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Review Article

Telemedicine in Chronic Diseases in France: A Review, with a Focus on Projects Dedicated to Heart Failure and Diabetes Mellitus

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Abstract

Monitoring patients with chronic diseases, e.g. chronic heart failure, chronic obstructive pulmonary disease or diabetes mellitus, using telemedicine systems is a potential means for optimizing the management of the patients. In the case of chronic heart failure and diabetes mellitus, several projects in France sets out to develop an "intelligent" communicative platform designed for home monitoring of these patients, using non-invasive sensors along with contextual information and patient profiling. These projects aim to assist healthcare professionals by providing automated processing of sensors' data transmission in order to promptly detect and report signs of cardiac or glycemic decomposition or unsuitable treatment adherence.

INTRODUCTION

One of the greatest challenges that healthcare professionals have been facing since the beginning of the twenty-first century is the increasing burden of chronic diseases. Greater longevity, lifestyle modifications, and exposure to chronic disease risk factors (e.g., inactivity, tobacco, rich and greasy food, etc.), combined with the growing ability to keep people alive who would otherwise have died, has changed the burden of diseases confronting healthcare systems [1].

Chronic diseases, e.g. chronic obstructive pulmonary disease heart failure (HF), diabetes mellitus (DM), chronic obstructive pulmonary disease (COPD), have a profound impact on the health and quality of life of the population, not to mention the financial burden often associated with long-term illness. To date, more than 80% of the hospital resources are devoted to the care of such diseases, for examples in internal medicine departments. Over 50% of national health budget are devoted to the care of patients with chronic diseases. In practice, the majority of patients with severe chronic disease present iterative decompositions requiring hospitalization (10 to 15 000 euro for each hospitalization).

In response to the emerging challenge posed by chronic diseases, new models of healthcare delivery have been developed, models that achieve better service coordination within the continuum of care [1,3]. Telemedicine appears to be one of the promising approaches.

In the present paper, we review the use of telemedicine for monitoring patients with chronic diseases, with a focus on projects in France related to chronic heart failure and diabetes mellitus.

General information on chronic diseases

The chronic diseases are defined by the World Health Organization (WHO) as diseases requiring "ongoing management

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over a period of years or even decades" and cover a wide range of health problems [2].

In industrialized countries, the main chronic diseases includes: chronic HF, chronic COPD, cognitive disorders (such as Alzheimer's disease), and cancers. In the near future (5 to 10 years), other disorders will also frequently be observed and cause issues as type 2 DM, obesity, hypertension, metabolic syndrome (X syndrome), renal failure, and anemia.

In practice, around 70% of adults suffer from two or more chronic disease (polypathologies). Thus in this context, one of the challenge is to manage the whole patient with a cross-disciplinary vision.

In Europe, the WHO predicts an "epidemic" of chronic diseases for the next 20 years. Increased life expectancy changes the primary causes of morbidity and mortality, with more than 70% attributable to chronic diseases [3]. It is estimated that more than 15 million patients today are developing such diseases, and this figure is expected to rise to 20 million by 2020.

In the United States, four of the chronic diseases: heart disease, cancer, stroke, and diabetes are currently responsible for almost two-thirds of annual deaths.

Telemedicine in chronic diseases

In our experience, chronic diseases require a complex response taking into account several conditions within the same patient, over an extended time period. This must involve coordinated inputs from a wide range of healthcare professionals (doctors, nurses…) with access to essential medicines and monitoring systems, all of which must be optimally embedded within a system that promotes patient empowerment and home support.

In this context, telemedicine appears to be a promising approach for patients, especially in the event of frailty, or for those whose condition is not too serious [3]. This is particularly the case for chronic conditions where early detection of impairment or complications proves essential.

Many of the illnesses, disabilities, or even death associated with chronic disease can be avoided through preventive measures, telemedicine, and telemonitoring. When a person is diagnosed with a chronic condition, this provokes an immediate feeling of loss of freedom and autonomy, along with a sense that days of independent living at home are numbered. The telemedicine system offers the patient the possibility of a high-quality life at home.

Nevertheless, the results of telemonitoring studies and meta-analyses have proven controversial. In reviews relating to this topic, telemedicine approaches varied from computer-based support systems to ones founded on structured telephone support, including programs managed by nurses and physicians [4,5]. Based on current knowledge, it is difficult to render a definite judgment as to whether telemedicine has a significant role to play in chronic disease settings.

To the best of our knowledge, telemedicine and telemonitoring have proven their efficacy in two chronic disorders, namely chronic heart failure [4], and diabetes mellitus [6]. For avoiding iterative hospitalizations, telemonitoring appears particularly suited for chronic disease settings.

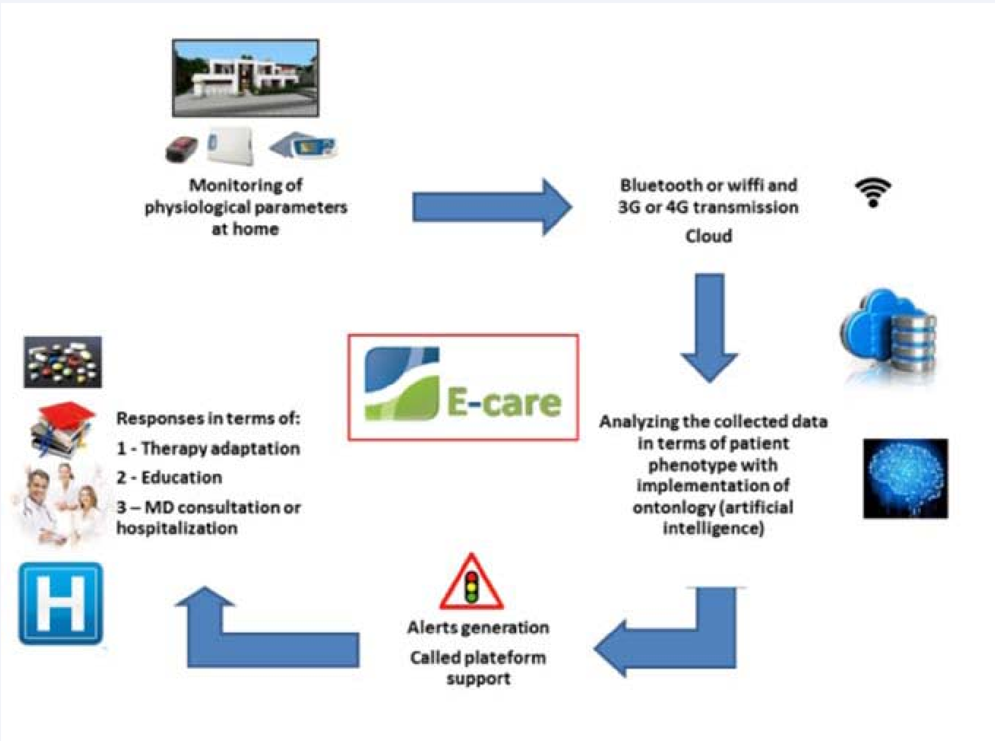

Figure 1 The E-care platform.

Telemedicine in chronic heart failure

In France, nearly one million people are affected by HF, with 120,000 new cases emerging each year.

Chronic HF is characterized by high mortality (50% of deaths within 5 years of first symptoms) and major disability in daily life (shortness of breath, fatigue, etc.), in addition to prolonged and recurrent hospitalizations [7].

Chronic HF diminishes patients' quality of life and has a major economic impact. This is primarily accounted for by healthcare costs resulting from re-hospitalization, especially for people aged over 65 years, due to the recurrent episodes of cardiac decompensation [7,8].

Current patient care aims to improve patients' quality of life by alleviating symptoms (shortness of breath, fatigue, etc.) and allow them to perform everyday activities, and by preventing cardiac decompensation episodes. As a result hospital stays are likely reduced, as well as disease progression and mortality rates [1,8].

The management of chronic HF is currently based firstly on the prescription of dietary practices and regular physical activity. In, fact, this diet and hygiene education has proven key to the therapeutic patient management. Secondly, the management is based on a well-established and efficient pharmacological treatment (i.e., drugs) against heart failure [1].

To improve chronic HF care, the most relevant means include preventing cardiac decompensation by anticipating patients' symptoms via regular monitoring of vital parameters, while promoting adherence to lifestyle changes and therapy [9]. These are the "philosophic" objectives that telemedicine, especially telemonitoring, aims to attain.

Meta-analyses have suggested that telemedicine along with healthcare monitoring by either patients themselves or healthcare professionals may reduce both morbidity and mortality in chronic HF patients [7].

In the exhaustive meta-analysis carried out by Anker et al., 11 studies were analyzed to compare the effects of telemonitoring to those of usual care, namely noninvasive telemedicine [4]. Tele monitoring was shown to reduce the outcome rates as follows: all-cause mortality (10.4% vs. 15.4%, P<0.0001); all-cause hospital admissions (47.2% vs. 52.1%, P=0.02); hospital admissions related to chronic heart failure (22.4% vs. 28.5%, P=0.008).

Nevertheless, two prospective clinical trials produced results contradicting these findings [4].

The Tele-heart failure trial randomly assigned patients hospitalized for HF to undergo either telemonitoring (n=826) or standard care (n=827) [10]. In this trial, no significant difference was observed within 180 days of inclusion between the telemonitoring and control groups in terms of re-admission rates or death from any causes (HR: 1.04; 95% CI: 0.91—1.19).

The TIM-heart failure trial conducted in Germany randomly assigned stable chronic HF patients to undergo either telemonitoring (n=354) or usual care (n=356) [11].

In this trial, the total mortality rate for the primary outcome parameter, namely death from any causes, was 8.4 per 100 patient-years of follow-up in the telemedical group compared to 8.7 per 100 patient-years of follow-up in the usual-care group (HR: 0.97; 95% CI: 0.67—1.41; P=0.87).

In France, several telemedicine projects have been developed in these latter years for treating chronic HF, such as:

- SCAD ("Suivi Cardiologique à Distance", remote cardiological monitoring);
- PIMP's ("Plateforme Interactive Médecins Patients santé", interactive doctor-patient health care platform);
- OSICAT ("Optimisation de la Surveillance Ambulatoire des Insuffisants Cardiaques par Télécardiologie", optimization of ambulatory monitoring for heart failure patients using telecardiology)
- MEDICA ("Monitor age Electronique à Domicile de l'In suffisanceCardiaquechronique", electronic home monitoring in chronic heart failure) [12-15].

At the time of writing, no published results from these projects were available.

All these non-invasive projects have been designed to enable patient management either at home or in nursing homes. They are mostly based on standard tools for monitoring chronic HF, such as blood pressure (BP) monitors, weighing scales, etc., while sometimes integrating tools that enable feedback and transmission of collected information (Bluetooth, 3G, 4G, etc.), as well as interaction between patients and healthcare professionals (e.g., call centers, digital tablets, websites, etc.) [5]. A few projects have also integrated motivational and educational tools.

The PIMP's project also comprised biological telemonitoring by means of brain natriuretic peptide (BNP) levels [13].

These projects are based on prospective or cohort studies that largely stem from "evidence-based medicine" and involve widely varying sample sizes ranging from 100 to 1,000 HF patients, and different follow-up periods from 3 months to 2 years [5].

It should be emphasized that the outcomes of these various projects vary and can be defined from "modest" to "more ambitious". These outcomes could be as follows: improved morbidity and mortality rates reduced hospital readmission rates, enhanced quality of life, or reduced health care costs.

Telemedicine in diabetes mellitus

Globally, an estimated of more than 420 million adults are living with DM, according to the latest 2016 data from the WHO [16]. Type 2 diabetes makes up about 85-90% of all cases.

Diabetes prevalence is increasing rapidly. Increases in the overall diabetes prevalence rates largely reflect an increase in risk factors for type 2, notably greater longevity and being overweight or obese as see bellow [16].

The WHO estimates that diabetes resulted in 1.5 million deaths in 2012, making it the 8th leading cause of death [1]. However another 2.2 million deaths worldwide were attributable to high blood glucose and the increased risks of associated complications (e.g. heart disease, stroke, kidney failure), which often result in premature death and are often listed as the underlying cause on death certificates rather than diabetes [16] .

As for chronic HF the management of DM is based on the prescription of dietary practices and regular physical activity and on a well-established and efficient pharmacological treatment (i.e., drugs) for glycemic monitoring, control and equilibration [17].

Emerging telemedicine programs offer potential low-cost solutions to the management of DM. In a meta-analysis, Zhai et al., identified 35 randomized controlled trials, reporting quantitative outcomes for hemoglobin A1c (HbA1c) [17]. Twelve of the 35 studies provided intervention via telephone, either in the form of a call or a text message; 19 studies tested internet-based programs, employing video-conferencing and/or informational websites; and four studies used interventions involving electronically transmitted recommendations made by clinicians in response to internet-based reporting by patients.

Overall, pooled results from these studies revealed a small, but statistically significant, decrease in in hemoglobin A1c (HbA1c) following intervention, compared to conventional treatment (pooled difference in means=-0.37, 95% CI=-0.49 to -0.25, Z=-6.08, P<0.001). Moreover 2 of the 35 studies included assessment of cost-effectiveness.

In another meta-analysis, Marcolino et al., have studied the impact of telemedicine interventions on change HbA1c, blood pressure, LDL cholesterol (LDL-c) and body mass index (BMI) in diabetes patients [18].

In this study (n=4207), telemedicine was associated with a statistically significant and clinically relevant absolute decline in HbA1c level compared to control (mean difference -0.44% (95% CI) -0.61 to -0.26%; P<0.001). LDL-c was reduced in 6.6 mg/dl (95% CI -8.3 to -4.9; P<0.001). No effects of telemedicine strategies were seen on systolic (-1.6 mmHg and 95% CI -7.2 to 4.1) and diastolic blood pressure (-1.1 mmHg and 95% CI -3.0 to 0.8).The 2 studies that assessed the effect on BMI demonstrated a tendency of BMI reduction in favor of telemedicine.

In type 2 DM, a recent randomized study well-documented the clinical efficacy of telemedicine (104 Cases (patients following telemedicine) and 208 controls) [18]. The ProgettoDiabete Calabria project propose a new organizational model for the management of patients with DM, based on General Practitioners (GPs) empowerment and the use of a web-based electronic health record, shared in remote consultations among GPs and Hospital Consultants. In this study, the mean number of accesses to the Consultants during the study was 0.6±0.9 for Cases, and 1.3±1.5 for Controls (P<0.0001). At follow-up, HbA1c significantly decreased from 5.8±6 to 5.4±8 % in Cases only (P=0.01); LDL cholesterol decreased in both groups; body mass index decreased in Cases only, from 31.0±4.8 to 30.5±4.6 kg/m2 (P=0.03).

In type 1 DM, the objective of the TeleDiab 1 study is to demonstrate that Diabeo software enabling individualized insulin dose adjustments combined with telemedicine support significantly improves HbA1c in poorly controlled type 1 diabetic patients (n=180) [6]. At the 6^{th}month, the Diabeo system gave a 0.91% (0.60; 1.21) improvement in HbA1c over controls and a 0.67% (0.35; 0.99) reduction when used without teleconsultation.

In France, based on these results [6], the reimbursement of this system (to date licensing by SANOFI Laboratory) by the health insurance fund is discussed with public authorities.

Personal experience of the development of an intelligent automated non-intrusive telemedicine platform for the management of several chronic diseases

For the management of chronic diseases we develop in Strasbourg (France) an intelligent automated non-intrusive telemedicine system called E-care. This system was designed within the framework of the « Investissementsd'Avenir » program (a national project financed by the French Government for the promotion of translational research, 2010).

The main actors of this project are: the university hospital of Strasbourg (Strasbourg, France), the technological university of Belfort-Montbéliard (Montbéliard, France), the CenTich center on autonomy (Angers, France) and the NEWEL society (Strasbourg, France).

The plateform is used to monitor patients at home in order to promptly detect chronic disease decompensation signs, promote adherence to treatment, and facilitate interaction among healthcare professionals (doctors, nurses…) [19]. This system was first developed for the management of chronic HF.

E-care is an interconnecting, intelligent, and non-intrusive platform, using non-invasive Bluetooth measuring devices (BP, heart rate, oxygen saturation, and weight). The E-care platform provides assistance to healthcare professionals by automating the processing of sensor-derived data, while automatically generating alerts enabling the detection and prompt reporting of HF risk situations (Figure 1) [19].

E-care processes in real-time each patient's sensor-derived personal data, prior to analyzing it, alongside with the domain ontologies describing the patients' pathologies, medications, and symptoms [5].

The first inference reached constitutes the first learning process by adding new information to the patient ontology. In the second stage, E-care consolidates the information relative to all patients in order to improve the system. New rules are then added by searching for similar patterns describing critical events. This second step becomes effective as soon as there is sufficient data available to be processed.

The system was deployed in a 20-bed unit in Strasbourg University Hospital's Department of Internal Medicine, Diabetes and Metabolic Diseases (Medical Clinic B) [20,21]. This unit is ''open'' to the emergency wards, with about 800 patients hospitalized per year. In the experimental phase,>150 patients were enrolled with>1,500 measurements performed.

These patients were mainly elderly suffering from various chronic diseases chronic as follows: HF >60%; anemia>40%; arrhythmia due to atrial fibrillation (AAF)>30%; type 2 diabetes>30%; COPD>30%; cancer 20%; chronic renal failure>15%; dementia>15%. Overall, 25% of these patients experienced a total loss of autonomy.

Nurses used the E-care measurement devices on a daily basis while carrying out their patient rounds [20,21].

This experimentation relied on establishing a robust comprehensive intuitive human-machine interface and inference engine (Figure 2). This testing comprised a satisfaction and practical use survey pertaining to the system's ergonomics, which was filled out by both caregivers and patients.

From a strictly medical point of view, a preliminary analysis of the alerts proved their relevance.

To date, the E-care platform is deployed in the region of Strasbourg (France) through the PRADO-INCADO project. This project is support by the French government (ARS d'Alsace et du Grand Est; and CPAM du Bas Rhin).

In the near future, we seek to successively develop the E-care generic platform through the:

- Implementation of several non-intrusive sensors, such as glucometers, thermometers, scales, and electrocardiograms in order to monitor vital signs;

- Implementation of an electronic pillbox to promote therapy adherence;

- Insertion of a questionnaire to monitor patients' hygiene and diet;

- Development of a questionnaire to monitor patients' therapy adherence together with contextual information and patients' profiles (e.g., patients' age and medical history, etc.).

The DIABETe project, built on E-care platform, is currently developed to the follow-up of patients with type 2 DM.

In addition, the patients are scheduled to benefit from full therapeutic education through the development of a comprehensive and complete man-computer interface [21,22].

Information monitoring and data collection will then be utilized to investigate the combined evolution of patients' vital signs, behavior, and personal health practices [19,20]. This is meant to detect the most relevant repetitive sequences, or markers, allowing the earliest and best suited medical support to be administered to a given patient affected by chronic diseases. The perspective taken is that of a transverse section of the patient exhibiting several comorbidities, rather than that of a longitudinal section with only one disease.

Semantic Web technologies as using by our E-care platform provide a solid approach to both associated information and process management. These technologies are increasingly employed for a broad spectrum of applications. To this end, the domain expertise is modeled and formalized (ontology) in order to widely support diversified computer processing (thinking) [20-23]. Using ontologies effectively for reasoning purposes entails that operational semantic must be added in order to determine how the ontology's modeled expertise will be used for reasoning purposes and for the automated generation of new expertise and knowledge.

By this means a considerable amount of data is collected daily in a wide cohort of patients, together with their specifications and information relating to their health practices. Statistical and data mining methodologies consequently play a key role in the acquisition of new knowledge. Data mining and ontological meta-data are powerfully correlated. Data mining technologies help build the Semantic Web which in turn helps to retrieve and acquire new knowledge [22-24].

Our work in the E-care project is focused on the utilization

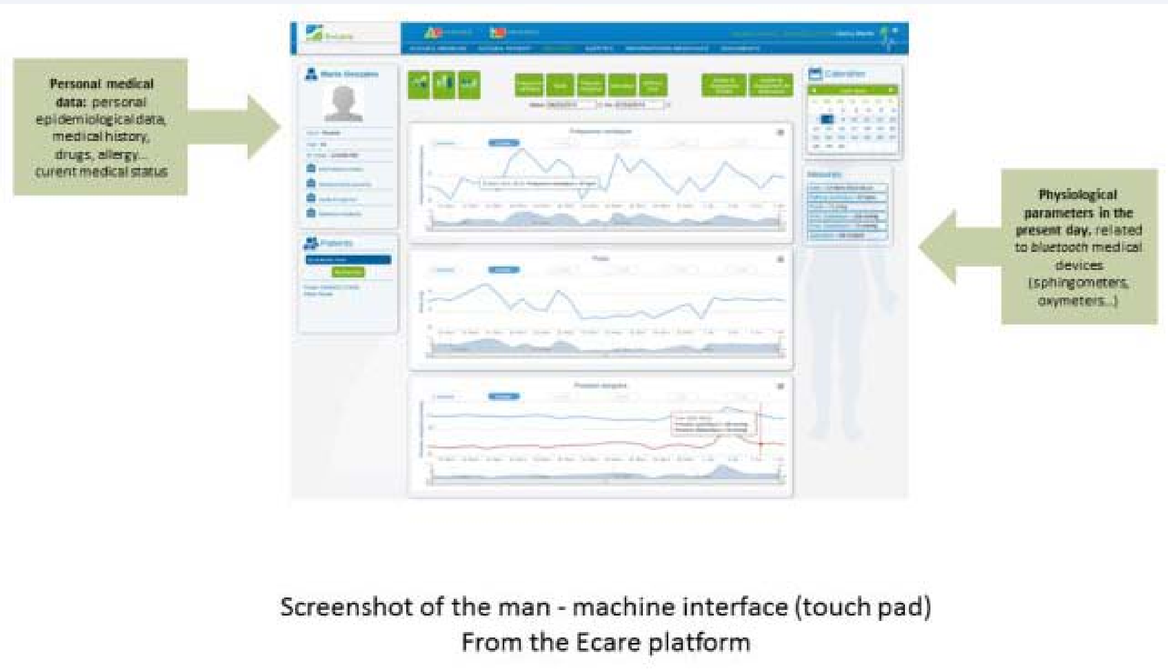

Figure 2 The interface man - machine from the E-care platform.

of data mining technologies in order to enrich ontology and generate new knowledge [5,9,23]. Such enrichment is defined as "adapting ontology to the need for change and the dissemination of these changes to the depending artifacts while preserving consistency". This enrichment will likely generate an assessment that will take into account several quality aspects, such as structure and utilization. In the defined field, we seek to achieve consistency validation and quality assessment. Consistency validation consists of verifying that all medical rules remain true once changes have been applied. Quality assessment allows the decision to be made to accept the final changes.

In a second approach, Kohonen self-organizing maps (Self-Organizing Kohonen Maps: SOM) and non-supervised learning neural networks are scheduled to be utilized. This is meant to obtain a data interpretation process that shows the evolution of vital signs [25]. To improve during the operations, the process must be able to "stand-alone", be automatically self- configurable, adjustable to any context change or evolution, and capable of building up knowledge. Symptom specification taking into account each vital sign's evolution, as associated with hygiene and a healthy lifestyle, will enable detection at the earliest possible stage, thus ensuring efficient treatments. One of the main objectives will be the consolidation of all collected data in order to enrich the ontologies to which the projects will be applied.

CONCLUSIONS

Monitoring patients with chronic diseases, using telemedicine systems constitutes a promising approach for optimizing patient management.

In the case of chronic HF and DM, several projects sets out in France to develop an "intelligent" communicative platform designed for home monitoring of these patients, using non-invasive sensors along with contextual information and patient profiling.

These projects aim to assist healthcare professionals by providing automated processing of sensors' data transmission in order to promptly detect and report signs of cardiac or glycemic decompensation or unsuitable treatment adherence.

The E-care project is developing an "intelligent" communicative and non-intrusive platform enabling the home monitoring of patients suffering from chronic HF and, in the near future, type 2 DM. This platform is scheduled to assist healthcare professionals by providing automated processing of sensor-derived data transmission, enabling them to detect and report signs of chronic disease decompensation.

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