Designing Patient-Centered mHealth Technology Intervention to Reduce Hospital Readmission for Heart-Failure Patients

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Abstract

In the US, approximately 5.8 million people suffer from Congestive Heart Failure (CHF). It is the most frequent cause for hospital readmissions such that 21.2% of Medicare patients diagnosed with CHF were readmitted to hospital within 30 days of discharge. Tele-monitoring daily self-management regimens may reduce hospital readmission. MyHeart is a telehealth system, which we have designed for CHF patients to bridge the current gap in the Congestive Heart Failure care continuum when the patient moves to the home environment. The system uses wireless health devices and a mobile application to collect patients’ data; moreover, it sends messages to patients to encourage self-care as per Fogg’s behavior model. On the clinician’s end, we designed a rule-based expert system and a dashboard to process and display patients’ vitals, symptoms, and health risk. MyHeart is currently being used at Loma Linda University (LLU) Medical Center and we report here our initial findings.

1. Introduction

Congestive Heart Failure (CHF) is a chronic condition that is common among individuals older than 65 and it is caused by Coronary Heart Disease, Hypertension, or Diabetes [1,3]. CHF is described as the inability of the heart to meet the body’s needs for oxygen and nutrition. Thus, the amount of blood that the heart pumps decreases, causing fluid such as water to leak from vessels. Therefore, the symptoms of such a condition are detected by weight gain, shortness of breath, fatigue, and edema “swelling” [2]. This, of course, affects a patient’s ability to exercise and the fluid congestion may impair lung and liver functions. Additionally, there are non-cardiac and cardiac comorbidities that play an essential role in CHF progression and patients’ response to treatment such as Anemia, Hypertension, Arthritis, and Diabetes [25,26].

Approximately 5.8 million people in the US suffer from CHF [3].

The estimated cost of diagnosis and treatment of CHF was 37.2 billion dollars in 2009 [4]. A report published by the American Heart Association (AHA) indicated that CHF is the most frequent cause for hospital readmissions. Of the Medicare patients diagnosed with CHF, 21.2% were readmitted to the hospital within 30 days of discharge. CHF is not curable but evidence shows that the quality of life and life expectancy of patients could be improved if the condition is managed by adhering to medications, monitoring symptoms, and reducing salt intake in the diet. However, individuals with CHF face increasing complexity in self-managing their care in their homes as it demands consistent monitoring, taking medication, reducing sodium intake, and improving physical activity [5].

Prior studies have shown that providing better support for patients in the home could have a dramatic effect on the cost and efficacy of healthcare [6, 7]. Recently, such technical systems have been applied to assist CHF patients [12, 13]. The problem is that self-care requires behavior change and support from clinical personnel.

Theoretically, three elements 1) motivation, 2) ability, and 3) a trigger must converge at the same time for a behavior to change. According to Fogg’s Behavior Model [8], when at least one of the above elements is missing, behavior doesn’t change. Typically, people have low motivation and a low ability to change. If one’s ability is high, then change can occur. Similarly, if one’s motivation factor is high, change can occur. What leads to higher motivation? If the activity is pleasurable instead of painful, if there is hope as opposed to fear, and if doing the activity leads to acceptance as opposed to rejection. Our ability to act is higher when it takes less time, less effort, and less
cost. However, Fogg states that an external “trigger” is required to propel a person to change. We believe “just-in-time” messaging via smartphone apps can act as effective triggers and our recent work has provided support for this hypothesis [14].

With the growing number of cases and the limited number of clinicians, finding more effective strategies to support self-care is critical. Home tele-monitoring has the potential to improve the outcomes of chronic disease self-management [8, 13].

Loma Linda University (LLU) Medical Center is currently facing a significant problem with hospital readmissions. About 30% of their CHF patients are readmitted within 30 days, while nearly 50% are readmitted after 60 days compared to around 50% or more readmission nationwide according to AHA. Regularly measuring vitals (weight, blood pressure, glucose, heart rate) and monitoring the patient symptoms may reduce the readmission rate and provide more control over patients’ condition. We see tremendous potential in healthcare information technology to improve patient health outcomes as well as reduce hospital readmission. In this paper, we extend our research in [24] on MyHeart, a novel home tele-monitoring system designed and built to support CHF self-care of patients at LLU. This paper presents a background of tele-monitoring for heart failure management, the design and architecture of MyHeart system, its preliminary evaluation, and our initial results and analysis.

2. Background Literature

“Daily home care tele-monitoring reduced the frequency of home nursing visits, provided cost savings, and was associated with improved self-perceived quality of life.”[29] A number of home monitoring systems have been developed to support heart failure. For instance, a home monitoring system that only measured weight on a daily basis was found to reduce the length of patients’ stay at the hospital [30]. Another system that incorporates artificial intelligence in the design was also reported [31]. Additionally, CARDIAC was designed to provide support through a conversational assistant [32]. A telephone support and implantable devices were among the interventions [28]. Heart Failure Management is an example that consists of two platforms: one dedicated to the patient, who suffers from heart disease, and the other to professionals, who are clinicians and practitioner nurses [27]. Our system is based on this two-faced system with innovative interface design and customized, encouraging messages.

3. System Design & Architecture

For system usability, two main principles have to be met: ease of use and clarity. With MyHeart, CHF patients are required to measure their vitals every day using the devices and to submit their symptoms using the app. Additionally, based on their data, they will receive customized reminders and motivation messages to adopt a healthier lifestyle. The system leverages the concept of persuasive technologies, defined as applications and devices intentionally designed to change user behavior [15-18]. It is comprised of three major components: 1) a patient-facing home architecture to collect data 2) a mobile app; 3) a healthcare provider’s dashboard (Figure 1).
3.1. Home architecture to collect data

In order to collect measurements, the Blood Pressure Monitor (A&D) and MyGlucoHealth devices that connect via Bluetooth through a 2Net communication hub and which wirelessly transfer data to MyGlucoHealth platform, are used. Data transmission uses cellular technology and is initially collected at the MyGlucoHealth data repository. These devices measure patients’ vitals and biometrics through a weight scale, blood pressure cuff, and glucometer (Figure 2) [9].

3.2. Mobile App

A smartphone app for an Android OS was designed to display vitals and gather CHF patients’ symptoms. The app contains an authentication window (Login) that is displayed one time to the patient (Figure 3). After that, his/her credentials are stored into the phone and they are used every time the s/he communicates via web services API. The patient’s vitals are displayed in the first tab (Figure 4). In the second tab, his/her symptoms such as chest pain, waking up at night, tiredness, shortness of breath, swollen feet (edema), and other related data like taking medication are collected (see Figure 5). At the patient’s end, the Vitals tab displays the Body Mass Index (BMI) (Figure 4) and is designed to be simple and clear using large text with a different color for each vital measurement. User experience principles are employed via friendly or dynamic colors because they are more comprehensible to the elderly. For the Symptoms tab, we started with 5 questions following the nurse practitioner request, some have (yes/no) answer and others can be answered with a slider from 0-10 (Figure 5). The slider provides flexibility for range values that participants were very comfortable with and who, after being trained, did not show any hesitation in using the device.

After the first prototype was released to LLU practitioners, they asked that we add the fatigue question (Figure 5).

Additionally, one of the questions is “Did you take your medication? Yes/No” is included in the Symptoms tab to save the patient from an extra step in navigation and another button to press.

Reminders and Messages tabs are aimed to serve different purposes: remind the patient of missing data (vitals measurements) and encourage/motivate self-care behaviors, respectively. Thus, they were in two separate tabs (Figure 6 & 7). A reminder example would be “Please remember to enter your symptoms and vitals,” while a behavior change message would be "Great job for weighing yourself daily" or "God loves..."
Google Cloud Messaging (GCM) Notification is used to send those reminders and messages.

Patients’ vitals are plotted on a daily basis using a linear graph and displayed in the Chart tab to detect trends. To provide consistency on what patients and health providers see, we display the web content for the chart on the smart phone, which is the same one for the dashboard (Figure 8). Considering some patients’ preference to use their own glucometer, the Input tab will enable them to do it manually (Figure 9).

3.3. Dashboard for Clinicians and Nurses

The dashboard displays a table with color indicators for critical conditions. A three-color schema: green, yellow, and red are used for low, medium, and high risk, in order. Additionally, historical trends are accessible with drill down functionality; yet, clinicians cannot query all data at this time (Figure 8).

Dashboard information is collected daily from the patients’ homes. Each data point is analyzed using a rule-based expert system refined by LLU practitioners; it processes daily incoming data (weight, blood pressure, blood glucose, and symptoms) then calculates a risk score. This risk score informs healthcare providers of any possible relapse of a given patient on a daily basis. Additionally, it triggers urgent notifications (email and SMS messages) to providers about the patient’s current health status. Because high-risk score patients are more likely to be readmitted to the clinic, the system notifies the nurse to make a call and speak with high score patients, either to resolve the issue or to ask them to come back to Emergency Room (ER).

In order to make MyHeart system able to mimic how a human nurse would process the health data, an interview was conducted with the director of cardiac health and wellness at LLU Medical Center to design a flexible and scalable rule-based expert system. Even though there are well-established guidelines available from American Heart Association (AHA), the nurse suggested incorporating the values shown in Table I as the source for rules. The rules are fixed now, but after the pilot is over, we will revisit them to ensure currency and relevancy.
Table I. Expert System Data Ranges for Rules Creation (based on input from Cardiac Nurse)

<table>
<thead>
<tr>
<th>Measurement/Risk</th>
<th>Normal</th>
<th>Medium-Risk</th>
<th>Medium-Risk</th>
<th>High-Risk</th>
<th>High-Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Below</td>
<td>Above Average</td>
<td>Below Average</td>
<td>Above Average</td>
<td>Above Average</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>60-79</td>
<td>50-59</td>
<td>80-99</td>
<td>&gt;=49</td>
<td>&gt;=100</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>90-129</td>
<td>80-89</td>
<td>130-139</td>
<td>&gt;=79</td>
<td>&gt;=140</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td>60-79</td>
<td>50-59</td>
<td>80-89</td>
<td>&lt;=49</td>
<td>&lt;=90</td>
</tr>
<tr>
<td>Weight</td>
<td>+/-1 lb</td>
<td>-1.5 lb</td>
<td>+/-1.5 lb</td>
<td>-2 lb</td>
<td>+2 lb</td>
</tr>
<tr>
<td>Blood Glucose</td>
<td>60-200</td>
<td>&lt;60 and &gt;50</td>
<td>&gt;200 and &lt;240</td>
<td>&lt;50</td>
<td>&gt;250</td>
</tr>
</tbody>
</table>

3.4. System Security & Structure

Because of data sensitivity, security measurements are implemented at every stage from data collection, transfer, transformation, and finally to display. As the data is collected, a unique key is generated at the patient’s mobile application side and data will be encrypted and encoded in a json format. In conjunction with the patient’s phone number, the unique identifier is transferred to the central database every time the patient’s phone communicates with the database. At the app level, to protect the patient’s identity, there is no identification of him/her displayed on the app. Data collection between MyGlucoHealth and the database is established based on an automated schedule that runs daily. Security for MyGlucoHealth is developed at the vendor’s location [24].

All data are collected and stored on a Microsoft SQL 2008 server with Windows-based authentication. Patient and rule-based metadata are stored with traditional transactional normalized design for scalability. With this approach, additional patients can be quickly added without any overall impact to the system. Similarly, all reporting and information displays, such as the information dashboard, utilize a data mart design philosophy for speed and security purposes. Although a data mart design forces data transformation between raw data and final display, the data mart design presents two additional benefits: data traceability and data security.

The dashboard is designed with open-source high charts for charting needs [10] and the main web server uses Microsoft’s IIS for hosting ASP.NET and VB.NET code. Google Analytics is used for additional usage tracking [11].

4. Pilot Study Details

After obtaining approval from the Claremont Graduate University (CGU) and LLU Institutional Review Boards (IRB), we conducted a pilot study at Loma Linda University Medical Center to evaluate the system. The pilot targeted 10 subjects who were recruited and consented through the clinic. A survey, focus group, and usage statistics are used to evaluate the system. Two researchers from IDEA lab...
trained the patient one-on-one at the hospital location to use the devices and the app. A practitioner was presented during training and some patients brought a family member with them. Some eligibility criteria that we included in our recruitment efforts were:

- Subject must have heart failure condition
- Age is over 21
- Gender and race – no preference
- Have a broadband internet connection at home

Eight patients are currently enrolled and practitioners use the dashboard to view their home data daily. The pilot trial started on March 14, 2014.

All patient data that flows from the homes to Cloud to the Clinician’s dashboard is encrypted as per HIPAA requirements. Patients are being asked to measure their vitals and submit symptoms in the morning. They can also do the measurements and submit symptoms many times as they will be saved in the database; however, the system will process data at 12:00 PM, trigger notification at 1:00 PM, and display only the first measurements on the dashboard and the app per LLU practitioner’s request.

5. Preliminary Evaluation

5.1 Patient evaluation

The mobile app usage statistics show that the average session duration is around 20 seconds (Figure 10.b) and that overall, patients viewed the vitals screen over 1,272 times, the symptoms screen almost 1,245 times, the reminders screen 1,345 times, the messages screen 961 times, and the chart screen 765 times over an approximately five month period (Figure 10.a). Other statistics such as unique screen views and percentage of each exit where users navigate outside the screen are also reported. The symptoms were submitted a total of 419 times and manual input of glucose a total of 55 times (Figure 11).

![Figure 11: MyHeart App Event Statistics](image)

According to Google analytics for the app, the Reminders, Vitals, and Symptoms tabs were reviewed the most. Messages are less since patients may be unaware of the notification bar at the beginning of the trial. Additionally, some patients preferred to use the manual entry in the app for glucose (55 events) (see Figure 11).

5.2 Provider evaluation

Since system deployment, Google Analytics showed that the dashboard had almost 360 sessions with over 980 pages viewed over a 45-day period. An average session usually lasts slightly over 2 minutes with a peak time at mid-morning (10:00 AM) and early afternoon (1:00 PM) (Table II).

![Figure 10: MyHeart App Screen Views Statistics](image)

<table>
<thead>
<tr>
<th>Sessions</th>
<th>Pageviews</th>
<th>Avg. Session Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>359</td>
<td>985</td>
<td>00:02:10</td>
</tr>
</tbody>
</table>

Table II. Dashboard System Session Statistics
Additionally, six dashboard users evaluated the quality of the system using an online survey. The results of the survey are shown in Table II. Participants agreed that it was easy to understand information on the dashboard and make decisions; however, about 17% said that text messages were not that useful for them (Table III).

### 6. Results and Analysis

After a two-month trial, we conducted a focus group with patients and here are the observations, recommendations, and challenges:

One patient was readmitted for heart failure during the trial. Her heart rate dropped to a similar level as before her last admission, although, according to the nurse, she reported no symptoms. The patient had some edema. Another patient, who stopped using the devices and the app, needed to go back on dialysis and he is not a candidate for a Left Ventricular Assist Device (LVAD). As such, the patient needs to explore having a kidney and heart transplant; yet, he stated that the system prevented him from readmission since his vitals were collected in real-time, at which point, the nurses immediately intervened.

Some patients asked to have a more flexible way to input information regarding symptoms and to plot that data into a chart. Also, patients were not aware of the message and reminder notifications on the app, so our team intervened to clarify them.

Some patients faced issues with the glucometer which made them manually input data using the app. Additionally, the Wi-Fi connectivity issue of the smart phone at two subjects’ homes hindered their app usage. As a result, enabling a simple data plan or providing a hot spot are just a few solutions currently being discussed.

Another incident involved one subject running out of test strips for the glucose meter. Also, the blood pressure cuff was not giving the right reading in rare cases for one patient and there was a need to unplug the 2Net device once to make sure it was working properly.

<table>
<thead>
<tr>
<th>Table III. MyHeart System Quality Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Statements</td>
</tr>
<tr>
<td>1. This dashboard has all the functions I expect it to have</td>
</tr>
<tr>
<td>2. The information displayed on the dashboard was easy to understand</td>
</tr>
<tr>
<td>3. It was easy to navigate and find the information I needed</td>
</tr>
<tr>
<td>4. As a cardiac health professional, this dashboard captures all the necessary vitals and patient data</td>
</tr>
<tr>
<td>5. I trust the data presented in this dashboard</td>
</tr>
<tr>
<td>6. It was easy to learn to use this dashboard</td>
</tr>
<tr>
<td>7. I can easily pin point critical areas by using this dashboard</td>
</tr>
<tr>
<td>8. Using this dashboard would make it easier to do my job</td>
</tr>
<tr>
<td>9. Using this dashboard would enhance my effectiveness on the job</td>
</tr>
<tr>
<td>10. Using this dashboard saves me time in determining high risk patients I need to focus on</td>
</tr>
<tr>
<td>11. I utilize the patient detail page to make informed decisions about patients</td>
</tr>
<tr>
<td>12. The organization of information on this dashboard was clear</td>
</tr>
<tr>
<td>13. The dashboard allows me to make decisions about which patients to call or visit</td>
</tr>
<tr>
<td>14. The color highlight scheme is easy to understand</td>
</tr>
<tr>
<td>15. The charts in the patient detail page are clear and easy to understand</td>
</tr>
<tr>
<td>16. I find emails about patient’s risk condition very helpful</td>
</tr>
<tr>
<td>17. The text alerts about patient’s risk condition is extremely useful to me</td>
</tr>
<tr>
<td>18. The text message and email content notifying the patient’s risk condition was easy to understand</td>
</tr>
<tr>
<td>19. Overall, I am satisfied with the dashboard</td>
</tr>
</tbody>
</table>
Overall, the two objectives of this project—(1) Reduce hospital readmissions; (2) enhance self-care management of patients at home—were positively met. For example, patients liked the experience and that the devices worked properly for most of the time. Moreover, the system helped patients to adopt a more organized lifestyle; thus, achieving behavior change and self-management goals that improve the health outcomes of CHF patients. Finally, in a focus group session, a patient mentioned that consistent monitoring prevented him from readmission.

The LLU staff observations of dashboard regarding the risk score received for patients’ vitals and symptoms are:

Some patients’ weight losses were appropriate while others were not due to inconsistency of taking a diuretic that causes fluctuation in weight measurement. Also, some weight values were not representative due to some patients’ family members using the weight scale, which caused fluctuation in weight measurements sent to our database and triggered urgent notifications to healthcare providers.

Another patient who doubled up on her diuretic intake displayed symptoms of increased shortness of breath, which was also detected by the system. She was strongly urged by the doctor to come in to the Emergency Department (ED) if symptoms worsened.

Additionally, we had an incident involving the incorrect manual entry of blood glucose (very high value) that triggered a notification. Some patients had a high-risk score due to blood pressure. The nurse suspects that this stems from Autonomic Nervous System (ANS) dysfunction and diastolic dysfunction.

A nurse asked the CGU team to plot symptoms in a graph with a range of 0 to 5 and to have a baseline to observe the trends. In this way, significant changes will be easier to detect.

According to one of the involved nurses:

“for the patients with a high risk message, I rarely need to call. For instance, patient R had a high risk score for a weight loss of 3 pounds overnight. I am glad he lost 3 pounds, but it isn’t unusual or worrisome. Patient C sometimes has a high-risk score because of her HR—low HR is normal for her, in the high 40’s at times. If BP is running high (like Patient D), I just watch it and look for trends—to be addressed at clinic visit. Patient P often has an elevated HR due to his Atrial Fibrillation (AFIB)—today was high risk for 90—that is not too bad for him. The alerts need to be individualized—one size will not fit most patients! I did call Patient D for his weight loss of 4 pounds overnight—that is not usual for him.”

According to clinicians, sending out alerts and email for high risk after 24 hours is too late as they may not be able to take action. So instead of a 24-hours data collection time frame that we started with, we shortened it to 12 hours (midnight to 12:00 noon). Any data entered after 12:00 pm are considered tardy and not used for risk calculation. However, they will still be collected into the database. This change was huge and had the following effects:

- Automated data collection will start at 12:00 pm of the same day instead of 1:00 am for the prior day’s data.
- Notification (SMS/Email) will be triggered at 1:00 pm instead of 6:00 am.
- Dashboard will display current data instead of prior day's data.
- The app’s vital will display current data instead of prior day's data.

Overall, clinicians liked using the dashboard according to the survey results. The ease of use and the comprehensive information displayed allowed them to closely monitor the patients.

7. Conclusion

In this paper, we present the design and implementation of MyHeart, a system that aimed to:

- Reduce hospital readmissions
- Bridge the gap when patients move to the home environment in order to enhance self-care management.

The pilot trial is still ongoing as we write this paper. There are several health outcome parameters that are being measured at 30, 60, 90 and 120 days to do a pre-post comparison. Hospital readmission of any of the enrolled patients will be compared with the Electronic Health Record (EHR) data on LLU’s hospital system. Detailed analysis of those results will be reported in a future paper.

To the best of our knowledge, this telehealth system for heart failure self-care does not exist. It uses the concept of behavioral model to trigger behavior
change using messages. According to the focus group session, Consistent monitoring and motivating messages have helped patients to be more organized and cautious. Also, it provides a communication channel between patients and heart failure clinicians to detect any changes in patient’s health and avoid the readmission process.

Initial results are reported here and they indicate that the clinicians and patients are using the system. Future work will focus on incorporating feedback from the clinicians and the patients into the design of the system, such as inputting more information in the Symptoms tab. Additionally, deploying the app version on Apple store is one of our future plans. A predictive module to anticipate one’s blood pressure, weight, and Hemoglobin A1c (HGA1C) levels in advance, is also under development. Furthermore, we are planning for a larger clinical trial in order to better analyze the system’s impact on readmission rates and health outcomes.

8. Acknowledgment

The authors would like to acknowledge the grant from Loma Linda University Medical Center (CGU-LLU contract 21301903) that supported portions of this study. Additionally, appreciation goes to the nurse practitioners Sharon Fabbri and Denise Petersen for their insights into patients’ data during the trial.

Terms

Autonomic Nervous System (ANS): is the part of the nervous system that work as a control system below the level of consciousness to control body functions, including heart rate, breathing, and swallowing [22].

Hemoglobin A1c (HGA1C): it is a test that provides an average of blood sugar control over a six to 12 week period [20].

Atrial Fibrillation (AFIB): It is the most common cardiac arrhythmia (heart rhythm disorder); it is associated with congestive heart failure [23].

Left Ventricular Assist Device (LVAD): It is a mechanical pump implanted inside chest to help pump blood throughout the body [21].

9. References


