Research Article

New Non-Invasive Technologies for Optimal Management of Chronic Heart Failure

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ABSTRACT

In recent years, several technological innovations have become part of the daily lives of patients suffering from chronic diseases. It is the case for chronic heart failure with non-invasive sensors, telemedicine, and artificial intelligence. A review of the literature dedicated to these technologies and tools supports the efficacy of these latter. Mainly, these technologies have shown a beneficial effect on chronic heart failure management with an improvement of: patient ownership of the disease; patient adherence to therapeutic and hygiene-dietary measures; the management of co-morbidities (hypertension, weight, dyslipidemia); and at least, good patient receptivity and accountability. Especially, the emergence of these technologies in the daily lives of these patients suffering from chronic disease, as chronic heart failure, has led to an improvement of the quality of life for patients. Nevertheless, the magnitude of its effects remains to date debatable or to be consolidated, especially with the variation in patients’ characteristics, methods of experimentation, and in terms of medical and economic objectives.

Introduction

According to the World Health Organization (WHO), “chronic disease” is defined as a long-term condition that changes over time, e.g.: high blood pressure, diabetes mellitus, chronic heart failure or chronic obstructive pulmonary disorders, cancer, chronic kidney diseases, cognitive impairment and deterioration, etc. [1, 2]. In France, it is estimated that 15 million people (about 20% of the population) are estimated to have a chronic disease compared to 30% of the population in Canada [2].

To date, despite major therapeutic advances, most chronic diseases remain serious in terms of functional or survival prognosis, with high morbidity and mortality rates [1]. Yet, this type of disease is responsible for 17 million deaths worldwide each year. A 5-year mortality rate of 30 to 50% has been reported in patients with NYHA stage III-IV chronic heart failure [3]. In this setting, patients also frequently present for emergency hospitalization and re-hospitalization, with long hospital stays, resulting in impaired quality of life [1, 3]. In France, acute and chronic heart failure is thus responsible for over 210,000 hospitalizations per year, accounting for 5% of all hospitalizations and being the main cause of hospitalization among elderly subjects [1, 2].

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The management of these chronic diseases proves very challenging for healthcare professionals. In this setting, chronic diseases benefit from both the contributions of molecular biology and innovative therapies, e.g. new drugs, cellular therapy, etc. [3-5]. They also benefit from major advances in technologies (e.g.: sensors, infusion systems, connected objects, etc.) and in artificial intelligence (AI) (e.g.: big data analysis, deep learning, etc.) [6-24]. Combined with the information and communication technologies (ICT) and the social and educational sciences, these technological advances and derived tools will probably revolutionize the care of chronic diseases with an optimization of the management [7].

This chapter focuses on current and new technologies and non-invasive sensors and tools used in clinical routine at the service of the patients with chronic disease, especially chronic heart failure.

**Telemedicine for Chronic Heart Failure**

Over the last ten years, several new generation telemedicine projects and trials has emerged in the era of chronic heart failure, particularly in Europe [25]. These projects have for main objectives: the prevention and treatment of heart failure exacerbations and the promotion of self-empowerment. Main projects are listed in (Table 1).

| Name of the study | Results |
|-------------------|---------|
| The Trans-European Network – Home-Care Management System (n=426) | Compared to standard care alone, mortality and re-hospitalization rates were shown lower in the groups receiving either telemonitoring or nurse telephone support, without any statistically significant differences between both intervention groups. |
| The BEAT-HF study (n=437) | All-cause readmissions within 180 days post-discharge occurred in 50.8% (363 of 715) patients from the intervention group versus 49.2% (355 of 722) of those from the control group (adjusted hazard ratio: 1.03 [95%CI: 0.88-1.20]; p=0.74) |
| The TIM-HF (n=710) | All-cause mortality rate (primary end point) 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, without significant difference (OR: 0.97 [95%CI: 0.67-1.41]; p=0.87) |
| The Telemedical Interventional Management in Heart Failure II (TIM-HF2) (n=1,570) | The percentage of days lost due to unplanned cardiovascular hospital admissions and all-cause death was 4.88% (95% CI 4.55-5.23) in the remote patient management group versus 6.64% (6.19-7.13) in the standard care group (ratio 0.80, 95%CI: 0.65-1; p=0.0460) |

In this setting, the number and variety of physiologic sensors and the useful clinical parameters derived from those sensors is likely to continue to increase rapidly [25]. For example, in addition to the capabilities described above, future devices may include additional sensors to track respiration parameters (including rate, minute ventilation and perhaps apnea and dyspnea detection), tissue perfusion (via optical sensors), cardiac output and stroke volume (via impedance, acute ischemia or myocardial infarction via S-T segment monitoring), electrical alternant and heart rate turbulence. Indeed, some recently released devices already contain some of these fascinating capabilities. To date, several projects include BNP monitoring, ECG monitoring, and even a video-call [25-27].

Recently, the TIM-HF2 study is the first to well document the interest of telemedicine in the chronic heart disease field, resulting in clinically relevant outcomes with statistical significance [28]. In fact, the percentage of days lost due to unplanned cardiovascular hospital admissions and all-cause death was 4.88% (95% CI 4.55-5.23) in the remote patient management group versus 6.64% (6.19-7.13) in the standard care group (ratio 0.80, 95%CI: 0.65-1; p=0.0460). Patients hospitalizations, the role of non-invasive methods for the remote monitoring of chronic heart failure patients is still under debate.
assigned to remote patient management lost a mean of 17.8 days (95% CI: 16.6–19.1) per year compared with 24.2 days (95% CI: 22.6–26) per year for patients assigned to standard care. The all-cause death rate was 7.86 (95% CI: 6.14–10.10) per 100 person-years of follow-up in the remote patient management group versus 11.34 (95% CI: 9.21–13.95) per 100 person-years of follow-up in the standard care group (hazard ratio [HR] 0.70, 95% CI: 0.5–0.96; p=0.0260) (Figure 1) [28].

Cardiovascular mortality did not significantly differ between both groups (HR 0.671, 95% CI: 0.45–1.01; p=0.056).

For this TIM-HF2 care strategy, the key component was a well-structured telemedical center with physicians and HF nurses (“coordination center”) available 24 hours a day and every day a week, able to act promptly according to the individual patient risk profile [7, 28]. The actions taken by the telemedical center staff included changes in medication and admission to hospital, as needed, in addition to educational activities.

**Artificial Intelligence in Chronic Heart Failure Telemedicine**

In this setting, the E-care project has been initially developed and designed to optimize home monitoring of chronic heart failure patients by detecting, via a telemonitoring 3.0 platform (Figure 2), including artificial intelligence (AI) via the software MyPredi™ (Predimed Technology, Schiltigheim, France), situations with a risk of cardiac decompensation and re-hospitalization [29-32].

Between February 2014 and April 2015, 175 patients were included into the E-care project [33]. During this period, the E-care platform was used on a daily basis by patients and healthcare professionals, according to a defined protocol of use specific to each patient.

The mean age of these patients was 72 years, and the ratio of men to women 0.7. The patients suffered from multiple concomitant diseases, with a mean Charlson index of 4.1. The five main diseases were: CHF in more than 60% of subjects, anemia in more than 40%, atrial fibrillation in 30%, T2D in 30%, and chronic obstructive pulmonary disease in 30%. During the study, 1,500 measurements were taken in these 175 patients, which resulted in the E-care system generating 700 alerts in 68 patients [33]. Some 107 subjects (61.1%) had no alerts upon follow-up. Follow-up data analysis of these 107 patients revealed that they exhibited no clinically significant events that might eventually have led to hospitalization.

Analysis of the warning alerts showed that the MyPredi™ system automatically and non-intrusively detected any worsening of the patient’s health, particularly heart failure decompensation (between 2 to 9 days), with a sensitivity, specificity, as well as positive and negative predictive values of 100%, 72%, 90% and 100%, respectively. In this study, both the healthcare professionals and patients, even the frailest, used the E-care system without difficulty until the end of the study (Figure 3). For non-autonomous patients, the system was employed by a nurse in addition to her other assigned tasks, such as washing and administering medication, or by close ones and family members [33].

To date, an enhanced version of the E-care platform and the AI (MyPredi™) will be experimented in the homes of CHF patients as part of a project called PRADO-INCADO [7]. PRADO is a French program to support patients returning home after hospital, while PRADO-INCADO will specifically target HF patients in this setting. Over a period of several months, it will follow 300 patients with NYHA Stage I to –IV HF using the PRADO organizational model for CHF patients developed by the national health insurance.

![Figure 1: TIM-HF2 trial (n=1 515). Rate of cumulative events in patients randomly assigned to remote patient management (n=796) or usual care (n=775) (adapted from [28]).](image1)

![Figure 2: Structure of MyPredi™ platform.](image2)

![Figure 3: Schematic illustration of the operation of the MyPredi™ platform (Predimed Technology, Schiltigheim, France). Following hospitalization for cardiac or diabetes decompensation, the patient goes home with connected devices (connected scale, pulse oximeter, blood pressure monitor, glucometer, tablet). Every day, he takes his vitals using the connected devices, and then the measurements are sent to an intelligent platform. Using algorithms, the software detects abnormal measurements and sends an alert to the healthcare professionals in charge of the patient at his or her place of residence. These professionals check the alert with the patient and modify the treatment if necessary.](image3)
Conclusions

This review supports the efficacy of numerous current and new technologies and non-invasive tools for a better management of patients with chronic diseases, particularly patients with chronic heart failure. Nevertheless, in chronic diseases, the magnitude of its effects remains to date debatable or to be consolidated, especially with the variation in patients’ characteristics, methods of experimentation, and in terms of medical and economic objectives.

To our opinion, innovative technologies based on AI (machine learning, Big Data) are going to build the future of chronic disease and they invent the medicine of tomorrow.

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Consent and Ethical Approval

None.

Competing Interest

M. Hajjam is the scientific director of Predimed Technology (www.predimed-technology.fr). All other authors have declared that no competing interests exist.

Ethical Approval

None.

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