Blood Glucose Monitoring with Smartphone as Glucometer

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Keywords:

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Abstract

In this short communication, we redefine smartphone and enable it monitoring blood glucose as glucometer. The proposed smartphone is not only a mobile phone but also a medical device-glucometer. An electrometer module, acquiring the electrochemical current from the disposable enzymatic test strip on which a 0.5 μL human peripheral whole blood drop is placed, was integrated in the smartphone. The medical smartphone is capable of directly measuring blood glucose concentration and uploading into personal health center by the 4G mobile communication internet.

Keywords:

Biosensor, Glucometer, Instrumentation for POCT, Microfluidics, Smartphone electrochemical analyzer

Color online: See article online to view Figs. 1–5 in color.

1. Introduction

Microfluidics-based biosensors have emerged as a very powerful analytical platform for biomedical application, especially for the point of care test [1-5]. It integrated the sample preparation, manipulation, and detection on a single chip [6]. During the pre-processing function component, thermal control, fluids manipulation, biological sample washing and detection were implemented. According to the characteristic methods, there are several divisions such as optical, magnetic, electrical, acoustic, thermal sensing mechanism [7-9]. Therefore, microfluidic biosensor is a highly interdisciplinary techniques which employ scientists and engineers from the areas of electronics,

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medicine, physics, chemistry, biology knowledge together to implement the micro-total analysis system.

On the other hand, wireless biomedical sensors have received increasingly considerable attention from both industries and academic researchers since it provides the feasible solution for personal health management [10-11]. However, the current prevailing wireless biomedical sensors still focus on the non-invasive biophysical sensor such as blood pressure, respiration rate, ECG and EMG, etc [12-13]. Such non-invasive biomedical sensors can only provide very limited medical information to evaluate the health consumer's heath level. Biochemical parameters such as glucose, cholesterol, uric acid etc. [14]. plays emphasis role in evaluating the health level. Commercial glucometer and its corresponding test strips has gained the unprecedent success in diabetes application as the point of care test device in the world since it provides a fast, compact and low-cost tool for both patients self-monitoring and the help for doctor.

In this communication, we integrate glucometer module with the smartphone and enable it work electrochemical analyzer. The Fig.1 illustrated the photograph of the medical smartphone as glucometer. The glucose test strip can be directly inserted into the medical smartphone through the test strip connector located at the smartphone edge. A micro-controller unit (MCU) for resolving the electrochemical current generated in glucose test strip was integrated on the main-PCB of the smartphone. The glucose module send the measured glucose level into smartphone, which act as the data interchange station. The internet hospital resource (Tianxia120 APP system, supplying the medical consultation, family doctor service etc) can be obtained from the smartphone by the health consumers.

2. **Theory and methods**

In the process of the enzyme catalysing reaction, glucose oxidase was catalysed by the oxidation of glucose into gluconic acid with concomitant reduction of Fe(III) to Fe(II); The $Fe(II)(CN)_6^{-4}$ ions generated were evaluated by the amperometric method. Ferricyanide as a kind of electron transfer mediator, plays a critical role in the reaction combining with concomitant reduction of Fe(III) to Fe(II); the $Fe(II)(CN)_6^{-4}$ ions were quantized by evaluating current change between WE (working electrode) and CE (counter electrode) through buried electrochemical analyser within smartphone. The buried glucometer is able to convert the current signal to the concentration of glucose which can be easily displayed in the smartphone and upload through the 4G mobile internet.

The glucose test strips were composed of reaction channel and screen-printed electrodes. As Fig.2 illustrated the fabrication process of the glucose test strip. The working and counter electrodes were made by printing the conducting carbon on a polypropylene film with the screen printer. For the sake of making the electrode higher conductivity, the silver layer was pre-printed before the carbon ink layer on the PET substrate. The glucose test strip was baked under drying-box with the temperature at 75◦C for 40min, which makes the electrode aging. A plastic insulator layer with partial hollow was subsequently pasted above the electrode layer for form the reaction channel. The enzyme solution was immobilized within the reaction channel. At last, top layer was pasted and cover on the insulator layer and form the complete glucose test strip.

3. Results and discussion

The linearity and sensitivity of the proposed system were initially tested by applying standard glucose solutions with concentration from 2.25 to 25.0 mmol/L. Normal human being usually have the blood glucose scope from 3.9 to 11.1 mmol/L glucose. Higher level of blood glucose may indicate the abnormal health condition and may result from diabetes etc. As a universal method to describe the performance of electrochemical test strips, chronoamperometry is sensitive, fast and convenient solution to evaluate the characteristics of the test strips. In this communication, the proposed medical smartphone plays a role as a compact electrochemical analyser instead of the cumbersome electrochemical station. The medical smartphone is capable of recording the electrochemical current response under different glucose concentration. Fig.3 illustrated the chronoamperometric current response curves with respect to applied glucose solution: 2.25 mmol/L; 9.25 mmol/L; 13.5 mmol/L; 17 mmol/L; 25 mmol/L. The current sampling time interval was set between 4.0s-4.1s for the current recording in the medical smartphone. The measured current was linearly proportional to the glucose concentration with regression coefficient (R^2=0.9797; y=1.146x+0.755). It indicated the proposed sensory system has a good linear property.

For the sake of investigating the accuracy, the result by the proposed system was compared with the result from commercial biochemical analyser by plotting a scatter plot between Y-value (measured by clinical biochemical analyser with venous blood sample) and X-value (measured by medical smartphone with finger blood sample) as shown in Fig. 4. 232 blood samples were used in the comparison test. Finger pricked whole blood was applied to the glucose test strips by a disposable needle. Venous blood samples were taken from the same patient in the test by a clinical vacuum tube with EDTA anticoagulant. The centrifugation at 4 ℃, 3000rpm for 30 minutes extracted the blood serum, which was applied for bulky biochemical analyser. The comparison result demonstrated the proposed glucose monitor system meets the accuracy requirement of FDA criterion for glucose biosensor.

Incorporating with the internet based remote digital hospital, the proposed provided a promising way for glucose management with diabetes patients. Fig.5 shown the frontpage of the Tianxia 120 APP (one mobile system aiming for the solution to digital health by combining the good medial resource and the health consumers). The measured blood glucose can be read into the Tianxia120 APP pre-installed in the smartphone. The Tianxia120 APP can build up the bridge between the health consumers and the professional doctor directly. As Fig.4 indicated, the smartphone can automatically record the glucose after each test. With the widely available usage of smartphone, smartphone-based personalized health management is emerging as the most feasible solution.

4. Concluding remarks

To improve national self-management of diabetes, the desired products ensures not only the accuracy and precision to meet the requirements of in vitro diagnostic medical devices but also flexible, mobile, easy carrying, healthy and safe. In this communication, we redefine smartphone and enable it monitor glucose as glucometer. The patient equipped with such medical smartphone can upload their blood glucose level and can consult the on-line doctor for better recovered life.

The author has declared no conflict of interest.

5. References

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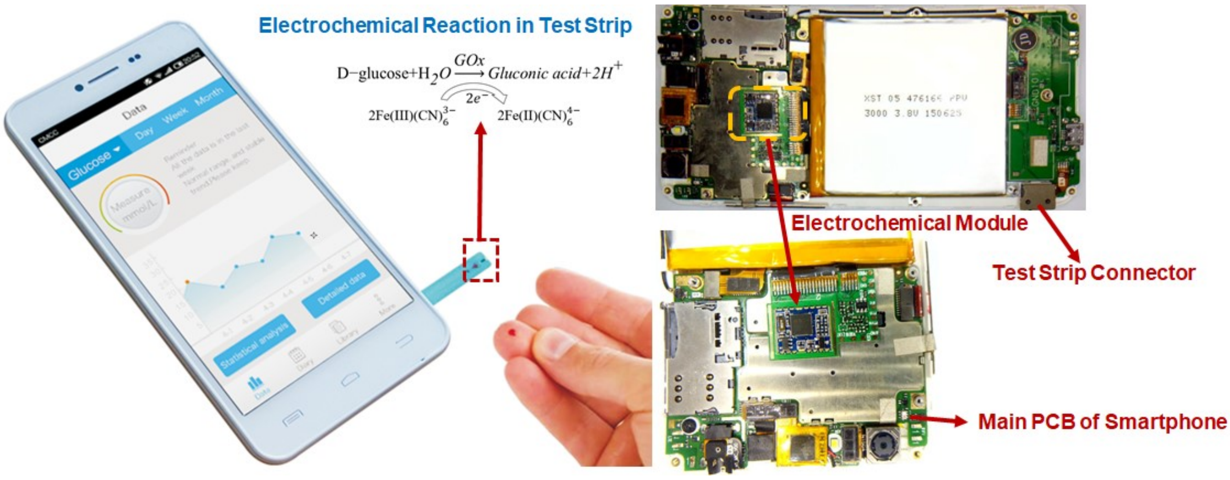


Fig. 1 the photograph of the proposed medical smartphone integrated with the glucose module. A specific interface located at the edge of the smartphone was used for the test strip insertion.

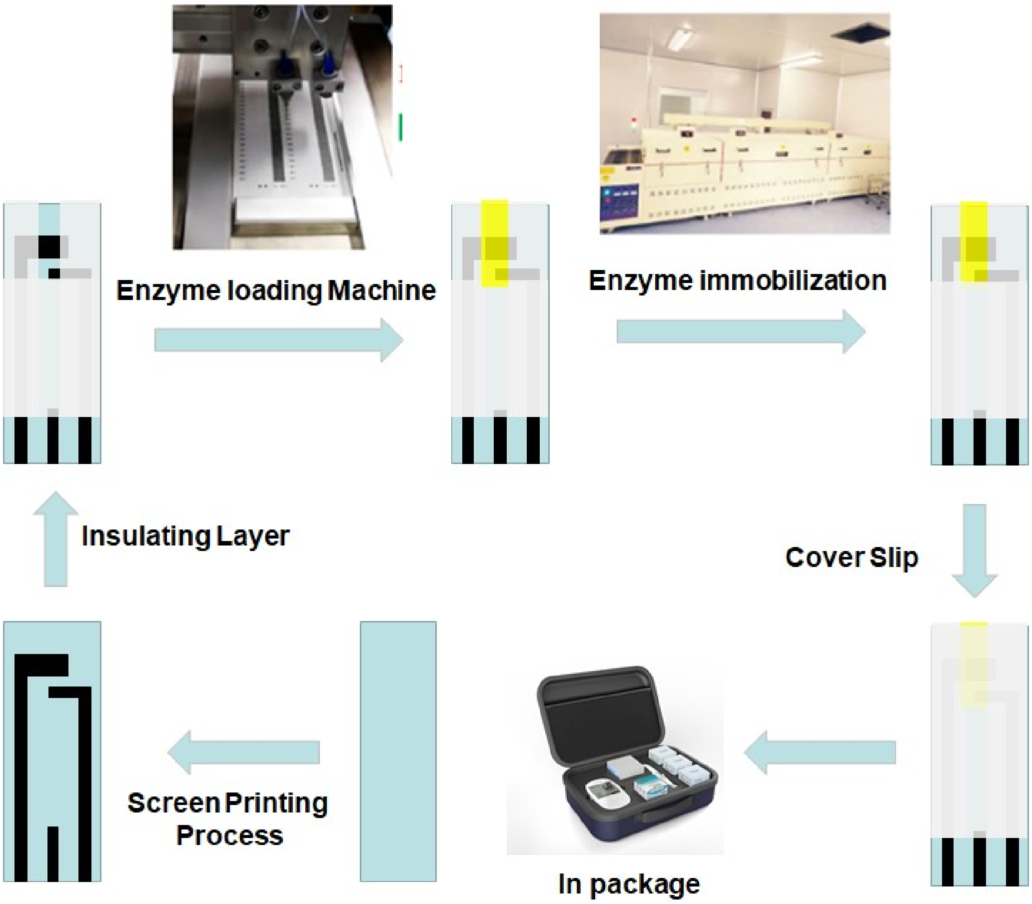
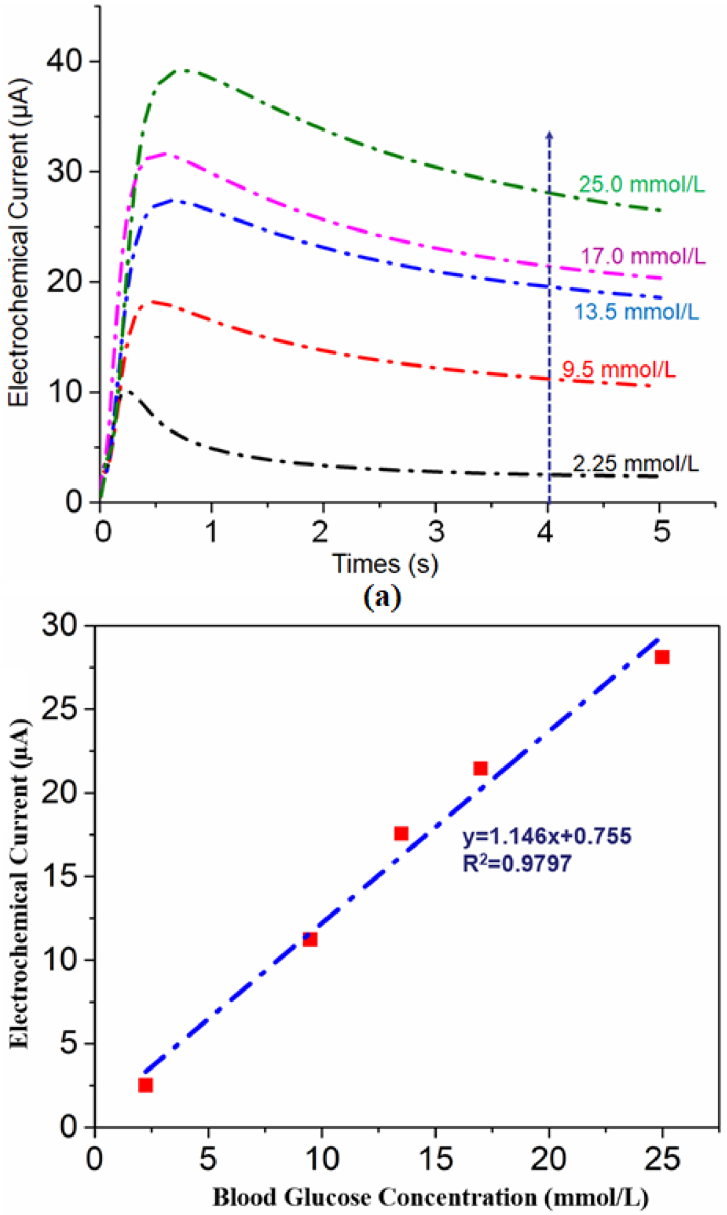


Fig.2 The fabrication process of the proposed test strip



(b)

Fig. 3 a. the typical electrochemical current curve of the test strips under different standard glucose concentration; b. the linear relationship between the glucose concentration and measured electrochemical current.

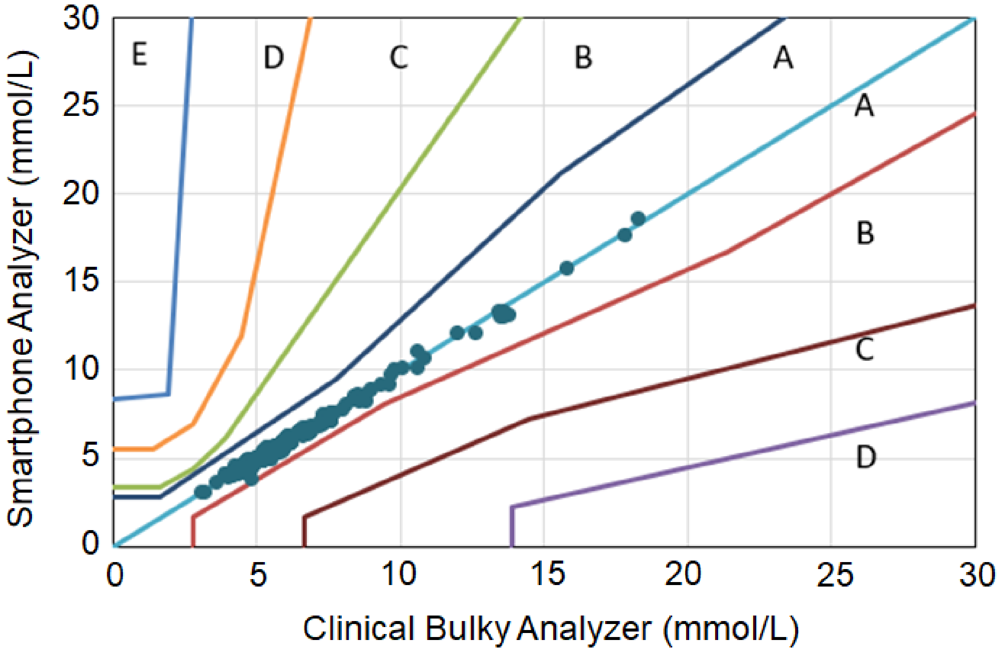


Fig.4 The measured glucose result comparison between proposed medical smartphone and clinical biochemical bulky analyzer.

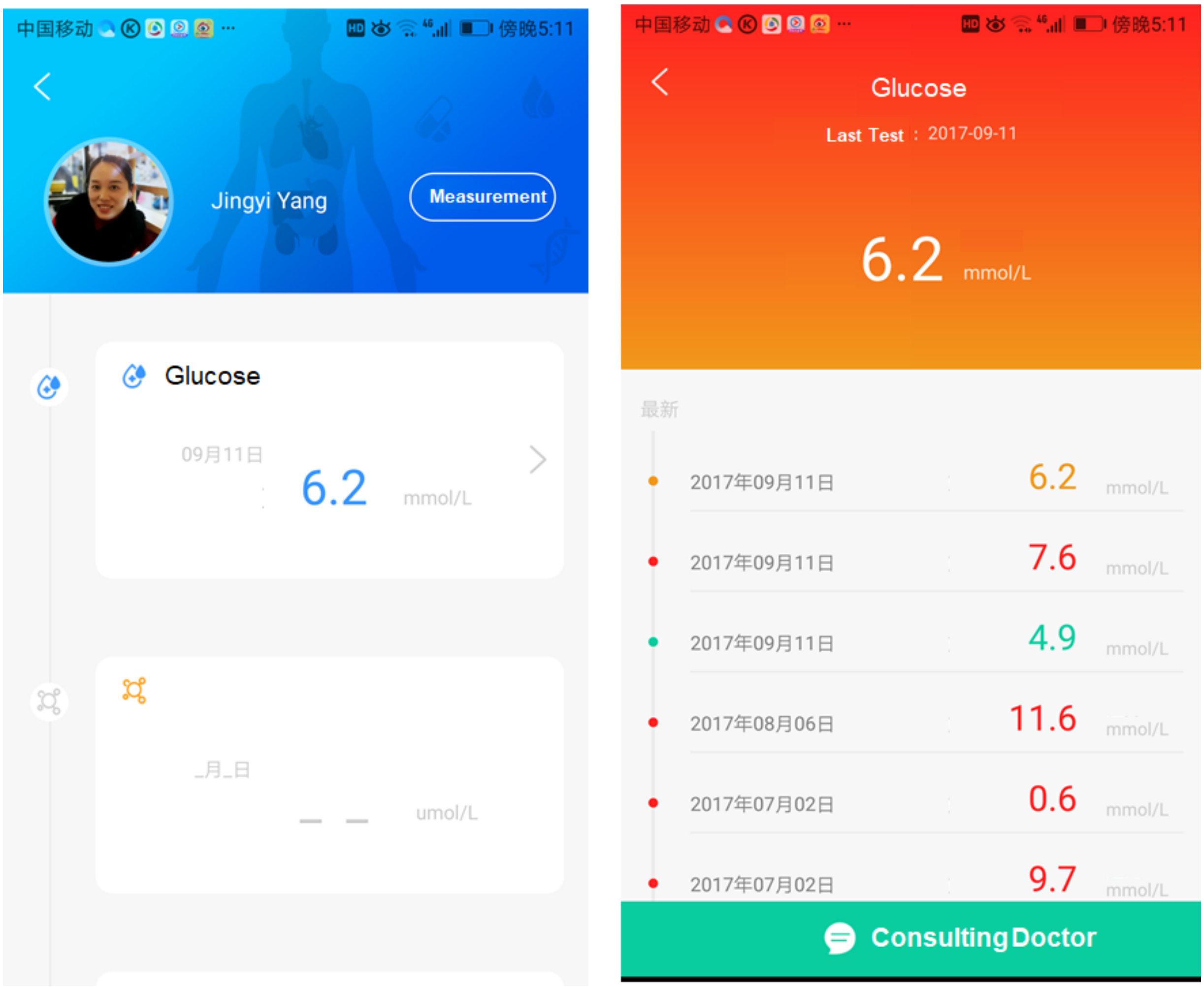


Fig. 5 The frontpage of Tianxia120 smartphone APP. It is capable of recording the health consumer's glucose automatically and provide the medical consultation service.