Chapter 22
Wearable Technologies and Telehealth in Care Management for Chronic Illness

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Abstract Telehealth is the use of technology for remote patient monitoring and care. Wearables are small electronic devices that can seamlessly collect data about a patient for prolonged periods of time and support the implementation of telemedicine in the patient's natural environment. In a reality where patients are becoming older and sicker, medicine is becoming more and more a multidisciplinary team work and healthcare resources are limited, telehealth holds promise as a way to improve patient care while cutting on costs. It may improve coordination between care providers, allow for bringing top notch expertise to remote, rural settings, provide a more complete picture of the patient's condition and support independent living of the elderly and patients with chronic diseases. In this chapter, we review some of the related technology and application and portrait how they may be integrated in the near future in the healthcare delivery system.

Keywords Wearable • Sensor • Telehealth • Chronic condition • Care management

22.1 Outline

After presenting the medical, technological and financial context for the rise of telehealth in Sect. 22.2, we will introduce the (sometimes ambiguous or overlapping) main terms and concepts in this domain in Sect. 22.3. Section 22.4 will explore the roles of telehealth in delivering healthcare and the potential held by wearable devices in facilitating telehealth use. In Sect. 22.5 we illustrate the use of telehealth

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technologies in a few real-world applications. Section 22.6 elaborates on challenges that implementation of telehealth faces, and Sect. 22.7 offers a glimpse into the near future of wearables. We conclude this chapter in Sect. 22.8.

22.2 Introduction

22.2.1 Wearables Revolutionize the Capture of Clinical Data

Traditionally, medicine was practiced at the presence of the physician, either at the patient's home, in the clinic or hospital. This was because the tools used for diagnosis and treatment were sparse, expensive and manually-operated. With the advent of technology, some diagnostic and therapeutic procedures could be performed automatically or by other professionals (e.g., lab technicians). These allowed for the concept of patient monitoring to develop.

Yet, even today, most of the clinical data is collected in the clinic- be it the physician's office or an inpatient ward. Enormous amounts of patient-related data such as temperature, heart rate, blood pressure and blood oxygen saturation are captured and stored. These data may be used for secondary analysis, to leverage insights on disease characterization and progression, improving prediction of future events and supporting individualized care. However, the data captured in the clinic settings does not necessarily reflect the patient's condition in other setting such as at home or at work. For example, a patient's blood pressure measured at the physician's office may systematically differ from that taken outside the clinic. Moreover, clinical (diagnostic and therapeutic) decision points are limited to times when new data is available. Since data is collected on a periodic basis, often with long intervals between observations, opportunities to react to changes in a patient's condition are limited.

Indeed, several monitoring devices are widely available for home use. These include blood pressure monitors, simple EKG devices and pulse oximeters, to mention some. However, continuous monitoring using such devices is impractical and rarely done. A few monitoring systems that allow for continuous outpatient data collection are available (e.g. Holter test, ambulatory blood pressure monitoring) but these are cumbersome, expensive and are used for short, infrequent monitoring sessions. Moreover, interpretation of the data collected by such devices requires expertise and is not commonly done in real time.

Recent years have brought about the ubiquitous use of smartphones and wireless connectivity (e.g., WiFi and Bluetooth technologies). Enabling this revolution in part was the development of various small and cheap sensors and transmitters. As computers have become closely intertwined with our daily life, it was only natural for gadgets based on such technology to be introduced, that can be carried around continuously and interact with computers and with one another. Wearable technology has emerged and it is growing fast.

For the most, commercially available wearables target the wellness market. Heart rate sensors continuously monitor pulse, whereas motion sensors and accelerometers are used to count steps and minutes of sleep. Wearables are frequently integrated with smartphone and personal computer applications that allow for review of the recorded data as well as for capturing of other types of data (e.g., caloric intake). Such applications often provide recommendations related to wellness maintenance including diet and exercise.

Strict regulations enforced by the FDA and other governmental agencies, higher development costs and liability concerns have kept medical wearables lagging behind. Yet the healthcare ecosystem is undergoing tremendous changes which are likely to turn wearables into an integral and important component of patient care in the next few years.

22.2.2 Medical, Economic and Social Factors Are Driving the Development of Telehealth and Wearable Systems

22.2.2.1 Chronic Patients Are Increasing in Number and Require Costly Care

Healthcare costs are constantly rising. Sophisticated imaging techniques and advanced therapeutics offer hope to patients whose diseases have previously been beyond cure. The successes of modern medicine in prolonging life are leading to more and more patients living with chronic conditions for many years. The population is aging, and Baby Boomers are gradually entering the eighth decade of life, further increasing the burden on the healthcare system. As medicine is growing in knowledge and expertise, patients are becoming more complex. The traditional model of a “village doctor” has been replaced by a multidisciplinary team of care providers, including physicians of various specialties, nurses, physical therapists, psychologists, social workers, pharmacists, nutrition consultants and others. Their coordinated actions are essential in achieving therapeutic goals.

Chronic patients consume a large volume of medical services. The United States alone spent $2.8 trillion on health care in 2012 [12], with more than 75 % of these expenditures directed toward the treatment of patients with chronic diseases [45]. Chronic diseases—such as diabetes, cardiovascular disease, chronic obstructive pulmonary disease, and cancer—are persistent or recurring, and frequently debilitating conditions that require prolonged care. Due to their fluctuating nature, effective management of chronic diseases requires frequent follow up and treatment adjustments. Good control of chronic conditions may reduce morbidity and mortality. Adherence issues play a major part in achieving good control over chronic conditions, as patients have to be active monitoring measures such as blood glucose or weight and persistent in taking their medications. Patients are required to keep a log of their home measurements, to help their doctor have a better understanding of their day to day condition, but keeping such records is very demanding and many of them fail to do this.

22.2.2.2 Technologic Solutions Are Part of the Attempt to Contain Healthcare Costs

In light of the increasing burden of healthcare costs, ways to provide good medical care at reduced costs are vigorously sought. The understanding that better coordination between healthcare agencies and practitioners is required has contributed to the Meaningful Use Act, which drives the computation of health records and information communication between providers. Adaptation of a “pay by performance” model is increasing the incentives for stakeholders to prevent diseases rather than perform procedures. Attempts are made to shorten hospitalizations and reduce readmission rates. As it turns, this new model aligns medical and financial incentives.

Telehealth and wearable technology offer tools that are a natural fit to the new healthcare model demands. Sensors used to continuously capture and record patient data provide a more complete, real-time understanding of the patient’s condition. Combining such sensors systems with advanced analytic tools and audiovisual communication may turn the collected data to actionable knowledge to enable better care at reduced costs while maintaining independent living and improved quality of life to the elderly and to patients with chronic diseases. With telehealth, care providers can utilize communication technologies to provide education, assess patients, supervise procedures, and monitor patients with chronic conditions at home. Telehealth for patients with chronic disease can not only improve symptom management, but also provides an avenue to assess and improve compliance and adherence to prescribed regimens of care.

22.2.2.3 Cost Effectiveness of Telehealth

Expansive promises have been made about the potential role of telehealth in reducing healthcare expenditure. For example, Cusack et al. [16] modeled cost savings of $4.3 billion a year if telehealth were implemented to facilitate consultations between healthcare providers in the USA, and this is without considering savings associated with the provision of care direct to the patient. However, demonstrating the effect of telehealth on costs in real world settings is challenging, and in fact, no valid answer exists. This is due to the marked and multidimensional variability between studied applications, the continuous and rapid progress in the field as well as methodological flaws in published studies. Recently, Bergmo [6] reviewed the quality of economic evaluations in telemedicine, reporting highly diverse evaluations, many of which did not adhere to standard economic evaluation techniques. Specifically, statistical, sensitivity, and marginal analyses, and information on the perspective of the studies were often lacking. Whereas this review pointed out methodological deficiencies, it did not aim to draw conclusions about the cost-effectiveness of telemedicine.

Here we bring a few examples of cost effectiveness studies summarized by Wade et al. [49] to illustrate their strengths and limitations. A review of telehealth provision of accident and emergency support to primary care found several studies with utility analysis, all indicating cost-effectiveness; however it concluded that the case was far from proven [10]. Two reviews of telepsychiatry concluded that cost-effectiveness could not be demonstrated because the volume of consulting was too low [34, 37], while a third review reported conflicting evidence of both increased and decreased costs [19]. A review of the use of telehealth in intensive care units found two clinical trials reporting cost savings [15]. Paré et al. [40] conducted a number of reviews on home care for chronic disease and reported that very few detailed economic analyses had been done, leading to no confirmation of economic viability. Applied to heart failure patients, home monitoring reduced costs of hospital admissions [31] in one study, and in another, despite initial excess costs, substantial long term cost savings were found [47].

22.3 Definitions

22.3.1 Telehealth

The Health Resources Services Administration defines telehealth as the use of electronic information and telecommunications technologies to support long-distance clinical health care, patient and professional health-related education (e.g., continuing medical education), and public health and health administration [21]. Through telehealth technology, medical practitioners are able to evaluate and diagnose patients remotely, prescribe treatment, e-prescribe medications, and quickly detect fluctuations in the patient's medical condition at home, to be able to alter therapy or medications accordingly. Under the general scope of telehealth are include *telemedicine*, i.e., remote doctor-patient consultations, and *telecare*, referring to the remote monitoring of vital signs and other health condition metrics, and patient assessment (Fig. 22.1). Telehealth technologies include videoconferencing, the internet, store-and-forward imaging, streaming media, and terrestrial and wireless communications. Based on timing of communication, two types of telehealth systems are defined:

- Real-Time Interactive Systems (Synchronous) telehealth: requires the presence of both parties at the same time and a communication link between them that allows a real-time interaction to take place. Video-conferencing equipment is one of the most common forms of technologies used in synchronous telehealth. There are also peripheral devices that can be attached to computers or the video-conferencing equipment which can aid in an interactive examination.

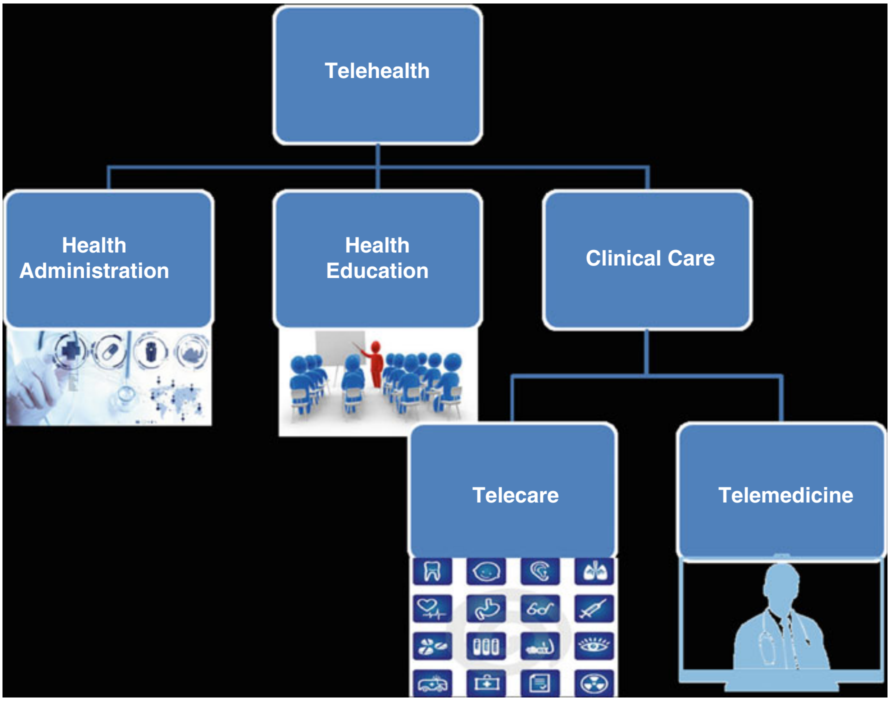

Fig. 22.1 Components of telehealth

- Store-and-Forward (Asynchronous) telehealth: involves acquiring medical data (like medical images, biosignals, voice recordings, etc.) and then transmitting this data to a doctor or medical specialist at a convenient time for assessment offline. It does not require both parties to be available at the same time

22.3.2 *Telecare*

Telecare uses remote monitoring of patients to receive alerts about real-time emergencies and to track lifestyle changes over time. Telecare is managed through the use of telecommunications technology including telephones, computers and mobile monitoring devices such as warden alarms, automatic gas shut-off devices and home entry videophones. Telecare allows patients to stay safe and independent in their own homes. The concept of remote patient monitoring (RPM) relates to medical applications of telecare, utilizing information and communication technology (ICT) to deliver health services at a distance. RPM includes the collection of disease-specific metrics from biomedical devices used by patients in their homes or other settings outside of a clinical facility. RPM systems typically collect patient readings and then transmit them to a remote server for storage and later examination by healthcare professionals. Once available on the server, the readings can be used in numerous ways by home health agencies, clinicians, and informal care providers.

22.3.3 Telemedicine

Telemedicine is a subtype of telehealth defined as the use of electronic communications and information technologies to provide clinical services to patients in locations and times other than where the care provider is present. While telehealth can refer to remote non-clinical services, telemedicine refers specifically to the provision of health care services and education over a distance through the use of telecommunications technology. Examples of telemedicine include video consultations with specialists, remote medical evaluations and diagnoses and the digital transmission of medical imaging.

22.3.4 Mobile Health, Wearable Technologies

Broadly and somewhat loosely viewed, a wearable sensor is typically a small electronic device located in proximity to, or implanted within, the body of a user, which can transduce information related to the user or their ambient environment. Wearable sensors (commonly referred to as "wearables") use various technologies to capture physical or chemical signals [42].

Some wearable sensors have been used for decades. These include home blood pressure monitors, glucose sensors and pulse oximeters (measuring blood oxygen saturation). Most of these are stand-alone devices that perform on-demand measurements. Some of the newer ones can keep a log of results or communicate them to a personal computer application. Event-triggered devices include, for example, implantable cardiac pacemakers equipped with loop recorders to capture episodes of arrhythmia, or home apnea monitors for infants.

However, the wearable technology revolution now offers much more sophisticated designs. These rely on miniaturized sensors, with some at the micro- and even nano- scale being developed. For instance, off-the-shelf millimeter-scale products with a triaxial accelerometer, a gyroscope and magnetometer are currently commercially available and widely used in gadgets [42].

Wearables use sensors that transduce various types of signals to electric impulses. They can be classified by their location, the technology they use or the determinants they monitor (Table 22.1). A general distinction can be made between physical and chemical sensors. Physical sensors measure vital signs such as heart rate, blood pressure and temperature, but also activity (e.g., movement, and location). Chemical sensors monitor the concentration of substances in or on our body (known

Table 22.1 A classification of parameters associated with wearable systems features and capabilities

Determinant	Type [examples]
Location	External (Apple Watch (Apple Inc.), Samsung Gear (Samsung Inc), fitbit bracelet (Fitbit Inc.), tattoos)
	Implanted- usually embedded in another implantable medical device [cardiac pacemaker, Implantable cardioverter-defibrillator, cardiac resynchronization therapy]
Sensing type	Physical (heart rate, blood pressure, respiratory rate, peak-flow, oxygen saturation, body movement, speech, pupil diameter, electrodermal activity, speech)
	Chemical (glucose, sodium, potassium, lactate, pH)
Power supply	Battery- rechargeable (including wireless charging) or replaceable
	Energy scavenging/harvesting (using mechanical movement, vibration or heat)
Configuration	Stand alone
	Coupled with an external device (smartphone, laptop)
Data storage	Store on device memory and/or transmit to other devices for storage
Transmission technology	Wired (uncommon)
	Wireless (radio frequency, bluetooth)
Transmission frequency	Continuous
	Scheduled: at predetermined intervals
	On-demand: user activated
	Triggered: such as by signals from other sensors
Data analysis	Local- integral (within the device)
	Local-external (e.g. on a smartphone)
	Remote (on the cloud)
Data clients	User
	Care provider
	Hotline
Notification- content and scope	All data collected
	Interpretation of raw data, such as in the form of outstanding values, summaries or alerts
Guidance/advice	None
	Local- relying on an adjunct device such as a smartphone
	Remote- web-dependent
Therapy administration	User supervised/facilitated (patient-controlled analgesia)
	Autonomous-closed loop (bionic pancreas)

as biosensors). This is commonly done using an electrochemical sensor. The measured substance (analyte) attaches to a receptor (e.g. an antibody) and a physico-chemical transducer then generates an electric signal that is proportionate to the substance concentration. While attractive, this approach faces some challenges, including low sensitivity at low substance concentration and limited long term resilience [4]. Other technologies, particularly using spectroscopy are being adapted to wearable devices and avoid the need for using a receptor.

Smart fabrics are made with conductive material which allows for sensors to be embedded in textile (e-textile). These provide convenience of use while performing continuous monitoring, facilitated by a wide contact area with the body.

Body area networks (BAN) are formed by an array of sensors that measure various physiological parameters [17]. BAN's, aka Smart Wearable Systems (SWS) [27] use wireless technology such as radio frequency (RFID) or Bluetooth for communicating captured data. Data collected can be stored and transmitted to a local microprocessor (in a smartphone or personal computer) or to a distant server for analysis. Information can then be made available to the user or a care provider (Fig. 22.2). If a need for immediate action is detected by the system, the user and/or a care provider may be alerted, and interim advice may be provided independently by the system. Coupling sensing with decision rules or artificial intelligence may be used to autonomously control the administration of therapeutics in closed loop systems. Many concerns are associated with this idea, however a working Bionic Pancreas, coupling continuous glucose sensing and insulin administration has been recently evaluated in patients with type-1 diabetes in a clinical trial [44]. SWS are most commonly noninvasive, although implantable systems are also being developed. Novel ways to power such devices, including miniature batteries, wireless charging using induction, and ways to use energy harvested from the sensor's environment are explored [32]. Table 22.1 lists the different levels of capabilities offered by wearables.

22.4 Impact of Telehealth and Wearables

22.4.1 Telehealth Supports a Healthier Healthcare System

The advantages offered by telehealth are multifold, and all of the healthcare system stakeholders may benefit from its use:

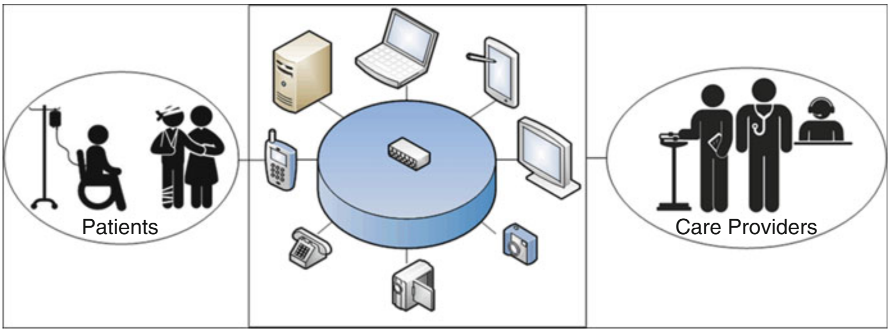

Fig. 22.2 Communication networking of mobile telehealth systems

- **Patients** may achieve better access through telehealth to specialists who can apply higher standards of care associated with their clinical discipline, avoiding long distance travel. With the ability to better manage their health situations at home using remote monitoring, patients can remain closer to the support network of family and friends to avoid unnecessary admissions or delay readmissions.
- In **outreach clinics**, telehealth services enable clinical staff to better cope with challenging diagnostic and therapeutic questions arising during patient care by having real time access to specialist support networks. Easy access and geographical convenience offered by widespread outreach clinics can help attract clients, as well as improve patients' adherence to appointments and treatment. The ability of outreach clinics to retain patients rather than transfer them to another facility or possibly out of their health system altogether has the potential to improve care continuity and coordination.
- **Consulting physicians** may extend their clinical reach to a wider range of patients who can benefit from their expertise. They can save the time lost traveling between facilities to see patients, and increase their productivity.
- **Payers** may reduce expenditures by optimizing the use of specialist resources. For example, remote consultation may save unnecessary transfers, admissions or readmissions, and reduce length of stay. In addition, timely access to physicians with right expertise may help optimize care and reduce the risk for costly complications.
- Telehealth can be beneficial to the **healthcare system** as a whole by providing tools to cope with the growing shortage of physicians, delaying the need to provide nursing home services to elderly and chronic patients, and shortening the lifecycle needed for new practices and guidelines to be implemented in the community setting. Overall costs can be reduced by telehealth through more comprehensive preventive and early stage care rather than having to face patients with conditions complicated by delayed medical intervention.

22.4.2 Wearables Power the Widespread Use of Telehealth Services

Wearable systems provide better data on patients. Quantitatively, they can capture much more data; a sensor is used on a single patient and does not have to be shared with others, so it can be used to monitor the patient continuously for prolonged periods of time. Moreover, data is collected in the patient's natural environment, not only in a designated point in time and space. As such, it is of higher clinical quality or utility since it better reflects the patient's true condition.

Improved data collection means not only better understanding of a single patient's disease characteristics and course, but also, in the aggregate, better understanding of conditions at the population level. Coupled with advanced analytics, data capture by wearable devices may generate insights that could transform the way in which diseases are diagnosed and managed.

22.4.2.1 Diagnosis

Widespread use of sensor systems among healthy individuals offers a potential to diagnose conditions before patients actively seek medical advice and even before they are symptomatic. Take for instance silent cardiac ischemia, a condition wherein impaired blood supply to the heart is not accompanied by chest pain. This condition is easily missed unless specifically sought. ECG changes consistent with ischemia may be captured by wellness wearable devices during physical exercise and prompt performing additional tests to exclude or establish ischemic heart disease.

Wearables may be useful in diagnosing other conditions as well. Continuous home monitoring of blood pressure could more efficiently identify conditions such as white coat hypertension (abnormally high clinic blood pressure with normal out-of-clinic readings) and masked hypertension (normal readings in the clinic that mask hypertension in other settings).

Importantly, wearables can provide useful data in real time. A commonly performed test in traditional medicine is the Holter test, which is used to capture episodes of arrhythmia (abnormal heart rhythm) by continuously monitoring ECG in the outpatient setting for 24–48 h. The ECG is recorded and stored in the memory of the device. When the test is completed, the device is returned to the clinic and a physician reviews the data stored on it. If there is an episode of arrhythmia during the test, it would only be detected days or even weeks after it had occurred. In some cases, immediate intervention to control potentially fatal (and sometimes asymptomatic) arrhythmia may be indicated, and so real time detection of abnormalities may be life-saving. Smart Wearable Systems offer the ability to capture and transmit data from monitors in real-time, as has been used in Remote-ICU (intensive care unit) programs [11].

Sensors can be used in the patient environment to collect data without even touching the body. Although not truly wearables, wall-mounted motion detectors installed in a patient's home may be used to detect changes in patients' behavioral patterns potentially indicative of an arising or aggravating health problem.

22.4.2.2 Management

SWS engage patients in managing their own conditions by making them aware of their state without requiring them to invest time in measuring and documenting the monitored attributes. They allow care providers to be kept updated about their patients' condition, giving them the opportunity to follow up on their recommendations in a fast and flexible way, and facilitate effective communication between patients and providers. Close home monitoring may allow for earlier hospital discharge, as well as for timely measures to be taken to avoid readmission. Monitoring can provide reassurance to elderly persons living alone and their families. Their input can be used to optimize a treatment protocol to achieve better disease control, so as to anticipate events and address them preemptively. As part of an integrative outpatient care program framework, better patient data can be used to prioritize interventions. Moreover, ongoing monitoring of patients, dynamic evaluation of their needs and flexible allocation of resources to meet them may enable healthcare systems to cope with increasing needs and ever-limited funding. Such enhanced monitoring capabilities utilized in advanced care models may be able to delay the need for institutionalization and improve the quality of life of persons living independently.

22.5 Real-World Applications on Telehealth and Smart Wearable Systems

There is an almost infinite number of potential applications for telemedicine using SWS. In this section, we bring a few examples of solutions that have been developed and clinically evaluated.

22.5.1 At-Home Monitoring of Patients with Heart Failure

Patients with heart failure tend to be complex, commonly having comorbidities and taking multiple medications. In the course of heart failure, exacerbations may manifest as fatigue and shortness of breath, sometimes severe enough to lead to respiratory failure. Patients with heart failure are required to maintain a strict diet and monitor their weight frequently as a marker of fluid retention. Sensors embedded in implantable devices such as cardiac pacemakers and implantable cardioverter-defibrillators have been developed, that can measure heart rate and heart rate variability, EKG, patient mobility and intra-thoracic impedance. Their use has been demonstrated to improve the prediction of heart failure decompensation at home, which may allow for preventive measures to be taken. A trial in which a pressure sensor was implanted in the left atrium of the heart of patients with severe heart failure and used to support patient self-management by titration of medications reported a reduced risk of acute decompensation or death compared to the control group reviewed in [14].

22.5.2 Early Detection and Management of Atrial Fibrillation

A program in which EKG streams were transmitted by cardiac pacemakers routinely to a medical team showed improved early detection of arrhythmia (atrial fibrillation) that affected patient management [43]. The European Union-funded MobiGuide project developed an intelligent decision-support system for patients with chronic illnesses, including atrial fibrillation. Wearable sensors monitor heart rate and blood pressure and transmit data wirelessly to the patient's smartphone, and through it to a back-end server. A decision support framework that can access the patient's medical records analyzes the data streams and uses clinical practice guidelines adapted to be computer-interpretable to reach management recommendation. The system can interact with the patient to collect additional information and prompt alerts to the patient and to caregivers. Advice is personalized to meet the patient's circumstances (e.g. living alone). A limited set of off-line decision support tools is also available through the mobile device [33].

22.5.3 Automatic Detection of Fall Among the Elderly

Falls occur yearly in one third of adults older than 65. Apart from potentially serious injuries inflicted by falls, fear of fall is common and adversely affects quality of life [25]. Half of the patients falling are unable to get up, resulting sometimes in a "prolonged lie", which carries medical and psychological consequences. Patients with impaired cognitive function are at increased risk of fall and may not even be able to activate a user-operated wearable panic alarm device [7]. Wearable sensor-based applications to detect falls are usually based on accelerometers. Real life evidence for their effectiveness is limited, perhaps due to the low frequency of falls, and reported performance measurements based on simulated falls may be overly optimistic [3]. A comprehensive review on automatic fall detection has been recently published [39].

22.5.4 Mental Health Monitoring Applications

Assessing the level of stress is commonly done using markers of increased tone of the autonomic sympathetic nervous system (e.g., heart rate, heart rate variability, and electrodermal activity). Attempts to capture electroencephalogram (EEG) streams to assess cognitive and mental function are also made. Speech analysis, using semantics or on patterns of speech flow have been able to detect thought disturbances [35]. The European PSYCHE project couples e-textile and smartphones in the outpatient mental patient environment for long-term (day and night) recording of physiological and clinical parameters, including voice recording. It aims to detect and eventually predict mood changes in those patients, directing preemptive interventions to be carried out [23].

22.6 Challenges

22.6.1 Information Challenges in Telehealth Applications

The amount of health data collected from patients is growing rapidly and the volume of which can be overwhelming. A telehealth system using biomedical devices or video conference tools to generate, collect, and transfer patients' health data presents challenging requirements in the area of content management and system capacity.

- **Scalability**: Millions of patients suffering from chronic conditions are the potential clients of telehealth systems. Such systems are required to scale to support large numbers of patients and their associated care providers while adhering to proper identity matching when managing patients and their associated devices and data streams.
- **Interoperability**: to ensure effective and efficient delivery of health care and maintain transparency regarding care quality and pricing, any new telehealth system development or acquisition faces the challenge of using a wide range of health information exchange standards and protocols, to the greatest extent possible. Interoperability and certification standards are important but take time to develop and are constantly evolving. Among many efforts, one notable initiative is the eHealth Exchange, formerly known as the Nationwide Health Information Network (NwHIN), developed under the auspices of the U.S. Office of the National Coordinator for Health Information Technology (ONC), and now managed by a non-profit industry coalition called HealtheWay [38].
- **Reliability**: As the complexity of telehealth function increases, there is a higher demand on network bandwidth and reliability. While patient access to online electronic medical record or Web-based health information requires lower bandwidth, clinical video conferencing or image streaming can pose a greater challenge in terms of system infrastructure support. Patients may be at home or travel to places where network connectivity is poor. Even in the face of network failures, the system should collect, cache, or store patient data for later transmission to the back-end system to avoid data loss.
- **Privacy and security**: The U.S. Congress has passed the Health Insurance Portability and Accountability Act (HIPAA) [18] to improve the efficiency of electronic health record systems while protecting patients' rights by reducing instances of information fraud and abuse. Medical privacy and confidentiality issues involved in the telehealth industry may be extremely complex. When communicating with patients through telehealth, there are risks that the telehealth encounter itself would result in a privacy or security law violations. Because these interactions, by definition, involve communications with patients who are not physically present, there is a heightened risk of disclosing information to the wrong person, which would likely be an unauthorized disclosure under the HIPAA Privacy Rule. Telehealth encounters may also be vulnerable to third party interference, signal errors, or transmission outages. These types of incidents can result in data loss, interrupted communications, or the alteration of important clinical information, which, in addition to other liability risks, could be considered HIPAA privacy and security violations. In certain cases, transmission outages or the loss of important clinical data during transmission could be seen as a failure to adequately maintain the integrity or availability of protected health information (PHI) as required under the HIPAA security regulations. In addition, electronic transmission of information can be susceptible to hackers and other

breaches of security. Telehealth networks often require technical teams to run the systems, independent of medical staff, which means more people have potential access to patient records. This is associated with higher risks of undue exposure to private patient data. The HIPAA privacy rules provide a framework for securing protected health information held by covered entities and specify patients' rights with respect to that information. Under HIPAA, telemedicine clinicians have the same responsibility to protect patients' medical records and keep information regarding their treatments confidential. Electronic files, such as images or audio/video recordings, must be stored with the same precaution and care as paper documents. Telehealth providers should have in place reliable methods for verifying and authenticating the identities of the patient and practitioner(s) at the beginning of each telehealth encounter. Patients and clinicians should communicate via phone, text, emails through a secure portal to protect PHI.

22.6.2 Regulation and Licensure

Licensure is a major concern facing telehealth, especially in the United States. The US has federal standards for medical training and testing, however licensure is on a state-by-state basis with each state having its own licensing board. Providing telehealth services across state lines therefore creates licensure and insurance challenges. Most states require not only that physicians providing tele-consultation services be licensed to practice in their original state, but also in the state where the patient is located [20].

Another factor that has been limiting the acceptance and growth of telehealth is reimbursement. Today, not all telehealth costs are reimbursed. The Centers for Medicare and Medicaid Services (CMS) views telehealth as a cost-effective alternative to traditional medical care, but the decision to reimburse for telehealth services is at the discretion of each state [13]. Indeed, most states have chosen to reimburse for Medicaid telehealth services, and some also require that such services be covered by private medical insurance plans. Medicare reimburses for telehealth services when the originating site (where the patient is) is in a Health Professional Shortage Area (HPSA) or in a county that is outside of any Metropolitan Statistical Area (MSA), defined by HRSA [22] and the Census Bureau respectively. This originating site must be a medical facility and not the patient's home. Medical facilities include practitioners' offices, hospital, and rural health clinics. This reimbursement is not affected by the location from which the telehealth services are being delivered (the "distant" site). Medicare will only pay for synchronous, "face-to-face" interactive video consultation services wherein the patient is present. In most states, asynchronous "store-and-forward" applications such as teleradiology, telepathology and remote EKG are not reimbursable.

There is no single widely-accepted standard for telehealth adoption and reimbursement by private payers. Some insurance companies value the benefits of telehealth and will reimburse a wide variety of services [1]. Others have yet to develop comprehensive reimbursement policies, and so payment for telehealth may require prior approval. Likewise, different states have various standards by which their Medicaid programs will reimburse for telehealth expenses [36].

The American Telemedicine Association publishes standards and practice guidelines for delivering telehealth care in different clinical domains, including but not limited to telemental health, teledermatology, teleICU, telerehabilitation and telepathology [2].

22.6.3 Technical Support and Informatic Training on Telehealth Services

22.6.3.1 Physician Information Overload

Because telehealth aims to leverage scarce care resources and improve care efficiency, medical practitioners may treat more patients in a telehealth environment than in the traditional face-to-face medical settings. As clinicians are already overwhelmed by information, more electronic data in the form of numbers, images, or messages may be too much to handle. Proper use of technology is a key factor in the long-term success of telehealth programs, and this entails finding ways to avoid dumping of information on physician.

22.6.3.2 Patient and Clinician Technical Skills

Operation of sophisticated telehealth devices and wearable technologies can be challenging for clinicians and patients alike. Comprehensive training programs will be needed, particularly in the early stages of implementation, to overcome the lack of familiarity with new technologies, or an initial reluctance to rely on telehealth technologies to make diagnosis and treatment decisions. For example, properly using fiber optic scopes (e.g., dermascope and naso-pharyngoscope, remote otoscope, telephonic stethoscope) by a patient during video conferencing, and correct interpretation of this information by a remote physician without operating them require coordinated interaction achieved by experience and practice by both parties. A telehealth program should not underscore the importance of training to achieve increased utilization of the system, improved data collection capabilities, and greater confidence in diagnosis when relying on data collected through telehealth technologies.

22.6.4 Challenges to Utilizing Wearable Technologies

Noninvasive sensing involves considerable "noise" generated by various factors. Assuring an acceptable signal to noise ratio, as well as maintaining sensor resilience under real-life conditions is therefore not trivial. The more data is collected about patients, the higher the chances of detecting abnormal patterns. Whereas this serves the goal of early diagnosis and close follow up on patients, some abnormal patterns may generate false alarms, which are counter-productive. Ways to minimize false alarms should be sought, and the use of collateral data captured by different sensors to validate the readings of one another may be beneficial in this regard. All systems require energy to power data capture, storage and especially transmission. Providing power supply for prolonged periods of time is mandatory in the case of implanted sensors, the replacement of which requires invasive interventions. Solutions using energy scavenged from the body or environment are sought but are not yet ripe.

The volume of data generated by continuous monitoring is another challenge. It has been estimated, for example, that a single multifunctional sensor may generate over 150 MB of data per day [42]. The amount of data that has to be saved and transmitted may be reduced by filtering or processing of captured data at the sensor level. Reducing unnecessary data transmission may also be used to prolong battery life. Analyzing the enormous amounts of data collected by multiple sensors over time carries the promise of leveraging new insights, but requires sophisticated expertise and expensive technical resources.

As of yet, there is no agreed method for standardization of data measurements, storage and transmissions that supports integration of inputs from various sources. Even if there were such standardization protocols, the patterns identified in the data from a particular patient may not be characteristic of those of another patient. Between- subject variability increases the complexity of analysis and limits the generalizability of its results. On the other hand, using patients as self-controls by comparing data from multiple time points may help reduce the noise and improve the prediction of future events based on past trends. Moreover, uncommon patterns or signal features shared by a subset of the population may be discovered using the power of so called Big Data.

In the development of SWSs, special attention should be given to the discomfort and inconvenience of use, societal stigma and privacy considerations [42]. A wearable device should have minimal impact on the user's daily life. A small device which may be discretely carried is more likely to be accepted by patients than a visible, bulky one, especially when wearing it implies a disease (this does not apply to fashionable gadgets used for wellness management). Privacy considerations arise from the transmission of data from sensors to other devices such as cell phones, which may be intercepted. As with other personal medical information, measures to assure that only those approved by the user could access data collected by SWS should be taken.

22.7 Future Directions

Telehealth and wearable technologies are gaining increasing attention from healthcare organizations across the globe, and the body of evidence supporting telehealth and wearable technologies and their outcomes continues to grow. Telehealth promises immense potential on cost savings. Improved communication between doctor and patient telehealth facilitates will inevitably make remote medical services and telemedicine technologies an integral part of many healthcare organizations. The following are some of the most prominent emerging telehealth trends:

22.7.1 Emerging Telehealth Trends

22.7.1.1 Patient-Centered Home Telehealth

The ability to record and capture vital patient and environmental information makes telehealth a powerful assessment service for home care. Vendors are focusing on home-based healthcare solutions that give patients more control over their own care, especially for patients suffering from one or multiple chronic conditions. In this environment, telehealth technologies assist home care nurses to monitor a patient's vital signs, capture images and video of wounds or perform stroke assessments at home and share it with other health care professionals. These applications also enable nurses to identify changing trends in the patient's physiological state from a distance. The home care team can discuss next steps of management and attach the information to the client's record. This type of technology can also assist with medication compliance and decrease the need for in-home care or office visits.

22.7.1.2 Health and Wellness

Health and wellness programs, including diet and exercise routines and consultations with life and wellness coaches, are being implemented to provide disease prevention or to improve post-discharge care to reduce complications and avoid costly readmissions. Many chronic conditions can be improved or prevented through lifestyle management.

22.7.1.3 Long-Term Care Facilities

Often long-term care facilities do not have physicians on premise and health concerns can be beyond an onsite care giver's scope. In these situations, traditional telehealth technology is not sufficient. Patients are typically transported by ambulance to an acute care facility, which is resource and labor intensive and also stressful for patients. The mobility of a telehealth kit can be used in these situations to bring a physician or specialist right to the resident's bedside to make a proper assessment of the situation and decide on appropriate follow-on actions.

22.7.1.4 Remote Nursing Stations

Remote nursing stations can benefit from many of the use case applications described above. Nurses can engage medical specialists to provide enhanced quality of care while saving money on transportation costs and logistics. Connectivity options for remote nursing stations can be accomplished through terrestrial internet options or cellular and satellite communications if available.

22.7.1.5 Telesurgery

Remote robot-assisted surgery has recently been made feasible through Asynchronous Transfer Mode (ATM) technology, which was designed for the high-speed transfer of voice, video, and data through public and private networks [29, 30]. Telementoring, a subset of telemedicine, allows a surgeon at a remote site to offer intraoperative guidance via telecommunication networks. As robotic surgery continues to evolve, telementoring will become a viable alternative to traditional on-site surgical proctoring, particularly minimally invasive surgery (MIS). Newcomers to MIS need the guidance of more experienced, 'high volume' mentors to achieve the superior outcomes promised by MIS over conventional techniques [46]. As the cost of surgical systems decreases and reliable data networks become more available, barriers preventing the routine use of telesurgery may fall, allowing a more broad involvement in future surgical practice. Teletransmission of active surgical manipulations will continue demonstrating the potential to ensure availability of surgical expertise in remote locations for difficult or rare operations, and to improve surgical training worldwide.

22.7.1.6 Teleradiology

Teleradiology is the practice of transferring medical images electronically through the internet from a primary system to a remote location for the diagnosis or treatment of patients. Today teleradiology has many purposes worldwide ranging from services for expert or second opinions to international commercial diagnostic reading services. Not only does teleradiology improve the accessibility of radiologists but it also improves the quality of the interpretations for the patients [5]. Although teleradiology has become a reality for several years to date, its existence still has not been freed from all obstacles. Over years, the main issues have shifted from image quality, transmission speed and image compression to clinical governance, legal concerns and quality assessment. The increasing use of teleradiology reflects the changing world of clinical practice, service delivery and technology. With the widespread availability of fast connectivity, adoption of picture archiving and communication systems (PACS) and other advanced technologies, the sharing of medical imaging between physicians will become more commonplace in the foreseeable future [9].

22.7.1.7 Social Networking

Social networks are being recognized for their potential in helping people maintain healthier lifestyles. Keeping people accountable to family and friends can be much more effective than mandates from physicians, especially for patients with chronic conditions. Convergence of wearable, mobile technologies, telehealth and social networking is leading to a new healthcare delivery model. Patients can not only connect with other patients with similar medical conditions, they can also track and compare health data to better understand their bodies and contribute data to research. Telehealth and mobile health markets are anticipated to reach $2.9 billion and $1.5 trillion by 2019 due to the use of billions of smart phones and connected tablet devices all over the world [50]. Without a doubt, telehealth and mobile health markets are poised for tremendous growth and one could predict that these markets collaborate and innovate for devising healthcare delivery models in the coming years.

Over recent years, telehealth has increasingly demonstrated its value in supporting the delivery of healthcare. From teletriage services as a portal into healthcare through to telemonitoring of patients with chronic conditions, technology is already increasing the ability of practitioners to provide care remotely, empowers patients and improves clinical outcomes. In the future, telehealth services have the potential to have an even greater impact on the provision of healthcare. Embedding telehealth services into mainstream medical care, the development of more sophisticated devices and the utilization of technology in a wider range of clinical contexts will help to accelerate the adoption of telehealth throughout healthcare. In the fast-growing telehealth and wearable technology fields, new and valuable trends and telehealth technology solutions will continue to emerge and be adopted. Making use, or at least being aware of these trends will benefit providers, practitioners and patients as the market advances.

22.7.2 The Near Future of Wearables

A vibrant research and development environment exists, in which technological advancements are being explored to overcome some of the challenges of widespread use of SWS and to address more clinical needs. Technologies and projects are too numerous to cover here, and this section does not aim to be comprehensive but only to give a taste of this evolving industry through examples.

Energy harvesting methods may eliminate the need for battery charging or replacement [32]. Wireless-enabled garments with sensor-embedded textile (e-textile) are already appearing in the market to capture multiple signals simultaneously and continuously in a seamless manner [27]. Some systems incorporate electro-chemical sensors that can measure electrolyte concentration, pH, lactate, ammonium, glucose and other substances in saliva, sweat or tear fluid [4]. Noninvasive glucose monitoring is one of the most sought after applications. Various technologies have been attempted to achieve reliable glucose readings. The GlucoWatch® wristwatch-mounted glucose sensing device used an electric current to extract interstitial fluid through the skin and determined glucose concentration by reverse ionophoresis. The device has been withdrawn from the market following reports on skin irritation. Occlusive spectroscopy is used in the approved for marketing in Europe finger-mounted NBM-200G (OrSense Ltd., Israel) device for glucose, hemoglobin and oxygen saturation monitoring. For a comprehensive review on noninvasive glucose sensing, the reader is referred to [48]. Micro- and nanotechnology is making its way towards clinical use [26] with demonstrated ability of a tattoo-like flexible printed electrochemical biosensor to measure lactate in sweat [24]. Aids for the visually impaired include electronically augmented walking sticks [28], wearable systems [41] and even (at a prototype phase), a bionic contact lens which transforms images captured by a front facing camera to tactile stimulation of the densely innervated cornea [8].

22.8 Conclusions

Advancements in medicine, technology and the need to find more efficient ways to sustain the heavily burdened health system are strong forces driving the development and implementation of telehealth solutions. The evolving telehealth market will soon have a dramatic impact on the way healthcare services are provided.

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