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Wearable Sweat Biosensors and Their Biomedical Applications

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***Abstract*- Perspiration or sweat is one of the waste products produced by the body which can be potentially used as carriers of biomarkers. For real-time analysis of composition of sweat and to find information about health of an individual even at a molecular level, wearable perspiration or sweat biosensors can be used. With regard to this, we use various detection techniques and also understand developments in sweat sensing platforms. In the future, these sensors will enable personalized diagnosis and physiological monitoring.**

Keywords-Presperation,

I. INTRODUCTION

Wearable biosensors have a major role to play in the coming years as they enable real-time analysis and non-invasive technique for health monitoring. At present, the wearable sensors used can only help to find person's fitness level but it fails to provide information about the molecular activity. Human sweat is a body fluid which can be obtained non-invasively. It reflects the individual's health and fitness conditions. Therefore, sweat is the best option to develop chemical biosensors that provides detailed information on physiological conditions of a person. Fig.1 illustrates how wearable sweat biosensors can measure levels of various chemicals present in sweat which helps in monitoring the overall health. These wearable biosensors had been developed over a decade now and are capable of detailed measurement analytes including metabolites, electrolytes and heavy metals during different physical activities.

II. SYSTEM DESIGN

A. Biosensor Platform

The sweat is collected and analyzed by collecting required volume after maintaining conformal contact with the skin. For optimal performance efficiency sweat biosensors are prepared on a flexible substrate. Various platforms have been developed in the last decades for obtaining better sensitivity. The different sensing platforms used are shown in fig.2.which includes epidermal tattoos, textiles, flexible bands etc.

B. Targeting the Analytes

A wide spectrum of sweat biomarkers are related closely to the human health condition. Hence, they act has target analytes for sweat bio sensors. Some of the examples are:
a. Sweat Chloride Test to diagnose cystic fibrosis
b. Loss of Na^+ and K^+ ions result in muscle cramps dehydration and hypokalemia
c. Sweat ethanol and glucose reflect the levels of ethanol; and glucose in blood.
d. Sweat lactate marks the presence of pressure ischemia.
Hence, these biomarkers help in physiological and clinical analysis.

C. Techniques for detection

For detection of various chemicals in the body we use the following types of sensors. Each sensor helps in detecting a particular type of chemical.
a. Optical Sensors: used for sweat rate and sweat pH analysis.
b. Impedance based sensors: used for sweat rate and sweat conductivity monitoring
c. Ions selective electrodes: used to sense electrolytes such as Na^+, K^+, $NH4^+$, Cl^- etc.
d. Enzyme Amperometric Sensors: used for sensing metabolites such as glucose, ethanol, lactate etc.
e. Stripping Based Sensors: used for analysis of heavy metal such as Cu, Zn, Hg, etc.
Fig.3. shows the various sensors used.

D. System Integration

Multiple sweat biomarkers have to be detected and useful information has to be extracted simultaneously. Therefore,

system integration is important. A fully functional system is integrated with the following parts:
a. Plastic based sensors that interface with the skin.
b. Silicon integrated circuits assembled on a flexible substrate (circuit board) for processing the signals from the subject.
Fig.4.a shows a sweat sensor array with:
a. Metabolite sensors for analyzing glucose and lactate levels.
b. Electrolytes sensors to analyze Na^+ and K^+ levels
c. Skin temperature sensor
Fig4.b shows the overview of the system that performs signal transduction, processing and wireless transmission to enable on-body measurements.
The data from the system after proper analysis is transmitted to a cellphone wirelessly and displayed.

III. REAL-TIME SWEAT ANALYSIS FOR MONITORING HEALTH

During various physical activities sweat biosensors can be worn on the body that allows non-invasive monitoring of health. Analysis and evaluation of these sweat biosensors extend its range in physiological and clinical application.

A. Real time analysis of major metabolites and electrolytes

During cycling exercise sweat lactate and sodium levels were measured. At the same time, multiple sweat analyte levels were reported from fig.5 which represents lactate and glucose levels as perspiration begins. Distinctly, both the levels decrease and it is caused due to dilution effect as sweat rate increases. As perspiration begins with advancement in physical activity the general trend is increased in Na^+ level and decrease in K+ level. Also both the ions concentration stabilizes with continuity in physical activity.

B. Real time sweat Ca^{2+} and pH monitoring

Human metabolism is characterized by calcium content and pH level is required for disease diagnosis. This wearable sensing device evaluates pH level and Ca^{2+} concentration simultaneously. This is done simultaneously because the level of Ca^{2+} in body fluids depends upon the acidic or basic conditions. Hence, pH plays an important role in measuring Ca^{2+} level. This is shown in fig.6.a. when the subject is cycling sweat pH increases for about 5mins and stabilizes throughout the activity whereas, Ca^{2+} levels decrease for initial 5 minutes showing an opposite trend. The results from the wearable biosensors were validated using commercial pH meter and inductively coupled plasma-mass spectrometer.

C. Heavy metal monitoring

In the past decade, Zn monitoring was done using printed tattoo based sweat sensors but currently for simultaneous measurement of heavy metals such as Zn, Cd, Hg, etc. in sweat we use micro-sensor array with biocompatible gold and bismuth electrodes as shown in fig 7.a-c. We use stripping voltammetry for this purpose. Fig7.d shows on body monitoring of Cu and Zn levels in sweat during cycling.

D. Ethanol monitoring

It is known that blood alcohol concentration is same as that of sweat ethanol levels. Fig.8 shows the responses before and after alcohol consumption. It can be clearly differentiated as there is an increase in ethanol level after alcohol consumption.

E. Glucose level detection

These sensors can be used for diabetes monitoring as well recently for real time sweat glucose measurement. A pH calibrated chemical devices was developed recently for this purpose which also aids to find correlation between sweat glucose data from diabetes patch and from commercial glucose assay also blood glucose data from commercial glucose meter was absorbed as shown in fig.9. These observation were made over 24 hours.

F. Dehydration monitoring

These biosensors used the noninvasive monitoring electrolyte loss as shown in fig 10.a. It was noticed that sweat Na^+ level was stable throughout running in trials that involved regular water intake as shown in fig 10.b. On the contrary, there was an increase in sweat Na^+ levels during dehydration trials as shown in fig.10.c. Both the observations were made after 80 minutes of running. These results may help in providing vital information to improve athletic performance.

IV. CONCLUSION AND FUTURE

These biosensors provide a practical wearable sensor technology that facilitates physiological and clinical investigations. Even though, there has been a significant progress in this field. There are certain challenges such as:
a. On-body instability
b. Reliability on chemical sensors
c. Need to develop wearable power sources
d. Minimizing the power consumption
e. Controllable extraction from biomarkers

To overcome the challenges data sets could be collected from population studies that greatly influence the physiological and clinical investigations of the society.

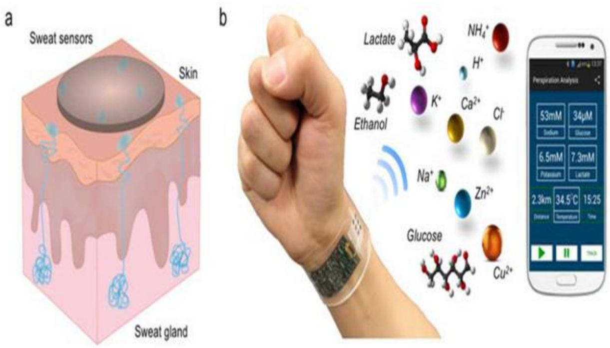


Fig.1: wearable biosensors used for overall health monitoring

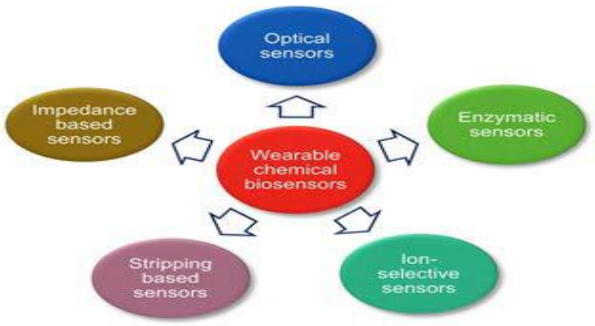


Fig. 2. The categories of wearable chemical sensors

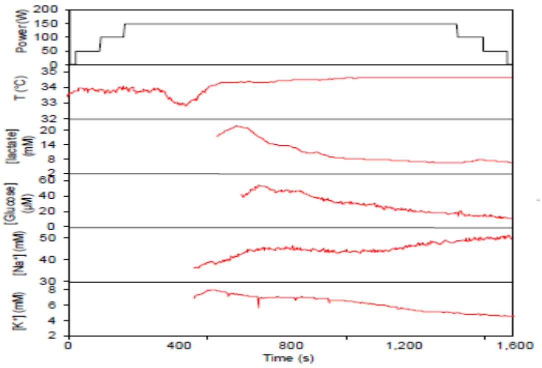


Fig.5. On-body real-time multiplexed monitoring of sweat glucose, lactate, sodium, and potassium and body temperature using a band worn on a subject's forehead during a constant-load cycling exercise.

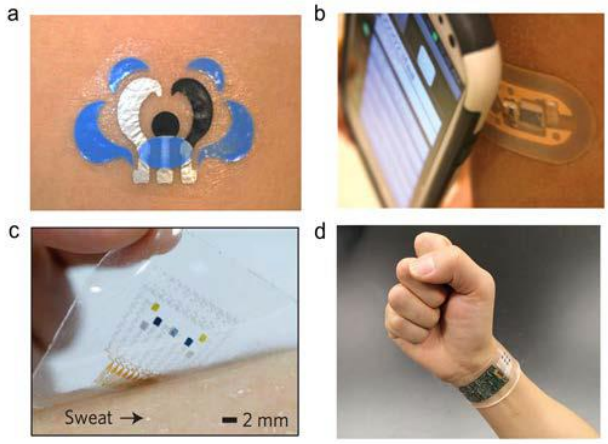


Fig.3: The representative sweats bio-sensing platforms:
a) Epidermal temporary tattoo b) Adhesive RFID sensor patch
c) Flexible and stretchable sensor patch d) fully integrated flexible sensor band

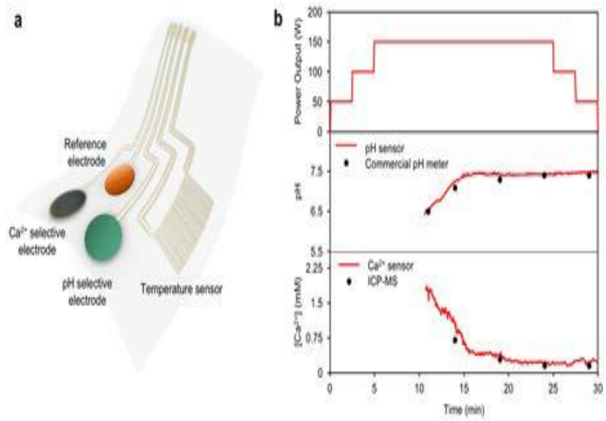


Fig. 6. Wearable sensors for Ca2+ and pH monitoring of body fluids : a) A schematic of a flexible sensor array. b) On-body Ca2+ and pH analysis during a constant-load cycling exercise

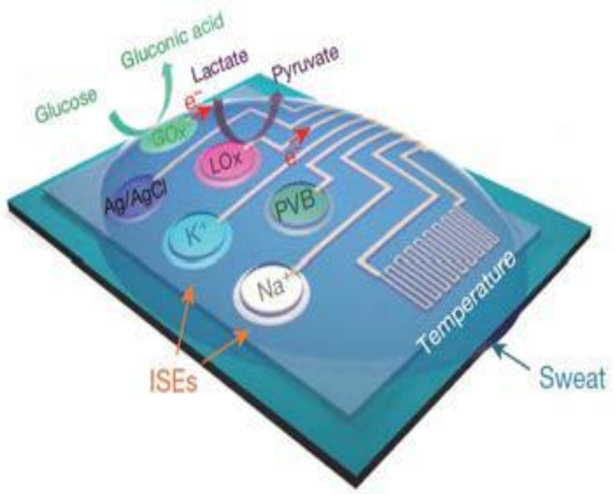


Fig.4.a shows a sweat sensor array

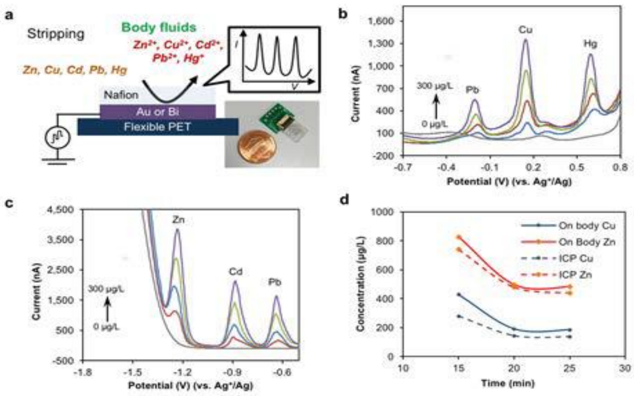
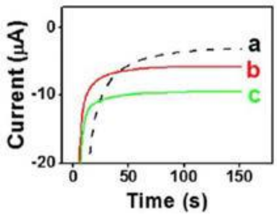
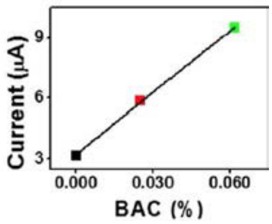


Fig. 7. Flexible micro-sensor arrays for multiplexed heavy metals analysis

a) Schematic of microelectrodes. B) potential measurement c) Characterization
of Au and Bi microelectrodes for trace metal detection. d) On body trace metal detection during a constant-load cycling exercise.





Current response BAC level measurement

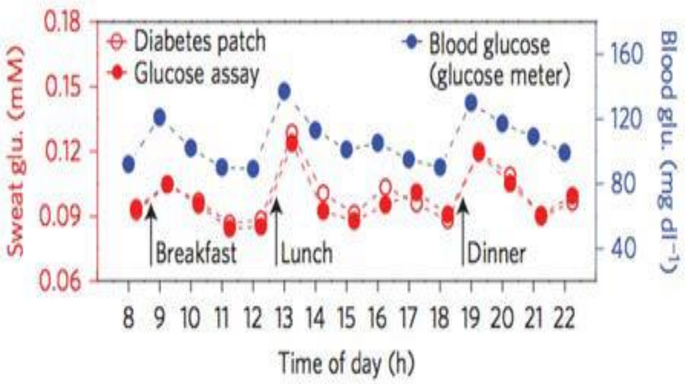


Fig.9 One-day monitoring of sweat glucose concentrations using wearable diabetes patch and blood glucose levels using commercial blood glucose meter

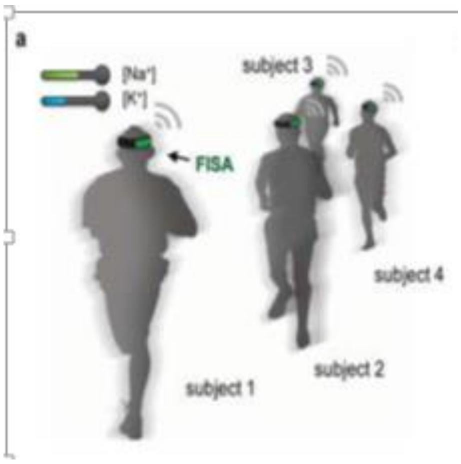
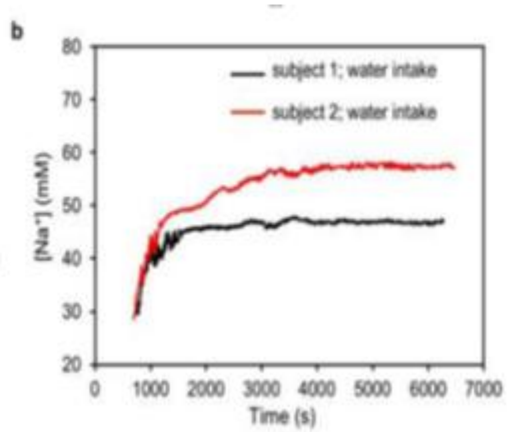
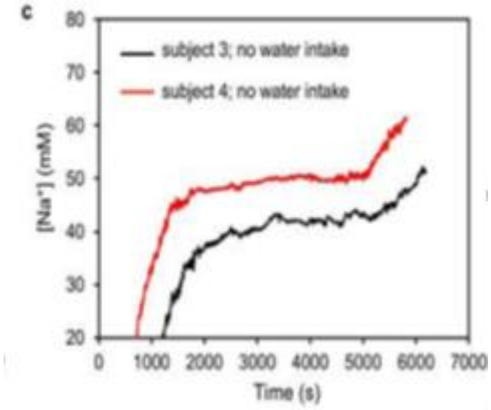


Fig. 10. Hydration status analysis during group outdoor running using the wearable sensors

a) Schematic illustration showing the group outdoor running trial using wearable smart head-bands. The data are real-time transmitted to the user's cell phone and uploaded to cloud servers.



b) Representative real-time sweat sodium levels during an endurance run with water intake



c)endurance run without water intake .

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