WEARABLE HEALTH MONITORING SYSTEM BASED ON HUMAN SWEAT ANALYSIS USING ELECTROCHEMICAL SENSORS

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Abstract. With the recent development in the field of electronics, it has made possible to continuous monitor health of patients and elderly and even of normal person. Since many years we are using blood-based diagnosis for diagnosis of various health conditions and diseases. However, recent research done by many researchers shows that there are other potential biomarkers such as, sweat which can provide diagnosis of various health conditions and diseases. Sodium and chloride concentration in sweat provides status of hydration status in human body. Here we have designed a health monitoring device based on sweat analysis using different types of electrochemical sensors. Ion-selective electrodes for Na^+ and Cl^- are used which gives details about a person's hydration status and a glucose sensor is also used to measure the sweat glucose levels. The sensors are calibrated for artificial sweat solutions with different concentrations of Na^+, Cl^- and glucose. On body testing is done to confirm functionality of designed system for sweat analysis. The system is compact so can be used as a wearable device that is capable of continuously monitoring and wirelessly transmitting sensor data to the personal computer or smartphone.

Key words: Sweat, wearable, health monitoring, electrochemical sensors, ion-selective electrodes.

INTRODUCTION

The ability of water to evaporate to cool the body is the primary cause of perspiration. The production of fluids produced by the sweat glands in the skin of mammals is known as perspiration, sometimes known as sweating or diaphoresis. Humans have eccrine glands and apocrine glands, two different types of sweat glands. There are numerous locations in the body where eccrine sweat glands are found. A typical person has more than 2.5 million sweat glands. The excretion of

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poisons and waste materials is greatly assisted by perspiration. Although the chemical composition of sweat and plasma are identical, some components are preferentially kept or expelled. By evaporating on the skin's surface, sweat maintains a balance between heat gains and losses. The major constituent of sweat is water (99 %). But it also contains many different chemical and biochemical compounds [1]. Similar to sweat, urine is another important biofluid to which more attention is given for its pathological study. This study resulted in establishing a relationship between the presence of certain bodies and variations in the percentage of the normal constituent as a result of some pathological disorder [3]. From the literature study it is observed that very less importance has been given to the analysis of the important biofluid sweat. But nowadays sweat has grabbed the attention of researchers because it contains various biomarkers which can be used for the detection of certain diseases or health conditions. Sweat is one of the most accessible human biofluids and can be used to determine the electrolyte levels in the body [25, 37].

A number of sweat sensors have been developed in recent years to monitor this important biomarker which provides non-invasive and continuous health monitoring of athletes and patients with certain diseases [5, 15]. Recent research has focused heavily on the detection of analytes that are related to human diseases and disorders using wearable sweat-based sensors. A few studies have also designed wearable electronics with circuitry and multi-analyte sensing for *in situ* calibration and analysis. Many researchers are working on how wearable technology can be used for disease diagnosis, exercise monitoring, drug metabolism monitoring [10, 23]. Hypohydration and hyperhydration have received the greatest attention. To realize these applications a small miniaturized, integrated, wearable system should be developed. Recently developed microfabrication technologies and advances in the very large-scale integration (VLSI) field have enabled the integration of sensors and controllers and analyzing acts into a small portable device. With the help of IoT and wireless collection of health monitoring data and its use for future advanced medical and healthcare applications is possible.

More disease-related, calibration-free sensors must be added to systems. Due to current limitations, wearable sweat devices have not yet been made clinically useful. However, it can be said that non-invasive health monitoring systems for sweat analysis have only just begun to tap into their potential for health monitoring, and further significant development in the medical sector is surely on the horizon based on recent, significant advancements. More research in this area is needed before this approach is widely used. Additionally, it's crucial to have simple, dependable design solutions that are affordable and simple to reproduce.

CONSTITUENTS OF SWEAT

Sweat is chemically alike to the plasma, but specific components are selectively retained or excreted in sweat. By evaporating on the skin's surface, sweat maintains a balance between heat gains and losses.

The major constituent of sweat is water (99 %). But it also contains many different chemical and biochemical compounds. Table 1 shows the standard contents of sweat and their relative concentrations observed by many researchers using different methods such as high-resolution NMR spectroscopy, ion chromatography, inductively coupled plasma sector field mass spectrometry, etc.

Table 1

Summary of standard sweat constituents and their concentrations found by researchers

Sweat constituent	Concentration	Method used	Reference
Lactate	1.34–4.12 ppm	High-resolution NMR spectroscopy	[21]
Sodium	60 mM	High-resolution NMR spectroscopy	[21]
Potassium	40 mM	High-resolution NMR spectroscopy	[21]
Chloride	70 mM	High-resolution NMR spectroscopy	[21]
Alcohol	5 mM	High-resolution NMR spectroscopy	[21]
Sodium	35.2–81.0 mM	Ion chromatography	[33]
Potassium	2.7–6.8 mM	Ion chromatography	[33]
Calcium	0.0–2.9 mM	Ion chromatography	[33]
Magnesium	0.0–1.5 mM	Ion chromatography	[33]
Chloride	31.6–70.4 mM	Ion chromatography	[33]
Arsenic	3.7–22 µg/L	Inductively coupled plasma sector field mass spectrometry	[14]
Cadmium	0.36–36 µg/L	Inductively coupled plasma sector field mass spectrometry	[14]
Lead	1.5–94 µg/L	Inductively coupled Plasma sector field mass spectrometry	[14]

Mercury	0.48–1.5 µg/L	Inductively coupled Plasma sector field mass spectrometry	[14]
Sodium	0.9 g/L	Inductively coupled Plasma sector field mass spectrometry	[14]
Calcium	0.015 g/L	Inductively coupled Plasma sector field mass spectrometry	[14]
Potassium	0.2 g/L	Inductively coupled Plasma sector field mass spectrometry	[14]
Magnesium	0.0013 g/L	Inductively coupled Plasma sector field mass spectrometry	[14]
Glucose	200 µM	Enzymatic amperometric	[13]
Lactate	30000 µM	Enzymatic amperometric	[13]
Potassium	1000–30000 µM	Potentiometric ISE	[13]
Sodium	10000–60000 µM	Potentiometric ISE	[13]
Calcium	125 – 2000 µM	Potentiometric ISE	[13]

SWEAT COLLECTION

Designing wearable sweat analysis devices requires careful consideration of sampling or sweat collection techniques. Use an appropriate sample procedure that detects very small amounts of an analyte and supplies a regulated amount of that analyte to a receptor without contaminating it. Sweat collection involved the use of numerous conventional methods. The whole-body washdown approach was the most traditional method. In this method, the person is weighed before and after exercise, and the amount of sweat on their entire body is calculated. For analysis, all of the fluid lost throughout the workout is kept. It has been found that the method produces findings with a large variance coefficient and that it cannot be used in wearable technology. Other sweat collection techniques that can be employed for continuous sweat analysis were developed as a result. Low or no power passive pumps based on the capillary force are utilized for sweat sampling and collection. One of the known approaches in these procedures is the employment of a macroduct sweat collector 11], which directs the sweat excreted by the sweat glands to the skin pores and a collection channel. This method involves making a tiny hole in a plastic object through which sweat is piped. The polydimethylsiloxane-based sweat collector created by G. Liu, C. Ho *et al.* is an illustration of this kind of sweat collection system [24]. Due to the pressure difference, they mounted this sweat collector so that it comes into contact with the user's skin [24]. Although capillary forces are also present in the tubing, sweat secretion from the sweat glands, which work as a hydraulic pump, is a major force. A capillary-based macroduct system employed by a research team for a study on cystic fibrosis is another illustration of this kind of sweat collector [9]. The wrist was subjected to iontophoresis before the macroduct system was installed. They employed capillary tubing that was coiled and put on a wrist strap [9]. Additionally, Benjamin Schazmann measured the salt levels in sweat using a macroduct system. It comprises coiled-length capillary tubing attached to a wrist strap [31]. Sweat enters and mixes inside the coil through a tiny opening on the underside that is maintained in place against the skin. Due to the narrow collection aperture, very little contamination happens [31]. Many scientists also choose to obtain samples from textiles. Without the use of external pumps, it can deliver controlled fluid flow. Deirdre Morris, Shirley Coyle, and others developed a textile-based fluid management platform as a recent example of the textile-based patch [26]. Sweat has been moved through a pre-determined channel using a passive pump to collect it for analysis. This sweat collector's design is based on a specific fabric with moisture-wicking capabilities. It gathers sweat from the skin's surface and wicks the sample to the detecting area through a pre-established route [26]. One more example is a wearable, flexible, and non-toxic pH sensor fabricated by assembling a cotton fabric treated with an organically modified silicate (ORMOSIL)[6]. Vincenzo F. Curto *et al.* have developed a flexible and wearable micro-fluidic patch for the measurement of the pH value of sweat consisting of four independent reservoirs. The platform of this patch is constructed on poly(methylmethacrylate) (PMMA) and pressure-sensitive adhesive (PSA) [6]. A Wearable electronic-free microfluidic device for the continuous monitoring of pH in sweat is developed by them.

WEARABLE SYSTEMS FOR SWEAT ANALYSIS

The main requirement for a wearable sweat analysis system is that the sensors must be in close contact with the skin. The use of flexible electronics allows us to design flexible wearable sensors. Materials used for flexible patches are required to have properties such as porosity, conductivity, and flexibility. A mechanically flexible polyethylene terephthalate (PET) substrate is used to pattern the electrodes [28]. Polydimethylsiloxane (PDMS) [3, 23], polyimide (PI) [30], polyethylene naphthalate (PEN) [34], polyethylene terephthalate (PET) [13], poly (methyl methacrylate) (PMMA) [7], poly(vinylidenefluoride-co-trifluoroethylene) (PVDF-TrFE)) [11], etc. To trigger the sweat secretions generally iontophoresis method is used. A lot of cholinergic substances (like pilocarpine) that stimulate sweat gland secretion are present in the hydrogels [34]. Different sweat secretion patterns can be achieved depending on the chemical formulation used [34]. The amount of sweat collected in an ambient indoor workplace for half an hour is nearly 475 µL for males and 180 µL for females [10]. But still with some challenges, such as the convenience to wear it for a long time, the capability of enduring dynamic use, etc. Fast response times, excellent sensitivity and selectivity, stability in a variety of environmental conditions, and power-efficient operation are essential features for skin-interfaced sweat sensors. These wearable sensors are designed with integrated signal processing circuitry for real-time data analysis and wireless transmission of data to computing devices. Communication technologies such as Bluetooth, Wi-Fi, or Zigbee can be used.

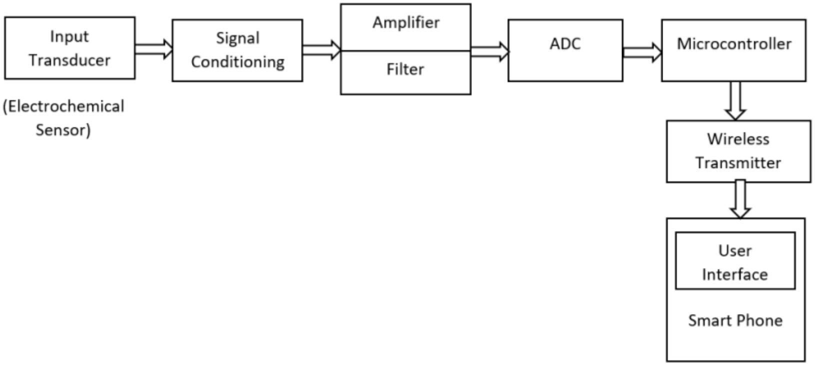

Fig. 1. General block diagram of wearable sweat analysis system.

ELECTROCHEMICAL SENSOR FOR SWEAT

Due to improvements in material sciences along with digital communication technologies and wireless sensor networks, the field of electrochemical and biochemical sensors has experienced enormous growth in recent years. Chemical sensors work in a complicated manner. The sample medium's unique molecular targets must interact with these sensors. A chemical sensor typically comprises of a transduction element joined to a recognition element (receptor). Chemical information, such as the concentration of a certain substance, is turned into an energy that may be measured by a transducer in the receptor component. The receptor engages in chemical equilibrium with the analyte, catalyzes the reaction, or interacts with the analyte molecules.

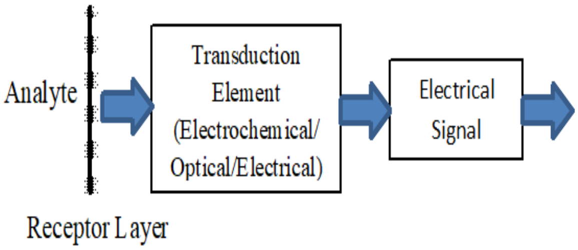

Fig. 2. Sensing mechanism of electrochemical sensors.

Many challenges are faced by the researcher in designing of wearable chemical sensor. One of the major challenges is that these chemical sensors get easily affected by various environmental effects which affect sensitivity, stability and reproducibility. Designing of low power miniaturized interfacing circuit is also a challenging task but with the remarkable development of nanoscience in last decade which helped researchers to develop miniaturized and low power circuits. Consequently, a number of chemical and electrochemical sensors have been developed recently. They incorporate sensors for measuring the pH of sweat as well as a number of electrolytes such lactates, sodium, and chloride. The selectivity of sweat sensors is vital because various electrolytes and metabolites in sweat influence the accuracy of the sensor readings. Presence of non-target electrolytes and metabolites in sweat can influence response of each sensor [13].

Various methods such as screen printing, stamp transferring, photolithography, electron beam evaporation used to deposit 150 nm Au [10], Ag/AgCl reference electrodes fabricated by depositing Ag/AgCl conductive ink, etc. are reported for manufacturing of wearable sweat sensors.

An example of this method is a wearable electrochemical sensor developed by Fraser *et al*. [10]. A sodium sensor belt was developed to monitor sodium concentration of sweat in real time. It consists of an integrated ion-selective electrode platform that can interface with the human body while exercising [10]. They have shown how an on-body sampling and sensing technology can analyze sweat electrolytes in real time. The findings found in this analysis were confirmed with an AAS reference method and are largely consistent with literature ranges. According to the several ionophores that can be used in ISEs, a huge number of cations and anions can theoretically be selectively evaluated. According to the scientists, they can either be utilized as a sensor array or to simply replace the present sodium selective ionophore. The delay might be decreased if these sensors were placed closer to the sweat sample inlet and the system was made smaller.

A wearable electrochemical sensor for the real-time monitoring of sweat sodium concentration was developed by Benjamin Schazmann *et al.* [31]. Capillary zone electrophoresis was used to quantify the amount of sodium in the sweat. They built ISE with PVC tubing acting as the barrels. 0.1 M KCL solution was used as a filling solution for reference electrodes which are connected to a potentiometer [31]. According to this paper there is no definite relation between sweat electrolyte concentrations and gender, maturation and aging and different body parts [31].

One more example is a flexible chloride electrode designed by V.A.T. Dam *et al*. For real-time monitoring of the chloride content in sweat, it is made up of a reference electrode and an array of chloride selective electrodes [8]. AgCl paste has been printed using screen printing method on a polyethylene terephthalate (PET) substrate. During calibration, they achieved a chloride sensitivity of 56 mV/decade [8]. A small amount of sweat that had been absorbed in a layer of gauze was able to be continually detected by the sweat patch for the chloride ions. The patch revealed that the test subject's sweat had a chloride concentration close to 55 mm, which is within the range noted in the literature [8]. A wearable multielectrode platform based on electrodeposited platinum nanostructures was developed by Francesca Criscuolo *et al*. In artificial sweat, they were able to get a linear response with accuracy of 0.97 and 0.81 for Na^+ and K^+, respectively [5].

MATERIALS AND METHODS

Here we have designed a wearable health monitoring system based on human sweat analysis. Ion-selective electrodes, for sodium, chloride, and glucose are used. For designing of the wearable health monitoring system, we are intended to monitor three significant constituents of sweat, Na^+, Cl^-, and glucose. The concentration of sodium is essential for cystic fibrosis patients. Sodium and chloride is a crucial diagnostic biomarker to monitor hydration status in athletes. Non-invasive continuous glucose monitoring can prevent hyperglycemia and its life-threatening effects. For designing this system, we have selected to use screen-printed electrodes which are best suitable for wearable applications due to their small size and ease of use. Three commercial screen-printed three-electrode cells from Zimmer Peacock are used. These Na^+ and Cl^- ion-selective electrodes have measurement range 2 of 40 mM to 360 mM concentrations, which is adequate for measuring concentrations of Na^+ and Cl^- in human sweat. As depicted in Table 1, Na^+ and Cl^- median concentrations are 60 mM and 70 mM, respectively. A capillary filling technique is provided for all the sensors which makes it suitable for continuous sweat monitoring. For this system, a small sweat volume is sufficient to get the measurement of sweat constituents. All three sensors have three electrodes, a working electrode, a reference electrode, and a counter electrode as shown in Fig. 3.

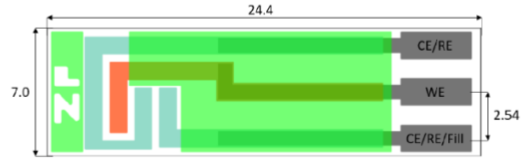

Fig. 3. Schematic of sensitive electrodes [38].

Fig. 4. Na^+, Cl^- and glucose sensors.

Here we used Ecflex which is a stamp-sized, flexible electronics platform that supports the readout of electrochemical sensors wirelessly. It can be deployed in the field in most applications due to its compact size and light weight (22×25×1 mm, 21 g) weight. Because of its flexibility, it may be fixed to curving or moving surfaces, such as the human body. It can be modified to do more dynamic techniques like square-wave voltammetry, but its primary use is for reporting continuous, steady-state signals vs. time, such as in chronoamperometry and open-circuit chronopotentiometry. The potentiostat is the most elementary piece of instrumentation used in electrochemistry in three electrode systems. Its objective is to keep the voltage between the reference and working electrodes constant. It accomplishes this by attempting to balance the potential difference between the working electrode and reference electrode due to any additional external potential at the input terminals. A potentiostat IC LMP9100 is used for measurement of output in three electrode system. Instrumentation amplifier chip MAX4461 is used for reading open circuit-potentials. Voltage regulator IC TPS 61220 is used for power management. 32-bit Arm CC2541 is used which supports Bluetooth low energy wireless communication it also contains integrated 12-bit ADC.

For contact with human skin, the circuit and sensor assembly were bonded to the backside of the platform. It provides wireless communication with BLE protocol. The circuit is made fit on arm with the help of an adjustable sports band, common in sportswear. Sports band is wrapped on arm in such a way that sensor is in contact with the skin to sense the sweat.

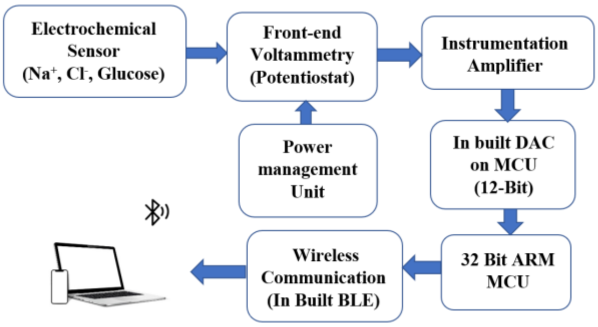

Fig. 5. Block diagram of sensor reader.

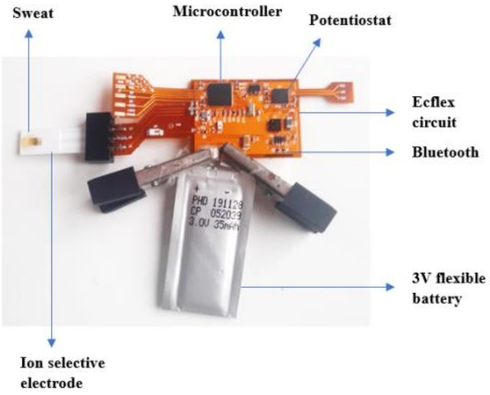

Fig. 6. Sensor and reader interfacing.

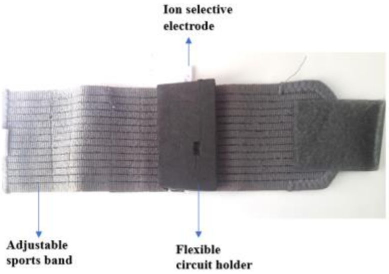

Fig. 7. Circuit bonded on adjustable sports band.

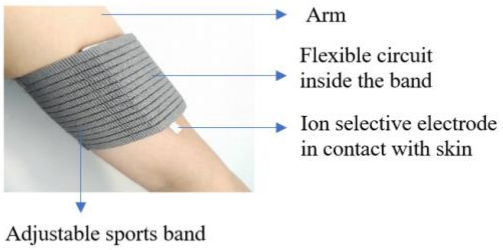

Fig. 8. Wearable sweat monitoring system on arm.

RESULTS

All the sensors were initially tested by preparing a solution of sodium chloride and glucose in deionized water. The range was based on standards of 10, 30, 50, 70, 90, and 110 mM NaCl and was selected to encompass sodium and chloride concentrations in sweat that are frequently observed. All the solutions were prepared by dissolving accurately weighed NaCl salt in 10 mL deionized (DI) water. The sensor's correct operation was ensured by doing this. The sensor’s output can be seen in graphical format on the Ecflex BLE readout platform. Fig. 12 shows the output of sodium sensor for different concentrations of NaCl solutions. It is depicted from graph that there are logarithmic increases in output potential with sodium and chloride ion concentration. Ecflex BLE readout platform is used for reading sensor data. Data is also available in graphical form as shown in Fig. 9. It shows output of Na^+ sensor for 10 mM, 50 mM and 100 mM solution. Sensor data can also be downloaded in Microsoft excel format which can be used for further analysis.

Table 2

Output of Na^+ and Cl^- sensors for different concentration of NaCl

NaCl concentration (mM)	Output voltage of sodium sensor (mV)	Output voltage of chloride sensor (mV)
0	0	0
10	6.19	12
30	12.01	23.824
50	17.04	35.648

70	20.64	47.472
90	23.49	59.296
110	25.54	65.208

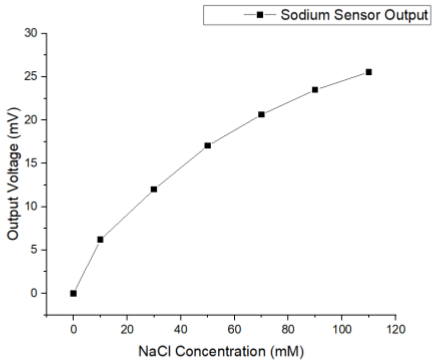

Fig. 9. Output of Na^+ sensor for different concentrations of NaCl solution.

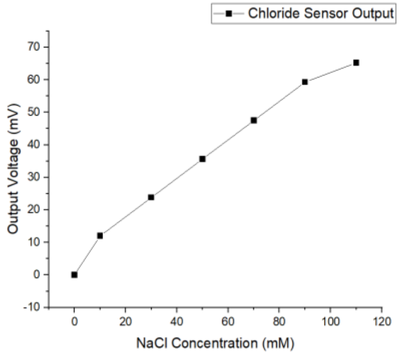

Fig. 10. Output of Cl^- electrode for different concentrations of NaCl solution.

To test the glucose sensor, 0.5 mM, 1 mM, 1.5 mM, 2 mM, and 2.5 mM glucose solutions were prepared by dissolving glucose in 10 mL deionized water. The output was measured. The results obtained are given in Table 3.

Table 3

Glucose sensor output for different glucose concentrations

Sr. No.	Glucose concentration (mM)	Output of glucose sensor (mV)
1	0.5	23.52
2	1	29.35
3	1.5	34.41
4	2	41.28
5	2.5	45.65

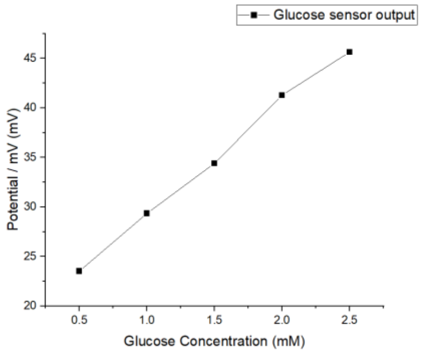

Fig. 11. Glucose sensor response for different concentrations of glucose solution.

On body trail was taken on 38-year-old healthy male individual. The designed wearable sweat analysis device was strapped to the left arm of the subject after calibration. Sports band was wrapped on arm in such a way that sensor is in contact with the skin to sense the sweat. Proper consent was obtained from the person. Initially trials were taken at sedentary condition. The Figs 13, 14, 15, and 16 show the graphs plotted for sodium, chloride and glucose sensor from the received data.

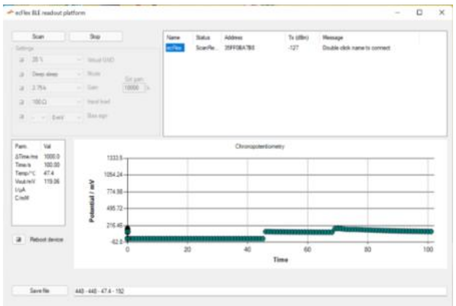

Fig. 12. Output voltage displayed on Ecflex BLE readout software for 10 mM, 50 mM and 100 mM NaCl solutions.

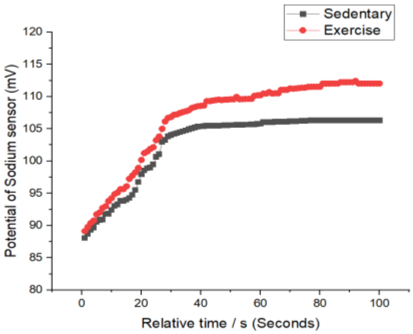

Fig. 13. Sodium sensor response for sweat during exercise and at sedentary state of a subject.

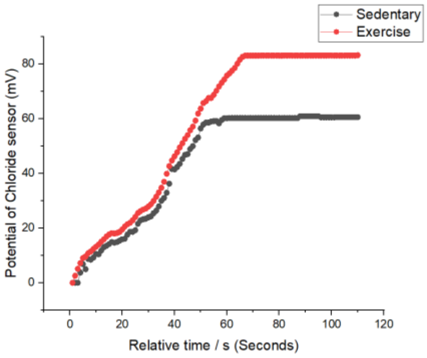

Fig.14. Chloride sensor response for sweat during exercise and at sedentary state of a subject.

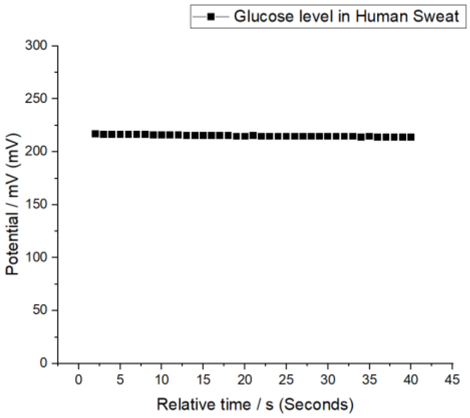

Fig. 15. Glucose sensor response for sweat at sedentary condition.

EXERCISE TRIALS

Three healthy subjects doing their routine and normal exercise were studied. The subject who volunteered for the trials were made to wear the device while exercising. Time and potential values were noted periodically during these trials. the Subjects were asked to perform a mild cycling exercise typically for 30 minutes. While the potentiometric response of the device to sweat sodium and chloride was recorded (Figs 13 and 14). The potential increased with time, corresponding to an increase in the amount of sweat. It showed variations ranging from 40 mM to 60 mM for both sodium and chloride.

The sensor-based system was employed to measure the concentration of glucose. The subject consumed 200 mL of glucose water before exercising to increase blood glucose levels. The individual was advised to engage in a light cycle exercise after 20 minutes of digestion while the device's potentiometric response to sweat glucose was being measured (Fig. 11). With variations, the potentiometric response grew with time, increasing together with the amount of perspiration.

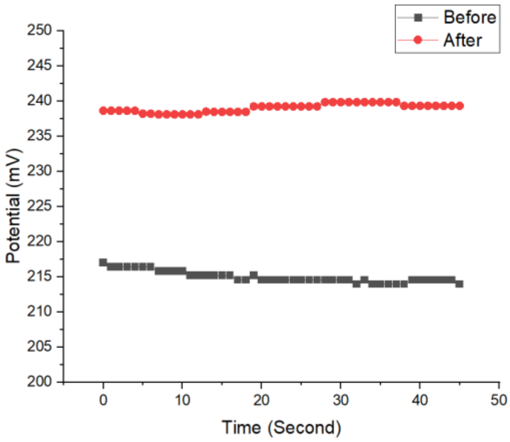

Fig. 16. Glucose sensor output before and after consumption of glucose water.

DISCUSSION

This sweat sensor based electronic system is suitable for continuous health monitoring. The sensors are working in the prescribed range. This wearable health monitoring system provides concentration of sodium chloride and glucose levels in sweat, which can be used as an indicator of current hydration status and glucose levels in individuals. Further data is to be collected from different individuals with different health conditions and age groups and then proper calibration can be done to send alert signals. In this system, small size screen printed electrochemical sensors are used which are suitable for wearable applications and provides good accuracy as compare to optical sensors. Sensors comes with inbuilt capillary actions which eliminates the need of separate sweat collector. This system provides wireless data transmission using BLE protocol which makes it convenient for wearable health monitoring applications. The system can be easily reproduced at low cost for wide applications.

DETECTION OF DISEASES

Sweat consists of various disease-specific markers. Recent investigations have revealed the potential of sweat as a significant technique for detection of various diseases and health conditions. Recent advances in wearable electronics have made it possible to use sweat based wearable biosensors for point-of-care medical or continuous health monitoring. Various diseases and health conditions can be detected and monitored in more convenient manner and with a less invasive approach than conventional invasive monitoring methods. In the following examples, an overview of the current research and potential impact of sweat as a biofluid in clinical diagnostics is provided.

Cystic fibrosis

One of the most common examples is for diagnosis of cystic fibrosis in children. Sodium and chloride levels in sweat are measured for detection of sweat analysis.

Dehydration

Sweat can be used to provide information about one's electrolyte concentrations. Hypohydration and hyper hydration have received the greatest attention. Dehydration leads to increase in sodium concentrations in sweat. Electrolyte levels in sweat including sodium (Na^+) levels vary considerably [25, 27]. Concentration of these electrolytes also depends on the point of the body where they are measured, genetic predisposition, diet, and heat acclimatization rate. Conversely, gender and aging do not have a large effect on sweat electrolyte concentrations. The proposed system is capable of measuring sweat sodium and chloride concentration and hence can be used to monitor hydration status in human body. The sensors provide stable and repetitive output after settling time of 90 seconds. The relation between concentration and output potential is logarithmic, which was observed for the concentration range of 10 mM to 100 mM.

Diabetes

Sweat has also been considered for continuous monitoring of glucose levels of diabetes patients by noninvasive method. Blood glucose levels can be reliably evaluated through glucose detection in sweat [9, 15, 18, 20]. The designed system can be used as a crucial tool for advancing sweat testing beyond the research stage for point-of-care medical and athletic applications. In this research we have calibrated the sensor under a variety of experimental conditions including electrical enhancement, revealed a quick response and stability for the range 0 to 2.5 mM glucose range.

CHALLENGES FOR FUTURE RESEARCH

With recent advances in nanoelectronics and screen-printed technologies leading to make it possible to fabricate miniaturized wearable and flexible wearable sweat analysis systems with screen printed sensors and miniaturized low power signal conditioning circuits along with wireless communication technology. Furthermore, advances must be made in sensor manufacturing to improve sensitivity, selectivity, repeatability, and reliability. Correlation between blood and sweat constituents should be carefully studied using *in vivo* validation tests. For better accuracy and proper calibration, a study should be conducted on a large and diversified population. More research is needed to examine the impact of temperature and humidity. To achieve widespread adoption of sweat-based devices, equipment for the detection and continuous monitoring of particular diseases needs to be developed. The limitation of the system is that simultaneous sensing of multiple analytes cannot be done, and this technology needs to be transferred to a flexible substrate for long-term use as a wearable health monitoring device.

CONCLUSION

Sweat is a potential biomarker, can be used for continuous health monitoring and as a non-invasive diagnostic tool. Various methods such as optical, conductivity and electrochemical sensing are used by many researchers for measurement of sweat constituents. Electrochemical sensing is the most promising method due to its accuracy and reliability. With the recent evolution in fabrication technologies, it has become possible to fabricate low-cost miniaturized screen-printed electrochemical sensors for sensing sweat constituents such as sodium, chloride, potassium, glucose, lactate, urea etc. With the emergence of advance wireless communication technologies and smartphone-based applications it has become possible to use sweat-based devices for diagnosis and clinical implementations in near future. Despite this for widespread use of sweat based devices still needs improvement in various factors such as need of continuous calibration, effect of ambient temperature and humidity on concentration of sweat composites and correlation of blood and sweat components. The designed sweat sensor based electronic system is suitable for continuous health monitoring. It can provide information about current hydration status and glucose levels.

The system is highly replicable and performing, which addresses some of the inherent problems with current wearable technology. A wearable configuration is used to demonstrate the system's reversibility and selectivity in artificial sweat.

Further work is to be done to monitor multiple analytes simultaneously. Further data is to be collect from different individuals with different health conditions and age groups and then proper calibration can be done to send alert signals.

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