FEATURE ARTICLE

Evaluation of a Mobile Application for Heart Failure Telemonitoring

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Adequate adherence to treatment is indispensable in preventing adverse consequences in heart failure patients. Such adherence can be managed through heart failure clinics and various methods of follow-up. In recent years, the use of telemonitoring has shown promising benefits in supporting clinicians' follow-up, as well as contributing to patients' self-care. This article presents the development and evaluation of a telemonitoring application for heart failure, through a Web-based interface for clinicians and a mobile application for patients. The application was evaluated through a 6-month pilot observational descriptive study in 20 outpatients with reduced ejection fraction and two nurses, in the context of a heart failure clinic. A technological acceptance questionnaire was applied to all patients and nurses at the end of the study period. In use, the application generated 64 real-time alerts for early decision-making to prevent complications, and 91% of patients did not present hospital readmissions. Such results, along with high user acceptance, show potential utility of the application as an effective complementary strategy for follow-up of patients with heart failure.

KEY WORDS: Heart failure, Technology acceptance, Telemonitoring

Heart failure (HF) is a disease with worldwide negative impact on quality of life, morbidity, disability, and mortality. In addition, it represents high costs for any nation's health system and in many cases for the patient and family. Accordingly, from a hospital or clinic perspective, avoiding unwanted HF events should result in a reduction in hospital readmissions, as well as in indirect costs.[1] In consequence, it is important to develop strategies that promote good adherence to HF treatment and allow continuous monitoring.

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In terms of treatment, the goal for patients with HF is to improve symptoms, reduce the risk of hospitalization, reduce mortality, and contribute to general quality of life. However, as expected, these outcomes are dependent on adequate adherence to a comprehensive treatment plan. As such, it has been shown that close and frequent patient follow-up, especially when done by multidisciplinary groups, facilitates such comprehensive approach, promoting self-care and adherence to pharmacological and nonpharmacological treatment.[2–4]

When such follow-up is provided by an HF program, it should include regular medical checkups, nursing consultations, and access to other clinicians involved in the care of patients with HF. These multidisciplinary groups are usually found in hospitals of high complexity, with limited capacity for close and frequent follow-up of large volumes of patients. Therefore, other alternative follow-up measures for patients with HF have been evaluated, including body weight monitoring, home nursing visits, telephone follow-up with nurses, and telemedicine supervision, which have shown benefits mainly by reducing the risk of hospitalization.[5]

In particular, meta-analysis studies show that the use of telemonitoring has an impact on decreasing hospital readmissions, by allowing timely detection and management of decompensation symptoms, as well as promoting self-care and adherence to treatment.[6,7] And in terms of telemedicine technologies, mobile phone–based remote monitoring systems, in conjunction with drug treatment and education, are believed to be relatively inexpensive and convenient. This is because mobile phones, in addition to their portability, are widely available and have considerable computational power, while at the same time being less expensive, when compared with other specific remote monitoring devices.

Given the potential of mobile phone–based telemedicine, there has been a recent growth in smartphone applications (apps) for HF telemonitoring, which provide functionalities to record symptoms, manage medications, schedule appointments, or reinforce behaviors through educational components.[8–11] In fact, certain apps have been already available for years, such as Heart Partner (Novartis Pharmaceuticals Corp, East Hanover, NJ); Heart Failure Health Storylines (Heart Failure Society of America, Rockville, Maryland); or WOW ME 2000 mg—Heart Failure Self-management Tool for Patients and Caregivers (AtlantiCare, Egg Harbor,

NJ).[12–15] However, to the best of our knowledge, these apps are exclusively meant for the patient, not the multidisciplinary team behind an HF program. While some do provide alerts for clinicians, interaction between the patients and the clinicians is indirect at best, and the app is usually decoupled from other hospital information systems.

Adherence in this scenario has two aspects. First, it refers to a patient adherence to recommended treatment through self-care, with respect to medication adherence, dietary sodium adherence, and symptom management.[16] Second, adherence can refer to the actual compliance with the telemonitoring protocol, through adoption and use of a telemonitoring app.[17] This study considers both aspects through medical outcomes (alerts and readmissions) and through technology acceptance. In both cases, as is required of telemonitoring technology, two feedback loops are present.[18] The first feedback loop relates self-monitored data to the clinic, allowing the nurse to review the data and contact the patient if required (after an alert suggests an intervention). The second feedback loop allows the patient to visualize self-monitored data, contributing to self-care. Both feedback loops are intertwined and as such require an app for the patient, an app for clinicians, and daily communication between the two.

Within this context, a multidisciplinary team of researchers from nursing, medicine, and engineering have developed ControlVit, an HF telemonitoring mobile app, connected to a Web app for clinicians in an HF program. ControlVit is derived from a previous nursing research project focused on the effect of telephone monitoring on adherence of patients with HF.[19] With ControlVit, clinicians use the Web app to monitor patients permanently and in real time, in order to detect potential complications early. The mobile app itself provides information (education, tips) for the patients to improve self-care and allows them to record biometric data (weight, blood pressure, heart rate) and decompensation symptoms daily. If the data sent by the patient behave beyond a given threshold or align with a possible adverse effect, the Web app generates corresponding alerts for the nurses. Each alert includes a possible action to take, which is validated, discussed, or specified by the clinicians, for instance, resulting in modifying the drug treatment (dosage), avoiding progression of symptoms, and potential hospitalization. In addition, ControlVit is integrated to the EHR system of the institution and can be linked to any such system supporting the HL7 standard.

After the initial development processes of the ControlVit app, both in its mobile and Web-based interfaces, it was evaluated in terms of usability and utility through a technology acceptance survey with a group of 20 patients diagnosed with HF using the mobile app, along with two nurses using the Web version.

METHODS

Design Science Research

The methodology used to design and evaluate the ControlVit app was design science research.[20] This research approach aims at striking a balance between research and rigor in information systems research and has been applied in both healthcare and nursing informatics.[21,22] Science research stems from a problem-solving strategy firmly rooted in an applicable knowledge base and goes through iterative cycles of design and evaluation of an artifact to be deployed in a specific environment. In particular, we follow the methodological process proposed by Peffers and colleagues,[23] which suggests the following activities: (1) identify the problem; (2) define the solution; (3) design and development; (4) demonstration; (5) evaluation; and (6) communication.

The first step is to identify the problem, which in this case is related to HF treatment adherence, or indeed the possible negative impacts of poor adherence. The definition of the solution then emerged in three stages: first, a follow-up instrument to improve adherence with the support of an HF program; second, a software tool to support in recording and tracking telephone monitoring within said HF program; third, the development of an app with a Web-based interface for clinicians, to replace the initial call tracking software, along with a mobile app for patients to record biometric data and answer a questionnaire. In particular, the mobile app was focused on having real-time support both for patients and clinicians, as a complement to telephone-based monitoring. Additional motivation and supporting knowledge base for these first steps have already been presented in the Introduction section of this article.

Design and development then followed an iterative software engineering process. The multidisciplinary research team first developed an initial set of both functional and nonfunctional requirements. With the support of a professional software development company, several iterations were then carried out to generate incremental prototypes of the Web-based and mobile apps, which were verified until the refined definitive requirements were successfully met.

Demonstration and evaluation of the apps were carried out in a pilot study described in the following subsection. For the final step of the design science research methodology, this article constitutes one of the products intended for communication, in this case intended for an academic audience.

Telemonitoring Application for Heart Failure

ControlVit, as an HF telemonitoring technology artifact, consists of two main components: a Web-based app for clinicians and a mobile app for patients. The main Web app was developed with open-source frameworks and technologies: MySQL for database management, nodeJS for the back-end app logic, and AngularJS for the front-end Web interface. The mobile

app was also developed with an open-source framework, Ionic, which allows for both Android and iOS deployments.

On the one hand, the Web-based app is deployed within the bounds of the information technology infrastructure of a university hospital, which requires user authentication via the OAUTH protocol. Users are created specifically for the app, which in this case is intended for clinicians. The Web-based interface (Figure 1) contains the main functionality for telemonitoring. This includes administrative modules for creating patients (basic personal details are extracted from the hospital EMR system to guarantee consistency), medications, medical devices, alerts, and information capsules. Once this initial configuration is done, the interface offers menu items for managing each patient call. This means that the app supports the scheduling and control of phone calls, which are still carried out for personal follow-up, as well as for validating the data that are sent by the patients daily through the mobile app. In addition, the interface shows each alert that is generated when the variables exceed the values determined and configured in the administrative module. A visual depiction of the patient history in the app is shown through graphical timelines (bottom of Figure 1) where the clinician can choose the patient and the variables that he/she wants to visualize to get a quick glance at the evolution of such variables (weight, medication intake, etc).

On the other hand, the mobile app is deployed in the patient's mobile phone. This is done with the help of the app developers and/or the clinical system administrator (typically the nurse in charge of patient follow-up in the HF clinic). The app functionality is always available offline for recording daily biometric data, as well as for receiving daily educational capsules and tips related to HF self-care (Figure 2). Upon Internet access, the app will send any pending data related to the biometric measures. For this networked functionality to work, the user must be authenticated, which implies having been created in the main administrative module of the Web-based version.

Evaluation Setting and Participants

The demonstration and evaluation were carried out as a descriptive observational pilot study with 20 patients of the HF and heart transplant program of Hospital Universitario San

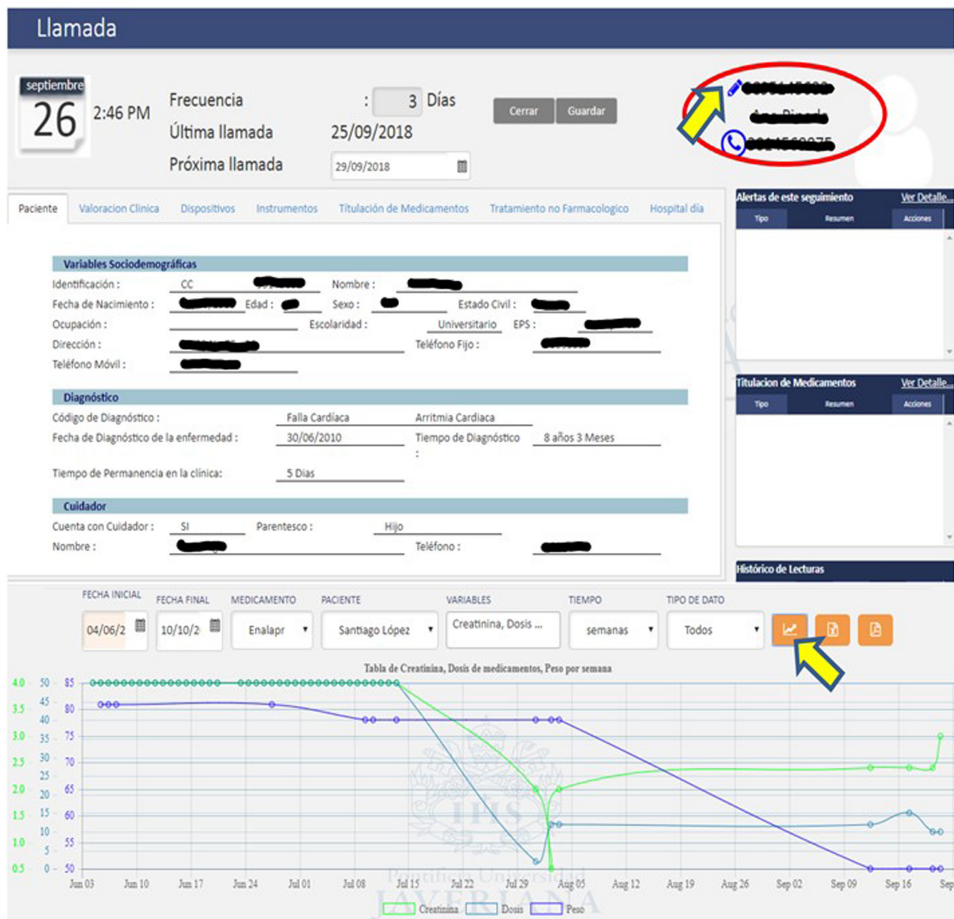

FIGURE 1. Screenshot of the Web-based clinician interface.

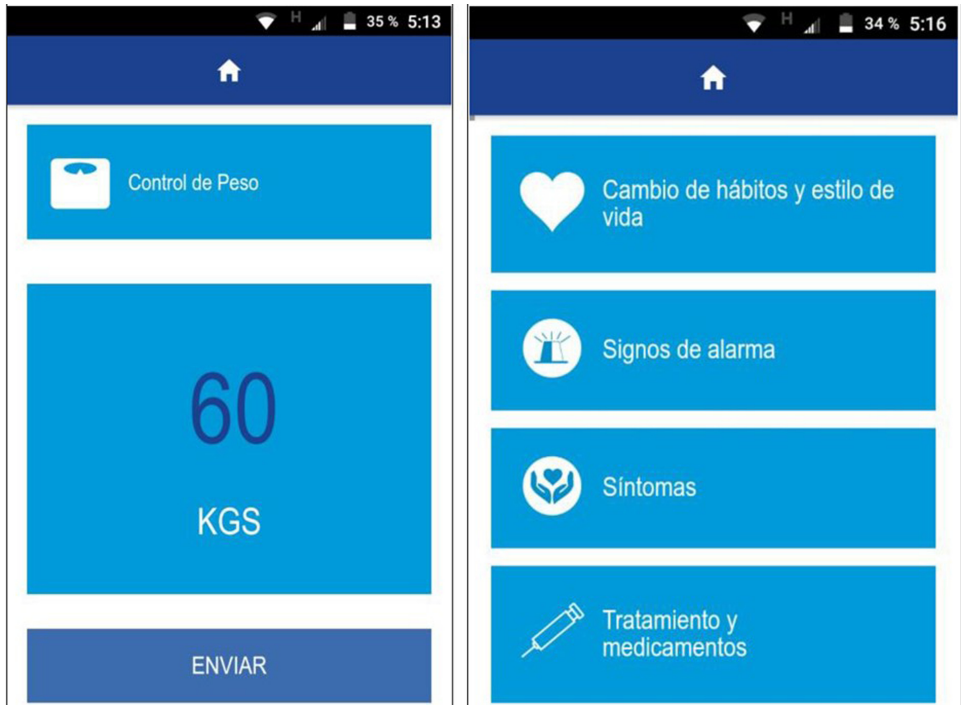

FIGURE 2. Screenshots of the mobile patient app.

Ignacio, monitored for more than 6 months, without hospitalizations for any cause 1 month before using the app. These 20 patients were all adults recruited and screened for belonging to the HF program, their ability to use mobile devices, and for having a regular connection to the Internet. Recruitment was carried out in person during scheduled clinical appointments. They were also screened to guarantee that no visual or auditive impairments would affect the use of the mobile app. There was no payment involved for participating in the study. In addition, two nursing professionals who were already employed as coordinators of the HF program in Hospital Universitario San Ignacio were included as part of the study, as users of the Web-enabled interface. Patients and nurses signed informed consent for participating in the study.

After recruitment, the mobile app was installed in the personal smartphones of the patients. An initial training in the use of ControlVit was provided to users, both patients and nurses. Training was carried out through live demonstration and use with the support of the app developers. In addition, a user manual was provided for the nurses, given the added complexity of the Web app. User support was available at all times through the software provider. Along with the app, patients were provided with clinically validated medical equipment to take home and capture the biometric data that they were asked to send every day using the app (weight, blood pressure, and heart rate). In addition, patients were expected to complete a daily questionnaire on symptoms of decompensation. Both kinds of data are sent over the Internet from the mobile app to a server that then displays the results in the Web-based version for clinician monitoring. In case of abnormal values, an alert is generated, which is received and handled in a timely manner by the HF clinic, using algorithms for decision-making, based on the recommendations of Clinical Practice Guidelines as well as institutional standards.[24]

Before the study, the apps in the mobile and Web versions were tested for compliance with functional and technical requirements from a medical and software engineering point of view. Once the study began, data from the system log were collected to routinely verify the frequency of data sent by patients. These data were used to check both that the app itself was working properly for all patients and, at the same time, that the patients were entering valid information every day.

At the end of the 6-month study period, a technology acceptance survey was applied for all 22 respondents. Paper-based patient surveys were distributed to each patient physically present at the hospital, providing context and clarification where needed and taking on average 15 minutes to respond. This survey is derived from the Technology Acceptance Model (TAM), whose purpose is to predict the acceptance of a given technology, based on its usability and ease of use, as well as a number of moderating variables.[25]

Technology Acceptance Instrument

The main premise behind the TAM is that perceived usefulness and perceived ease of use are of primary relevance for user acceptance of an information technology. This model has been revised over the years to include additional factors that precede or influence this initial perception, including experience, voluntariness, subjective norms, image, job relevance, output quality, and result demonstrability.[26] The TAM has been widely used for decades to assess the potential utility of a technological artifact, and as such, it has demonstrable predictive power in determining whether it will be accepted and used by a user group. Variants of the model have been often applied to validate technologies in various contexts, including medical apps.[27,28]

Because there are variants of the TAM, we applied a unified model that should provide the strongest predictive power.[25] In this model, the constructs are as follows:

- **Performance expectancy**: "the degree to which an individual believes that using the system will help him or her to attain gains in job performance"[25]
- **Effort expectancy**: "the degree of ease associated with the use of the system"[25]
- **Social influence**: "the degree to which an individual perceives that important others believe he or she should use the new system"[25]
- **Facilitating conditions**: "the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system"[25]

Finally, an intermediate dependent variable is behavioral intention, which accounts for the intent (personal prediction) to use the system. All previous constructs contribute to the final dependent variable: use behavior.

Ethical Considerations

The study was approved by the local ethics and research committee.

RESULTS

After the study period of 6 months, the 20 patients recruited all used the app and answered a technology acceptance survey. From patient self-reported data, 164 alerts were generated. These alerts were related to weight gain or low blood pressure values or as a result of positive symptoms in the questionnaire (Figure 3).

As mentioned earlier, a key outcome in determining the positive health impact of HF treatment from an HF program perspective is a reduction in hospital readmissions. In the study period, 91% of patients who used the app did not present hospital readmissions due to decompensation (Figure 4).

In terms of acceptance, results are divided into patient and nurse user groups. With respect to patients, results indicate general acceptance (Table 1). One hundred percent of patients found the mobile app useful (performance expectancy) and easy to use (effort expectancy). With respect to social influence, 90% totally agreed that other people significant for them would recommend or expect them to use the app. Facilitating conditions were perceived favorably in all cases, with 80% total agreement and 20% agreement. Coherently, all patients had positive behavioral intention to continue using the app (90% in total agreement, 10% with agreement).

The other groups of respondents were the two nurses using the Web interface within the HF clinic. They agreed with the performance expectancy, effort expectancy, facilitating conditions and behavioral intention (Table 2). The only instance

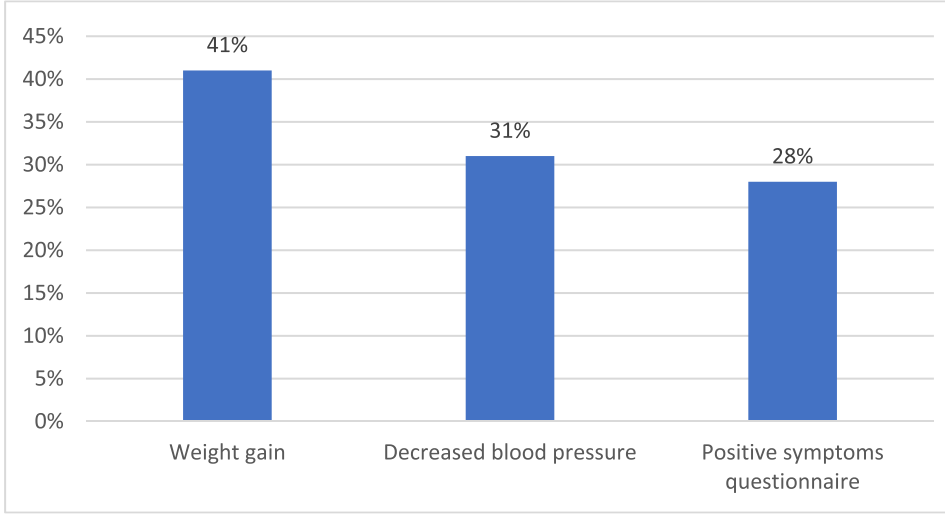

FIGURE 3. Alerts generated through the patient app.

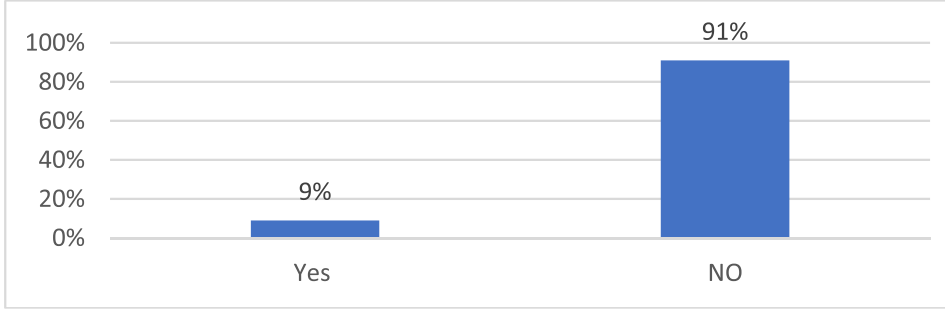

FIGURE 4. Hospital readmissions due to decompensation.

where there was neither agreement nor disagreement was social influence to use the app.

DISCUSSION

The promotion of adherence to treatment and the resulting reduction in hospital readmissions are crucial in the management of patients with HF. The use of strategies such as home noninvasive telemonitoring, through the use of electronic devices and telecommunication technologies, has been adopted for the digital transmission of biometric or other relevant data from the patient's home to the health institution responsible for their care. In this way, complications can be detected in a timely manner, along with encouraging patient participation in the management of their own disease. As such, these telemonitoring technologies have the potential to increase adherence and reduce readmissions.

According to Aamodt et al,[8] home telemonitoring of chronic diseases seems to have a promising future in patient management because it produces accurate and reliable data, empowers patients, influences their attitudes and behaviors, and potentially improves their medical conditions. Furthermore, the Cochrane review[29] on noninvasive telemonitoring programs for patients with HF shows a reduction in the risk of mortality from all causes and hospitalizations. These interventions also demonstrate improvements in health-related quality of life, clinical variables, degree of knowledge of the illness, self-care behaviors, and increased participant satisfaction with most of the proposed interventions.

In this context, the results of this study have shown the utility of the ControlVit app. Such utility is evidenced by the generation of verified alerts for timely clinical decision-making and by the reduction in hospital readmissions with respect to historical averages. In addition, the study also provides evidence of the acceptance of ControlVit as a technological artifact, in terms of perceived utility and ease of use. This is important, because despite a technology having a potential benefit, its actual impact is dependent on users adopting it. Moreover, the satisfactory acceptance of the app contributes to patients' empowerment and commitment to their self-care.

In terms of the reduction in hospital readmissions, which validates ControlVit as a complementary tool for the timely detection of complications, it is important to note that most of the patients in the study had reduced ejection fraction and compromised functionality, an aspect that can become a risk factor in terms of decompensations. As such, the alerts generated by ControlVit and the timely response from clinicians potentially improve treatment for this population at risk.

The TAM used in the clinical test of ControlVit was based on three fundamental axes: perceived utility of technology, ease of use of technology, and attitudes toward technology.[30] The first two constitute two types of beliefs, and the third is a type of attitudinal disposition. This stems from the understanding that one of the key aspects in predicting the success or failure of the implementation of new processes and technologies is to know the opinion of the stakeholders involved.[31]

Table 1. Technology Acceptance of the Mobile Application by Patients

Construct	Totally Disagree %	Disagree %	Neither Agree Nor Disagree %	Agree %	Totally Agree %
Performance expectancy	0	0	0	0	100
Effort expectancy	0	0	0	0	100
Social influence	0	0	10	0	90
Facilitating conditions	0	0	0	20	80
Behavioral intention	0	0	0	10	90

Table 2. Technology Acceptance of the Web Application by Clinicians

Construct	Totally Disagree %	Disagree %	Neither Agree Nor Disagree %	Agree %	Totally Agree %
Performance expectancy	0	0	0	100	0
Effort expectancy	0	0	0	100	0
Social influence	0	0	100	0	0
Facilitating conditions	0	0	0	100	0
Behavioral intention	0	0	0	100	0

Source. Results of trial.

The results of the TAM survey show that all patients recognized the utility (performance expectancy) and ease of use (effort expectancy) of the mobile app. Facilitating conditions, for their part, are factors that influence potential use of a technology.[9] They are explained as environmental factors that facilitate or prevent acceptance of the use of technology. This construct indicates the perception that users have about the technological support available for the use of apps. In the case of apps in general, they will require some knowledge from users. This would indicate that knowledge of app management can influence its use. Users with greater knowledge are more likely to use apps.[32] Although this item did not achieve total agreement, it was generally accepted, and it went beyond expectations, along with effort expectancy. Although not all patients with HF are senior citizens, most of them will be, and this might imply difficulty in adopting mobile apps. However, we found that, on the one hand, in cases where there was difficulty, there was always support from family members or carers. On the other hand, we found enthusiasm, empowerment, and motivation not only in using the app to send data to the clinic, but also in using it to improve self-care. In a few instances where patients did not get immediate confirmation of data sent, for example, senior patients would contact the clinic to make sure their data had arrived. In addition, many patients asked for the possibility of getting the kind of dashboards meant for clinicians, again with the intent to empower themselves and take a more active role in their care.

Moreover, as is usually the case with information technology, once the user has acquired some level of competence, the necessary effort decreases and the pleasure increases, from the perspective of the user experience, which is a strong driver for a product based on information and communication technology[33]; this aspect coincides with what was manifested by the patients who reported that it was easy to learn, clear and non-intrusive.

The acceptance of the app was not only evident with patients, but also nursing professionals identified the usefulness of the app in operational management in the HF clinic, highlighting the ease to install and manage the app. Social influence was a weak point. In conversation with the nurses, they manifested that because it is a novel technology, they did not feel pressure or motivation from colleagues to use it. And because it was a pilot study, there was no institutional mandate to adopt.

STUDY LIMITATIONS

The results of the pilot clinical test show that ControlVit constitutes a promising telemonitoring tool in the follow-up of patients with HF. Being a preliminary pilot study with 20 patients during 6 months is the main limitation of the study. We are developing a larger-scale clinical trial with more patients in order to verify the preliminary results here reported. In addition, the study has used the number of alerts and readmissions as an indirect measure of positive health outcomes. Tracking patients over a longer period, considering additional variables (such as specific complications), and taking cost saving into account should strengthen the evidence behind the benefits of telemonitoring apps for patients with HF, such as ControlVit.

CONCLUSION

A telemonitoring app, called ControlVit, has been designed and evaluated in an HF program, specifically through a mobile app for patients and a Web app for clinicians. A preliminary clinical pilot study indicates that ControlVit is a potentially effective tool to detect complications and modify drug treatments, avoiding symptomatic progression and potential hospitalization in a timelier manner than traditional approaches, such as telephone-based follow-up. In addition, it can contribute to patient empowerment and thus have a positive effect on self-care and treatment adherence. Acceptance of the app by patients and nurses suggests the possibility of implementing it as a complementary follow-up strategy in patients with HF.

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