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RESEARCH ARTICLE

WEARABLE E-TEXTILE INTEGRATED SENSORS FOR DETECTING HYPERKALEMIA AND HYPOKALEMIA

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Abstract

Recent evolutions in wearable and personalized healthcare devices have led to the emergence of real-time monitoring of the physiological and metabolic status of human beings. Detection of disorders related to potassium levels including hyperkalemia and hypokalemia is very much challenging in the current scenario. Potassium imbalance leads to massive change in electrical activity of the body especially disturbs the function of the brain, heart, nerves, bone and muscles in hospitalized patients. Potassium loss is a major concern in disorders such as hyperhidrosis and Cystic Fibrosis. Hence the real-time monitoring of potassium levels in the hospitalized patients may provide information related to latent cardiac problems and also assist in the diagnosis of apparent life-threatening diseases. Comprehensively, the real-time monitoring of potassium concentrations may shed light on the electrolyte loss, dehydration status and also the other associated diseases. In this study, the correlation between the Electrocardiogram (ECG) signals and the potassium levels can diagnose the potassium imbalance in a non-invasive manner. The novelty of our work is to develop a wearable E-textile integrated sensor for the detection of hyperkalemia and hypokalemia through ECG signal. The main advantage of this product is wearable and portable, and also ensures the patient safety and user friendly particularly for elderly and disabled patients and also for children.

Keywords: Hyperkalemia, Hypokalemia, ECG.

1. INTRODUCTION

Unexpected cardiac deaths have been raised due to the impact of hyperkalemia and hypokalemia in clinical sectors (C. S. Lin et al., 2020). This dyskalemias has been occurred during the correction of potassium (K^+) ions. To track these ions, point-of-care blood tests have been recommended for quick analysis of electrolyte levels in blood and plasma (Dylewski & Linas, 2018; Gavala & Myrianthefs, 2017). Potassium is one of the pivotal electrolytes like sodium, chlorine and plays a significant role in the generation of bio-potential signals of our body which helps to maintain the function of brain, heart, nerves, bone and muscles (Aburto et al., 2013). Potassium is the third most abundant minerals in the body and also regulates the water balance and the acid-base balance in the blood and tissues (Stone, Martyn, & Weaver, 2016). Potassium is highly reactive in water which produces the positive charged ion (K+) and assists in the maintenance of intracellular fluids and trans-membrane electrochemical gradient. Potassium has no effective way to be conserved like sodium in our body for future uses. Even when a potassium shortage exists, the kidneys continue to excrete it. Because the human body relies on potassium balance for a regularly functioning of the heart and nervous system, it is essential to strive for potassium's balance. Insufficient potassium causes a change in electrical activity of the body (Kuntjoro, Teo, & Poh, 2012).

Bioelectric potential or bio-potential are produced as a result of the electrochemical activity of the excitable cells, which are components of the nervous, muscular or glandular tissues. It is mainly occurred due to trans-membrane electrochemical exchange with the action of sodium, potassium and chlorine. A typical potassium level for adult falls between 3.5 and 5.0 milli equivalent per liter (mEq/L). Hyperkalemia is a condition due to high potassium minerals in human blood usually greater than 5.0 mEq/L and 5.5 mEq/L; the range in infants and children respectively. Levels higher than 7 mEq/L can lead to significant hemodynamic and neurologic consequences, whereas potassium levels exceeding 8.5 mEq/L can cause respiratory paralysis, arrhythmias or cardiac arrest (Alfonzo, Isles, Geddes, & Deighan, 2006). For example, hypokalemia and hyperkalemia are paucisymptomatic, and generally found in cardiac or renal disease patients. Therefore, in this study, we developed the emerging non-invasive and blood-free potassium tracking method for the advance clinical purposes.

2. MATERIALS AND METHODS

2.1. Basic components

The basic components including Node Micro-Controller Unit (NODE-MCU), Electrocardiogram (ECG) Sensor, Arduino IDE and connecting wires are used in this system. In this block diagram, ECG sensor is connected to core controller which accesses the sensor values and processes them to transfer the data through internet. NODE-MCU ESP8266 is used as a core controller. The obtained ECG signal can be viewed on the internet Wi-Fi system. Figure 1 shows the block diagram of the proposed wearable E-integrated sensor.

2.2. Internet of Things based ECG monitoring system

The ECG electrode (dry) is attached to the textile in three different positions as shown in the figure 2. The three electrodes were connected to the heart rate sensor and microcontroller which will acquire the ECG signal. Microcontroller signal could be received in the computer containing Arduino Integrated Development Environment (Arduino IDE) software via the Internet of Things (IoT). The signals were analyzed in smart phone application named blynk. The IoT-based ECG monitoring system is implemented using the advanced techniques of mobile sensing, cloud computing and Web. The ECG monitoring node is responsible for collecting ECG data from the human skin and then sending these data to the access point via a wireless channel.

2.3. Implementation

E-Textile integrated sensors are connected with the electronic textile including electrodes, sensor, and microcontroller, which are used to detect the ECG signal from the human body. Obtained ECG signals (Figure 3) can be viewed through phone application blynk. The data can be transferred from microcontroller to this application. A guardian or doctor can log in to this web portal to access the potassium levels in the blood serum. Through this E-Textile integrated sensor, the early detection of potassium homeostasis can be diagnosed from the obtained ECG signal in a non-invasive manner. Potassium is an important component for electrical activity of the human body. Variations in the potassium levels in the blood serum may lead to medical conditions called hyperkalemia and hypokalemia. A low potassium level called hypokalemia has many causes but usually results from vomiting, diarrhea, adrenal gland disorders or use of diuretics. Hypokalemia can make muscles feel weak, cramp, twitch or even become paralyzed and abnormal heart rhythms. A high potassium level called hyperkalemia can cause life-threatening heart rhythm changes, or cardiac arrhythmias. It can also cause paralysis and weakness. The novelty of our study is to develop a wearable E-textile integrated sensor for the detection of hyperkalemia and hypokalemia through ECG signal. The main advantage of this product is wearable and portable, and also ensures the patient safety and user friendly. It can be easily used for elderly and disabled patients and also for children.

3. RESULTS AND DISCUSSION

In general, the ranges of the serum potassium were clinically observed in blood as 3.5 - 5.0 mEq/L for adults, and greater than 5.0 mEq/L and 5.5 mEq/L; the range in infants and children. Similarly, < 3.5, < 3.0 and < 2.5 mmol/L ranges were observed in case of normal, moderate and severe hypokalaemia conditions (Palaka, Grandy, Darlington, McEwan, & van Doornewaard, 2020).The changes in the ECG signal can be used for indirectly predicting the serum potassium level in the hospitalized patients. The peaked T waves have been obtained when the serum potassium level is increased. Further increase in serum potassium level leads to the ECG report with wide range of PR interval, wide QRS duration and peaked T wave (Chew & Lim, 2005). At severe hyperkalemic condition, the ECG presentation will be like loss of P wave and sinusoidal wave (Galloway et al., 2019). At moderate hypokalemic condition, the ECG presentation looks like flattening and inversion of T waves. During severe hypokalemia, the ECG changes include prolonged Q-T interval, visible U wave and mild ST depression. Ultimately, the obtained ECG can be used to predict the potassium levels at various conditions like hyperkalemia and hypokalemia during remote monitoring without performing the blood test in an unobtrusive manner (Attia et al., 2016).

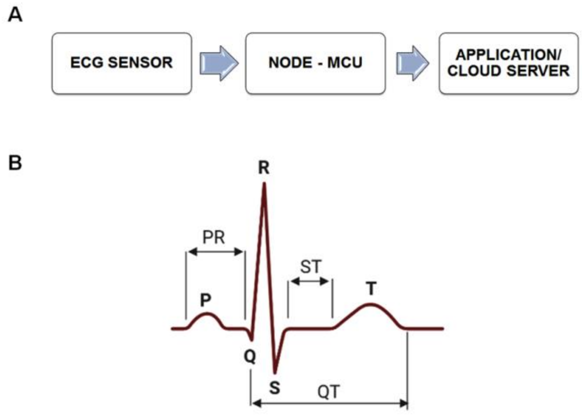

Figure1: Block Diagram of the proposed wearable E-integrated sensor (A) and normal ECG Waves (B)

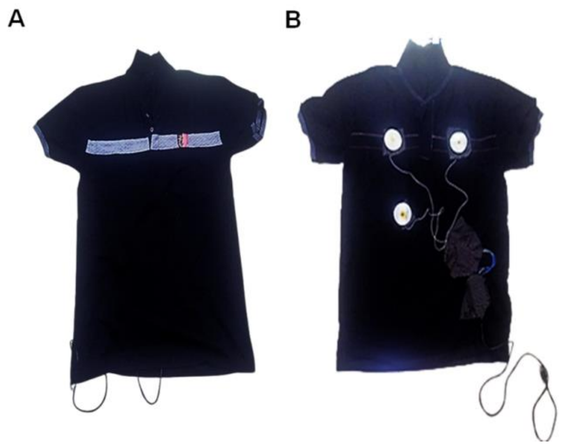

Figure 2: Positioning of Electrodes in the textile outside view (A) and inside view (B)

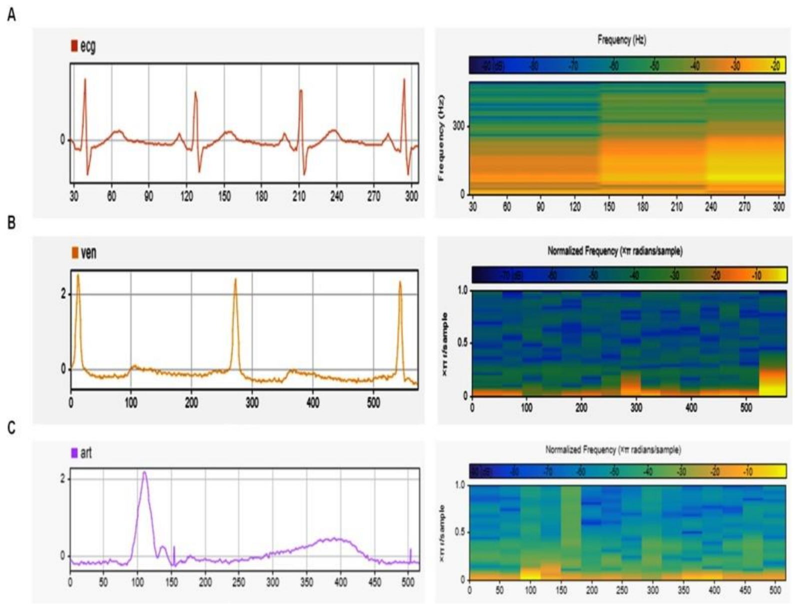

Figure 3: Comparative analysis of Normal ECG wave (A) ventricle wave (B) and atrium wave (C) and their frequency

ECG wave pattern depends on the level of serum potassium. When the serum potassium level is 5.5 to 6.5 mEq/L, the ECG will show tall, peaked T-waves. When the serum potassium level is 6.5 to 7.5 mEq/L, ECG will show loss of P-waves or prolonged PR interval (Kim, Oh, & Jeong, 2005).When the serum potassium level is greater than 9 mEq/L, the ECG will show widening of the QRS complex for greater than 0.12 seconds and leading to cardiac arrhythmia associated with severe hyperkalemia (Walter & Bachli, 2002).Potassium Loss Syndrome is a condition when the serum potassium isas below 3.5 mEq/l (Rastegar & Soleimani, 2001). 20% of hospitalized patients are susceptible to hypokalaemia. When the serum potassium level is < 3.0 mmol/L, this condition is called as moderate hypokalaemia, and when the serum potassium level is < 2.5 mmol/L, the condition is known as severe hypokalaemia. In mild hypokalemia, ECG changes include flattening and inversion of T waves, and in more severe hypokalemia condition, the Q-T interval prolongation and visible U wave and mild ST depression occurs. Severe hypokalemia can result in arrhythmias and ventricular tachycardia (Kishimoto, Tamaru, & Kuwahara, 2014).

The proposed work represents the detection of serum potassium levels using electrocardiography. Real-time monitoring and detection of electrolyte imbalance is essential for the management of metabolic disorders. Kwon et al demonstrated an artificial intelligence based model using ECG presentations for the detection of electrolyte imbalance including hypokalemia, hyperkalemia, hypercalcemia, hypocalcemia, hypernatremia and hyponatremia. In this report, the artificial intelligence based model is employed to promptly visualize the important ECG regions for detecting imbalances of each electrolytes, and variations in the P wave, QRS complex, or T wave helped to detect the electrolyte imbalances (Kwon et al., 2021). Deep-learning based model, ECG12Net guides physicians to expeditiously recognize severe hypokalemia and hyperkalemia and thereby possibly reducing cardiac events. In this study, six clinicians-three emergency physicians and three cardiologists were participated in human-machine competition and reported that the specificity, sensitivity performance of ECG12Net has better results compared with that of the physicians for detecting dyskalemias based on ECG signals (C. S. Lin et al., 2020).

Wang et al developed and validated a deep learning model (DLM) for non-invasively screening hypokalemia condition in hospitalized emergency patients and reported that artificial intelligence can be used as promising tool for the detection of hypokalemia after ECG examination. The Convolutional Neural Network based DLM has high accuracy and rapid detection capability and reliable detection of serum potassium level compared with the other traditional methods, and thereby improvising the clinical outcome of the hospitalized patients (Wang et al., 2021). Recent studies suggested that AI assisted ECG can be not only used for early detection of electrolyte imbalance but also employed for prediction of adverse outcomes of hospitalized patients. Lin et al also determined that this point of care non-invasive AI assisted ECG has improved clinical accuracy, specificity and sensitivity compared with that of the invasive blood tests (C. Lin et al., 2022).

The evolution of e-textile technologies is expansively used for various medical applications especially for real-time health monitoring of physiological parameters. The design and development of wearable e-textile based integrated sensor is used for detection of serum potassium level using the obtained ECG signal. In this study, the ECG sensors were completely integrated with clothing which can be used for continuously monitoring the ECG signal. The obtained ECG signal can be sent to the physicians and clinicians for indirectly calculating the serum potassium level. It is also helpful to detect the heart related abnormalities like hyperkalemia and hypokalemia in our body. The main aim of our project is to propose a method to remotely record the ECG of a patient and thereby detecting the serum potassium levels by correlating it with normal ECG waves. This ECG based authentication of serum potassium level has many advantages over the conventional ECG techniques. The main advantage of our system is portable, wearable and comfortable, reduces anxiety level among patient, and ensures patient safety and no need of technicians to obtain the ECG signal.

6. CONCLUSION

The wearable e-textile integrated sensors for ECG measurement were constructed and the obtained ECG signals were indirectly correlated with serum potassium levels. The obtained ECG can be analyzed to detect the conditions like hyperkalemia and hypokalemia which are life threatening conditions in hospitalized elder and disabled patients. Based on our results, we conclude that the changes in ECG presentation can be strongly correlated with the serum potassium level for detecting potassium homeostatic conditions. However, the correlation between the ECG presentation and serum potassium level might be refined and improved towards the accuracy of estimation of serum potassium levels in the larger population. The unobtrusive and non-invasive E-textiles based potassium level prediction strategy can be implemented with more advancements and sustainability in the future.

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