The evolution of mHealth solutions for Heart Failure Management

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Abstract In the last decade, the uptake of information and communication technologies and the advent of mobile internet, resulted in improved connectivity and penetrated different fields of application. In particular, the adoption of the mobile devices is expected to reform the provision and delivery of healthcare, overcoming geographical, temporal, and other organizational limitations. mHealth solutions are able to provide meaningful clinical information allowing effective and efficient management of chronic diseases, such as heart failure. A variety of multi-parametric data can be collected, such as lifestyle, sensor/biosensor and health-related information. The analysis of these data empowers patients and the involved ecosystem actors, improves the healthcare delivery and facilitates the transformation of existing health services. The aim of this study is to provide an overview of (i) the current practice in the management of heart failure, (ii) the available mHealth solutions, either in the form of the commercial applications, research projects and related studies, (iii) the several challenges related to the patient and healthcare professionals' acceptance, the payer and provider perspective and the regulatory constraints.

Introduction

Mobile telecommunication technologies has penetrated multiple sectors, such as commerce, media, and finance with health being the one with the greatest potential [1]. The acceleration of the electronic health records (EHRs) uptake by the Health Information Technology for Economic and Clinical Health Act legislation and the access of patients to mobile devices, enabled the advent of the mobile health technology (mHealth) [2]. Specifically, the last years, the concept of mHeath as “the use of mobile computing and communication technologies in healthcare and public health” is continuously gaining place and expanding. Governments are interested in involving mHealth as a complementary approach for improving healthcare delivery and achieving the health-related Millennium Development Goals (MDGs) in low and middle- income countries [3]. This interest has enhanced the development and application of several mHealth systems in Europe and worldwide, which provide early evidence for mobile and wireless technologies potential.

One of the key factors for this rapid mHealth growth is the healthcare transformation and the penetration of the mobile technology in the everyday life. The number of smartphone devices surpassed the world population, which accounts for 7.22 billion [4]. About 80% of the world’s population has access to a smartphone device with advanced technical capacities [5]. From 2011 to 2014, there was a remarkable increase from 35% to 64% in the proportion of Americans who owned a smartphone [6]. Smartphones may include several sensors, such as accelerometers and cameras, which can be used in different application areas. The spread and sophistication of such devices is growing rapidly. Wearable devices, such as smart watches, wristbands and clothing, have been designed and fabricated incorporating physiological sensors and they are able to collect and transmit data to the smartphones in order to be analyzed locally or to the Cloud. Taking into account the popularity, availability and technological capacity of the smartphones, their integration with the mHealth has the potential to address the issue of disease management.

The mHealth technology is able to address specific needs and serve a wide range of purposes of heterogeneous audiences, including healthcare professionals, caregivers, patients, or even healthy people [7]. The mHealth solutions are evaluated in diverse scenarios: (i) timely access to emergency and general health services, (ii) patient monitoring and management, (iii) reducing drug shortages at healthcare institutions, (iv) improving clinical diagnosis, and (v) assisting in overall adherence. One of the key characteristics of mHealth is the ability to serve the patients not only in the everyday life, but also during hospitalization or even rehabilitation. The acquisition and collection of patient specific information and the use of mHealth strategy in the clinical practice have been shown to be an easy and efficient way for improving service delivery in healthcare systems, and in turn for providing health benefits to the patients [8].

mHealth in chronic diseases

Chronic diseases are among the leading cause of mortality and morbidity [9], [10]. The management of chronic diseases requires a long-term treatment. Patients spend about one hour per year with their healthcare professional and around 10,000 hours to manage their health and disease symptoms by themselves. Self-management involves the management of symptoms and disease monitoring to prevent further complications. This can be achieved through the adherence to the suggestions provided by the experts. The adherence is one of the key factors for improved health outcomes and quality of life, however 50% of the patients with chronic diseases are non-adherent [11]. This burden is higher in the developing countries [12]. According to the World Health Organization (WHO), "increasing adherence may have a greater effect on health than improvements in specific medical therapy" [13]. Given the growing prevalence of chronic diseases combined with the increasing adoption of smartphone devices, the use of mHealth for patient self-management and disease monitoring seems promising. Several studies have shown the benefits gained for the patients after the adoption of mHealth systems. A meta-analyses on mHealth interventions for self-management of diabetes [14] showed that significant improvements in the control of glycaemic levels for diabetes patients can be achieved. The interactive approach of mHealth for monitoring blood glucose, diet, physical activity and medication adherence was revealed by Saffari *et al.* [15]. Various analysis on diabetes self-management approaches through the utilization of mHealth showed that the monitoring of specific features, such as measured haemoglobin A1c, can result in significant health outcomes [16]. Parkinson's disease is a movement disorder of the central nervous system affecting about 6.3 million worldwide [17], [18]. The integration of sensors in smartphones sensors resulted is a powerful tool, allowing the accurate measurement and evaluation of different movement-related metrics, and it has gained the interest of researchers [19], [20], [21].

mHealth for cardiovascular diseases

Cardiovascular disease (CVD) is a chronic disease with a high prevalence [22] and it consists a clinical field in which mHealth could provide several advantages. A variety of unhealthy lifestyle behaviors are related to CVD. The on time and continuous monitoring of these factors could significantly lower individuals CVD onset risk. For example, obesity is associated with several physical and mental health conditions, such as CVD, and according to evidence a weight loss of 3% - 5% may delay or even prevent CVD onset and progression [23], [24]. In recent years, the use of smartphones and the provided functionalities for weight loss interventions have increased exponentially [25], [26]. In addition, for those at risk, the access to diagnostic tools, which are able to detect the disease at an earlier stage and provide outpatient monitoring with the associated improved care delivery and quality of life (QoL), has great promise. This can be achieved by the incorporation of informative ECG tools in smartphone-enabling technologies, which provides diagnostic ability in a scalable and cost-efficient way [27].

mHealth and Heart Failure

Heart Failure (HF) is a chronic cardiovascular life-threatening condition. It is characterized by high rates of hospitalizations, readmissions and outpatient visits. These facts transform HF to a substantial economic burden for healthcare systems. The statistics, show that: (i) 26 million adults globally are diagnosed with HF, (ii) 3.6 million are newly diagnosed, every year, (iii) 3-5% of hospital admissions are attributed to HF incidents. Recent studies reveal that the direct and indirect costs are up to 2% of all the healthcare expenditure [28], [29], [30]. All these, in combination with the fact that the HF population is rapidly growing, make the improvement of the HF management the main objective and priority of cardiovascular healthcare systems. The available approaches and interventions assisting HF patients in disease management include: (i) nurse or healthcare professional group consultations [31], (ii) internet-based tools [32], (iii) printed materials [33] and, (vi) mHealth applications [34] being the most promising [35].

The mHealth based interventions can have several characteristics that give them the potential to be more effective, among which the most important are: (i) *interactivity* that allows the bidirectional communication and the care delivery, as a form of personal coach, (ii) *personalization* that makes the mHealth interventions customizable to the individual's needs, (iii) *timeliness* which permits the evaluation and delivery of targeted information at the right time point, (iv) *context sensitivity* expressing the ability of interventions to be adapted on the circumstances and/or the individual's environment, (v) *ubiquity and accessibility* of the technology to all segments of population [36].

The use of mobile technology in HF management has attracted the interest of several researchers, resulting thus to the presence of a large number of reviews in the literature. The reviews focus on the description and comparison of different existing, in the last decade, mHealth interventions, as well as on their impact [37], [38], [39], [40], [41]. The aim of this study is to present a short review of the mHealth HF interventions including also commercial available mHealth HF interventions and mHealth research projects related to HF patient management.

Heart Failure clinical problem and current practices

HF is a clinical syndrome that results from any structural or functional impairment of heart function, including: (i) dilated and familial cardiomyopathies, (ii) endocrine and metabolic causes of cardiomyopathy (obesity, diabetic cardiomyopathy, thyroid disease, acromegaly and growth hormone deficiency, alcoholic cardiomyopathy *etc.*), (iii) tachycardia-induced cardiomyopathy, (iv) myocarditis, (v) peripartum cardiomyopathy, (vi) cardiomyopathy caused by iron overload, (vii) amyloidosis, (viii) cardiac sarcoidosis, (ix) stress cardiomyopathy. The HF patients suffer from a variety of symptoms, such as dyspnoea, fatigue, low exercise tolerance, retention of pulmonary and/or peripheral fluid, urinary disorder [42], fast or irregular heartbeat [43], breathing difficulties during sleep [44], at rest or at exercise [45]. According to the ESC guidelines [29], the procedure for evaluating the disease in HF patients in a non-acute setting includes the following steps.

Step 1: History and physical examination. The healthcare professional, during the first step of the HF evaluation process, estimates the probability of HF based on the following parameters: (i) family history, (ii) NYHA class, (iii) weight, (iv) duration and severity of symptoms, (v) received medication, (vi) history of rehospitalization, (vii) lifestyle of the patient (nutrition and exercise), (viii) medical condition – comorbidities, (ix) adherence to treatment.

Step 2: Electrocardiogram (ECG). The resting ECG provides information regarding the presence of abnormalities, such as atrial fibrillation, left ventricular (hypertrophy and repolarization. In case all elements (collected during first and second step of the diagnosis process) are normal, HF is unlikely, otherwise laboratory tests (third step) should be performed.

Step 3: Laboratory tests. Laboratory tests include routine blood and urine analysis, examination of Natriuretic peptide (NT-proBNP) [46], [47], Cardiac Troponin T or I [48] and other emerging biomarkers. Based on these measurements, the experts are able to identify the patients who need echocardiography. Echocardiography is the method that is followed in patients with suspected HF, due to its high accuracy, increased safety and low cost.

Step 4: Non-invasive and invasive testing. Other imaging modalities, such as chest X-ray, stress echocardiography, cardiovascular magnetic resonance imaging, *single photon emission computed tomography radionuclide ventriculograph* and positron emission tomography, can complement echocardiography in case specific clinical questions must be answered. Invasive tests, such as coronary angiography, right-heart catheterization, endo-myocardial biopsy, can be performed when they have a meaningful clinical consequence.

Step 5: Risk Scoring. Certain risk scoring to homogenize the daily clinical practice, and to assist the healthcare professionals in making therapeutic decision (Seattle HF, CHARM Risk Score, CORONA Risk Score, EFFECT Risk Score, etc.) is currently used in the clinical practice.

Framingham, Boston, the Gothenburg and the ESC criteria are among the most common criteria used in the clinical practice for the determination of the presence of HF [49]. For the estimation of HF severity, the experts use the New York Heart

Association (NYHA) or the American College of Cardiology/American Heart Association (ACC/AHA) guidelines classification systems. These criteria/classification systems are based on the combination of information collected through the diagnosis process and allow the experts to determine the most appropriate treatment for the HF patients [50].

The objectives of treatment in patients with HF are to improve their clinical status, functional capacity and QoL, prevent hospital admission and reduce mortality. Among the recommendations for the treatment of HF patients are [51], [52], [53]: (i) Medication treatment, (ii) Nutrition suggestions, (iii) Exercise training, (iv) Education and, (v) Adherence.

The evolution in the field of medicine contributed to a widely available amount of medication for HF. In specific HF stages, patients are more likely to be prescribed more than one kind of medication [54]. Lifestyle modifications (nutrition and physical activity) should also be performed by HF patients on a daily basis. Specific attention should be paid to the weight monitoring since it is a key element in HF self-management [55], [56], associated with repeated hospitalization [57] and increased mortality [58]. Non-adherent behavior places barriers to the exploitation of existing knowledge and thus has a negative impact on the patient's clinical status and overall QoL. Even though the HF patients have at their disposal a plethora of health-based knowledge, the adoption of this knowledge in their life is lacking. Recent evidence reveal that less than 50% of the HF patients are regularly monitoring their weight, while about 33% of HF patients do not take any action [59]. This percentage is in accordance with the fact that patients' non-adherence, is among the major factors contributing to the increase of hospitalizations [60].

mHealth based HF interventions

The barriers, reported in the previous section, can be overcome by the use of mobile technology. mHealth enables the promotion of health intervention and can positively affect health related behavior in real-time [61]. A large pool of primary and review studies are available in the literature describing, comparing and evaluating the mHealth solutions, with the mHealth based HF solutions attracting the highest number [62]. The clinical, structural, behavioral and economic effects of mHealth solutions on HF are among the objectives of primary studies, while the systematic review focus on different aspects. A systematic review of mHealth-based HF interventions was presented recently by Cajita *et al.*, [41]. This study describes the already available interventions and their impact in terms of all-causes of mortality, cardiovascular mortality, HF-related hospitalizations, length of stay, NYHA functional class, Left Ventricular Ejection Fraction, QoL and self-care. According to the authors, the most commonly presented solutions are those that are able to remotely monitor the HF patient's status, using a mobile communication device in combination with a blood pressure sensor, weight scale and an ECG recorder. Similar observations are reported in [63], [64], which indicate the feasibility of portable home-monitoring devices connected to a smartphone to monitor the HF patients with high diagnostic quality and integrity of vital measurements. Specifically, the study of Ledwidge *et al.* [65] showed that the weight could be monitored through a wireless weight scale. Specifically, the patient's daily weight data were transmitted to a mobile phone and analyzed by an algorithm to predict the clinical deterioration in HF patients. The TEMA-HF 1 RCT used a telemonitoring system for enabling the healthcare professionals and the HF clinic communication [66]. The study included 160 HF patients from seven hospitals who used different sensors for measuring the daily weight, blood pressure (BP) and heart rate (HR). In case the predefined limits were exceeded, automatic alerts were created. The results of TEMA-HF 1 RCT showed that this telemonitoring system achieved a reduction in the hospitalization rate. A telemonitoring system which was used in 50 HF patients showed its value and impact on self-care, disease management and health related outcomes [67]. The quantitative outcomes revealed the empowerment of the HF patients and the ability of the clinicians to monitor and manage their patients in a more efficient and effective way. Another, similar study suggested that the use of the mobile phone telemonitoring approach could result in improved patient's medication regimen [68]. Additionally, this mHealth system provided the HF patients with automated suggestions related to lifestyle behavior. 120 patients from eight clinical centers who participated in the MOBITEL prospective, randomized study [69], were equipped with a smartphone device, a weight scale and, a sphygmomanometer for BP and HR measurements. All the measured vital parameters were transmitted to the mHealth application, while the patients were able to manually insert the perceived medication. Then, the data were collected and analyzed to a secure website, which enabled the numerical and graphical data representation. This mHealth system allowed the remote monitoring of the patients by the physicians and in case the transmitted values exceeded the personalized limits and/or early warning signs of decompensation existed, an automatic alert was created. The inclusion of the ECG sensor in mHealth systems has also been examined by several studies. Yap *et al.* [70] used a chest-belt of an ECG device and a specific mHealth application. Leijdekkers *et al*. [71] showed that a self-test mHealth application enables the HF patients to evaluate their clinical condition and support them in avoiding heart attacks, without the need of a healthcare professional. The main concept included (i) the collection and analysis of the ECG data depending on the patient's status, (ii) informed the patient and suggested a visit to the doctor, (iii) automatically alerted the emergency services providing the location and the status of the patient. Based on the findings of the previous studies, Seto *et al.* [68] created a rule-based HF mHealth system for measuring the weight, the BP, the HR and the ECG. After the data collection by the mHealth application, an analysis by the hospital data servers was followed. The aim of this mHealth solution was to create and send alerts to the patients and the clinicians automatically, taking into account the clinical guidelines.

On the other hand, the systematic reviews aimed to summarize the available evidence [72]. Kitsiou *et al.* [72] reviewed the effectiveness of home telemonitoring interventions for HF patients aiming to inform the policy makers, the practitioners and the researchers. The authors collected, evaluated and combined existing evidence from 15 reviews published from 2003-2015. The evaluation revealed that: (i) a better investigation is needed regarding the process by which home telemonitoring provides improved outcomes, (ii) an optimal strategy should be followed for such systems, (iii) the optimal follow-up duration for achieving the expected benefits should be defined, and (iv) further investigation of the differential effectiveness between chronic HF patients and types of home telemonitoring is proposed. Whitehead *et al.* [73] examined the effectiveness of mobile phone and tablet apps in the self-management of key symptoms of long-term condition management, among which was HF. The authors concluded that mobile phone and tablet apps have the potential to improve symptom management through enhanced symptom control. However, further innovation, optimization and rigorous research around the field is suggested for allowing the provision of improved healthcare and outcomes. The design, implementation and evaluation of mHealth technologies for chronic diseases management, like HF, is approached in the review study of Matthew-Maich *et al.* [74]. The authors concluded that in order to develop a feasible, well-acceptable and usable mHealth system the following should be taken into consideration. (i) A user-center design approach should be followed. (ii) A multidisciplinary approach, in which all ecosystem actors are involved in the disease management process should be applied. (iii) An iterative development process supported by theoretical background knowledge should be designed. (iv) The evaluation of the end-user's experience should be based on feasibility, acceptability, usability and health related criteria. (v) Barriers regarding organizational and systems readiness to adopt mHealth solutions, the perception of different group of end-users, as well as the user-technology interface that is used and the existing sociodemographic disparities should be taken into account.

In consideration of the primary and review studies [41], [72], [75], a taxonomy of mHealth-based HF interventions is presented in Table 1.

Table 1 Taxonomy of mHealth based HF interventions.

Dimension		
Functionality	Remote monitoring	Clinical monitoring
		Home monitoring
		Self-monitoring
	Training/Education	
	Point of care diagnostic	Embedded software application
		Connected devices
		Sensors
		Mobile attachments

Dimension		
	Behavior modification	Cessation Promotion Self-management
	Efficiency and productivity	Data collection Communication Telemonitoring
	Compliance	Treatment Medication Self-testing
Technical modalities	Mobile features	Text messaging Features developed ad hoc for a specific condition Add-ons Voice Video Multimedia messaging services
	Type of devices	Mobile devices, including a blood pressure measuring sensor, weight scale, electrocardiogram recorder or an implantable defibrillator equipped with a heart rhythm monitoring function Videoconference equipment Automated tele-monitoring stations Mobile phones Tablets
	Technological approach employed for the collection and transmission of data	Central monitoring center/platform Automatic data transfer between the participants and the monitoring center Manually input and transfer of patients data to the monitoring center Algorithms determining whether the patient's values are outside their predefined limits which would then trigger an alert message to be sent to the participants physicians Nurses and physicians in their central monitoring centers who regularly monitored the participants status Structured approach in contacting participants regarding their status

Dimension		
Design process	User-centered design	
	Multidisciplinary team approach	
Policy Consideration	Data management	On-device storage On-site servers Cloud computing
	Food and Drug Administration regulation	
	Mobile security	

Commercial available mHealth-based HF applications

Transformation of research results to a commercial product lead to commercial available mHealth-based HF solutions. The solutions are presented in the table below (Table 2) along with their privacy policy [76], their Institute for Healthcare Informatics (IMS) functionality scoring [77], their Mobile Application Rating Scale (MARS) score [78] and their Heart Failure Society of America (HFSA) guidelines score [76]. A short description of IMS, MARS and HFSA scores is presented in Table 3.1, Table 3.2 and Table 3.3, respectively.

Based on the HFSA guidelines score, the application that addresses all the HF specific self-care behaviors is the Heart Failure Health Storylines [79]. *AskMD* application followed by *WebMD*, *Symple*, *Heart Failure Health Storylines*, and *ContinuousCare Health App* had the highest average MARS score. The evaluation of the applications in terms of 4 subscale scores (engagement, functionality, aesthetics, and information) revealed that *AskMD* has the highest score for engagement, functionality, aesthetics and information, while *Heart Failure Health Storylines* application is on the top of the list for behavior change [76]. The commercially available applications were also evaluated regarding the functionalities they provide based on the IMS score. The results indicated that the *WebMD*, *Symple*, and *ContinuousCare Health App* had a total of 11 functionalities, while *Heart Failure Health Storylines* follow with 10 functionalities [76]. The five top applications based on the three scores are the following: *Heart Failure Health Storylines, Symple, ContinuousCare Health App, WebMD, and AskMD*. A description of the Heart Failure Health Storylines application is provided in Table 4.

Table 2 The scoring of the commercially available mHealth applications for HF.

Application name (platform)[a]	Privacy policy	HFSA guidelines score	IMS	MARS
ASCVD[c] Risk Estimator (Apple)	No	3	6	3.6
AskMD (Apple)	No	4	9	4.9

Application name (platform)[a]	Privacy policy	HFSA guidelines score	IMS	MARS
BloodPressureDB (Google)	Yes	3	7	3.2
Cardiograph (Google)	Yes	2	5	3.2
Continuous Care Health App (Apple and Google)	Yes	6	11	4.0
FAQs in Heart Failure (Google)	No	0	2	3.6
Health Manager (Apple)	Yes	4	7	2.5
Healthy Ally (Google)	Yes	1	6	3.8
Healthy Heart (Google)	No	0	1	0.8
Healthy Heart Numbers (Amazon)	No	1	2	1.3
Heart Disease (Google and Amazon)	No	0	1	2.2
Heart Disease & Symptoms (Google)	No	1	0	2.7
Heart Failure Health Storylines (Apple and Google)	Yes	8	10	4.1
Heart Guide (Google)	Yes	1	4	3.4
Heartkeeper (Google)	Yes	4	7	3.9
Heart Log (Apple)	No	2	5	3.8
Heart Services (Google)	No	0	3	2.5
iTreat-Medical Dictionary (Apple and Google)	Yes	0	4	1.7
iTriage (Apple and Google)	Yes	5	9	3.5
mediSOS (Google)	Yes	2	4	3.9
Miniatlas Hypertension (Apple)	No	0	3	3.5
My Cardiologist (Google)	No	1	2	2.0
My Health Tracker (Amazon)	No	1	3	1.7
My Heart Rate Monitor & Pulse Rate (Apple)	No	2	5	2.4
MyHeartApp (Apple)	No	4	4	3.7
Pulse Pro (Apple)	Yes	2	4	2.9
REKA (Google)	Yes	2	3	3.5
SelfCare-My Health Record (MHR) (Apple)	No	2	5	3.4
Symple (Apple)	Yes	3	11	4.3
Track your Heart Failure Zone (Amazon)	No	0	2	1.3
Urgent Care 24/7 (Apple)	Yes	4	9	3.7
URI Life (Google)	Yes	5	6	3.1
WebMD (Apple and Google)	No	7	11	4.4
WOW ME 2000mg (Apple and Google)	No	7	7	3.4

[a] Applications are available in Android Google Play, Apple iTunes, and Amazon Appstore

Table 3.1 IMS Institute for Healthcare Informatics functionality scoring criteria.

IMS Institute for Healthcare Informatics functionality scoring criteria	
Functionality scoring criteria	**Description**
1. Inform	Provides information in a variety of formats (text, photo, video)
2. Instruct	Provides instructions to the user
3. Record	Capture user entered data
Collect data	Able to enter and store health data on individual phone
Share data	Able to transmit health data
Evaluate data	Able to evaluate the entered health data by patient and provider, provider and administrator, or patient and caregiver
Intervene	Able to send alerts based on the data collected or propose behavioral intervention or changes
4. Display	Graphically display user entered data/output user entered data
5. Guide	Provide guidance based on user entered information, and may further offer a diagnosis, or recommend a consultation with a physician/a course of treatment
6. Remind or Alert	Provide reminders to the user
7. Communi-cate	Provide communication with healthcare provider/patients and/or provide links to social networks

Table 3.2 MARS- Mobile Application Rating Scale score.

Mobile Application Rating Scale score	
Engage	fun, interesting, customizable, interactive (e.g. sends alerts, messages, reminders, feedback, enables sharing), well-targeted to audience
	1. Entertainment: Is the app fun/entertaining to use? Does it use any strategies to increase engagement through entertainment (e.g. through gamification)? 2. Interest: Is the app interesting to use? Does it use any strategies to increase engagement by presenting its content in an interesting way? 3. Customization: Does it provide/retain all necessary settings/preferences for apps features (e.g. sound, content, notifications, etc.)? 4. Interactivity: Does it allow user input, provide feedback, contain prompts (reminders, sharing options, notifications, etc.)? Note: these functions need to be customizable and not overwhelming in order to be perfect. 5. Target group: Is the app content (visual information, language, design) appropriate for your target audience?
Function	app functioning, easy to learn, navigation, flow logic, and gestural design of app
	6. Performance: How accurately/fast do the app features (functions) and components (buttons/menus) work?

Mobile Application Rating Scale score	
	7. Ease of use: How easy is it to learn how to use the app; how clear are the menu labels/icons and instructions?
	8. Navigation: Is moving between screens logical/accurate/appropriate/ uninterrupted; are all necessary screen links present?
	9. Gestural design: Are interactions (taps/swipes/pinches/scrolls) consistent and intuitive across all components/screens?
Aesthetics	graphic design, overall visual appeal, color scheme, and stylistic consistency
	10. Layout: Is arrangement and size of buttons/icons/menus/content on the screen appropriate or zoomable if needed?
	11. Graphics: How high is the quality/resolution of graphics used for buttons/icons/menus/content?
	12. Visual appeal: How good does the app look?
Information	contains high quality information (e.g. text, feedback, measures, references) from a credible source.
	13. Accuracy of app description (in app store): Does app contain what is described?
	14. Goals: Does app have specific, measurable and achievable goals (specified in app store description or within the app itself)?
	15. Quality of information: Is app content correct, well written, and relevant to the goal/topic of the app?
	16. Quantity of information: Is the extent coverage within the scope of the app; and comprehensive but concise?
	17. Visual information: Is visual explanation of concepts – through charts/graphs/images/videos, etc. – clear, logical, correct?
	18. Credibility: Does the app come from a legitimate source (specified in app store description or within the app itself)?
	19. Evidence base: Has the app been trialled/tested; must be verified by evidence (in published scientific literature)?
Satisfaction	
	20. Would you recommend this app to people who might benefit from it?
	21. How many times do you think you would use this app in the next 12 months if it was relevant to you?
	22. Would you pay for this app?
	23. What is your overall star rating of the app?
Behavior change	
	24. Awareness: This app is likely to increase awareness of the importance of addressing [insert target health behaviour]
	25. Knowledge: This app is likely to increase knowledge/understanding of [insert target health behaviour]
	26. Attitudes: This app is likely to change attitudes toward improving [insert target health behaviour]

Mobile Application Rating Scale score	
	27. Intention to change: This app is likely to increase intentions/motivation to address [insert target health behaviour]
	28. Help seeking: Use of this app is likely to encourage further help seeking for [insert target health behaviour] (if it's required)
	29. Behaviour change: Use of this app is likely increase/decrease [insert target health behaviour]

Table 3.3 HFSA- Heart Failure Society of America–recommended non pharmacologic management behaviours.

Heart Failure Society of America–recommended non pharmacologic management behaviours	
Weight	daily weighing
Check swelling	checking extremities for swelling
Physical activity	doing physical activity or exercise
Diet	eating a low-salt diet
Medication	taking daily medications
MD appointment	attending doctor's appointments
Monitor symptoms	daily monitoring of HF symptoms
Symptom response	actively responding to symptoms when they change

Table 4 Heart Failure Health Storylines application short description.

Heart Failure Health Storylines

By Self Care Catalysts Inc

https://play.google.com/store/apps/details?id=com.selfcarecatalyst.healthstorylines.hf&hl=el

Developed in partnership with the Heart Failure Society of America, and is powered by the Health Storylines™ platform from Self Care Catalysts Inc.

Heart Failure Health Storylines provides tools to better manage and monitor heart failure:

- ***Medication Reminder:*** sends reminders for medication intake in the users mobile device
- ***Symptom Tracker:*** allows tracking of symptoms and side effects and provide patterns that should be shared with the healthcare provider
- ***Daily Vitals:*** user can keep a record of important vital measurements and provides graphical representation of them over time
- ***Physical Activity Tracker:*** keeps track of physical activity levels
- ***Sync a Device:*** user can import data from other health and fitness applications
- ***Daily Moods and Journal:*** track and understand users' emotions and what might be driving them. Additionally, keep a journal for increasing wellbeing.

mHealth projects related to HF management

Several projects are related to HF management. A short description of indicative projects accompanied with their comparison is depicted in Table 5.

The objective of RENEWING HEALTH (Regions of Europe Working together for Health) project [80] was to implement, validate and assess innovative telemedicine solutions for chronic diseases' management. Specifically, the project follows a patient-centered approach with the patient having a central role in the management of his/her own disease. It allows the (i) choice and dosage of medications for improving the medication adherence, (ii) early detection of early signs of worsening.

The exploitation and further deployment of the telemedicine services implemented within the RENEWING HEALTH project is the main objective of the United4Health project [81]. The patient-centered approach and the use of telemonitoring for the treatment of patients with diabetes, Chronic Obstructive Pulmonary Disease or CVD diseases is applied to all the service solutions. Services engage patients in the management of their disease, optimize the choice and dosage of medications, promote compliance to treatment, and help professionals to detect early signs of worsening. The patients use medical devices to measure the heart rate, blood pressure, pulse-oximetry and weight. The collected data are wirelessly forward from the medical device to a central gateway and a clinical operator evaluates them. The telemedicine solution is able to detect abnormal measurements and triggers an alert to the operator to investigate further the collected data and proceed to the appropriate decisions and actions.

The HeartCycle project [82] proposed a disease management solution, based on Phillips commercial platform Motiva® [83], for supporting and empowering the patients with HF. This is achieved by monitoring and analyzing vital signs and other measurements, including weight and physical activity activities. The patients are using a shirt with an embedded sensor for collecting the patient's vital signs during exercising. The communication between patient and healthcare professional is enabled through the patient's television. Personalized suggestions and educational material related to the patient's disease are projected through television after being analyzed by specific algorithms.

The HeartMan project [84] developed a personal mHealth system for assisting the HF patients and providing them personalized advice and support. The key components include: (i) the development of evidence-based predictive models, (ii) the creation of long-term models which focus on modifiable parameters, (iii) the delivery of a cognitive behavioral approach including mindfulness exercises, (iv) the use of advanced health monitoring devices for monitoring the physical and psychological state of the patient.

HEARTEN [85] takes advantage of the cloud technologies for computing and serving information. HEARTEN is a solution which can be used from all actors involved in the management of a HF patient, including caregivers and other ecosystem actors. The integrated Knowledge Management System and the Dynamic Patient Communication Protocol provide real-time monitoring, notifications and reminders, overcoming the barrier of non-personalized patient management and treatment. This is achieved through the employment of artificial intelligence and data mining techniques. Furthermore, HEARTEN's alerting mechanism adapts the behavior of its users and can change the channel and route of communication, enabling the active communication and interaction.

Table 5 Comparison of mHealth research projects related to HF.

	RENEWING HEALTH [80]	United4Health [81]	Heart Cycle [82]	HeartMan [84]	HEARTEN [85]
Users					
Patients	✓	✓	✓	✓	✓
Medical professionals	✓	✓	✓	✓	✓
Nurses	✓	✓	X	X	✓
Caregivers	X	X	X	X	✓
Patient centered ecosystem	X	X	X	X	✓
Devices					
Smartphones	X	X	X	✓	✓
Medical Devices/ Sensors	✓	✓	✓	✓	✓
Developed new Medical Devices/ Sensors	X	X	X	X	✓
Communication Hub/ Mobile Device	✓	✓	✓	✓	✓
Breath/ Saliva biosensors	X	X	X	X	✓
Data Monitoring					
Real-time Monitoring	✓	✓	✓	✓	✓
Integrated DSS	✓	✓	✓	✓	✓
Real-time triggers to Healthcare professionals	✓	✓	✓	✓	✓
Real-time triggering to patients	X	X	✓	✓	✓
Real-time triggering to other ecosystem actors	X	X	X	X	✓
Use of Artificial Intelligence					
Artificial Intelligence on Evaluation and Predictive model for collected data	X	X	X	✓	✓
DSS Patient Personalization	X	X	X	✓	✓
Data Mining Techniques	X	X	X	✓	✓
Sharing and Communication					

	RENEWING HEALTH [80]	United4Health [81]	Heart Cycle [82]	HeartMan [84]	HEARTEN [85]
Medical data available across all users	X	X	✓	✓	✓
Automated notifications/ reminders to the users aiming the patients	X	X	X	✓	✓
Escalation of notifications depending on the importance	X	X	X	X	✓
Automatic change of communication channel and/or route in case of no response within a time period	X	X	X	X	✓
Real-time communication between the users	X	X	X	✓	✓
Platform - Infrastructure					
Cloud services & services	X	X	X	✓	✓
Web access	✓	✓	✓	✓	✓
mHealth	X	X	X	✓	✓
Common Data Repository	X	X	X	N/A	✓

Challenges to the development and adoption of mHealth solutions

Although the impact of mHealth solutions is well accepted, several challenges for the development and adoption of the mHealth solutions should be addressed [27], [74]. Among the factors which support or hinder the implementation of mHealth solutions include: (i) the institutional environment such as culture, policies, and readiness to change and integrate such systems, (ii) the availability of a comprehensive business and exploitation plan, (iii) personal factors of the different end-users including perceived value of the mHealth solutions and (iv) factors related to the solution itself, such as usability by the different types of end-users. The challenges can be categorized to the following perspectives: (i) patient and healthcare professionals, (ii) payer, (iii) provider, (iv) regulatory bodies.

Patient and healthcare professionals

A barrier to the adoption of mHealth solutions by the patients and the healthcare professionals is that the applied approaches neglect to address the impact of the solution to the workload adjustments, practice preferences and to the existing daily routines of the end-users. Healthcare professionals will not be positive to the adoption of such a solution in case they are not convinced about the benefits and the added value in terms of professional role support. Furthermore, the perception that the solution can act as a supportive tool of organizational micromanagement reduces their willingness to adopt the solution. On the other side, patients prefer solutions that can be seamlessly integrated in their daily activities without consuming their functional and time capacity. Beside the perceived value, factors related to the usability of the solution and the level of engagement they provide to the different type of end-users are important factors for the adoption of the mHealth solutions. Solutions that are considered time-consuming, unreliable, burdensome, require the entry of information and/or provide feedback through non user friendly interfaces or even create doubts to the users regarding the protection of health information, remain a central concern.

The dispersion of mHealth solutions is affected by socioeconomic and demographic disparities. For instance, elderly and patients with low income are those most benefited by the mHealth solutions. However, such groups in general, have the least amount of access to the mobile devices.

Payers

The adoption/acceptance of a mHealth solution depends on payers. Payers should take into account the healthcare incentives and implementation reimbursement. Beyond the financial motivation, payers can aggregate and synthesize evidence to enhance learning and use of mHealth solutions. Additionally, the interaction of patients with payers through the utilization of mHealth allows patients' outcomes and experiences to be measured. Through mHealth based care management programs, payers and self-insured employees can manage previously outsourced prevention and wellness programs.

Providers

The mHealth tools focus on providers as the purchasers of the tools. Clinicians present the lowest rate of mHealth tools adoption. This could potentially be attributed to: (i) the clinicians frustration with current health information technologies. (ii) the poor workflow integration and lack of interoperability that results to the provider's reluctance to health information technology acceptance (iii) the uncertainty about the reliability of the data, (iv) the lack of adequate decision support, (v) the need of being provided with a holistic personalized care and delivering clinically meaningful support based on data analysis, (vi) the lack of high quality mHealth evidence based diagnostic and treatment strategies, (vii) the concern about the related ethical and legal issues, and (viii) the lack of clear reimbursement strategy.

Regulatory bodies

The rapid proliferation of mHealth products created regulatory challenges. The Food and Drug Administration has issued guidance to assist the manufactures to further understand what items fall under the purview of regulators. It limits its scope to mobile medical applications intended to "be used as an accessory to regulated medical device" or to "transform a mobile platform into a regulated medical device" [86].

Conclusions

A taxonomy of mHealth-based HF interventions, a comparison of commercially available applications of HF and a review of research projects related to HF are presented in the current study. Through this overview, the evolution of mHealth solutions for HF management is depicted concluding to several challenges, concerning patients, healthcare professionals, payers, providers and regulatory bodies, which should be addressed. It is clear that the advancements in mobile technology have spurred growth and innovation in the health sector. More specifically in the field of HF management, this is expressed through the increasing number of researchers and the corresponding studies focusing on the HF management (diagnosis, severity estimation, prediction, adherence estimation *etc.*), the transformation of the studies to European Union funded projects and consequently to consumer applications. Although the rapid evolution of mHealth solutions for HF management, the assessment of the impact of those solutions on patients' life and especially in HF outcomes should be further studied. Some initial studies indicate that, in order the mHealth solutions for HF to have substantial impact, a multidisciplinary approach should be followed where representatives of health care and technology fields should closely cooperate not only between each other but also with patients.

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