Meeting Sickle Cell patients' unmet needs with eHealth tools: a preliminary study

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Abstract

Background: Sickle cell disease is the most prevalent inherited blood disorder in the world. It can lead to many life-threatening chronic issues and comorbidities. The prevalence of the disease is more important in developing countries. In developed countries, self-help solutions for chronic patients are rising and are increasingly used. E-Health tools become companions for self-managing patients.

Problem: The use of mobile applications to support the self-management of chronic diseases has proved to improve the quality of life of patients. We try to identify the opportunities for people with Sickle Cell disease created by the use of such tools and investigate what are the patients' main concerns.

Method: We have performed a literature review to under-stand the main challenges of the disease. Additionally, we sent a questionnaire to patients to identify their needs. Finally we researched how the potential use of eHealth tools and Information and Communication Technologies based solutions could resolve some issues.

Results: The literature review has shown a low number of contributions but these studies had mainly positive outcomes. The results of the questionnaire have shown a significant dissatisfaction from patients about the health care system taking care of them. Patients' responses also showed their will to improve their general knowledge about the disease and their interest in using e-Health tools for improving their quality of life.

Keywords:

Sickle cell disease, eHealth, mHealth, self-care, self-management, self-monitoring, self-help devices, wearable devices, quantified self, public health informatics, global health, uHealth

Introduction

Sickle cell disease (SCD) is a complex hereditary blood disorder affecting red blood cells. It is a chronic disease that touches approximately 200 million people in the world. Originally the disease was spread from southern Europe to central Africa and from India through the Arabic peninsula to Western Africa. This distribution is thought to be correlated with the spread of malaria. Nowadays, due to migrations [1], there are cases worldwide with a high prevalence in the United States, Central America, the Caribbean, and in the UK [2,3]. However, SCD remains a rare disease in the 25 member states of the European Union, with a prevalence of about 1-5/10'000 [4]. Africa is the most touched continent but worldwide, around 400'000 babies are born with the disease each year. Consequently, the number of patients with SCD is growing continuously [3].

Moreover, most of African countries lack of financial resources. Beliefs [7] and organizational issues decrease the capacity of rapid action and the acceptance of treatments [8,9]. On the other hand, Sickle Cell disease is a neglected global health issue, requiring more awareness and a public agenda [6,10–14].

How SCD affects patients:

The disease manifestations are essentially debilitating vaso-occlusive crises (VOC) causing acute and painful episodes lasting around seven days. Deformed red blood cells get stuck in capillaries, organs don't receive oxygen anymore, causing dysfunctions and organs failures. The crises lead in most cases to hospitalizations but can sometimes be managed at home [15,16]. Patients are treated urgently by a supply of oxygen, hyper hydration, blood transfusions, fever control and strong opioids administration. This has to be performed promptly in order to avoid life-threatening complications [17]. These acute and chronic complications can be, among others, strokes, acute chest syndrome, pulmonary hypertension, generalized organ damages, priapism, blindness and gallstones. They are the cause of a short life expectancy and a low quality of life [18]. In average, acute VOC occur once per year but patients report pain every two days [19].

Management of SCD:

In developed countries, until few years ago, people with SCD rarely survived after childhood. Nowadays, thanks to guidelines [20,21], new treatments, pain management, systematic cares and early screening, the life expectancy, the quality of life and the quality of care are improving [22]. Half of patients survive beyond 50 years [23]. Therefore the main challenge is to avoid VOC as much as possible. The more complications happen, the more organs will be damaged. Subsequently, the treatment will become more expensive, difficult to manage, painful for the patient and the risk of premature death will increase.

Patients can reduce the frequency of VOC by following certain habits. The United States Center for Disease Control and Prevention released a self-care toolkit [24] that provides advices and guidelines on the treatment of complications and the manifestations of the disease. The document provides tips on how patients can get healthy habits, track, manage their chronic pain or prevent infections [25]. Infections are known to be a trigger of VOC and to avoid that, it is recommended to get vaccines. Furthermore, patients are advised to drink a lot of water in order

to keep the red blood cells hydrated. It is suggested also to maintain a moderate body temperature and to avoid putting the body in hypoxia. Therefore, patients should avoid high altitudes, tiredness and exhaustion due to physical activity and optimizing their diet to keep a certain level of blood acidity. Indeed, acid pH induce the sickling of red blood cells [6].

Lately, no studies have been published regarding the use of ICTs to support the self-management needs of people with SCD. We will present later in this paper some of patients' issues that could be tackled by the use of mobile apps.

Quantified-self movement and SCD:

The Quantified-Self (QS) movement illustrates the engagement of individuals in self-tracking many parameters like physical activity and performance, diet, psychological changes, health status or by physiological data. Tracking mental and cognitive states like depression or mood, environment variables for example weather or noise or social variables like charisma is also popular [26]. These data allow the self-tracker to be more aware and to understand himself better, by seeing data and charts. Thus, the user can be the catalyzer of lifestyle changes. However, making sense of data by creating knowledge and information is complex. The general idea is to aggregate data from many people and to process them with data mining techniques [27] in order to find new evidences or hidden insights.

For example, people can use wearable devices to collect data and use a mobile application that analyzes them and shows them in a meaningful way. The community of QS is continuously growing and many start-ups, companies or researchers are helping to solve the various challenges. Consequently, questions are raising about how to use, evaluate, protect and trust data [28,29].

The Quantified-Self movement opened the door to the use of Information and Communication Technologies (ICTs) as a resource for patients to cope and track their chronic condition.

Predictive analysis and early detection of VOC:

Useful information can be created from collected health parameters like tiredness, low blood oxygen, fast heart rate, difficult breathing or dehydration. It can even lead to predictive analysis for the early detection of crises. For instance by analyzing the oxygen consumption and oxygen needs [30–34]. These data could be tied to an alert system. When an unusual event or measure is detected, such a system could advise the patient to contact his doctor or take an action. When a patient need very close surveillance data could be sent directly to the doctor and potentially avoid complications.

We can argue that early detection of VOC could be tackled soon since sensors are now able to track in real-time comprehensive physiological data [35–37]. Some tools already exist and can be applied to SCD. For instance to prevent dehydration with non-invasive electrolyte sensors [38] and adequate drugs [39].

Developing them, in an accessible way for patients can benefit their health outcomes. Automating the recognition of such symptoms can give the opportunity to treat patients in a timely way and a system could for instance, help to prevent the triggering of crises or provide advices for behavioral changes or for a healthier lifestyle.

The use of eHealth tools for a more effective management:

Self-monitoring has been done for years by people with diabetes to control their blood glucose level. Results showed clinical benefits and an improved treatment management [40]. Providing caregivers an updated view on their patients' health status can help them to make better health decisions. Specifically for Sickle Cell disease, high-income countries lack of coordinated care and the scarcity of the cases can decrease the quality of care. People with SCD, but also caregivers, often lack of knowledge about the disease [41,42]. Information, on the health status of the patient, that are collected during doctors' appointments, exams or checkups, could be acquired by other means. Patients could, with devices available on the market, handle the measurement of their blood pressure [43,44], oxygen saturation, heart-rate and fatigue level [45]. These measures could help patients and caregivers to have a better control and understanding of their condition, lead to a better management of the disease and potentially avoid some visits at the hospital [46,47]. The data could be transmitted remotely and improve caregivers' decisions. We have seen some examples of earlier interventions and better health outcomes with the use of home tele-monitoring solutions for the management of chronic illness and long-term conditions like for instance diabetes, chronic obstructive pulmonary disease, hypertension or cardiac diseases [48–50]. However there are some challenges. It requires patients to be educated about their disease, to have knowledge about their specific case and to understand how to manage their condition with such tools. Likewise, a good level of compliance is necessary to maintain a long-term management [51] and all contexts are not suitable [46,52].

Prevention and early diagnosis:

To prevent the burden of sickle cell disease, patients can, thanks to genetic counseling, determine if their conjoint is also carrier of the sickle-cell trait [53]. It can allow them to avoid a high-risk pregnancy. Furthermore, if the disease is detected during pregnancy, parents can, in some countries, request a therapeutic abortion [54,55]. However, when patients actually have the disease, in addition to medical care, they can seek support from medical specialists, patients groups and communities. They can look for advices on how and where to find good cares and share experiences on how to organize their everyday life [56].

Globally, main issues are the negligence of systematic screening and the late diagnoses [57]. Consequences are a lack of appropriate care such as children immunization. Yet, organizing such screenings can decrease the infant mortality rate drastically and accessible technologies, as exemplified with the use of mobile microscopes, coupled to the automated counting of sickle cells, can facilitate it [58]. The recent development of small, mobile, cheap and simple to use e-Health tools is encouraging.

Access to information:

Mobile platforms can be used by patients and caregivers to retrieve and show information. They can also allow to create a knowledge sharing global network. And this can be a great opportunity to gain knowledge from patients around the world and a step forward for a disease lacking of awareness [59].

Some patients organizations give patients the opportunity to become more informed about the on-going research, the existing treatments, the new potential treatments [60] or the alternative treatments [61]. Such organizations like the Global Sickle Cell Disease Network [62,63] or Orphanet [4, 64] can help patients to get informed of their existence. Here, ICTs can facilitate the access to educational content and provide a list of the organizations of interest. The information could be used as well by medical educators and by families [65,66].

Methods

We conducted a literature review in order to identify relevant papers about ICTs solutions for Sickle Cell disease. We included all the systems created to tackle at least one of Sickle Cell disease issues as well as the innovative systems including

those without any focus on self-management. The systems included must also have be meant to be patients-operated. We used the terms "sickle cell disease" in combination with the keywords "mobile", "electronic", "self-management", "system", "mHealth and "cellular" on PubMed, IEEE Xplore, Cochrane, Web of Science and PLOS ONE.

Afterwards, we sent a questionnaire to several patients associations around the world (n=19; mean age 31.9 years; 21% males; 79% females) in order to identify patients' main needs and wishes in term of mHealth or healthcare organization. For this study, we excluded non-adult patients because our preliminary literature review revealed a lack of studies aiming adult patients and because of the recent life expectancy increase. The questionnaire included a total of 47 questions, including mandatory closed-ended questions with the possibility of adding an additional answer in free text and non-mandatory open-ended questions at the end.

Results

Literature review:

We identified 25 relevant papers. This low number contrasts with the millions of patients worldwide. It perhaps illustrates a lack of interest and awareness about the disease. Nevertheless, the reviewed studies showed interesting outcomes with the use of eHealth projects. The majority of the reviewed studies showed how relevant and promising can be the use of ICTs for patients with SCD. For instance, a mobile app aiming to provide patients a tool to manage patients' symptoms demonstrated their great interest in the use of technologies, and this, regardless of their demographics [67]. A project about a smartphone-based microscope suggested the potential use of a cheap tool to screen sickle cell disease in developing countries. Imaging techniques could be applied to detect abnormal red blood cells [68–72].

Several papers aimed to enhance patient-provider communication, pain-management and management of the everyday life. Other teams have developed a system using text messages helping to conduct psychotherapy interventions or monitoring the pain remotely [73–75]. They showed that technologies can help to improve the physical and mental health-status of patients. A web-based diary and a text messaging service for youth provided services for monitoring pain symptoms [76–78]. We also found an example of a system monitoring the school attendance and the daily activities of teenagers with SCD. This projects aimed to understand the extent to which the disease make children miss days of school [79,80]. These different projects indicated that patients had a good level of compliance with ICTs tools helping them to manage their disease.

The earliest telemedicine applications for the disease have been done in the early 2000s. They have shown better clinical productivity, as well as a good patient satisfaction. Patients could gain better access to healthcare, especially in rural remote areas [81–83]. Such projects are subject to some limitations. A study concluded that establishing medical homes is not always interesting [84]. Indeed, the lack of specialized medical staff is often too high and the lack of personal cannot always answer the demands [85]. Self-management solutions combined to telemedicine applications, for instance for pain management, were preferable [86]. A recent paper revealed an interesting use of sensors on portable embedded systems for patients living in remote areas [87].

Questionnaire:

The results revealed many interesting indications. First of all, the question about patient satisfaction revealed that many respondents were moderately satisfied (N=19; 30%) with the way the healthcare system treats them but most of the patients (N=19; 45%) were satisfied with the healthcare system (scale of 0-4, from not satisfied to extremely satisfied). Those contrasting results underline the interest of improving self-management tools. Further analysis will be required in order to understand the correlation with demographical and geographical information.

Enhancing patients' health-literacy level:

Mobile applications can provide information to patients about the disease and on how to have a healthy lifestyle. As described previously, there are some important actions that patients can take in order to improve their quality of life and decrease the occurrence of crises. Apps can then have an educational role.

Main patients' wishes are the following:

- Patients (N=19; 75%) want to receive information about what are the best behaviors to opt for in their daily life.
- They (N=19; 70%) also want to increase their knowledge of the disease in order to learn how to detect early signs of flare-up.
- Results (N=19; 55%) point out that they want to have access to information about how to self-care and get support to follow a healthy lifestyle (N=19; 45%).
- Respondents (n= 19, 65%) reported the will of getting access to support groups or patients' communities. They (N=19; 65%) also stated the wish of learning more about the available medicine, the new treatments and the ongoing research projects in which they could be involved.
- Finally, a slightly less important demand for patients (N=19; 45%) is to learn about the causes of triggering of VOC.

Self-care and daily activity support:

SCD patients being exposed to a wide range of symptoms that affect their everyday life, mobile applications, eventually used together with other electronic devices, can help them to collect data on their current health status and on variables that can affect it. In this case, apps can have a tracking as well as a warning role. The respondents' wishes in term of self-care and daily activity support are shown by the following results:

- Returned surveys showed that the two major causes of daily life disturbances due to SCD are pain episodes (N=19; 95%) and fatigue (N=19; 74%). These findings are supported by studies showing correlations between fatigue, pain and quality of life among patients with SCD [88, 89].
- Most of the people suffer every day (N=19; 25%) or every 2-3 months (N=19; 30%).
- Patients have difficulty to practice the recommended by WHO amount of physical activity (N=19; 60%) and at the same time, they struggle to manage their medication and to perform other self-care related activities (N=19; 50%).
- Patients visit their doctor monthly (N=19; 35%) or every 2-3 months (N=19; 75%).
- They reported a moderate desire to get information about their current health status (N=19; 50%).
- Respondents seem to be interested in wearing a device collecting their health data (N=19; 60%) and particularly to gather data about their state of fatigue (N=19; 65%), their pain symptoms (N=19; 55%), their health

status (N=19; 55%), their vital signs (N=19; 45%) and factors that could have an influence on their health like pollution, altitude, weather, alcohol or tobacco consumption (N=19; 45%). The survey showed that (N=19; 70%) of the patients are willing to share their health data.

- They explained also that receiving alerts when they should take medication or when their health status is worsening (N=19; 90%) would be of great value.

- Most of patients (N=19; 80%) found very important to carry permanently on themselves, information on their health condition and information about the disease, especially in case of emergency.

- Finally, the biggest fear of patients, as seen in some of the remarks they wrote in the free text zone at the end of the questionnaire, is to not wake up the day after, because of a stroke or a deadly complication caused by a crisis.

Non-functional requirements:

Patients also described what would motivate them to use a system responding their needs in a regular basis. The simplicity of use and the design were not crucial criteria (N=19; 45%) but a stable system providing accurate and trustworthy information (N=19; 65%) was the most important requirement.

Discussion

The literature review showed that mobile technologies, from embedded systems, physiological sensors or smartphone apps can be used together to support patients. For instance, among the studies found during the literature review, the papers of Jacob E. et al. [75-78] address some of the psychosocial issues of youth with SCD by facilitating the communication with their care provider in pain situations. The results of the study has shown an effective way to remotely assess the seriousness of a crisis and this can contribute to answer patients' demands of learning when their health status is worsening and of getting help about how to self-care in a daily base and in case of emergency.

The questionnaire results are also promising and emphasize the capacity of ICTs to help people with SCD. Patients seem motivated by the use of such tools in their everyday life. Their interest is marked about the use of mobile applications as an information provider, about the best behaviors to adopt, the disease and the treatment. The demand is less important concerning information related to self-care or to the causes of triggering of VOC. Patients answers demonstrate the impact of the disease on the everyday life with all the limitations that implies on normal activities. Fears mentioned in the free text comments illustrate the importance of the psycho-social issues in SCD [95,96]. Patients tend to internalize their worries and can also be subject to supplementary stressors [97, 98]. Patients have also acknowledged the importance to carry information about themselves and the disease in case it would be needed.

Efforts have been done about this last point in some countries to improve the care of patients in situation of emergency. The French Minister of Health provides for patients, information cards with information on the disease and a summary of patient's main conditions. [90]. Patients can have access to those cards by contacting their doctors. The first card, which must be signed by the patient, provides information on the doctor's contact and information about the people to notify in case of emergency. It also gives information about the best practices and the recommended interventions in emergency situations. Additionally, the card informs about websites talking about the disease and gives telephone numbers of specialists. Additionally, the

doctor can add personal medical information about the patient like the type of sickle cell disease, the basic level of hemoglobin, the special needs in terms of care, and the clinical antecedents. Finally, the doctor can write the complications that occurred frequently, the medicine regularly taken and the allergies. The last card is the information and advice leaflet. This document is meant to be used by the patient, his relatives and his entourage. It gives general information about the disease and practical advices about when to contact emergency services or how to prevent and manage early complications. Likewise, websites and contact information of the French patients associations are available. This kind of information can be helpful for patients and can be easily adapted to a mobile app or transferred on another device like an implantable chip readable by a caregiver [91]. This last point could raise other ethical issues and acceptance problems.

Rather than creating an entirely new system, it might be interesting to take into account the already existing solutions that solve some of the specific SCD issues. Some publicly available systems, for instance used in the diabetes self-management, can serve as a source of inspiration and could be used by people with SCD. Some mobile apps and wearable devices available on the market can track the sleeping patterns and the quality of the sleep, monitor the physical activity [92], symptoms of exhaustion, tiredness or fatigue, but also help to manage the medication, the dietary issues or the pain symptoms [93,94]. Results have shown that patients want to increase their knowledge of the disease, we can suggest that implementing evidence-based knowledge into a mobile app can potentially answer their needs. Furthermore, recent studies confirmed that systems developed using evidence-based knowledge could be more easily recommended by specialists and used by patients. [90].

As discussed, patients have multiple needs and wishes. Therefore, offer them systems with many functionalities that succeed to meet their needs while remaining simple to use and to understand is challenging. SCD patients have specific characteristics and face particular life situations that must be taken into account. For example during a VOC, pain can be so intense that any move is difficult and mobile tools could be designed to support patients in this moment by making emergency contacts easier. Needs are multiple and further study of the questionnaire answers will help to specify them in order to meet them accurately. At the same time, usability is one of the important factor able to keep patients motivated and invested. [99].

Future work

The next phase of our research will be to analyze in deep the results and to actively involve patients in the design of a solution that could fit their needs. We will also research the best devices that patient could use to track their health status. A participatory evaluation will help to assess the fulfilling of patients' requests. Previous studies have shown promising results when using such methods [100,101]. We will also investigate the specific characteristics of patients with Sickle Cell disease in order to identify which approaches are susceptible to keep patients motivated to use a system. Several games for health or apps using gamification items have reached a good level of compliance and popularity [102–104].

To illustrate our findings, we designed an early prototype of User Interface (UI) mockups. It is shown on Figures 1-4 The mobile app interface illustrated is meant to interpret some of the patients' main needs expressed in the results, for example their wish to get information about the best behaviors to opt for, their desire to get information about their current health status, the interest in collecting their health data, the demand of being reminded when to take medication or the need to get help in case of emergency. The UI design has been done by following the heuristic evaluation principles [105]. Thus, by using an iterative design process, we could increase the quality of the interface. Based on the proposed design, we will conduct focus groups with patients in order to get feedback, define their priority needs and the features they would like to use the most.

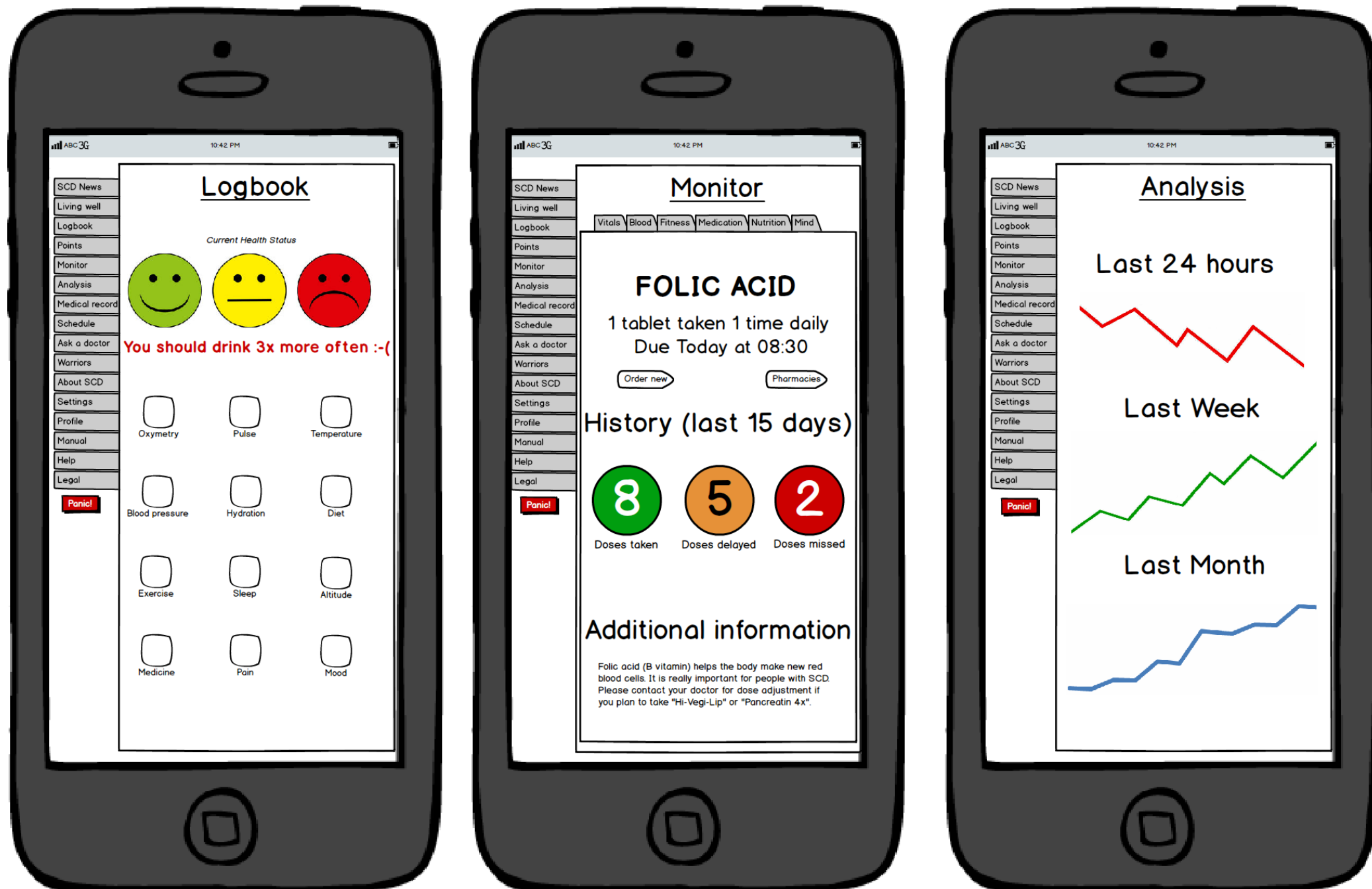*Figure 1 - First prototype of UI mockups proposed to patients*

Figure 2 - First prototype of UI mockups proposed to patients

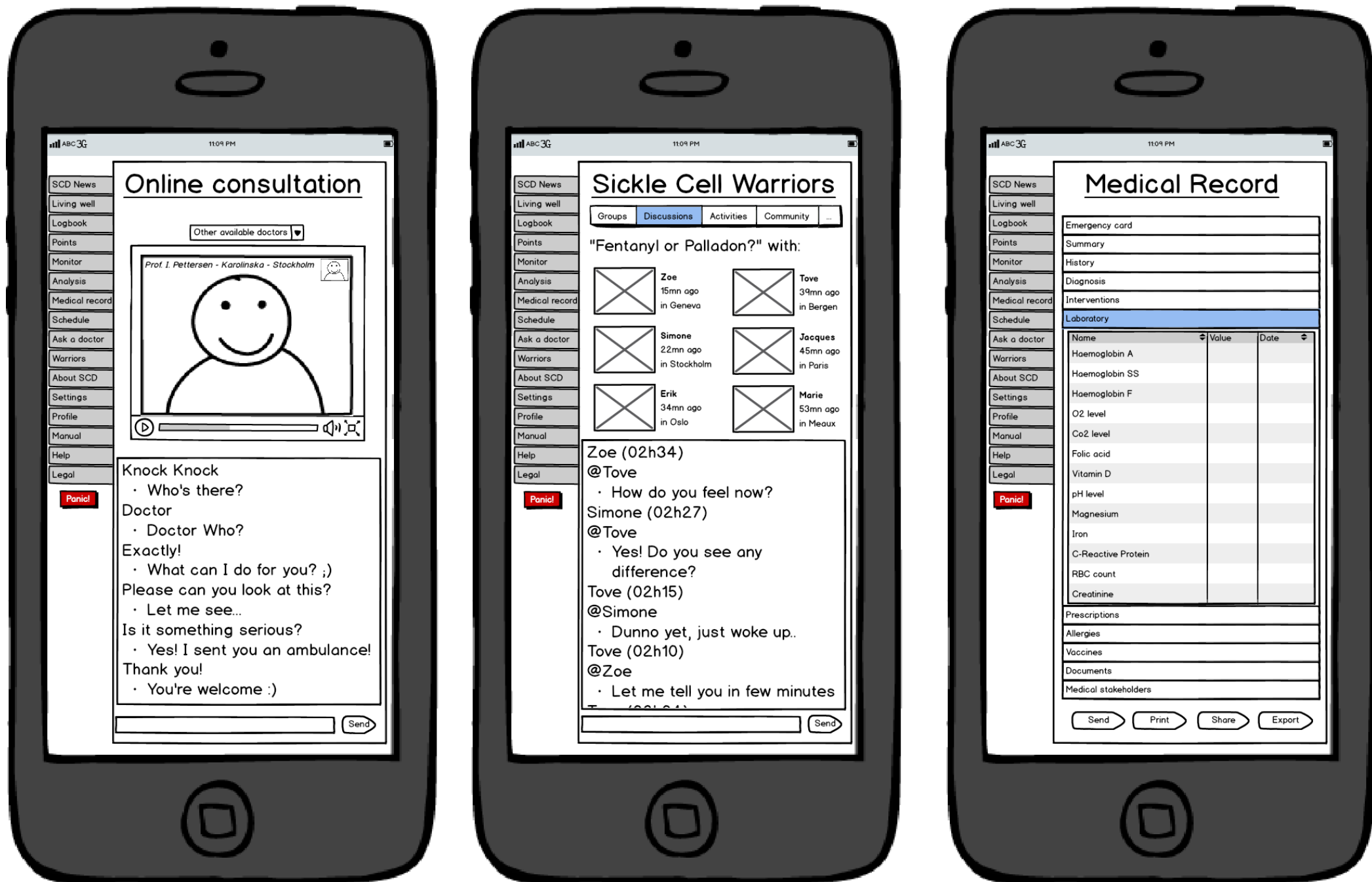*Figure 3 - First prototype of UI mockups proposed to patients*

Figure 4 - First prototype of UI mockups proposed to patients

Conclusion

To summarize, patients suffer daily of pain symptoms and fatigue, they report seeing a doctor on a regular and relatively frequent basis. The majority of them is interested in wearing a device, and in collecting data about their symptoms but less about their vital signs or about the extern variables that could affect their health. Finally, patients show a strong interest about sharing experiences, by being in contact with patient groups or sharing their health data.

Sickle Cell disease is the most common inherited disorder worldwide and provoke important symptoms that affect patients' quality of life significantly. However, it remains a mostly unknown and few documented health problem, as demonstrated by the low number of relevant papers found in the literature. The disease illustrates the inequalities in health faced by patients in different care settings, despite the fact that the medical knowledge about the malady is important and especially because it has been proved that simple treatments and specific habits can improve the life expectancy [106]. The differences in treatment of patients, whether they are in the same country or whether they are in low-income or high income countries have negative consequences on the health outcomes.

That's why, the current illiteracy and the lack of awareness in which the disease is still held is preoccupying. Health professionals remain inadequately trained and informed, as well as the family and the entourage. That could illustrate a lack of interest or an insufficient political will towards the implementation and the improvement of existing solutions susceptible to increase the quality of care.

Fortunately, the use of eHealth tools for patients with Sickle Cell disease, could constitute a progress in the support of the disease worldwide. By allowing patients to measure health parameters, such tools can help patients in the self-management of their disease. Likewise, reviewed papers have shown that ICTs can be of an important utility for the self-care and self-monitoring of people with SCD. Tele-monitoring applications have equally shown their usefulness in helping SCD patients with these concerns [73]. Such tools could contribute to reduce the number of crisis by improving the ability of the patient and his entourage to detect bad symptoms early and to react consequently but also by helping patients to adopt appropriate healthy habits. Also, and it is encouraging, patients expressed, through the questionnaire, a marked interest for these solutions. They want to improve their access to information, to educate their entourage and to raise the awareness on the disease. They also want tools allowing them to collect their health data and to receive a quick feedback and an appropriate treatment when necessary.

So, work remains to be done especially to improve the data collection required to know better the patients' needs and to assess which technologies are the most suitable. Finally, although fraught by many challenges, the use of eHealth tools for SCD patients has a potential of improving health outcomes by tackling main patients' concerns.

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