard, providing a versatile and technology-agnostic method for evaluating a wide array of products and services, including software applications, such as CPReCoder [23]. The scale consists of a 10-item questionnaire with five response options, ranging from strongly agree to strongly disagree, and is designed to probe various aspects of the user experience. The simplicity and comprehensiveness of the SUS make it an ideal tool for our study, as it allows for the efficient gathering of data regarding the application's ease of use, learnability, and overall user satisfaction, providing an understanding of how emergency medical professionals interact with the application during high-pressure CPR scenarios and thereby guiding further refinements to enhance its practical utility in critical medical settings.

2.4.2 Sample size calculation for system usability scale

The available literature indicates that the average SUS score is 68 points, with a standard deviation of 12.82 points [24]. A SUS score of 80 points, which is the minimum value required for an "excellent" score, was selected as the target value for the usability of the application. The number of samples was calculated using the constant (68) and differential ($80 - 68 = 12$). A one-sample *t*-test was used to assess the mean values. The following formula was used to determine the effect size:

$$Effect\ size = \frac{Mean\ of\ Experimental\ Group\ -\ Mean\ of\ Control\ Group}{Standard\ Deviation\ of\ Control\ Group}$$

Assuming an effect size of 0.936, the necessary number of participants was determined to be 12, using a two-sided test with a 5% threshold of statistical significance and power of 80%.

2.4.3 Semi-structured interview

In addition, a semi-structured interview was conducted to obtain a detailed user experience profile for the application. Questionnaire development involved a multistep process. Initially, we conducted a comprehensive literature review to identify the key factors influencing the usability and effectiveness of medical applications. We consulted a panel of experts including emergency medicine professionals and user experience researchers to refine the questionnaires. Emergency medical staff tested the pilot version of the questionnaire. We made the necessary revisions to the questionnaire based on the feedback from the pilot test.

After the simulation study, interviews were conducted using a convenience sample. All interviews were voice-recorded with the participants' permission. Examples of interview questions are presented in **Supplementary Table 3**. The questionnaires covered four sections: engagement and intention to use, information processing and quality, functionality and suggestions for application improvement [24]. We conducted a detailed text search and retrieval process on the transcripts of the semi-structured interviews. This involved identifying and extracting key phrases and terms related to the usability and functionality of the CPReCoder application to discern patterns and themes from the participants' feedback. We also utilized mapping techniques to link qualitative data with specific aspects of the CPReCoder application. This involved mapping the participants' responses to specific features and functionalities of the application, thereby providing a clear understanding of how different elements of the application were perceived and experienced by the users.

2.5 Outcome measurements

The primary outcome variable was the documentation completeness of the CPR recording. The secondary outcomes were temporal fidelity of the CPR recording, application usability represented by the SUS score, and an in-depth interview.

2.6 Statistical analysis

All data were presented as standard descriptive statistics. Data are presented as medians with interquartile ranges (IQRs) or means with standard deviations (SD) for continuous data and numbers with percentages for categorical data.

Data from the simulation study were clustered matched-pair data. In addition, the correlation between values measured repeatedly within each cluster should be considered in the analysis. The Obuchowski approach was used to determine the significance of differences in primary outcomes between the groups by comparing the correlated proportions for clustered matched-pair data [25]. The Obuchowski method is a statistical approach used in diagnostic studies in which multiple readings or assessments are performed on the same participants. This method is beneficial when there are numerous raters or practices (in our case, CPReCoder and paper-based recording) and the outcome is ordinal or continuous. The Obuchowski approach allows for paired data analysis, while accounting for the correlation between readings. The data were analyzed using R 3.6.1 (Vienna, Austria; http://www.R-project.org/) and STATA 15.0 (STATA Corporation, College Station, TX, USA).

3. Results

3.1 Phase I: application development

3.1.1 Discover and define the problem: challenges posed by the legacy input system during CPR

A flowchart of the study is presented in Fig. 1. The double-diamond design process for this application is shown in Fig. 2. Data documented on paper were subsequently transferred to the electronic medical record (EMR) system. According to the interviewees, this approach increased the workload of the medical staff. Recording CPR information on paper and then entering, scanning or saving it in an EMR may not only increase the workload of medical staff but also result in additional errors. Furthermore, medical staff reported elevated

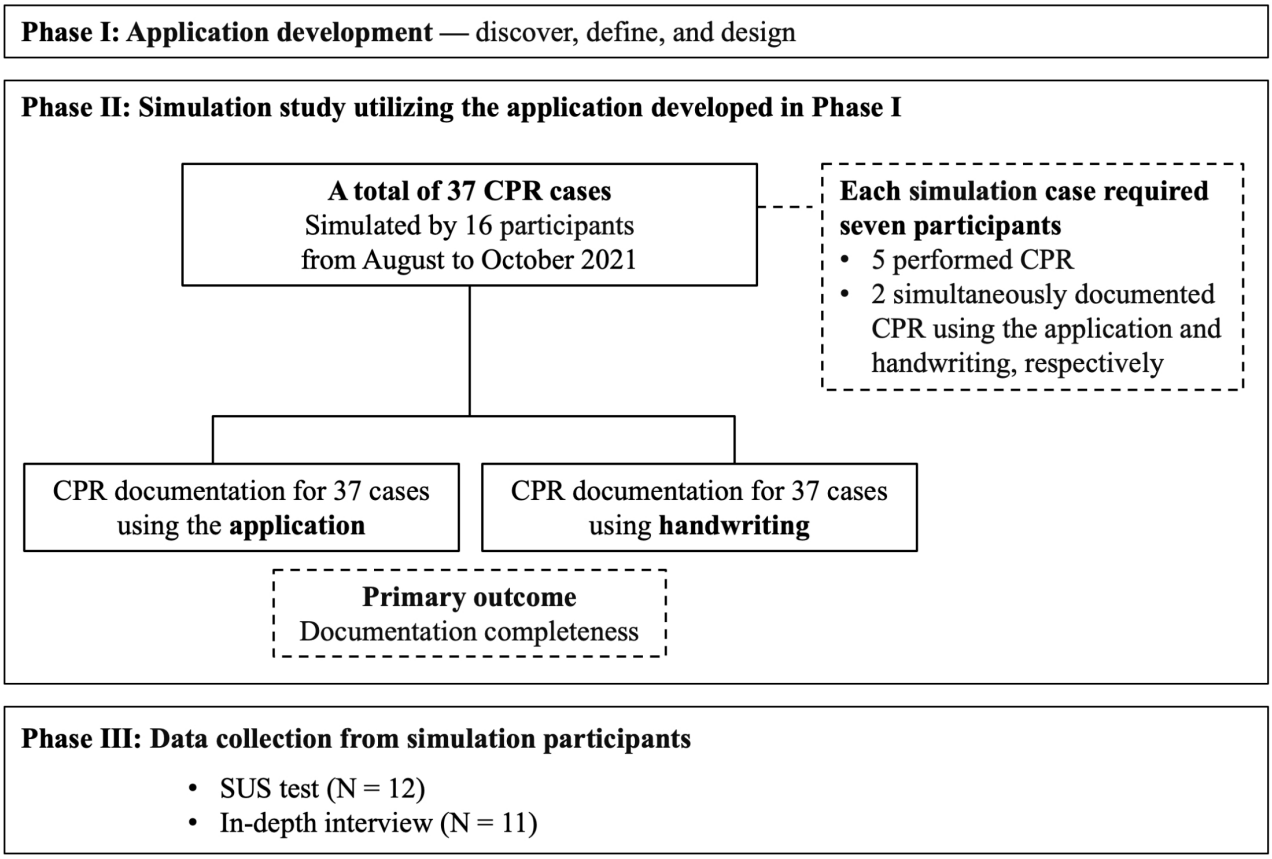

FIGURE 1. Flowchart of the study. CPR, cardiopulmonary resuscitation; SUS, System Usability Scale.

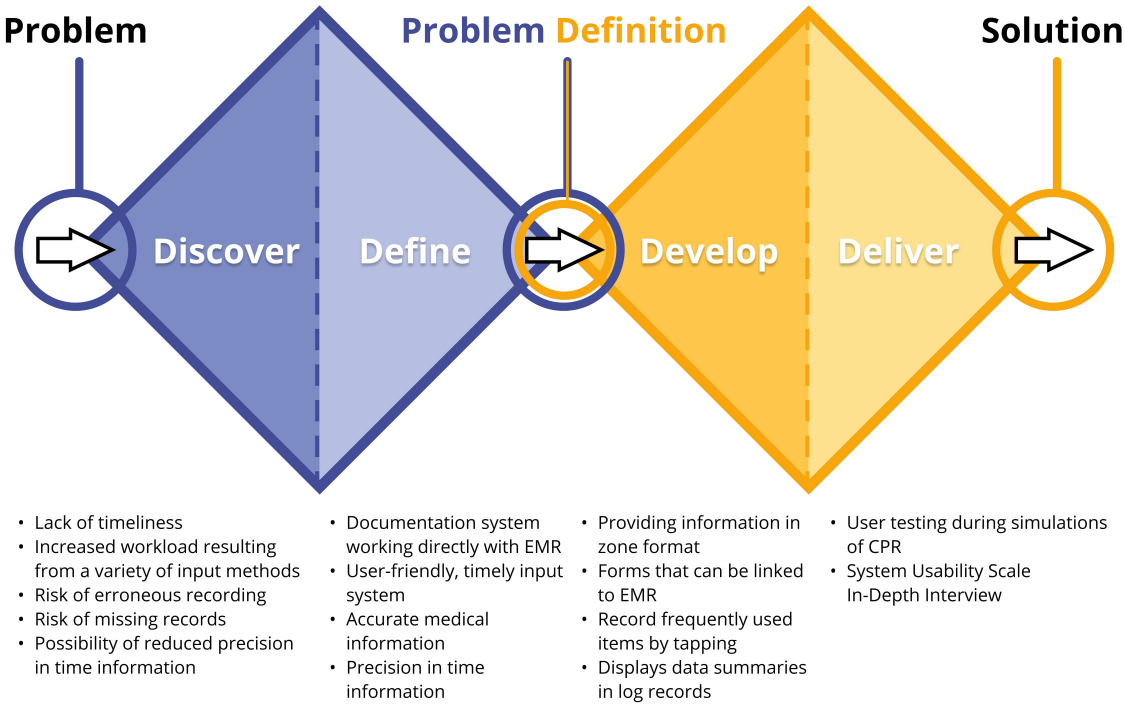

FIGURE 2. The Double Diamond design process of "CPReCoder". CPR, cardiopulmonary resuscitation; EMR, electronic medical record.

risks of misrecordings, omitted records, and inaccurate time information, which are not uncommon with paper recordings during CPR [26]. The requirements for a digital recording system can be defined as an intuitive and timely system for inputting accurate medical and temporal information compatible with the current EMR. Fig. 3 shows the wireframe drawn by the team after defining the tasks.

3.1.2 Application design

The layout of the CPReCoder interface is shown in Fig. 4. The application is currently being developed in Korean; however, screenshots in English have been provided to help readers understand it. This application consists of two screens, one for CPR recording and the other for reporting. The screen for CPR recording is further divided into three distinct zones: zone 1 (patient and prehospital area), zone 2 (CPR code button area) and zone 3 (time information area).

In zone 1, the patient's name, age and sex, as well as the time of cardiac arrest, presence of witnesses, status of bystander CPR, location of cardiac arrest, and intubation status are recorded.

Zone 2 consists of buttons for entering information such as initiating chest compressions, checking rhythm and pulse, defibrillation, airway management and medication administration. When the "CPR start" button is pressed, all the buttons in this area are activated. By tapping the screen, medical staff can record relevant information. When the user selects "other treatment", located at the bottom center of the screen, a new window opens, enabling the user to input text for special situations or note critical details. This feature was incorporated to accommodate a range of scenarios that may occur during CPR.

The time information section of zone 3 consists of four timers and a log history. The timer displays the CPR start time, current time, CPR duration and chest compression time. The information entered in zone 2 is displayed over time on the log history screen. A user can tap the "death" or "ROSC" button to access the recording result screen following the recording process. After all the CPR procedures are completed, a final report is generated using the collected data.

Basic patient information, information before the patient arrived at the hospital, how long chest compressions were performed for, how to keep the airway open, initial ECG rhythm, information about defibrillation, and information about medications are all included. After completing all CPR procedures, a final report is generated, incorporating data such as basic patient information, prehospital events, duration of CPR, airway management, initial ECG rhythm, defibrillation details, and medication information (**Supplementary Fig. 1**). Having been designed after a hospital' CPR document form, the screen for the final report does not present all specific details, such as every ECG change during CPR. The screenshot is saved as an image file when the recorder saves the final report. Additionally, a text file is saved on the tablet, capturing all the entered information and time data in chronological order. In contrast to image files, text files thoroughly document all the information entered, including each ECG change during CPR.

3.2 Phase II: simulation study using the application

The demographic information of the 16 participants is summarized in **Supplementary Table 4**. All participants were emergency medical professionals. In addition, they either had certifications from the American Heart Association or had successfully completed CPR training at our institution. A total of 37 distinct CPR simulations were conducted by 16 participants throughout the study period (Fig. 1). Each

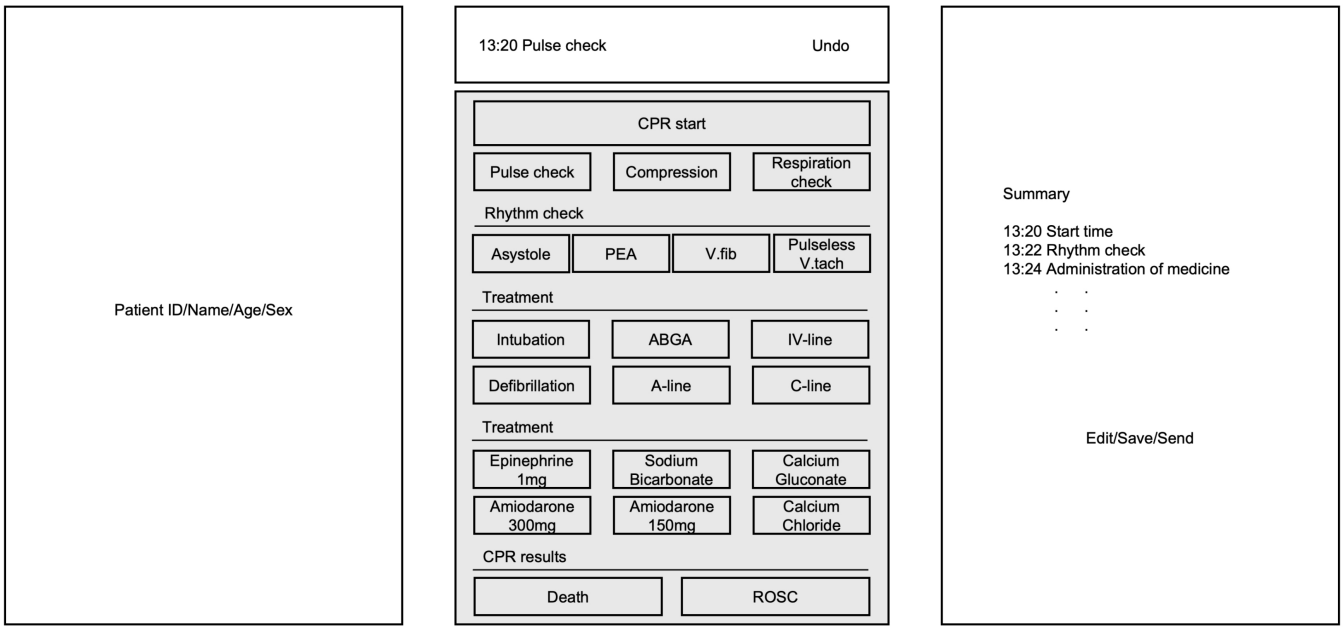

FIGURE 3. The wireframe of "CPReCoder". ID, identity document; CPR, cardiopulmonary resuscitation; PEA, pulseless electrical activity; V.fib, ventricular fibrillation; V.tach, ventricular tachycardia; ABGA, artery blood gas analysis; IV-line, intravenous line; A-line, arterial line; C-line, central venous line; ROSC, return of spontaneous circulation.

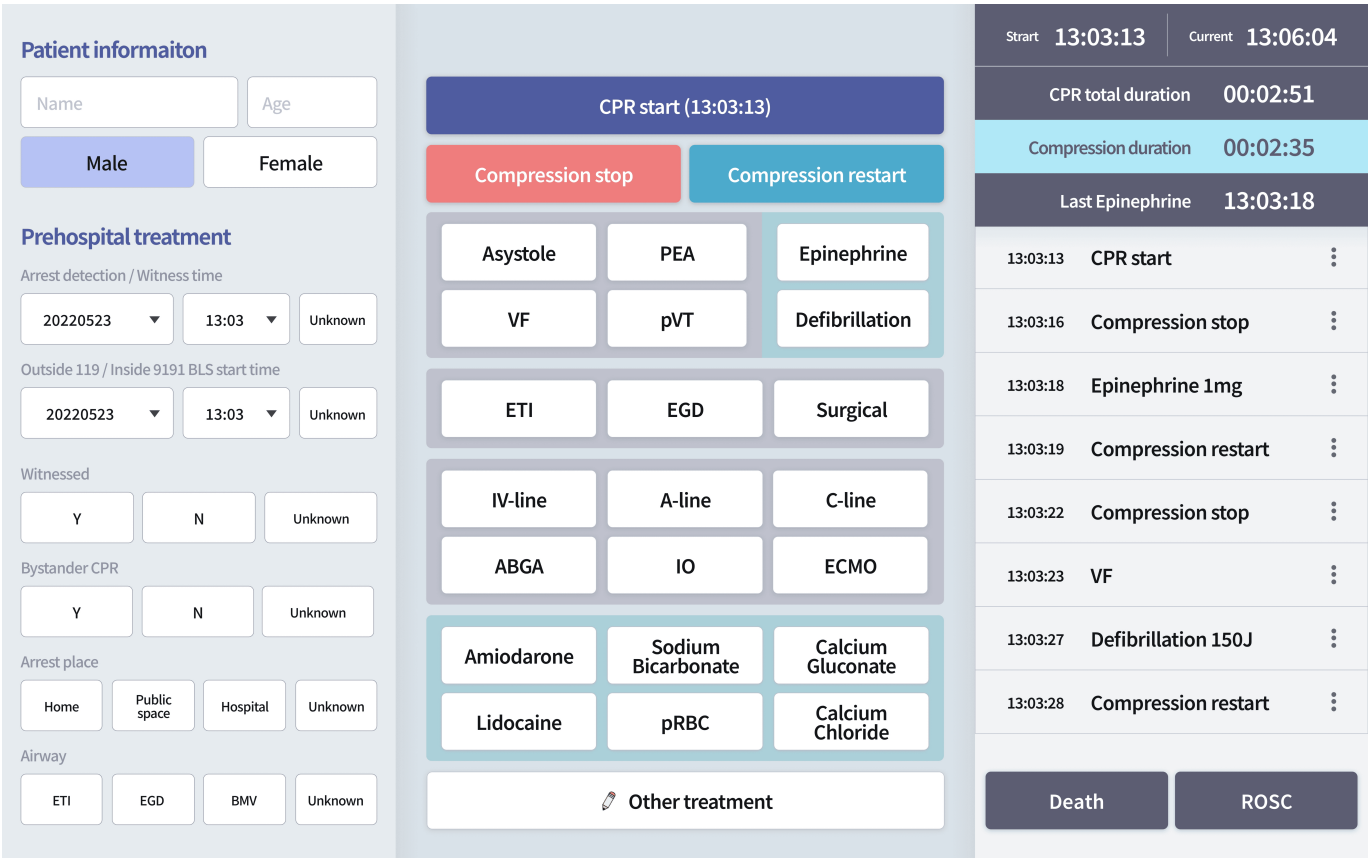

FIGURE 4. Screenshot of "CPReCoder": a screen for CPR recording. BLS, basic life support; Y, yes; N, no; ETI, endotracheal intubation; EGD, extraglottic device; BMV, bag-valve-mask ventilation; CPR, cardiopulmonary resuscitation; PEA, pulseless electrical activity; VF, ventricular fibrillation; pVT, pulseless ventricular tachycardia; IV-line, intravenous line; A-line, arterial line; C-line, central venous line; ABGA, artery blood gas analysis; IO, intraosseous; ECMO, extracorporeal membrane oxygenation; pRBC, packed red blood cells; ROSC, return of spontaneous circulation.

of the 37 scenarios was documented concurrently using both application—and paper-based approaches. An analysis of the video recordings from these simulations identified 1615 procedures performed across the various scenarios. The use of the application showed significantly higher documentation completeness compared to handwriting (96.8% (n = 1563) *vs.* 88.1% (n = 1422), $p < 0.001$) (Table 1). Compared to handwriting, the application demonstrated significantly higher documentation completeness in pausing and resuming chest compressions (n = 620 (94.8%) *vs.* n = 535 (81.8%), $p < 0.0001$), analyzing rhythm (n = 212 (99.1%) *vs.* n = 186 (86.9%), $p = 0.002$), and defibrillation and airway management (n = 151 (97.4%) *vs.* n = 141 (91.0%), $p = 0.036$).

In terms of temporal fidelity, there was no significant time difference (mean) between the two approaches (application, 1.41 (SD, 1.32) s *vs.* handwriting, 1.57 (SD, 1.87) s; $p = 0.512$) (Table 2). The maximum time difference was 9 s for the application and 17 s for the handwriting.

3.3 Phase III: user experience assessment using SUS scores and in-depth interviews

3.3.1 System usability scale

The mean SUS score was 87.9 points, which indicated that the participants thought it was "excellent". The SUS score of each participant is presented in **Supplementary Table 5**.

3.3.2 User experience with using CPReCoder

We sought to validate user experiences by conducting a qualitative analysis of CPReCoder (Table 3). Interviews were conducted to evaluate the design of CPReCoder based on the key themes and concepts of HCD.

(1) Engagement and intention to use

Questions about engagement were posed to determine whether CPReCoder met the users' demands for records during CPR, allowing them to continue using the service. Interviewees replied that the application was intuitive and user-friendly. Most participants were satisfied with the final summary reports, which were available in the same format as those generated by the legacy EMR system.

"It's very intuitive to use. Touching the screen of a tablet with a finger is the only thing I need to learn. I believe that the majority of medical professionals who perform CPR would agree completely" (study participant #1, physician).

"It was much simpler than handwriting or computer typing. To accurately record vital events during CPR with summary reports, I only needed to tap on the screen. When writing by hand, we had to repeatedly write the information. The summary reports of CPR would also reduce the workload of nurses" (study participant #2, EMT).

TABLE 1. Comparison of accuracy according to CPR recording method.

	N	Application	Handwriting	*p*
Total procedures	1615	1563 (96.8)	1422 (88.1)	<0.001
Initiation or termination of CPR	74	74 (100.0)	73 (98.65)	0.324
Pausing or resuming chest compressions	654	620 (94.8)	535 (81.8)	<0.001
Analyzing rhythm	214	212 (99.1)	186 (86.9)	0.002
Epinephrine administration	189	187 (98.9)	186 (98.4)	0.659
Other medication administration	101	101 (100.0)	100 (99.0)	0.324
Defibrillation or airway management	155	151 (97.4)	141 (91.0)	0.036
Vascular access	117	114 (97.4)	107 (91.5)	0.056
Arterial blood gas analysis	72	68 (94.4)	61 (84.7)	0.094
Other procedures	39	36 (92.3)	33 (84.6)	0.271

Data are presented as frequency (%). CPR, cardiopulmonary resuscitation.

TABLE 2. Comparison of time differences according to the CPR recording method.

	Mean (s)	SD (s)	*p*	Max difference (s)
Application	1.4	1.3	0.512	9
Handwriting	1.6	1.9		17

CPR, cardiopulmonary resuscitation; SD, standard deviation.

TABLE 3. Summary of user experiences with CPReCoder.

Key themes	Pros	Cons	Key concept of HCD
Engagement and intention to use	Participants' satisfaction with ease of learning and use Intuitive use. More accurate in recording medical information.	No cons.	Easy to learn Intuitive
Information processing & quality	Timeliness of the input system renders time information of the CPR records accurate. Log data supports sharing CPR information for team dynamics	When input is missed, upcoming input can be delayed as well.	Error-free
Functionality	Convenient and user-friendly UI/UX. Easy input system and summary reports of CPR reduce the burden of work.	Not familiar and time-consuming when editing records.	Intuitive User-friendly
Suggestion for improvement	When tapping the button, a confirmational signal is needed to ensure an input has been made. Handwriting mode is needed for quick memos can be missed.		

HCD, human-centered design; CPR, cardiopulmonary resuscitation; UI/UX, user interface and user experience.

(2) Information processing and quality

We evaluated whether CPReCoder contained sufficient CPR-related data and whether the data type, quality and ease of processing were satisfactory. Most of the users responded positively to these questions. Meanwhile, two participants proposed revising the buttons because there were too many data entry buttons due to the small space available on the tablet, and it was difficult to enter pediatric dosages of commonly used medications or defibrillation information.

"This application includes all of the key features, such as the type of rhythm, medications, and procedures with dosage information during CPR. The information is effectively organized in chronological order" (study participant #6, physician).

"I believe it would be most advantageous for novice nurses attending CPR training. They may have difficulty deciding what to record in a chaotic situation. This application suggests time-related information to record" (study participant #11, nurse).

(3) Functionality

We questioned whether CPReCoder was intuitive to use;

whether it increased access to vital information during CPR; whether it could support communication with medical personnel; and whether it had an appropriate layout, screen color scheme, size features, and navigation. The application appeared to be useful in emergency situations, and users reported that it was more convenient than the legacy system. Meanwhile, five participants reported that the input system required more time to edit the records because they were unfamiliar with the editing process.

"I believe the UI/UX is very user-friendly. It is simple to tap" (study participant #4, physician).

"Log data on the right side facilitates the sharing of CPR information for team dynamics" (study participant #5, nurse).

(4) Suggestions for improvement

We also inquired about additional application enhancements that could be implemented. There were opinions that it would be preferable to facilitate the correction of errors and addition of missing procedures.

"When the button is pressed, a confirmation signal is needed to make sure that the input has been made" (study participant #7, physician).

"A note-taking mode that enables rapid note-taking in case of missing some procedures would be required" (study participant #9, nurse).

4. Discussion

In this study, we developed a tablet-based CPR-recording application and evaluated its clinical applicability. CPR procedures were recorded more accurately with a tablet-based application than with a conventional paper-based record. There was no significant difference between the two methods in terms of accuracy of the recorded time. The mean SUS score was 87.9 points, indicating that the participants thought it was excellent. Through this application, medical staff were able to record CPR procedures easily and accurately.

The strengths of the application are that it is intuitive, convenient, and extensible. Additionally, we quantified the practicability and usability of the application. It is significant that the application was designed using the HCD process in collaboration with medical staff who will use the application to improve its usability. The design and functionality of the application were enhanced using an agile development methodology. In addition, the majority of CPR treatments were configured with buttons for easy input. Finally, the CPR document is saved as an image and stored as JavaScript Object Notation (JSON)-type data, which are structured in a systematically expandable form through communication with the server. Originally, this application was developed as an integral part of a project aimed at constructing a dashboard system, a sizeable wall-mounted monitor, for the real-time presentation of the CPR status (**Supplementary Fig. 2**). Data entered into the application is transmitted in real-time to the dashboard. This provides updates on ongoing CPR for the on-site CPR team, allowing them to review the current situation and enhance situational awareness.

One of the key strengths of this study is its comprehensive approach, which combines application development and rigorous testing in a simulated clinical environment. The participative human-centered design ensured that the application was tailored to meet the specific needs of emergency medical professionals.

The implications of this study are significant in the field of emergency medicine. The application of CPReCoder has the potential to revolutionize CPR documentation, making it more accurate and efficient, and ultimately contributing to better patient outcomes and more effective post-event analysis. From a practical standpoint, the application offers a user-friendly and efficient alternative to traditional documentation methods, which can be particularly valuable in high-pressure situations where every second counts. A reduced workload and the potential for minimizing errors can profoundly impact the quality of care provided during CPR. Furthermore, we recognized the critical importance of time efficiency in emergency medical care, particularly during CPR. This aspect of our analysis aimed to evaluate not only documentation completeness but also the efficiency of CPReCoder in a real-time, high-pressure clinical setting. We compared the time each procedure was executed as recorded by the participants against the gold-standard time obtained from video recordings of the simulations. This comparison provides valuable insight into whether our digital solution can enhance the CPR documentation process without introducing significant delays.

Several studies have compared digital tools, such as tablets, to traditional methods, the majority of which are paper-based, for documenting events during CPR. In their study on CPR simulations, Peace *et al.* [15] demonstrated that documentation using a tablet significantly outperformed the paper-based method in terms of documentation completeness (88.0% *vs.* 67.9%, $p = 0.001$) and temporal fidelity (3 s *vs.* 77 s, $p < 0.001$), highlighting the greater accuracy of digital tools for recording CPR procedures. In addition, Grundgeiger *et al.* [16] compared a tablet-based application and a conventional hospital information system (HIS) for documenting in-hospital resuscitations in real-time, noting no significant difference in documentation completeness (83% for both the application and HIS groups, $p = 0.300$), but significant benefits in intervention timing accuracy with the tablet application. The study concluded that the tablet-based tool enhanced data quality without compromising clinical performance, and offered potential benefits for real-time medical responses without increasing the cognitive burden on healthcare providers. Furthermore, Grigg *et al.* [26] found that an electronic documentation system reduced omission errors by 28% and irrelevant data by 36% compared to paper records during CPR simulations. In addition, the electronic system had approximately one-third fewer specification errors (incorrect details) while maintaining similar rates of commission errors (recording of imagined events) and timing errors. While the findings varied among the studies, the consensus indicated that digital tool usage provides significant benefits in terms of accuracy, accessibility, and real-time data capture during resuscitation procedures. Our findings are consistent with those of previous studies showing that application-based documentation outperforms conventional paper-based methods in terms of document completeness. Our study is noteworthy in that, compared to previous studies, SUS scoring and interviews were conducted in more detail to investigate the participants' perspectives on

the application's usability and usefulness.

The interviews revealed that the major benefit of CPReCoder was its ability to reduce the workload. Existing paper-based CPR documentation is burdensome because of the double work, as it is necessary to record patient information, treatment, or time-related information on paper during CPR and then input the data back into the EMR system. In addition, data loss is a concern during this process. In Korea, each institution utilizes a diverse array of EMR systems that are not standardized and have their own CPR documentation practices. To the best of the authors' knowledge, tablet-based documentation is not commonly used in this country. The final report generated by CPReCoder is identical to that generated by EMR. Because of its pilot development status, the application uses the JSON format to transfer data between a tablet and an EMR-accessible computer. The implementation of Fast Healthcare Interoperability Resources (FHIRs) will improve the scalability of the application, allowing it to be easily integrated with various EMR systems.

Although our application was designed to be user-friendly and functional, there are areas for future enhancement. Adding features to reduce the user's cognitive burden would significantly improve their utility. For example, a timer could show how long it had been since the last dose of epinephrine was administered to ensure compliance with guidelines. Additionally, recognizing the importance of CPR quality, it could be crucial to document physiological parameters such as end-tidal carbon dioxide levels and arterial blood pressure. Future updates should include fields for recording these parameters. Finally, the increasing adoption of extracorporeal membrane oxygenation (ECMO) in CPR has become a significant reason for CPR termination. However, in the current version of the application, there is no option to select ECMO initiation as a reason for CPR termination. Future upgrades should also consider this aspect. These enhancements ensure comprehensive documentation and support for high-quality CPR practices.

Our study has several limitations. First, it was conducted at a single site. Our findings may have limitations in terms of their generalizability to different contexts. Second, this study has inherent limitations because it was a simulation. CPR is a complex intervention in which medical personnel perform several tasks in a high-pressure and time-sensitive manner in an uncontrolled and confusing environment. Although we worked hard to recreate the atmosphere of CPR administration in an actual emergency setting to represent real-life clinical scenarios, producing a sense of urgency and stress was challenging. Third, the quality of CPR documentation can vary depending on an individual's competency, which is influenced by various factors, including professional and clinical experience. However, this study did not consider the impact of these factors (*e.g.*, nurses versus physicians) on the accuracy of CPR documentation, which could have influenced the findings. Fourth, the accuracy of documentation can be improved by using a standard format. However, in this study, we used unstructured plain paper, which may have affected the results. Finally, the application or device did not exhibit any critical errors, such as application crashes, delays, or low-battery issues. Despite careful planning to avoid these issues, unexpected failures can occur when applications and mobile devices are used. The limited number of scenarios may have prevented us from identifying these potential errors.

5. Conclusions

In conclusion, our study presents the development and evaluation of the CPReCoder application, a novel tool designed to improve the accuracy and efficiency of CPR documentation. The findings demonstrate that CPReCoder significantly outperforms the traditional paper-based methods in terms of documentation completeness. Additionally, the application's high SUS score underscores its excellent usability and potential to reduce the workload of the medical staff.

AVAILABILITY OF DATA AND MATERIALS

The datasets used in this study are available upon reasonable request from the corresponding author and are not publicly available.

AUTHOR CONTRIBUTIONS

JWK, TK and SYH—conceptualization; JWK, TK, BP, SK, DY, JEP, GTL, TGS, SH, HC, HY, WCC and SYH—methodology; JWK, TK, SK, DY and SYH—software; JWK, TK, BP, JEP, GTL and SYH—formal Analysis; JWK, TK, TGS, SH, HC, HY, WCC and SYH—investigation; JWK, TK, BP, SK, DY, JEP and SYH—resources; JWK, TK, BP, SK, DY, JEP, GTL, TGS, SH, HC, HY, WCC and SYH—data curation; BP, SK and DY—visualization; JWK, TK and SYH—project administration; JWK, TK and SYH—supervision; SYH—funding acquisition; JWK, TK, BP, SK, DY and SYH—writing original draft; JWK, TK, JEP, GTL, TGS, SH, HC, HY, WCC and SYH—writing review & editing. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the institutional review board (IRB) of Samsung Medical Center (IRB no. SMC 2021-06-094-004). Written informed consent was obtained from all the participants.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) (grant number: RS-2020-NR052731). However, the funding source was not involved in every phase of the research process.

CONFLICT OF INTEREST

The authors declare no conflict of interest. Won Chul Cha is serving as one of the Editorial Board members of this journal. We declare that Won Chul Cha had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to OK.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.signavitae.com/mre-signavitae/article/1876873884153593856/attachment/Supplementary%20material.docx.

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How to cite this article: Ji Woong Kim, Taerim Kim, Boram Park, Seulji Ku, Dajeong You, Jong Eun Park, *et al.* Using a mobile application to improve recording during cardiopulmonary resuscitation: a mixed-methods study. Signa Vitae. 2025; 21(1): 79-89. doi: 10.22514/sv.2025.010.