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Telemedicine for Chronic Heart Failure: An Update

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Abstract

Background: This is a short narrative review of the literature pertaining to telemedicine projects developed in the field of chronic heart failure (CHF), with particular focus on non-invasive telemonitoring projects including the French ones.

Results: Numerous non-invasive telemonitoring projects based on connected objects and information and communication technology (ICT) have emerged in the CHF field over the last 10 years. Others are under development, such as the main international randomized telemonitoring studies TELE-HF, TIM-HF, and BEAT-HF, or the French telemonitoring projects SCAD, OSICAT, PIMS, MEDICA, and E-care. The E-care project is a new-generation project supporting patients' returning home after hospital discharge. It perfectly fits within the framework of telemedicine 2.0 projects, including for the first time artificial intelligence (AI). This project has been specifically designed to automatically detect situations at risk for CHF. The potential contribution of these French projects (OSICAT, E-care), in terms of mortality, morbidity, number of hospitalizations prevented, as well as economic benefits, is currently studied or documented.

Keywords: telemedicine, telemonitoring, artificial intelligence, information and communication technology, Web, Telemedicine 2.0, chronic heart failure, diabetes mellitus, chronic disease

1. Introduction

The rising prevalence of chronic diseases, such as chronic heart failure (CHF) or metabolic disorders, combined with population aging, represents a major public health problem [1]. A prevalence of over 5.8 million affected people has been reported in the USA, and of over 26 million people worldwide. In France, between 120,000 and 150,000 new cases of CHF

are diagnosed every year [2]. The cost of this chronic disease has rocketed, and is currently estimated at several billion dollars in developed countries [1].

The management of CHF patients proves challenging for healthcare professionals, since CHF remains a serious disease in terms of functional prognosis, survival prognosis, and associated morbidity and mortality [1]. The mortality rate of CHF patients in Stage III–IV according to the New York Heart Association (NYHA) classification is 50% at 5 years (30% in more recent studies), approaching that of metastatic breast cancer [2, 3].

Moreover, CHF patients are frequently admitted for emergency hospitalization and re-hospitalization [1, 2]. In France, CHF is responsible for more than 100,000 hospitalizations per year [2], accounts for 5% of all hospitalizations, and is the first cause of hospitalization among elderly subjects [2]. Some of these hospitalizations could be prevented if patients had a better follow-up [1]. This last point has been particularly well documented in the field of CHF [1, 4].

CHF management requires extensive medical resources, just at a time when medical shortage is beginning to be felt, along with medical deserts and poor access to medical care, among other problems.

In this setting, telemedicine may be of real help. Indeed, heart failure (HF) telemedicine, particularly HF telemonitoring, may optimize the management of such chronic diseases, particularly by preventing emergency and repeated hospitalizations [2, 4].

In this article, we have reviewed the literature on telemedicine for CHF, with a particular focus on non-invasive HF telemonitoring and French HF telemedicine projects.

2. Search strategy

A literature search was performed on the *PubMed* database of the *US National Library of Medicine* and on *Google Scholar*. We searched for articles published between January 2010 and April 2018, using the following keywords or associations: “chronic heart failure”, “telemedicine”, “telemonitoring”, “telemedicine in chronic heart failure”, and “telemonitoring in chronic heart failure”; restrictions included: English- or French-language publications; published from January 1, 2010, to May 1, 2018; human subjects; clinical trials, review articles or guidelines.

Information and data collected from international meetings were also used, as was information from commercial sites on the *Web*.

All English and French abstracts were reviewed by at least two senior researchers from our working group on telemedicine in chronic diseases at the *University Hospital of Strasbourg* (Strasbourg, France), a referral center. After rigorous selection, only 30 papers were included in our review and analyzed. Only completed telemedicine projects meeting rigorous clinical evaluation, *e.g.*, using evidence-based medicine criteria or criteria usually used for clinical trials, were included in this work. Additional data retrieved from the *Web* (references [5–37]) were also used to enable us to write this chapter in the form of a narrative review. This review is limited by its focus on non-invasive CHF telemonitoring.

3. First-generation heart failure telemonitoring projects

Since the beginning of the 2000’s, numerous telemedicine projects have been conceived and developed in the area of CHF [5–21]. Practically all of them investigated “*telemonitoring*” (or telemanagement, as also termed in the literature), as defined under French legislation [22]. It should be noted that several systematic reviews pertaining to this medical field have been published in recent years [4, 16]. Nevertheless, in our opinion, these papers do not provide a general idea of the studies carried out, given that they were mainly restricted to morbidity and mortality studies (Table 1). To the best of our knowledge, no completed projects on “*teleconsultation*” or “*tele-expertise*” in the CHF area have been published so far. These terms are defined in Table 2.

Some of the projects specifically investigated CHF in subjects aged over 75 or 80 years, yielding good results [6, 23]. They are of special interest in (“real-life”) practice, given that the mean age of CHF patients in developed countries approximates 80 years.

It is worth bearing in mind that these projects, particularly the earlier ones, more closely resembled a telephone follow-up with care providers (such as a nurse) traveling to the patient’s home (“*structured telephone monitoring*” (Table 2)), rather than telemedicine as we consider it nowadays, with nonintrusive, automated, smart telemonitoring using remote sensors and modern communication technology or even artificial intelligence (AI) (“*telemedicine 2.0*”) (Table 2) [4, 20]. Hence, in our opinion, these studies represent the first generation of telemedicine projects [4, 14].

3.1. Clinical impact of first-generation non-invasive heart failure telemonitoring

As we will see, the results of telemedicine projects conducted so far in the CHF field differed from study to study, with fairly inconclusive results as to the potential clinical benefits in terms

Overall mortality	Therapeutic education
Heart failure mortality	Hygiene-dietary and therapeutic compliance
Hospitalization for heart failure	Optimization of food and sports hygiene
Re-hospitalization for heart failure	Patient self-management
Number of hospitalization days	Optimization of the care pathway
Health costs	Structuring of the care pathway
Heart failure management costs	
Number of days off work	City-hospital relations
	Information sharing among health professionals
Quality of life	System use by health professionals

Table 1. Potential parameters to be evaluated in a telemedicine project on heart failure.

Telemedicine	Provision of remote patient care and consultation using telecommunication technologies.
Telemonitoring (telesurveillance)	This telemedicine practice allows a healthcare professional to remotely interpret the data necessary for the patient’s medical follow-up in order to make decisions about his / her care. Remote data collection from a patient through a connected device or questionnaires to monitor his/her vital parameters and symptoms at home on a daily basis.
Tele-expertise	This practice of telemedicine consists, for a medical professional, to seek the opinion of one or more medical professional experts regarding elements of the patient’s medical file. Remote seeking by a health professional of a second medical opinion via sending of images (scanner, X-ray, eye fundus, etc.) and sometimes exchange by Internet-based videoconference.
Teleconsultation	This telemedicine practice allows a medical professional to hold a consultation with a patient remotely. In the context of a teleconsultation, the patient can have at his/her side a health professional assisting the remote professional as well as a psychologist. Second opinion consultation by specialist.
Structured telephone monitoring	This basic concept of care reaching beyond the health care setting relies on a simple phone call monitoring strategy where patient compliance, symptoms, vital signs, and weight are followed remotely.
Telemedicine 2.0	Over the last decade, the Internet has become increasingly popular and is now an important part of our daily life. The use of “Web 2.0” technologies in health/medicine care or in telemedicine is referred to as “Health 2.0” or “Medicine 2.0”, and “telemedicine 2.0”.
Artificial intelligence	This concept describes the simulation of human intelligence processes by machines, especially computer systems. These processes include learning (the acquisition of information and rules for using the information), reasoning (using the rules to reach approximate or definite conclusions) and self-correction. Particular applications of AI include expert systems, speech recognition, and machine vision.

Table 2. Glossary of terms and definitions in the field of telemedicine, as proposed by the Italian Association of Hospital Cardiologists, the Italian Society of Cardiology and the Italian Society for Telemedicine and eHealth on telemedicine and as laid out in article 36 of the French social security financing (adapted from w.ncbi.nlm.nih.gov [last accessed: April 2018] and references [1, 2]).

of re-hospitalization and decreased morbidity or mortality [5–21], particularly regarding the statistical significance of the results. As a consequence, experts have now widely divergent opinions on the actual utility of telemedicine in CHF patient management. Of note is that the European Society of Cardiology (ESC) has, nevertheless, recommended telemedicine with a low level of evidence for such patient follow-up [24].

The 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic HF for the first time recommended “*remote patient monitoring*” of CHF patients with a Grade of recommendation IIb, level of evidence B [25]. In this setting, telemonitoring is mainly focused on predicting acute decompensation episodes that are usually associated with fluid congestion and require therapy optimization (up-titration of angiotensin-converting enzyme inhibitors and beta-blockers). Clinical practice guidelines on CHF recommend daily weight measurements and define weight increases of >2 Kg per day as a warning alert.

It should be pointed out that the first studies on telemedicine for CHF were at times conducted with inappropriate methodologies, involving unsuitable patient groups (such as NYHA Stage

I) and small-sized patient samples (between 50 and 1000 patients), with very short follow-up periods (between 3 months and 1 year) [5–21]. Moreover, most of these studies were based only on weight variations, without including other warning or monitoring parameters (see **Table 2**). In our opinion, these drawbacks rendered any clinical benefits demonstrated illusory [4, 20].

The *Trans-European Network - Home-Care Management System* (TEN-HMS) study, conducted in 2005, was the first larger study that analyzed telemonitoring's role in selected HF patients [25]. In this study, 426 patients were randomly assigned to “telemonitoring”, “nurse telephone support”, or “usual care” in a 2:2:1 ratio. Telemonitoring allowed data transfer (weight, blood pressure, ECG) to a central Web server via a conventional telephone line, and then to workstations based at each investigator site via secure intranet connections. Patients were invited to proceed to data transfer twice daily. Values greater or lower than the predefined limits were signaled automatically to study nurses who could either provide directly advice to the patient or, in more severe cases, inform the primary care physician. In addition to usual care, patients in the group with nurse telephone support were allowed to contact the HF-specialist nurse by telephone at any time during office hours. Additionally, the nurse contacted the patients by telephone every month in order to assess their symptoms and current medication and provide advice. In comparison with usual care alone, mortality and re-hospitalization rates were proven lower in the groups receiving either telemonitoring or nurse telephone support, with no statistically significant differences between both latter intervention groups. Of note is that the hospital stay duration, and therefore the time until outpatient care was deemed sufficient, was 6 days less in the group of patients receiving telemonitoring.

Name of the study	Method	Results
Tele-HF study [17]	Telemonitoring (n = 826) vs. standard care (n = 827)	The study found no significant difference between the telemonitoring and standard management groups in terms of all-cause readmission or all-cause mortality in the 180 days following inclusion (odds ratio [OR]: 1.04 [95% CI: 0.91–1.19]) ($p = \text{ns}$). The primary endpoint, all-cause readmission or death within 180 days after enrollment, occurred in 52.3% of the telemonitoring group and 51.5% of the usual care group.
TIM-HF study [18]	Telemonitoring (n = 354) vs. standard care (n = 356)	The all-cause mortality rate was 8.4 per 100 patient-years of follow-up in the telemedicine group and 8.7 per 100 patient-years of follow-up in the standard care group (OR: 0.97 [95%CI: 0.67–1.41]; $p = 0.87$).
BEAT-HF Study [26]	Intervention group, which included pre-discharge HF education, regularly scheduled telephone coaching, and remote monitoring of weight, blood pressure, heart rate, and symptoms (n = 715), vs. usual care group (n = 722)	The rate of all-cause readmission at 180 days was 51% in the intervention group vs. 49% in the control group ($p = 0.74$). 30-day readmission rate: 23% vs. 22% ($p = 0.63$) for intervention vs. control group, respectively, and 30-day mortality: 3.4% vs. 5.4% ($p = 0.06$) for intervention vs. control group. 180-day mortality: 14% vs. 16% ($p = 0.34$) for intervention vs. control group respectively.

Table 3. Results of the main international randomized studies on telemonitoring in heart failure.

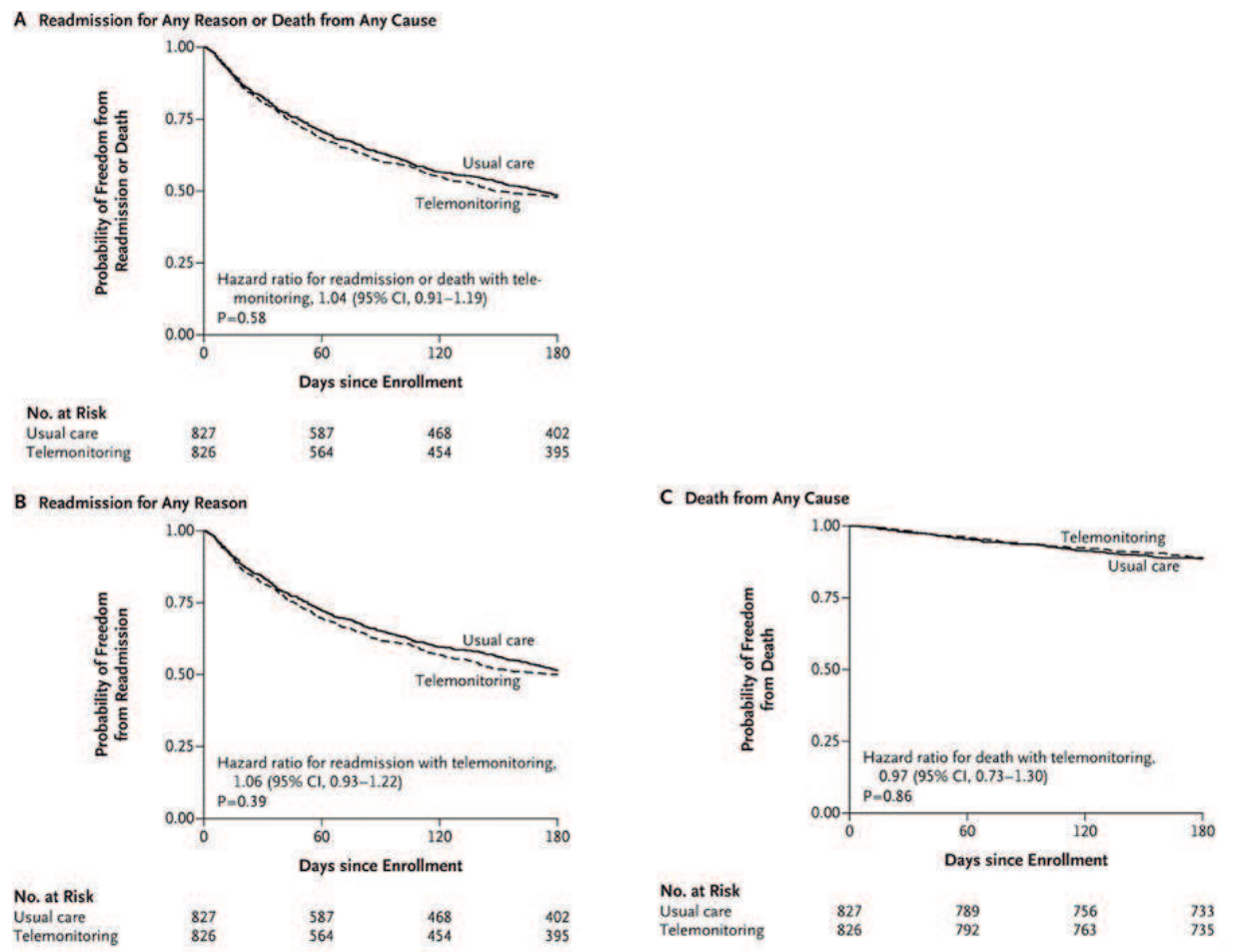


Figure 1. Tele-HF trial ($n = 1653$ patients included). Primary endpoint: “readmission for any reason” and “death from any cause”, and each component separately, according to treatment group ($n = 1653$) (*adapted from* <http://www.nejm.org/doi/full/10.1056/NEJMoa1010029> [last accessed: May 2018] and reference [17]).

Despite some limitations, several reviews and meta-analyses have apparently shown an undeniable utility of telemedicine [4, 16]. For instance, Inglis et al. [16] reported that telemedicine had an effect on all-cause mortality, which fell significantly by 34% ($p < 0.0001$) in the study they conducted. They also revealed a 20% decrease in the number re-hospitalizations for CHF, an improvement of the patient’s quality of life and management costs, and a good acceptance of the system. In the meta-analysis by Anker et al. [4], 11 studies were analyzed as part of a comparison between the effects of telemonitoring (non-invasive telemedicine) and routine care. Their research revealed that telemonitoring led to a reduction in all-cause mortality (10.4% *vs.* 15.4%; $p < 0.0001$), all-cause hospitalization (47.2% *vs.* 52.1%; $p = 0.02$), and hospitalization for CHF (22.4% *vs.* 28.5%; $p = 0.008$).

Conversely, three prospective clinical trials, the “gold standard”, displayed results contradicting the previous ones and thus questioned the potential utility of telemedicine in CHF [17, 18, 26] (**Table 3**). In the Tele-HF study, patients hospitalized for CHF were randomized to telemonitoring with voice-based interactive structured telephone support ($n = 826$) or standard care ($n = 827$) [17]. Patients in the intervention arm were asked to call a toll-free telephone system and answer

a series of questions regarding their general health, weight, and HF symptoms on a daily basis. A clinician then analyzed this information. No significant difference was found between the telemonitoring and standard management groups in terms of all-cause readmission or all-cause mortality in the 180 days following inclusion (odds ratio [OR]: 1.04 [95% CI: 0.91–1.19]) (Figure 1). The primary outcome, all-cause readmission or death within 180 days after enrollment, occurred in 52.3% of the telemonitoring group patients and 51.5% of the usual care group. However, adherence was poor despite system-generated reminders, given that 14% of patients in the telemonitoring arm of the study never used the system. By the final week, only 55% of the patients were using the system at least three times a week.

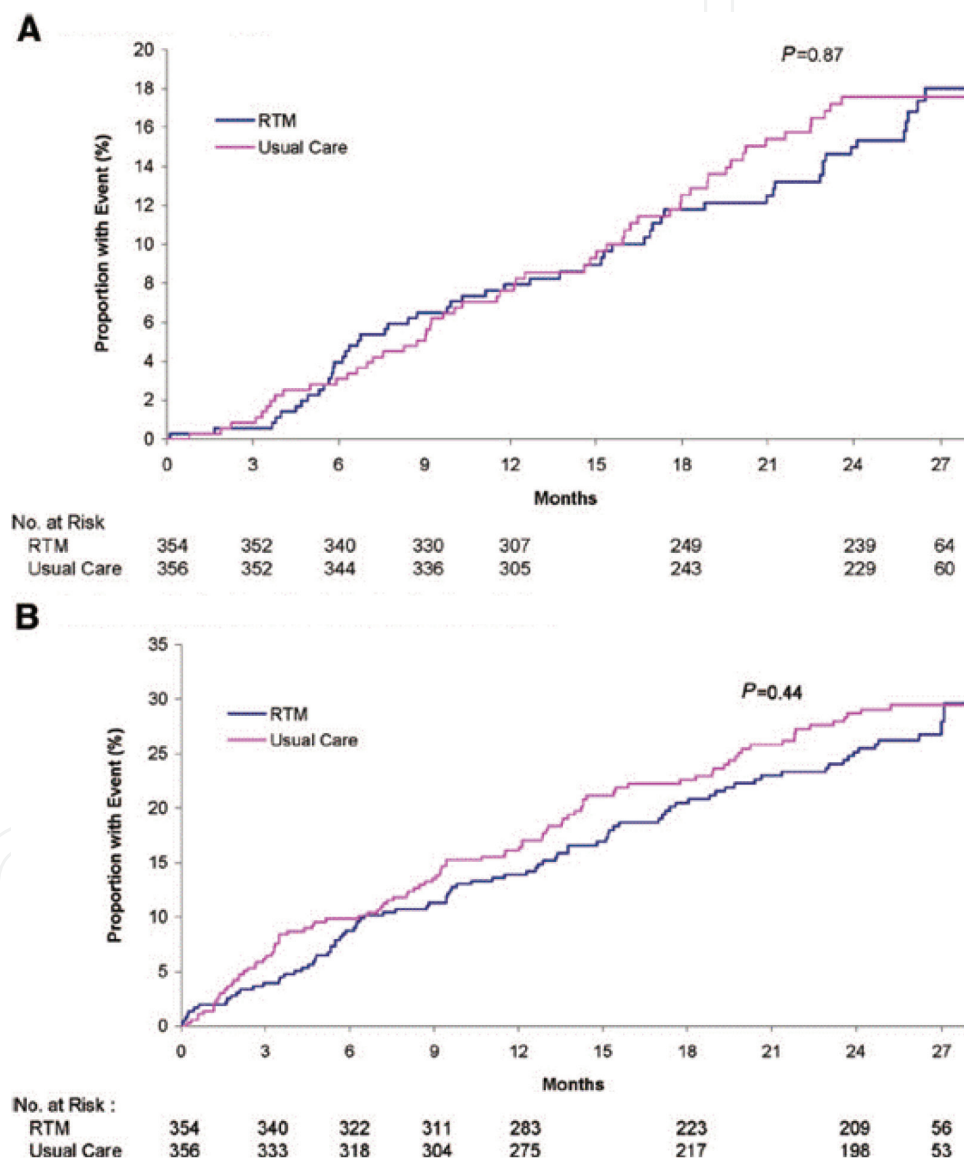


Figure 2. TIM-HF trial ($n = 710$). (a): Primary endpoint: “death from any cause”; and (B): Composite secondary endpoint: “Hospitalization for heart failure” or “cardiovascular death” during follow-up. RTM refers to remote telemedical management (adapted from <http://circ.ahajournals.org/content/circulationaha/123/17/1873.full.pdf> [last accessed: May 2018] and reference [17]).

The TIM-HF study, conducted in Germany, involved 710 stable CHF patients who were randomly assigned to one of the following two groups: 1) telemonitoring by means of remote monitoring and telephone support ($n = 354$); standard care ($n = 356$) [18]. Patients were given a personal digital assistant (PDA) with a wireless *Bluetooth* interface. The system collected ECG data, blood pressure readings, and body weight, which were then communicated wirelessly to a central location where a physician was present 24 hours a day, 7 days a week. In this study, the all-cause mortality rate was 8.4 per 100 patient-years of follow-up in the telemedicine group and 8.7 per 100 patient-years of follow-up in the standard care group (OR: 0.97 [95% CI: 0.67–1.41]; $p = 0.87$) (Figure 2). The TIM-HF trial was, however, underpowered to detect a significant difference in mortality between the two groups. The composite secondary outcome of hospitalization for HF and death due to a cardiovascular cause (14.7% *vs.* 16.5%) highlighted the stable nature of HF patients recruited into the study as compared to the population- and trial-based readmission rates approaching 50% reported in the literature.

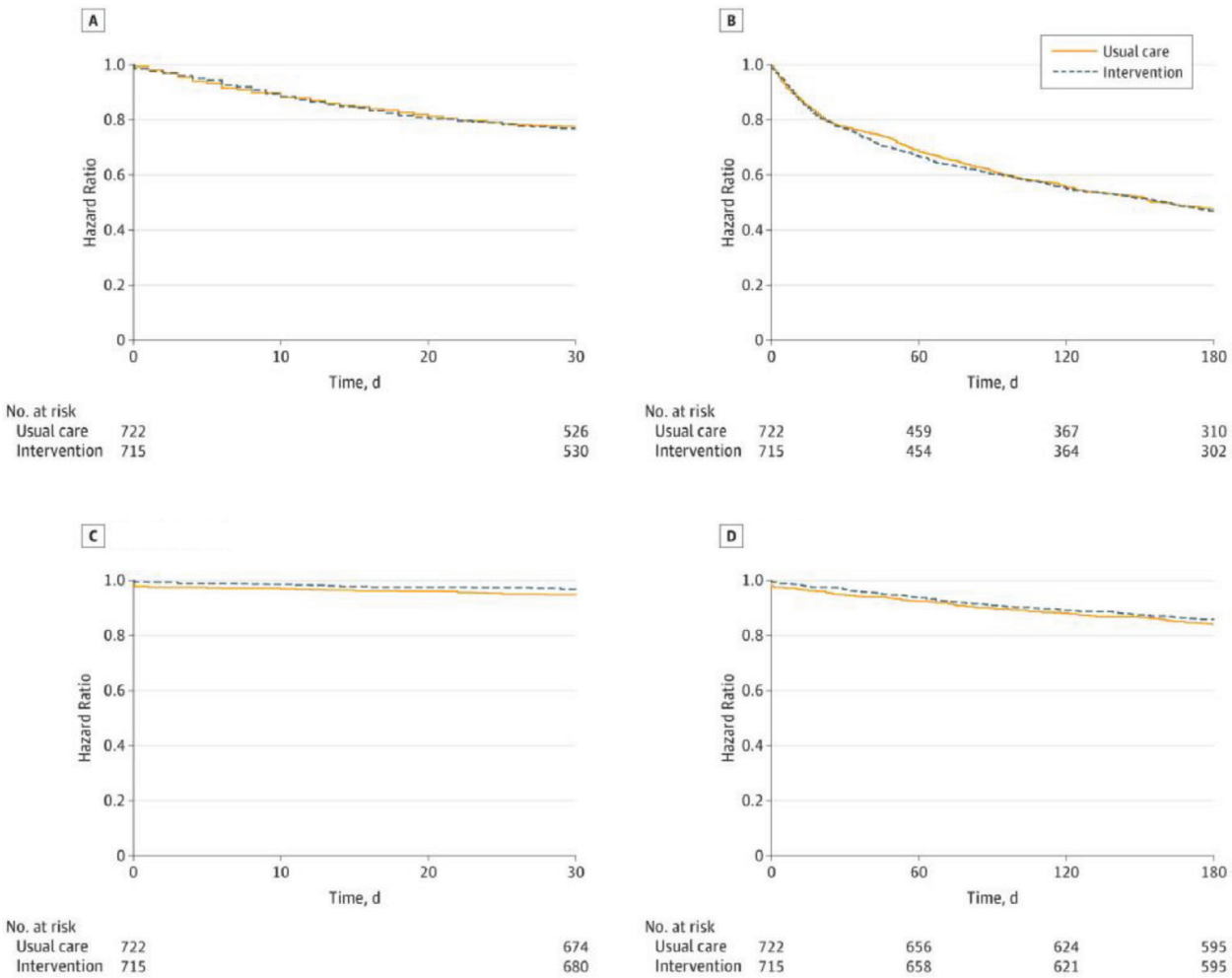


Figure 3. BEAT-HF trial ($n = 1437$). (A): 30-day readmission; (B): 180-day readmission; (C): 30-day mortality with the intervention; and (D): 180-day mortality (adapted from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4827701/> [last accessed: May 2018] and reference [26]).

Thereafter, only one large study on remote monitoring of this kind has been published, namely the BEAT-HF trial, which produced negative results, despite the inclusion of 1437 patients after cardiac decompensation [26]. In this study, there was no significant difference between the “intervention” group, involving pre-discharge HF education, regularly scheduled telephone coaching, and remote monitoring of weight, blood pressure, heart rate, and symptoms, and the “usual care” group regarding all-cause readmissions 180 days after discharge, which occurred in 50.8% (363 of 715) and 49.2% (355 of 722) of patients, respectively (adjusted hazard ratio: 1.03 [95% CI: 0.88–1.20]; $p = 0.74$) (**Figure 3**). In secondary analyses, while 30-day readmission or 180-day mortality did not significantly differ between both groups, there was a significant difference in 180-day quality of life between the intervention and usual care groups. No adverse events were reported.

3.2. Financial impact of first-generation non-invasive heart failure telemonitoring

Aside from these medical considerations, it is worth noting that all the studies seem to agree that using telemedicine solutions in CHF management proved at least economically beneficial (**Table 1**) [5–20]. Depending on the study, the savings were estimated at between \$5000 and >\$50,000/year/patient according to the CHF stage and study setting. In the study by Scalvini et al. [21], the cost of CHF patient management fell by 24%, and hospital costs fell by €45,186/patient/year.

In this context, the study by Burdese et al. [6] proves to be one of the most convincing for illustrating the utility of telemanagement in CHF elderly patients. In this study, a significant reduction was observed in re-hospitalizations (35 without *vs.* 12 with telemedicine, $p = 0.0001$), emergency department visits for an acute HF episode (21 *vs.* 5/year, $p = 0.0001$), and management costs (€116,856 *vs.* €40,065/year). Interestingly, only 8.6% of patients discontinued telemanagement, demonstrating that it was well accepted.

4. Ongoing French heart failure telemedicine projects

4.1. General data

Over the last 4 to 5 years, a second generation of projects has emerged in the CHF area, particularly in France [20, 27–32]. These projects are known as “*telemedicine 2.0*”, because they utilize the new information and communication technology (ICT) and the Internet. They meet the requirements of telemedicine, as laid out in Article 36 of the French Social Security Financing Act (**Table 1**) [22].

Most of these projects use the common connected tools for CHF monitoring (“*multi-channels*” or “*multi-sensors*”), such as blood pressure meters, weighing scales, and pulse oximeters, which transmit the collected information via *Bluetooth*, 3G, or 4G, along with tools for interaction between the patient and healthcare professionals, such as telephone support centers, tablets, and websites [20]. Some projects also include tools for motivation and education, and occasionally, questionnaires about symptoms, such as “*dyspnea*”, “*palpitation*” and “*edema*”, as experienced by the patient. Most of these studies also include AI tools.

4.2. Main non-invasive heart failure telemonitoring projects in France

The main telemedicine projects that are currently being developed in France are:

- SCAD: “*Suivi CARDiologique à Distance*” [remote cardiological follow-up], first initiated in 2005, deployed in Lower Normandy, France, between 2009 April and May 2012, and developed by the Caen University Hospital (Caen, France) [27];
- PIMPS: “*Plateforme Interactive Médecins Patients Santé*” [doctor–patient interactive health platform], initiated in 2013, developed by the René-Dubos hospital in Pontoise (Pontoise, France) [28];
- OSICAT: “*Optimisation de la Surveillance ambulatoire des Insuffisants CARDIAQUES par Télécardiologie*” [optimization of outpatient monitoring in heart failure patients using telecardiology], initiated in 2012 and involving 12 local investigation centers coordinated by the Toulouse University Hospital (Toulouse, France) [29];
- MEDICA: “*Monitoring Electronique à Domicile de l’Insuffisance CARDIAQUE chronique*” [electronic home-monitoring of chronic heart failure], initiated in 2014 and developed by the REUNICA domicile and GMC-solutions santé groups working in the social protection of the elderly [30];
- E-care: “*Détection des situations à risque de décompensation cardiaque chez les patients insuffisants cardiaques de stade III de la NYHA*” [detection of risk situations for cardiac decompensation in heart failure patients with NYHA Stage-III disease], initiated in 2014, with the project’s medical aspects developed by the Strasbourg University Hospital (Strasbourg, France) [31, 32].

All these projects make use of the telemedicine 2.0 tools discussed above. The PIMPS project also comprises laboratory monitoring of natriuretic peptide [26]. The projects focus on CHF patient cohorts or prospective studies. They have enrolled relatively large patient samples, and most of them are based on data derived from evidence-based medicine. The OSICAT study, which seems the most advanced [29], was launched in 2013 and has enrolled 990 patients divided into two groups: remote home monitoring (intervention group) and standard care (control group). The results, which are expected by 2018, will comprise an assessment of medical efficacy and cost-effectiveness.

The E-care telemonitoring project, conducted in Strasbourg, falls under this “*telemedicine 2.0*” category [31, 32]. It has been developed to optimize home monitoring of CHF patients by detecting, via a telemonitoring 2.0 platform, situations in which there is a risk of cardiac decompensation and re-hospitalization. The E-care platform automatically generates indicators of “*health status*” deterioration, *i.e.*, “*warning alerts*” for any chronic disease worsening, particularly CHF, that may lead to hospitalization if not treated. To our knowledge, it is the first project that uses AI in addition to ICT. The platform comprises connected noninvasive medical sensors, a touchscreen tablet connected by *Wi-Fi*, and a router or 3G/4G, making it possible to interact with the patient and provide education on treatment, diet, and lifestyle (Figure 4). The E-care system involves a server that hosts the patient’s data and a secure *internet* portal to which the patient and hospital- and non-hospital-based healthcare professionals can connect. E-care is based on a smart system comprising an inference engine and a medical ontology for personalized synchronous or asynchronous analysis of data specific to each patient and, if necessary, the sending of an AI-generated alert [33].

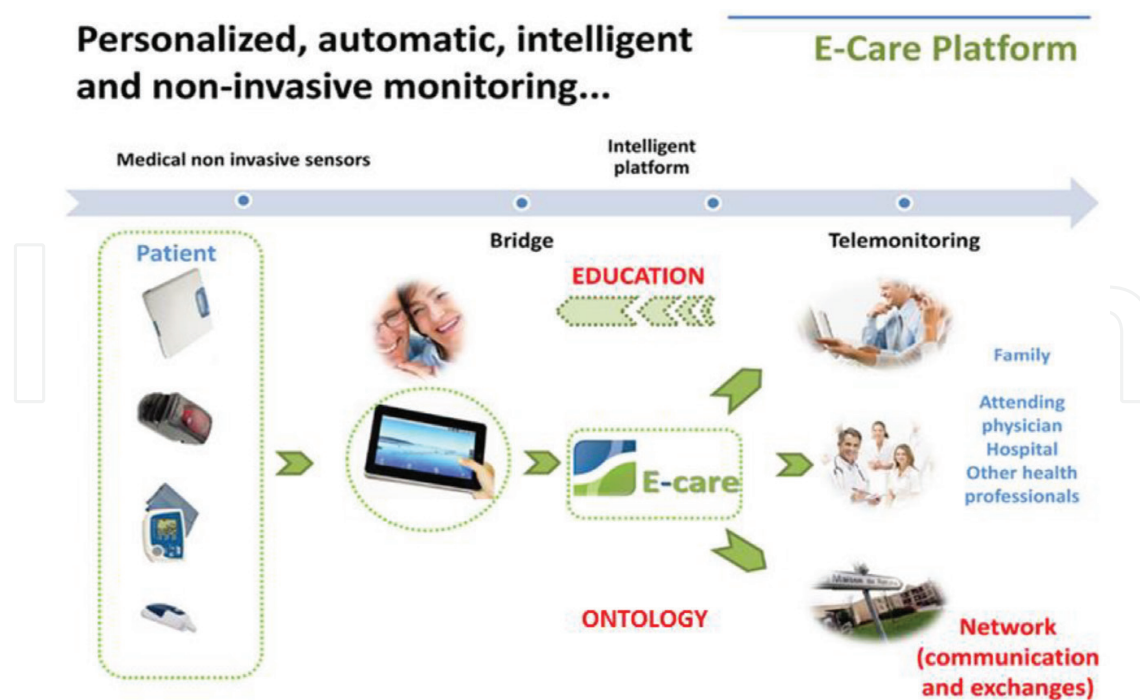


Figure 4. Version 1 of the generic telemedicine platform developed as part of the E-care telemonitoring project in heart failure patients. This platform utilized noninvasive medical sensors measuring blood pressure, heart rate, oxygen saturation, and weight connected by Bluetooth and relaying real-time physiological data on the health status of the patient; touchscreen tablets connected by Wi-Fi or 3G/4G; Internet server hosting an inference engine that generated the warning alerts. These alerts indicated a deterioration in the patient's chronic diseases, especially chronic heart failure. Health professionals could access them via a secure Internet portal (adapted from [last accessed: May 2018] and reference [31]).

4.3. Clinical impact of the French non-invasive heart failure telemonitoring projects

To date, clinical results are only available for the SCAD and E-care projects [27, 32, 34]. In the SCAD project, 90 patients were randomized between April 2009 and May 2011 ($n = 45$ for each group) (thesis from the Faculty of Medicine of Caen, France, and reference [27]). The population was composed of elderly patients (mean age of 78 ± 6 years), mostly of male gender (78%), and at high risk of re-hospitalization (mean brain natriuretic peptide [BNP] level of 1025 ± 950 pg./mL). At 12 months, 1040 days of hospitalization for acute HF were recorded. Monitoring by educational telemedicine significantly reduced the number of hospital days for acute HF: 590 days in the control group *vs.* 450 days in the telemedicine group ($p = 0.044$). The endpoint "*death or hospitalization for acute heart failure*" occurred less frequently in the telemedicine group: 57.8% in the control group *vs.* 35.6% in the telemedicine group ($p < 0.05$). In case of CHF-related readmissions, telemedicine-treated patients had lower intra-hospital mortality: 18.2% *vs.* 0% ($p < 0.02$).

Between February 2014 and April 2015, 175 patients were given the opportunity to participate in the E-care project [31]. During this period, patients and healthcare professionals had to use the E-care platform on a daily basis according to a predefined protocol specific to each patient. The patients' mean age was 72 years, and the male-to-female ratio was 0.7. The patients had multiple comorbidities, with a mean Charlson comorbidity index of 4.1, the

five more common being CHF in >60% of subjects, anemia in >40%, atrial fibrillation in 30%, type II diabetes in 30%, and chronic obstructive pulmonary disease in 30%. During the study, 1500 measurements were taken in these 175 patients, with 700 alerts generated by the E-care system in 68 patients [34]. Some 107 subjects (61.1%) had no alerts during follow-up. When analyzing the follow-up of these 107 patients, it appeared that they did not have any clinically significant event that might have led to hospitalization. Analysis of the warning alerts showed that the E-care platform automatically and non-intrusively detected any worsening of the patient's health, particularly with respect to CHF. Indeed, it was for the latter condition that the system yielded the best sensitivity, specificity, and positive and negative predictive values of 100%, 72%, 90%, and 100%, respectively. The E-care platform also showed its ability to detect a health status deterioration while taking into account the multiple diseases of the patients studied, with sensitivity, specificity, and positive and negative predictive values of 100%, 30%, 89%, and 100%, respectively.

5. Perspectives regarding new telemedicine projects in France

5.1. In the field of chronic heart disease

As mentioned above, the E-care platform appears capable of preventing hospitalization by detecting early any deterioration in the patient's health status and by alerting the care providers so that they can take appropriate measures [31, 32]. As other ongoing projects, the E-care platform is capable of structuring the patients' care pathways, a major theme in medicine for our governments and authorities (**Table 1**). It also provides a way for healthcare professionals to exchange with each other and facilitates access to medical resources.

With this in mind, an enhanced version of the E-care platform will be experimented for at-home monitoring of HF patients as part of a project called PRADO INCADO (**Figure 5**) [33]. The project is being run by a group bringing together the Strasbourg University Hospital, the Alsatian regional health agency, the Bas-Rhin branch of France's national health insurance, and the company PREDIMED Technology. This project will allow us to conduct an in-depth study so as to improve diagnosis by machine learning and detect abnormalities early.

This is in line with the research by Mortazavi et al. on the utility of AI in managing CHF patients, particularly regarding the possibility of predicting re-hospitalization for CHF [35].

5.2. In the field of diabetes mellitus

In addition to CHF, diabetes and metabolic disorders are other potential application fields of telemedicine that are intensively investigated in France. Innovative projects are being developed or deployed, such as the PLASIDIA platform that is run by the *European Center for the Study of Diabetes* in Strasbourg (France) [36]. It is in this setting that we developed an upgraded version of the E-care platform in order to follow diabetic patients as part of the DIABETe project. The new version of the E-care platform should be deployed in "complex diabetic"



Figure 5. PRADO INCADO project. This project uses the E-care smart telemonitoring platform to follow heart failure patients at home according to the organizational model established by the national health insurance as part of the national PRADO program for heart failure patients, which aims to support heart failure patients returning home from hospital and to optimize their management. The PRADO INCADO project integrates a telemedicine solution to structure the patients' care pathways, enable healthcare professionals to exchange with each other, and incorporate a telemonitoring solution (adapted from <https://www.omicsonline.org/open-access/telemedicine-to-monitor-elderly-patients-with-chronic-diseases-with-a-special-focus-on-patients-with-chronic-heart-failure-2167-7182-1000311.php?aid=73930> [last accessed: May 2018]).

patients, *e.g.*, diabetic patients at high cardiovascular risk or diabetic patients treated with multiple injections [37]. Most of these patients may develop an HF episode and possibly CHF over the long-term.

The DIABETe project is aimed at detecting early the risk of hospitalization in diabetic patients at "*very high cardiovascular risk*", defined as a personal history of myocardial infarction (MI) or stroke, limb amputation or cardiomyopathy, and "*intensive*" insulin therapy (at least 3 injections per day or pump), while offering them a personalized follow-up and education about their illness and its management [37]. This population is interesting, since it allows targeting polypathology and polymedication, and requires global support. It represents 50% of diabetics hospitalized in departments of diabetology and internal medicine.

Apart from cardiovascular complications (MI, arteritis obliterans of the lower limbs, etc.), these patients are also frequently hospitalized for hypoglycemia, diabetes imbalance, infections, etc.

The DIABETe project is based on an intelligent platform that will assist healthcare professionals by automatically processing the information obtained from noninvasive medical sensors (blood glucose meter, blood pressure monitor, actimeter, connected scale, etc.) as well as the subjective information provided by the patient himself (questionnaires) and his/her behavior (compliance) in order to detect and report early these situations at risk of hospitalization [37]. Patient- and situation-adapted therapeutic education tools will be made available to the individual, and communication with the subject will occur via a touch pad. Alerts indicating a deterioration of the patient's condition will be generated by AI and transmitted to the health professionals in charge of the patient so that they can anticipate the decompensation and initiate appropriate measures outside the emergency setting. These innovative and original solutions derived from new technologies should achieve the best acceptability to patients. Medical data can be shared between health professionals as part of a city-hospital network. Ultimately, an improvement in the patient's quality of life is also expected.

DIABETe does not compete with Diabeo or other expert systems aimed at optimizing the glycemic balance, which is *per se* one of the main objectives of diabetes mellitus management [38]. The DIABETe project focuses on the "global" management of diabetic patients through the detection of situations at risk of hospitalization: infection, cardiac decompensation, diabetic foot, etc. but also of course hypoglycemia and hyperglycemia leading to hospitalizations. Regarding the remote monitoring platform used in DIABETe, an integration of or interfacing with expert systems such as Diabeo is possible. As a reminder, the Diabeo application, carried by Sanofi, was tested as part of the Télésage clinical trial in 700 patients with type 1 and type 2 diabetes treated with basal-bolus regimen (multiple injections or pump) [38]. The primary endpoint of the Télésage study was the HbA1c variation (glycemic control) at 1 year. A previous study, Télédiab1, conducted between 2007.

6. Conclusions

Though many non-invasive telemonitoring projects have been conducted in the CHF area, relatively few have been run in the setting of telemedicine 2.0 using ICT and the internet. The E-care telemonitoring project totally falls under this category. The potential utility of these projects in terms of morbidity, mortality, and hospitalization prevention is being studied or documented, and their health saving potential is also being investigated.

The telemedicine 2.0 projects are perfectly compatible with the care pathways that are being developed for chronic diseases by the French health authorities (including the French ministry of health and the regional branch of the national health insurance). What's more, all these findings should be analyzed with regard to the benefits provided by these telemedicine solutions (**Table 1**).

These fascinating developments will help shaping the medicine of tomorrow. In the field of chronic diseases, given the epidemiological situation and expected shortage of time careers, we need a better follow-up and better education of patients, an improved prevention and anticipation, and above all a better selection of healthcare system-dependent patients.

Declarations

Competing interests: Mohamed Hajjam is the scientific director of PREDIMED Technology.

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