Connected health and integrated care: Toward new models for chronic disease management

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Review

Connected health and integrated care: Toward new models for chronic disease management

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ABSTRACT

The increasingly aging population in Europe and worldwide brings up the need for the restructuring of healthcare. Technological advancements in electronic health can be a driving force for new health management models, especially in chronic care. In a patient-centered e-health management model, communication and coordination between patient, healthcare professionals in primary care and hospitals can be facilitated, and medical decisions can be made timely and easily communicated. Bringing the right information to the right person at the right time is what connected health aims at, and this may set the basis for the investigation and deployment of the integrated care models. In this framework, an overview of the main technological axes and challenges around connected health technologies in chronic disease management are presented and discussed. A central concept is personal health system for the patient/citizen and three main application areas are identified. The connected health ecosystem is making progress, already shows benefits in (a) new biosensors, (b) data management, (c) data analytics, integration and feedback. Examples are illustrated in each case, while open issues and challenges for further research and development are pinpointed.

Contents

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1. Introduction

A demographic change has been recognized in Europe and worldwide, toward increase of the proportion of elders. As reported by WHO [1] "*Between 2000 and 2050, the proportion of the world's population over 60 years will double from about 11% to 22%. The absolute number of people aged 60 years and over is expected to increase from 605 million to 2 billion over the same period.*" This expansion of the aging population inevitably leads to increase of associated healthcare needs and costs, puts doubt on the adequacy of the current health and social care systems and resources, and increases the pressure for the investigation and deployment of new models of care that could meet these needs in a sustainable manner. This demand requires multifaceted approaches that encompass both technological developments and advancements in the care process and its potential to change.

Patients are foreseen to be at the center of the new health management models, accessing and controlling their own healthcare information to make informed decisions about their own care and treatment. Communication and coordination between patient, healthcare professionals in primary care and hospitals is facilitated, and contextual medical decisions can be made in a timely fashion and easily communicated. Health outcomes can be assessed at multiple levels and employed as indicators toward fine-tuning care services and health policies [2].

There are two main concepts that drive this effort on transformation of care, namely "Connected Health" and "Integrated Care", that can be regarded as partially overlapping, yet both contributing to the reorganization of care.

Integrated care refers to a model of patient-centered care, with organized link among multiple levels of care management, coordinated services and collaboration among professional across care delivery even of separate organizations [3], focusing on the continuum of healthcare delivery around patients and populations, on prevention and management of patients with chronic diseases and/or multiple morbidity [4–6]. While approaches and levels of implementation can be context – specific, depending on policies, legislations, focus on public–private partnerships, the objective is to ensure high quality and efficient care where and when it is needed, toward better health outcomes while controlling costs. A central concept in these approaches is to share health and care information at different levels, and that is the core of connected health.

Connected health [7] is based on advancing health technology and aims for the optimal access, sharing, analysis and use of health data via systematic application of healthcare information technology, in other words to "offer *the correct information to the correct person at the correct time*", so that health actors (citizens, patients, clinicians, policy makers) make better decisions for health and care (Fig. 1). Sharing of information and coordination of actions can be seen (a) among healthcare professionals (HCP) within an organization, (b) among HCPs in different organizations, including primary, secondary and social care, as reflected in integrated care models, (c) among HCPs and patients, as well as their care providers, and (d) among different analytics, knowledge discovery and decision support systems.

Relevant health technologies encompass clinical information management, tele-health, interoperability, and more. Importantly, health technology and increasing digital literacy have already provided examples for gathering continuous health-related data (e.g. activity and sleep), i.e. extending measurement in home setting and daily life via advanced wearable devices, while mobile computing and communications, as well as cloud-based management and analytics provide the framework for information analysis and sharing.

Having in mind the relation between integrated care and connected health, this paper aims to present the main technological axes and challenges around connected health technologies in chronic disease management, along with discussing examples that set the scene for the further development of integrated care models.

2. Main applications areas and scope of connected health research

2.1. Lifestyle, prevention and rehabilitation for the citizen and the patient

As lifestyle has been recognized as a major factor for health living and disease prevention, a series of projects now focus on healthy nutrition [8] and prevention of obesity, sleep hygiene and quality [9], maintenance of an adequate activity level, via advanced sensor systems and actuators (e.g. heated/cooling textiles for sleep), gamification and motivational strategies for adoption of healthier lifestyle, as well as patient modeling for predictions. A subcategory includes guiding patients of special groups in physical exercise training for rehabilitation purposes [10].

2.2. Management of chronic diseases and comorbidities management

As chronic disease management is a priority in an aging population, and additionally the major reason for hospitalization, connected health technologies concentrate around systems that will: (a) enable the disease management at home and facilitate treatment fine-tuning (e.g. by continuous monitoring of the motion symptoms in Parkinson's disease [11]), and (b) prevent hospitalizations by timely decisions and by training the patient for self-care and improved compliance. Recently, more focus was given on integrated management of multiple morbidity (e.g. COPD, heart failure, diabetes and depression [12]). While being a more realistic approach for elder patient management, it is also more demanding as regards both diagnosis (e.g. cause of deterioration) and treatment (preventing adverse conditions).

2.3. Frailty and ambient assisted living

This category of applications addresses the need for independent living and quality of life among elder population, via multifaceted approaches that include monitoring of activity and vital signs, physical and cognitive training, self-assessment, services for daily life facilitation (e.g. for shopping needs) and social support [13]. A series of factors pertaining to the elder population is taken into account, including cognitive decline, safe detection of movement and falls, and overall physiology. Smart home technologies are an area of experimentation in this direction [14].

3. Personal health systems

Moving beyond HCP – controlled electronic health record and traditional medical settings toward systems that aim at the empowerment and active engagement of patients and citizens in their own health and care, as well as the continuity of their health support, a central idea is that of a personal health system (PHS) for the patient/citizen, which can still be interoperable with the clinical information systems. Following the PHS2020 definition [15], PHSs assist in the provision of continuous, quality controlled, and personalized health services to empowered individuals regardless of location. They consist of:

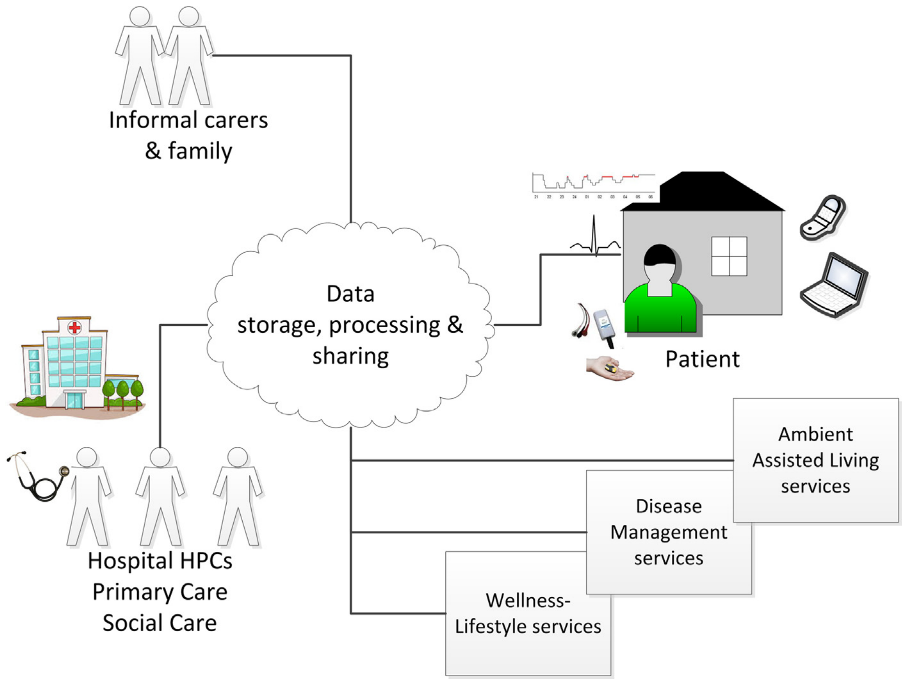

Fig. 1. The health ecosystem.

a) Ambient and/or body (wearable, portable or implantable) devices, which acquire, monitor and communicate physiological parameters and other health related context of an individual (e.g. vital body signs, biochemical markers, activity, emotional and social state, environment).
b) Intelligent processing of the acquired information and coupling of it with expert biomedical knowledge to derive important new insights about individual's health status.
c) Active feedback based on such new insights, either from health professionals or directly from the devices to the individuals, assisting in diagnosis, treatment and rehabilitation as well as in disease prevention and lifestyle management.

Such systems can involve the personal health records (PHRs), mobile health and medical apps for patient interaction, decision support for the patient and professional [16], communication tools and social networks [17], Fig. 2 depicts an abstract example of a PHS that can be used for wellness and improvement of lifestyle. Based on the recorded data, the cloud analytic system can detect whether the patient/citizen presents deteriorating trends (e.g. decreasing activity and sleep with increasing stress) and provide warnings or advice for improvement, or if necessary, facilitate a patient-HCP encounter for some intervention.

4. Sensor systems

A great variety of sensors and sensor systems have been developed in the connected health ecosystem, that are able to record a variety of signs and signals spanning from activity and pulse, to chest sounds and electrical impedance tomography, while multi-signal sensing systems aim at combination of multiple recordings for more sophisticated assessments [18,19]. Nowadays, miniaturization of sensors, energy efficiency, comfort of use and connectivity are main principles for the design of sensors. While numerous sensors are now commercially available and mobile-connected, mainly for wellness and basic lifestyle assessment, research also focuses on multi-sensorial wearable systems, for the thorough assessment of chronic conditions at home, with minimal burden for the patient [20].

Sensor systems developed and tested in the connected health arena present different properties as to (a) position, from smart wrist watches for activity and pulse, to chest belts [21], or sensorized vests, or even ambient sensors installed in the user's environment, like the bed-sensors [22], (b) invasiveness, e.g. capillary glucose measurements, (c) level of comfort, which will define also how much the sensor system is used, (d) type of sensor and data (e.g. ballistocardiography vs electrocardiography), (e) embedded processing, e.g. internal calculation of heart rate from ECG, calculation of alerts, (f) interactivity level and configurable properties (e.g. configurable sampling frequency) [23], (g) type of communication (Bluetooth, WiFi, USB, no communication).

5. Data management

Connected health technologies, enabling the recording of a multitude of data, and PHS adoption lead to an abundance of patient-generated health data available, in addition to existing health-related data. This includes longitudinal data on symptoms, vital signs and signals, treatment history, lifestyle and behavior along with contextual and environmental data recorded or inferred by patients and care providers, which can be integrated with the clinical or even molecular data. Thus, PHS data constitute an example of "Big Data" in healthcare [24], in terms of volume and growth, diversity, complexity of management and analysis, with further data management challenges.

Among the new challenges are data quality, and semantic coherence. The conceptual model depicted in Fig. 3, suggests that each individual should be represented by a series of hierarchically related entities and contain different data types, including discrete single-valued data, signals, annotations, etc., potentially originating from various sensors systems. Semantic technologies are typically employed in order to unambiguously express these sophisticated data models and support data validation and sharing [25].

It is worth noting that this can support more dynamic approaches for querying and processing data according to

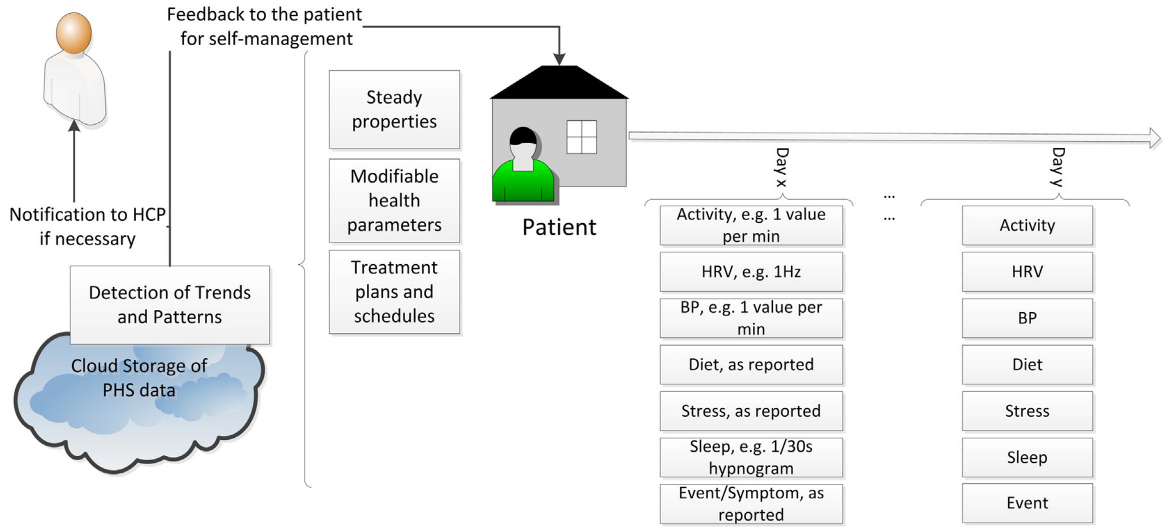

Fig. 2. An example project of a personal health system.

profile and context, for example "*Get the daily heart rate variability and lung sound signals from patients with diseases X, under medication plan Y, in days when activities ranged in Z, and diet was W*". Similarly, one can look at signals in days when typical or unusual lifestyle patterns occurred, or in days of known treatment compliance or non-compliance. In this respect, new research has to lead to standardized procedures that tackle the following four issues "How can large-scale annotated data be requested and acquired", "How can the various daily life conditions be mapped to unambiguous and quantitatively processable factors", "How to express contextual information, activity, place, lifestyle and out of regular events, medication, stress, symptoms, diet, in a standardized manner", and "How can these factors be combined to a model that may help interpret data, and guide patient/health professional".

Regarding storage, an emerging trend is the adoption of new technologies beyond traditional locally hosted relational medical databases for structured and unstructured data (NOSQL technology) [26] and deployment of data management as cloud services. Cloud computing has been considered as an attractive option due to its ability to connect users with their remotely stored data through any device, as well as increased flexibility and low cost in service deployment due to virtualization of resources. Yet cloud deployment of connected health systems still need the attention as regards the interoperability, security and privacy bottlenecks [27]. The separation of the massively recorded data to be stored and processed at

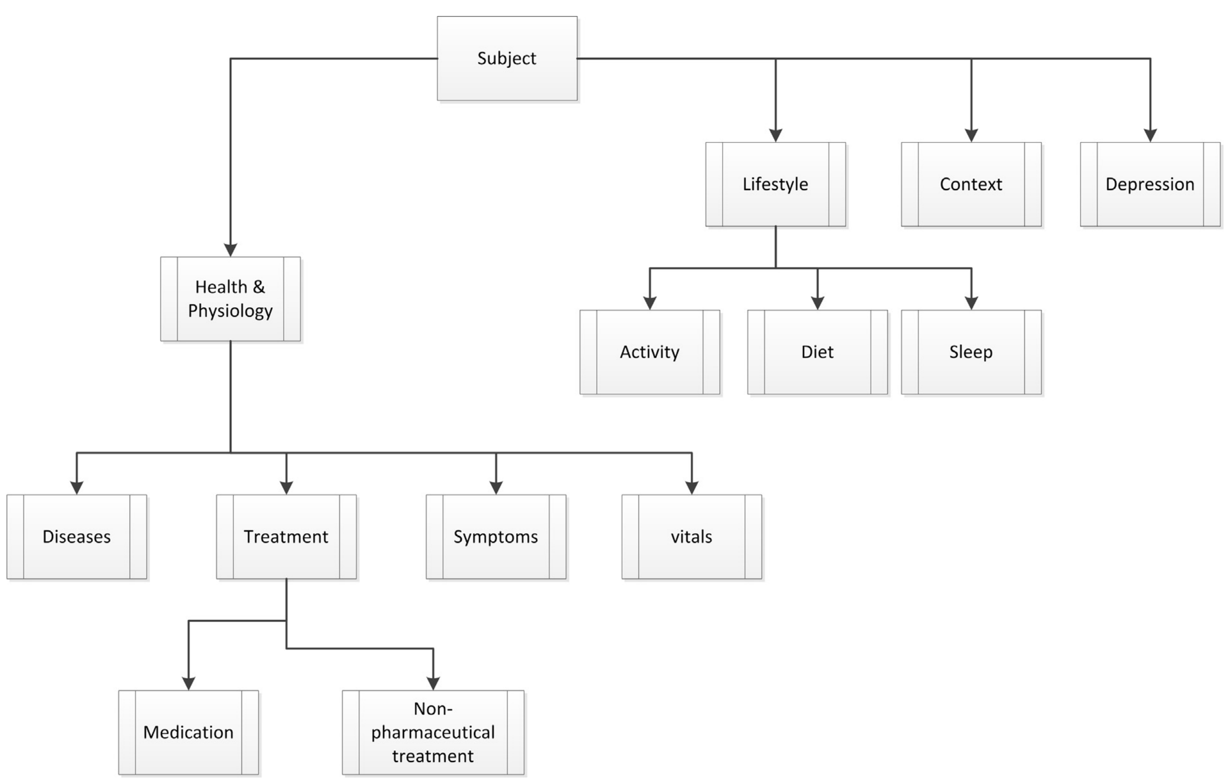

Fig. 3. Conceptual model to represent structurally complex data hierarchically.

cloud level from the personally identifiable information that should be more 'protected', yet allowing a combined view of both for the user (patient or HCP), when required, is an issue that requires attention.

6. Data analytics: integration of intelligence and modeling

An important component in the connected health ecosystem is data analytics, giving value and meaning to the collected data and enabling the personalized healthcare decisions in the full circle of care around an individual. Specifically, the collected data via sensors, patient experience and clinical input set the input for:

- Analysis and generation of features that can represent the condition (status and trend) of the patient, at multiple levels [28]. A crucial factor here is the data quality, especially as measurements are taken in unsupervised environments and presence of artifacts and noise can introduce fake variation. For example, heart rate recorded via wearables should be safely estimated in adequately long segments before using it for sleep staging estimation.
- *Intuitive visualization of status and trends for visualization in patient and professional applications.* Employment of persuasive technologies [29] for presentation of information and feedback to the patient is an active area of research. For example, in affective health system [30] new paradigms are explored (e.g. spiral view instead of linear) for visualization of temporal changes, that can ignite a different patient conceptualization of his/her health information.
- *Predictive models and decision support systems*, including risk models for clinical use, diagnostic tools (e.g. prediction of heart failure decompensation, or mental health), treatment support tools. For example, in PSYCHE project focusing on bipolar patients, the sample entropy of the heart rate variability (measured at home via wearable sensors) was found to increase according to the patients' clinical improvement [31].

While biodata analysis has a long history and significant achievements, the simple extension to PHS data is not trivial and introduces new challenges. In a PHS scenario, a big data collection can arise from a single coherent and consistent data acquisition process, but also quantities of data may be acquired from multiple sources and be combined. The quality of the original data varies, with inherent accuracy, and timeliness problems. When data is repurposed, the widely varying quality levels of data in the individual databases result in yet lower quality levels in the overall collection.

Of special importance is the effort to generate models and medical decision support systems addressing management of complex cases of patients with multiple morbidity, which are actually a big number of chronic patients. In such cases there is need to assess and combine multiple sources of information for diagnostic purposes, e.g. to predict deterioration and detect the reason for deterioration in a complex pathology, as attempted in WELCOME project [32]. An example of the intended care coordination among HCPs that manage a complex patient is to detect via the home system an upcoming depressive condition of the COPD patient, that might later affect compliance and lead to health deterioration, and have it timely managed by the appropriate expert.

The sparseness of concrete medical evidence and guidelines on co-morbidity management, that could otherwise be mapped to an expert system, poses a great challenge to be met for personalized treatment optimization, before deploying such systems in wider integrated care settings. Additionally, the best scale (and temporal detail) for examining physiological dynamics within daily context, with respect to disease deterioration, medication effect and compliance, remains a challenge for further investigation. Specifically, moving beyond simple average values (e.g. average heart rate within the day), new medical evidence will have to be investigated as to what are the most important markers that predict physiological status and change.

Finally, within this abundance of information and multi-professional involvement, frameworks for the contextualization of information sharing and coordination of decisions to increase collaboration of HCPs for chronic and multimorbic patients is another promising area of research [33].

7. Concluding remarks

The connected health ecosystem sets the basis for the investigation and deployment of new integrated care models, with greater engagement of citizens and patients, and coordination among healthcare professionals, and availability of information and support to all.

This overview presented the ongoing research and challenges as regards the fusion of sensing systems, making sense of sensed data, optimizing feedback strategies. Clearly, while healthcare technology sets the framework and opens opportunities, there is a huge need for continuous validation and concrete evidence on the new approaches, which will lead to their wider adoption. These will need the active involvement of the patients and the HCPs. Connected health technologies aim at personalized services tailored to the different health problems, and the needs of each user. Thus, not a single solution but an ecosystem of technologies and approaches is considered, that can be flexibly combined (pick and mix), provided that (a) standard and interoperable systems and services are developed, and (b) healthcare organization moves from monolithic to integrated modular approaches.

List of contributors and their role in the paper

IC designed the study, analyzed the data, participated in the results interpretation and wrote the manuscript (MS). DG along with IL participated in results interpretation, reviewed the MS and overviewed the whole study mainly concerning the medical aspects. NM designed the study, participated in the MS writing and results interpretation, and overviewed the whole study. All authors read and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interest.

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