Clinical Biosensors: Considerations and Development Process

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Abstract

The desire for efficient, timely, and cost-effective medical diagnostics has impelled biosensor technology and research progression. There are significant challenges in the development process of biosensors to meet the continually increasing demands. The fabrication and development process should produce high performance and yield without sacrificing cost-effectiveness. This need necessitates continuous and lean development methodologies to fabric, characterize, and miniaturize biosensors and biosensing systems to render more effective outcomes. Clinical biosensors combine detection and transduction units to detect chemical or biological substances or responses and transform them into electrical, optical, thermal, piezoelectric, or electrochemical signals. Most biosensors aim to detect a biological signal from a specific analyte to monitor the biological functions and environment. Another lesser-known class of biosensors, wearable biosensors for clinical applications, is used to measure biopotential, pathophysiological, or biological signals noninvasively. This chapter focuses on the lesser-known class of biosensors deployed using wearable form factors, emphasizing noninvasiveness, cost-effectiveness, and portability. This chapter also summarizes the technological challenges that have deterred the

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development and execution of biosensors., with a brief description of the opportunities and future outlook for biosensors in clinical and healthcare applications.

Keywords

Biosensors · Bioelectronics · Healthcare · Wearables · Nanobiotechnology · Vital signs

4.1 Introduction

Research on wireless wearable technologies and the healthcare industry have been closely intertwined in the modern era as noninvasive and ubiquitous monitoring solutions are gaining significant grip among patients and healthcare practitioners. Healthcare expenditure is on an increasing trend and a continuous upward spiral (California Health Care Foundation 2012; Health, United States 2017). Healthcare expenditures increased by 143%, from $1370 billion in 2000 to $3337 billion in 2016. The predicted cost will approximately be $4500 billion in 2020. Accordingly, ever-increasing costs influence health insurance and other healthcare-related tribulations. The potential means to control the healthcare costs include improving preventive medicine and early detection and identifying the underlying causes of disorders and diseases. Improvement in preventive medicine can be initiated by educating people about healthy lifestyles, origin and identification of symptoms of various disorders, and prevention of various chronic diseases.

However, the quality of the effort is only effective with a smaller group of people because of the abundant variables that climb with the population's growth. Early detection and identification of the causes of chronic disorders and diseases lead to a considerable decrease in the cost of treatments. Recurrent and uninterrupted monitoring is one of the critical factors in the early detection of chronic diseases. However, repetitive hospitalization or hospital visits may result in a substantial increase in cost. One of the solutions to address these issues could be remote point-of-care (POC). The remote POC systems facilitate monitoring the patient and utilizing the patient data to diagnose the diseases and disorders at the comfort of home instead of a patient requiring visiting a hospital or a physician. Therefore, the cost of hospitalization can be reduced by implementing POC systems. Identification of causes leading to chronic diseases can also reduce the cost of treatment. Hospital visits and readmissions are one of the major causes of this increase in healthcare costs. The ever-increasing healthcare costs are one of the primary motivating factors to reduce unnecessary hospital visits and readmissions by utilizing technology advancement. According to the Centers for Disease Control and Prevention, cardiovascular disorders were significant factors leading to death (Health, United States 2017; CHS Data Brief 2018). In the United States, cardiovascular disorders-related deaths resulted in 23.8% of all diseases resulting in mortality.

There is a need for compact, low-cost, reliable, and ubiquitous patient monitoring systems that can be used for health monitoring (Yancy et al. 2013; Bergmann et al. 2012). While multiple approaches (Farshchi et al. 2006, 2007; Mundt et al. 2005; Yao et al. 2005; Rasid and Woodward 2005; Fulford-Jones et al. 2004; Obeid et al. 2004; Mohseni et al. 2005; Irazoqui-Pastor et al. 2002; Modarreszadeh and Schmidt 1997) are used to build an efficient wireless system, robust and real-time monitoring systems that enable continuous diagnostic quality measurements are highly desirable. The measured parameters may include vital signs, electrocardiogram (ECG), electroencephalography (EEG), electrooculography (EOG), electromyography (EMG), skin conductance, or Galvanic skin response (GSR), blood pressure, rate, body and skin temperature, oxygen saturation, and the like. Generally, a biosensor consists of a sensing component and a transducer. The sensing component functions as a receptor that receives the signals from the source. Similarly, the transducer converts the acquired signals to electrical, optical, thermal, piezoelectric, or electrochemical signals. The biosensor typically works in conjunction with an electronics unit to amplify, filter, and process the signals. The processed signals are used to derive meaningful outcomes. The combination of the biosensor and the electronics unit is called the biosensor system. This chapter focuses on the fundamental aspects, considerations, development and fabrication processes, challenges, and future perspectives of biosensors and their healthcare and clinical perspective applications.

Scientific developments have sparked the need for refinement in the healthcare industry. Research groups and companies are looking forward to developing efficient and accurate systems by harnessing technology evolution and advancement. The use of technology, especially wireless communication in healthcare diagnostics, facilitates the acceleration of the diagnostics process, thereby harmonizing the primary goal of diagnostics to identify a medical abnormality in a shorter period. Currently available noninvasive monitoring systems, where electrical recording is the primary monitoring modality, use electrodes to establish contact with the patient's skin using a conductive gel. The electrodes are connected using leads or cables to the recording equipment. The patient must be near the equipment due to the wired electrical connections between the body and the equipment. The gel-based adhesive electrodes and numerous cables make it uncomfortable for the patient and cause poor patient compliance resulting in improper and low-quality signal recordings because of motion artifacts. Some of the commonly monitored biopotential signals are electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), and electrooculogram (EOG). The gel-based Ag/AgCl electrodes used for monitoring these signals also require skin preparation by cleansing and shaving to remove the dead skin and hair.

Moreover, the wet conventional Ag/AgCl electrode has some detriments such as skin irritation and difficulty in long-term monitoring because the gel dries out after a few hours resulting in an increase in the skin-electrode impedance. Generally, physiological parameters are monitored over an extended period during the patient's everyday life to obtain diagnostic quality signals. As the drying of the gel increases skin-electrode impedance, it results in low signal fidelity and quality. Additionally, noises, such as motion artifact and powerline interference, are introduced to the

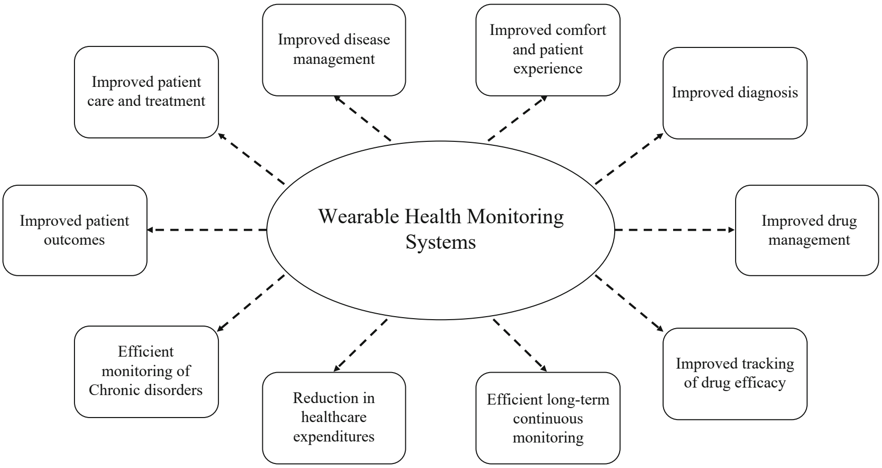

Fig. 4.1 Wearable health monitoring systems and outcomes

biopotential signals as the electrode floats over the electrolytic gel during monitoring. To overcome these drawbacks, dry electrodes can be used. These dry electrodes are held against the skin surface to establish contact with the skin without the need for electrolytic fluids or gels (Fig. 4.1).

4.2 Wearable Biosensors for Clinical Applications

Biopotentials are electrical signals generated by physiological processes. These signals are generated by the excitable cells and their electrochemical activity. The excitable cells produce an action potential, which acts as the primary source of biopotentials. Some of the commonly monitored biopotential signals are electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), and electrooculogram (EOG). Biopotentials are electrical signals generated by the pathophysiological processes in the human body. Biopotentials are the information transfer between the living cells by assisting all the biochemical processes. Some of the biopotential signals of interest are listed in Table 4.1 (Neuman 1998; Malmivuo and Plonsey 1995; CThompson02, CC BY-SA 4.0 n.d.; Rai et al. 2013; Shyamkumar et al. 2014; Ramasamy and Varadan 2018).

4.3 Applications of Clinical Biosensors

Hung et al. have designed a wearable system to address the growing need for long-term patient-centered health monitoring for aging and elderly patients. The system consists of integrated textile electrocardiogram (ECG) electrodes, intelligent finger-ring photoplethysmogram (PPG) sensor, miniaturized optical fiber-based

Table 4.1 List of parameters and measurement modalities

Parameter	Measurement modality	Description
Electrocardiogram (ECG)	Surface electrodes	Electrical activity of the heart by measuring the potential difference between the given lead positions
Electromyogram (EMG)	Surface electrodes	Electrical activity of the skeletal muscles
Electrooculogram (EOG)	Surface electrodes	Electrical activity of the resting potential of the retina
Electroencephalogram (EEG)	Surface electrodes	The neurophysiological activity of the neurons in the brain and recording the electrical activity of the brain
Blood pressure (BP)	Arm cuff-based monitor	Force exerted by the flow of blood
Temperature (T)	Temperature probe (body) or skin temperature sensors (skin)	Body or skin temperature
Respiration/respiration rate (R)	Piezoelectric/ piezoresistive sensor, surface electrodes	Movements indicative of inspiration and expiration with respect to time
Oxygen saturation (SpO_2/SaO_2)	Pulse oximeter	The amount of oxygen in the blood
Skin condition and metabolites (SC/M)	Galvanic skin response sensors, surface electrodes	The electrical conductance of the skin is associated with the activity of the sweat glands
Heart sounds (HS)	Accelerometer, microphone, condenser, acoustic sensors	A record of heart sounds and murmurs
Activity (A)	Accelerometer, gyroscope, magnetometer, GPS	Measurement of acceleration, orientation, and location

temperature sensor, eye dynamics monitor, global positioning system (GPS) module, and wireless capability (Hung et al. 2012) (Fig. 4.2).

4.3.1 Neurological Disorder Monitoring

4.3.1.1 Parkinson's Disease (PD)

Many movement disorders can be caused by abnormal functioning of the central and peripheral nervous systems. Long-term monitoring of the gait has been cited as a valuable tool in assessing patients suffering from Parkinson's disease. Moore et al. (Moore et al. 2007) have developed such a system. They used an ankle-mounted wireless sensor to capture every stride over 10-h epochs. They have shared results from five patients suffering from PD and demonstrated the efficacy of long-term gait monitoring in the home environment.

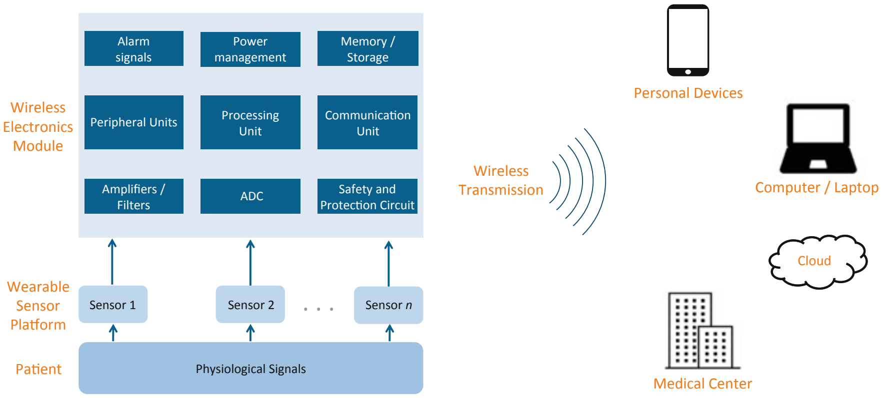

Fig. 4.2 Data flow in a typical biosensor system

Based on the hypothesis that acceleration measurements are reliable predictors of motor activity and can also be used as a classifier for normal and abnormal gait activity in patients suffering from PD, in 2004, Bonato et al. (Bonato et al. 2004) proposed nonlinear data mining approaches to detect the motor fluctuations associated with the manifestation of PD. They explored parameters like fractal estimates, approximate entropy values, and correlation dimension estimates and showed their association to tremors. For the collection of data for their study, accelerometer (ACC) and surface electromyographic (EMG) signals were recorded while patients were asked to perform a set of activities (sitting, finger-to-nose, tapping, sit-to-stand, walking, and stand-to-sit). They placed ACCs in the right and left upper arm, forearm, thigh, sternum, and right shin. In addition, they placed EMG sensors on the left and right biceps brachii, right erector spinae, right vastuslateralis, and right tibialis anterior. The EMG and ACC data were acquired with an ambulatory setup. Thus, they showed that data mining techniques coupled with wearable sensor deployments could be powerful tools to classify motor patterns of primary and secondary movement disorders in PD, such as tremor, rigidity, dyskinesia, akinesia, and dystonia in a manner that is both objective and automatic.

4.3.1.2 Tourette Syndrome

Tourette syndrome is a neurological disorder that exhibits as tics in motor and phonic function. The intensity of these tics may vary over time. Diagnosis and evaluation of this disorder require the practitioner to observe several signs, both visual and auditory. These challenges exist despite the definition of clear scoring procedures in the literature like the TS scale. In 2009, Bernabei et al. (Bernabei et al. 2010) analyzed a sample of 12 subjects diagnosed with TS. They used a 3D accelerometer, a wearable actigraph, and a Bluetooth© transmission module with a rechargeable Li-ion battery.

They post-processed the signal using nonlinear median filtering and an adaptive thresholding technique to differentiate abnormal tics from normal movements. They demonstrated that with specific frequency and threshold criteria, a wearable device could differentiate between normal and abnormal tics with an overall sensitivity, specificity, and accuracy of (mean ± SD) 75 ± 10%, 70 ± 15%, and 74 ± 14%, respectively.

4.3.2 Neonatal Care

In neonatal care, wearable monitoring systems based on sensorized textiles are desired due to two reasons: (1) traditional sensors use adhesives that are usually harsh on the skin of newborn children and (2) traditional monitoring systems have several wires that impede parent's access to the newborn, which is known to be important for the development of newborn children. The wearable system for newborn children can be in the form of a pajama, as described by Andreoni et al. (Andreoni et al. 2011). They have conducted a comprehensive survey on the choice of yarn applied to sensitive pajamas. The yarn consisted of different proportions of silver. The quantity of silver in the yarn was optimized for conductivity. The pajamas were connected to a wireless transmission device. The system composed of these two components was compared against standard Ag-AgCl adhesive electrodes and was shown to give excellent and reliable electrocardiographic measurements.

4.3.3 Blood Flow Monitoring

Kuwabara et al. have designed and implemented a new appcessory for monitoring peripheral blood flow in daily life. An appcessory is a combination of a smart device app and an accessory.

Their motivation comes from the fact that blood flow in the peripheral arteries can give us a great deal of understanding into an individual's physical and mental state. Moreover, blood flow is traditionally measured using laser Doppler equipment that is of a desktop form factor at this time. Their design is small, lightweight, and wearable. The smart device app that they have designed offers real-time data visualization and supports cloud connectivity to provide advanced data processing capabilities. The accessory is connected to the intelligent device wirelessly through low-energy Bluetooth. Through their use of Bluetooth low-energy and intermittent signal processing algorithms, they were able to have appcessory operation times of more than 24 h (Kuwabara et al. 2014).

4.3.4 Sports Monitoring

Both the general population and athletics teams have greater access to wearable devices and sensors that provide performance and body state metrics. For example, functional movement sequences, workloads, and biometric markers can all be used to gather information during training and provide valuable feedback to athletes that can reduce the risk of injury and improve their performance. Wearable devices used to observe movement can include pedometers, goniometers, accelerometers, gyroscopes, and global positioning satellite (GPS) devices. In addition to the movement measuring systems, physiological sensors measure heart rate, sleep quality, temperature sensors, and integrated sensors.

Li et al. have performed a comprehensive review of all sensor systems in research and development to monitor human performance. The ability to monitor high-acceleration movements is a significant advancement that gives us valuable information in training for competitive contact sports (Li et al. 2016).

4.3.5 Pregnancy Monitoring

In both developing and developed countries, maternal and infant health is a vital public health concern. Complication during pregnancy can lead to maternal and infant death and can also be associated with miscarriage, stillbirth, and preterm birth outcomes. Wearable technology has been shown to help in behavioral modifications and appropriate lifestyle choices that help in ensuring a healthy pregnancy and normal delivery. The challenges faced in research deal with the inference of physiological adaptations, lifestyle adaptations, and enabling longitudinal monitoring throughout pregnancy based on the sensor data collected by the wearable devices (Penders et al. 2015). The focus on using wearables to track lifestyles during pregnancy is on five attributes—physical activity, sleep, stress levels, diet, and weight management. Physical activity has mostly been captured using energy expenditure (EE) measurements, pedometer measurements, or through questionnaires. Studies have also combined these measures with physiological signal measurements but have not revealed conclusive predictors of activity (Berntsen et al. 2011). The findings conflict each other in overestimation and underestimation (Smith et al. 2012). Stress assessments are usually performed with wearables using extracted parameters like heart rate, heart rate variability (Shea et al. 2008), galvanic skin resistance, and respiration rate. The validation of these tools pertaining to their use for pregnant women is minimal at this time, but promising advancements have been made in studies involving the general population. Several factors during and immediately after pregnancy influence the sleep patterns of women, and some of these changes are detrimental. General discomfort, increased night-time urinary frequency, fetal movement, and fatigue during pregnancy will affect sleep patterns. Immediately after giving birth, the hormonal levels are restored to pre-pregnancy levels, and it may take up to 12 weeks to return to normal. Traditionally, sleep monitoring is performed using polysomnography (PSG), and these techniques are not suitable for at-home monitoring. The wearable solutions to this requirement have been in the form of actigraphy (Lee and Gay 2004), which gives information about the time of sleep but not the quality of sleep. Several activity trackers and wearables make assessments of sleep quality through measurement of ECG, EEG, and GSR.

4.4 Sensors and Materials

This report has thus far described the various implementations and deployments of wearable systems for health monitoring in different contexts, target individuals, and lifestyles. One of the critical components of a wearable system is the sensing element that performs the operation of transduction. Especially in the case of wearables, these sensing elements need to be lightweight, flexible, and consume as little power as possible, if not completely passive. This section describes the various advances in sensing technology categorized by the type of sensor and the measurand that it senses or measures.

4.4.1 Flexible Pressure Sensors

The design of flexible pressure sensors needs careful consideration for the functional material of the sensor. The choice of material with superior electronic properties and specificity in the transduction of external stimulus is key to designing an optimal sensor. Therefore, it is critical to developing appropriate functional materials for pressure sensing purposes. Especially for flexible pressure sensors, the combination of mechanical compliance, appropriate electrical performance, low temperature, and large-area processing is critical for creating flexible pressure sensors with desired qualities. The functional materials are most often chosen to transduce the pressure signals into changes in capacitance, piezoresistivity, or piezoelectricity. The most often used active materials are poly (dimethyl siloxane) (PDMS), rubrene, micro- and nanostructured polymers. Capacitance, piezoresistivity, and piezoelectricity are the most frequently used methods for signal transduction, while PDMS, rubrene, micro- and nanostructured polymers, polyvinylidene fluoride (PVDF) and poly [(vinylidenefluoride-co-trifluoroethylene] copolymers. A comprehensive survey of flexible pressure sensor structures and materials is presented in (Zang et al. 2015).

4.4.2 All Elastomeric Flexible Temperature Sensors for Body-Attachable Wearable Sensors

Motivation for the development of stretchable physical sensing devices comes from its potential applications in several deployments like human–machine interface, electronic skin, and personal health monitoring. For example, Trung et al. have reported a transparent and stretchable (TS) temperature sensor with a gated structure based on intrinsically transparent and stretchable materials to understand electrical properties and sensing mechanisms of sensing materials under applied stimuli. In their device, all of the layers of the device were intrinsically transparent and stretchable materials, which can be easily coated directly onto a transparent, stretchable substrate by using a simple spin-coating method and lamination techniques.

Composite materials formed by inserting conductive and temperature-responsive reduced graphene oxide (R-GO) nanosheets into an elastomeric polyurethane

(PU) matrix were served simultaneously as the temperature sensing layer. The temperature sensor exhibited stretching up to the strain of 70% and the impressively high sensitivity of ≈1.34% resistance change per °C. The responsivity of the device to temperature was nearly unchanged after 10,000 cycles of stretching at 30% strain. The TS-resistive and TS-gated devices were able to detect minute temperature changes as small as 0.2 °C and were highly responsive to the temperature of human skin. They further demonstrated that their sensor structure could detect temperatures on hot objects and also on human skin (Trung et al. 2016).

4.4.3 Potentiometric Sensor for Monitoring Wound pH

Guinovart et al. have demonstrated a pH potentiometric sensor incorporated in a bandage to measure the pH levels in a wound area. The potentiometric sensor used electro-polymerized polyaniline (PANi) for both the reference and the working electrode. The range of pH measured by the sensor was 5.5–8. They did not observe a significant carry-over effect. They were able to test the performance of the sensors in vitro using buffer solutions to emulate the composition of a wound (Guinovart et al. 2014).

Fiber-based sensor structures are highly desirable for wearable electronics because they are inherently light, flexible, and conformable. Textile-processing technologies that were effective at ambient conditions have been used extensively to fabricate many types of fibrous structures.

Recent advances in nanotechnology have facilitated the building of electronic devices directly on the surface of fibers or inside them. However, there are significant gaps in knowledge when it comes to the process of imparting electronic functions to porous, highly deformable, and three-dimensional fiber assemblies. Additionally, to incorporate wearable technologies, these structures need to have adequate resistance to wear from regular and daily usage (Zeng et al. 2014).

4.4.4 In Situ Perspiration Analysis

Human sweat is a rich source of physiological information. Since sweat can be sampled at the level of the skin, perspiration analysis is noninvasive. Analysis of perspiration requires the detection and estimation of several different analytes. Gao et al. have demonstrated a mechanically flexible and fully integrated sensor array for multiplexed in situ perspiration analysis. Their sensor has the ability to simultaneously measure several different types of analytes like glucose, lactate, sodium ions, and potassium ions. Furthermore, they have incorporated a temperature sensor to measure the skin temperature to calibrate the analyte sensors. They have presented a comprehensively integrated sensor system incorporating flexible sensing elements, signal processing elements on flexible substrates, and wireless transmission capabilities (Gao et al. 2016).

4.4.5 Electrochemical Sensors

Electrochemical, piezoelectric, and optical transducers have been used to detect various analytes in samples of body fluids. The high performance, portability, and sensitivity have made electrochemical sensors the predominant choice. However, most sensor systems require a blood sample from the patient, which makes them intrusive and causes discomfort and inconvenience. In addition, there are several application scenarios where continuous monitoring of analytes is required, for example, diabetes management, athletes requiring fitness level assessments, monitoring of drug treatments, and real-time monitoring of pathogens. In all of these scenarios, the use of an invasive sampling method of body fluids is not practical.

4.4.6 Saliva-Based

The area that has seen the most advancement in incorporating a saliva-based sensor is the partial dentures. There are several analytes of interest in the mouth, like pH and fluoride concentrations. There are several existing implementations of electrochemical sensors in partial dentures. However, they have practical limitations like temperature variations affecting the reading, replacing several teeth with the actual sensing devices, and possible leakage of internal solutions. Minamitani et al. (Minamitani et al. 2002) designed a temperature sensor-integrated liquid-free-iridium pH sensor to overcome these limitations. This sort of device can be miniaturized and worn by an individual. Ideally, a saliva-based sensor should follow the contour of the individual's mouth without causing any inconveniences. Recently, Mannoor et al. demonstrated a tattoo that can be placed on the enamel for continuous wireless monitoring of bacteria by bio-functionalizing antimicrobial peptides on graphene-modified silk tattoo substrates (Mannoor et al. 2012).

4.4.7 Tear-Based

Tears contain several biomolecules from various glands like lacrimal glands, surface epithelial cells of the eye, meibomian glands, blood, and goblet cells. Tears can even be used to measure glucose levels because of their high correlation with the levels in the blood. Strip-based substrates were used to fabricate the earliest form of ocular sensors. These devices are developed by first fabricating bare electrodes onto flexible or stretchable substrates using standard lithographic techniques. Low-cost thick film printing technology has also been used to develop high-fidelity ocular sensors. Then, fabrication methodologies, such as drop casting and polymer entrapment and direct mixing of biomolecules within inks, have been utilized to functionalize the electrode transducers with receptors. Strip-based ocular sensors have been developed for monitoring keratoconjunctivitis sicca (Ogasawara et al. 1996), transcutaneous oxygen (Iguchi et al. 2005), and glucose (Kagie et al. 2008). However, these sensors were made on semi-flexible substrates that could cause irritation of the eyes, which in turn could cause the analytes to be diluted. These limitations are overcome with sensor designs that are accommodated in soft lenses.

A polyethylene terephthalate (PET) contact lens with amperometric glucose sensors, which were bio-functionalized activated and deactivated glucose oxidase and built-in wireless communication and charging, was demonstrated by Yao et al. (Yao et al. 2012).

Real-life implementations are yet to be demonstrated. Power sources for such sensors are still a research challenge. Several of the analytes present in tears are potential candidates for energy sources.

4.4.8 Fabric/Flexible Plastic-Based Sensors

Fabrics are an excellent substrate for the fabrication of wearable sensors as they are worn close to the body, and materials such as wool, cotton, and nylon have highly conducive chemical properties for the incorporation of chemical sensors. For example, a wearable potentiometric sodium sensor for cystic fibrosis monitoring was demonstrated by Schazmann et al. (Schazmann et al. 2010). A conductometric sensor that is fabric-based for measuring the level of hydration was demonstrated by Coyle et al. (Coyle et al. 2009). Wearable potentiometric sensors for several other analytes like pH, NH^{4+}, and K^{+}, and Cl^{-} have been demonstrated by other research groups, which have fabricated them on carbon nanotube-modified fibers (Guinovart et al. 2013a) and by screen printing technology (Gonzalo-Ruiz et al. 2009). Other sensors have been reported to measure transcutaneous oxygen (Mitsubayashi et al. 2003) and humidity (Zampetti et al. 2009).

4.4.9 Epidermal-Based Sensors

Wearable sensor deployments often need conformal contact between sensing surface and the skin. Clothing and fabric are not always suitable for this requirement as they are often in contact with all parts of the skin. Moreover, chemical sensing is most efficient if sensors are placed directly on the skin surface and not on fabric that loosely contacts the skin. Thus, the fabrication protocols for temporary tattoo-based electrochemical sensors were formulated (Windmiller et al. 2012). Incorporating commercially available temporary tattoo papers with functionalized receptor and reagent layers induces selectivity in sensing-specific analytes like acidity, ammonia (Guinovart et al. 2013b), sweat lactate (Khodagholy et al. 2012), alcohol, and sodium levels in perspiration.

4.4.10 Skin Interstitial Fluid-Based Sensors

Vital information can be acquired from interstitial skin fluids (ISFs). One of the key areas of focus has been glucose monitoring (Vashist 2012). Iontophoresis-based electrochemical glucose sensing is the most widely recognized technique (Tierney et al. 2001). Several challenges have impeded the commercial success of products that utilize these techniques, like complaints of skin irritation. These types of challenges will need to be overcome with research in flexible sensing materials (Bandodkar and Wang 2014).

4.5 Conclusion

Wearable textile-based nano-biosensor systems with the mobile platform are a unique class of unobtrusive, continuous health monitoring with significant benefits for neurological and cardiovascular patients or high-risk patients. The bioelectromagnetic principles of origination and propagation of bioelectric signals (EEG, EOG, EMG, ECG) show that measured electric potential represents the cumulative electrical activity of the sources of these signals, i.e., neurons of the brain tissue and myocytes of heart tissue. The dry electrodes can be used for long-term monitoring because they do not face the problem of drying of gel, and they are reusable in the form of a wearable garment. The textile-based wearable nano-biosensor systems discussed in this article can measure neurological signals and identify anomalies to diagnose targeted neurological and cardiovascular disorders. These disorders range from a chronic condition to safety to rehabilitation and improved quality of life. The bioelectromagnetism principles of neural and cardiac bioelectric signals and the performance of textile-based nano–bio sensors provides a unique perspective to the potential for the development of novel wearable systems that harness the potential of textile-based nano–bio sensors and wireless platform for understanding the neural and cardiac function in and out of hospital setting in unprecedented detail. The sensor systems can be used to diagnose and treat neurological disorders such as autistic spectrum disorder, traumatic brain injury (TBI), and neuroprosthesis. In addition, they can be used for highly specialized cardiac monitoring, such as vectorcardiography (VCG), impedance cardiography (ICG) or tomography, tumor detection, and prevention from sudden cardiac death by detection of T-wave alternans. For the patients and medical healthcare professionals to adapt to wearable medical device technology, the devices and systems must meet challenges in form factor, device longevity, and wireless communication requirements specific to each application. Patterns of design for wearable systems architecture is an expanding body of knowledge and is becoming a viable alternative to conventional health monitoring technology.

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