Identification of electrical impedance correlation using interdigital transducer (IDT) electrode and blood glucose by giving variations of sugar concentration to male mice

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Abstract: The electrical impedance depends on the frequency and material with the specific frequency using a Bioelectrical Impedance Spectrometer (BIS), a material detection using an Interdigital Transducer (IDT) electrode, and data process using software Data Acquisition (DAQ). The current electricity used in this tool is AC. The purpose is to identify the electrical impedance correlation to glucose, the effect of natural sugar on male mice's blood, and identify impedance values in glucose conditions. The method is grouping the mice because they were given a variety of drinks for 1 month. The tails of mice were cut for blood and tested. Data stored using Microsoft Excel, Bode, and Nyquist plots of data stored in the form of images. Data processing using Ms. Excel. The results are glucose value generated from this study was normal. So far nothing significant has been found. The conclusion is that there is no discovery between electrical impedance and glucose in this study, due to several factors such as time, human error, measuring instruments, and the environment. Other animal factors are the effects of metabolism, lifestyle, size, body weight, and undetected disease. This study concludes that the value of glucose produced by each animal is different.

Keywords: Blood, Glucose, Impedance, Interdigital Transducer.

1. Introduction

Many objects around us use electricity. For example vehicles, electronic devices, kitchen equipment, and in the medical, industrial, etc. In the human body, there is also electricity. This electricity comes from ions that contain electrolytes so that they affect electricity. The higher the electrolyte, the greater the electrical conductivity [1]. Based on the atomic theory, there is an electric force that arises between atoms and molecules so that it can form a liquid and a solid, which will be used as an ingredient in the metabolic processes of the human body. It is known that from the cellular components, blood is used as an indicator to determine the disturbances that occur in the body. In the blood content, there is water (H₂O), K⁺, Na⁺, Cl⁻, Ca²⁺, Mg²⁺, etc. If the human body wants to generate electricity, it needs to consume foods and drinks that contain natural sugars that produce glucose. Glucose acts as an ingredient in producing energy for the body so that it can help the body's organs work system. In this study, the blood that has been concentrated or mixed with the sugar concentration will be measured for the impedance value using the Interdigital Transducer sensor (IDT) electrode which functions to change the measurement from one energy to an electrical value.
The electrical process that occurs in cells is called bioelectricity. The main factor in determining electricity is the distribution of ions that occur in the cell membrane. The electrical process that occurs in cells is called bioelectricity. The main factor in determining electricity is the distribution of ions that occur in the cell membrane [2]. To find out the health or damage of the material being tested, you can use an electrical impedance. Electrical impedance (Z) can be interpreted as the total resistance to AC whose components consist of a resistor (R), a capacitor (C), and an inductor (L). The type of current used is AC. To find out the impedance value of a material, you can use a Bioelectrical Impedance Spectrometer (BIS) device which used a small AC signal (current or voltage) to test the sample using an electrode, namely Interdigital Transducer (IDT). In this study, using a frequency of 100 Hz-100 kHz, the current strength uses 10 µA, and the gain uses 50x. The time required to measure the electrical impedance using BIS on the test material is less than 1 minute. Only the test materials measured are liquid. IDT is an electrode device that can detect the test material by requiring a minimal volume of material and the value of this volume is not based on measurement. IDT has reversible properties, namely as a transmitter and receiver [3]. The term interdigital refers to a periodic pattern such as parallel fingers which have electrodes and are used to make capacitance using an electric field intertwined with the test material [4]. In animal tissue, it will decrease with increasing frequency. In measuring blood impedance, the highest frequency used is 1 kHz, because red blood cells have a resistivity of 1000 Ω cm [5]. This is because normal blood and blood with high sugar cannot be differentiated [6].

A blood glucose meter is a tool for measuring blood sugar levels through testing outside the body (in vitro). In this study, the glucose-measuring instrument was Easy Touch GCU (Glucose, Cholesterol, Uric Acid). The working principle is giving blood around 0.5 - 0.6 μL (1 drop). Blood should not be less than the predetermined volume because it can cause an error or the blood cannot be detected by the blood glucose meter. Then the blood will react with the enzymes on the strip. So that the reaction results can cause a flow that is proportional to the amount of sugar in the blood. Furthermore, the tool will detect the current which then converts it into a blood sugar reading value [7]. This is the reason researchers use this tool so that they can compare current glucose values with previous glucose values. The limitation of this study is that it does not examine the structure of the blood.

2. Method

2.1 Research methods

The instruments and materials were prepared in advance consisting of connecting cables, IDT electrodes, digital scales, BIS-DAQ, easy touch GCU, blood, sugar concentration, and distilled water. Before using the device, it should be calibrated first. Mice that have been weighed will be grouped. Then the mice were acclimatized for 7 days. On the 8th day, glucose checking for the normal group was carried out by cutting the tip of the mice about 0.2 mm. On the next day, the sugar concentration was given to the treatment group, where the sugar concentration varied. Every 8th day, impedance measurements are taken and glucose checks for 1 month. To perform impedance detection on the test material using BIS-DAQ and IDT electrodes. Meanwhile, to detect glucose in the test material, you can use the Eas Touch GCU. The data that has been obtained can be processed using Microsoft Excel. There are several things you need to know when measuring blood sugar, namely:

| No. | Test results (mg/dL) | Information               |
|-----|----------------------|--------------------------|
| 1   | < 70                 | Low blood glucose (hypoglycemia). |
| 2   | > 240                | High blood glucose (hyperglycemia). |
| 3   | 70 ≤ result of ≤ 240 | Normal blood glucose.    |

Do retest if you do not get consistent results.
2.2 Dosage
The dosage of sugar used is based on the results of calculations and has been converted from humans to mice.

\[
\frac{\text{Dosage of human}}{1000} = \frac{x}{\text{BB mice}}
\]  

The amount of concentration to be used can use the following density equation:

\[
\rho = \frac{m}{V}
\]  

Information:
\( \rho \) = density (g/ml), \( m \) = mass of object (g), \( V \) = volume of object (ml).

| Species        | Body Weight (kg) | Working Weight Range (kg) | Body Surface Area (m²) | \( K_m \) Factor\(^f\) | Conversion Factor\(^f\) |
|----------------|------------------|----------------------------|-------------------------|-------------------------|-------------------------|
| Adult          | 60               | -                          | 1.6                     | 37                      | 1.00                    |
| Child          | 20               | -                          | 0.8                     | 25                      | 1.48                    |
| Baboon         | 12               | 7 – 23                     | 0.6                     | 20                      | 1.85                    |
| Dog            | 10               | 5 – 17                     | 0.5                     | 20                      | 1.85                    |
| Monkey         | 3                | 1.4 – 4.9                  | 0.24                    | 12                      | 3.08                    |
| Rabbit         | 1.8              | 0.9 – 3.0                  | 0.15                    | 12                      | 3.08                    |
| Guinea pig     | 0.4              | 0.208 – 0.700              | 0.05                    | 8                       | 4.63                    |
| Rat            | 0.15             | 0.080 – 0.270              | 0.025                   | 6                       | 6.17                    |
| Hamster        | 0.08             | 0.047 – 0.157              | 0.2                     | 5                       | 7.40                    |
| Mouse          | 0.02             | 0.011 – 0.034              | 0.007                   | 3                       | 12.33                   |

\(^f\)The \( K_m \) factor, body weight (kg) divided by BSA (m²), is used to convert the mg/kg dose used in a study to an mg/m² dose [9].

3. Results and Discussion
The result of researches obtained resistance and capacitance values from all graphs that determine the physicochemical properties of a material. Because of this information, it can be seen the electrical impedance value of a material. In this study, the material in question is the blood of male mice aged 2-3 months. Impedance is expressed in complex numbers consisting of resistance as a real component and a combination of capacitance and inductance as an imaginary component. In the bioelectric concept, there is also electricity in the body of living things. So that the electrical impedance value can be interpreted as a resistance value of an electric circuit that produces a response to the AC voltage applied to a material. Research data in week 1 obtained a capacitance value of 5807.571 nF and a resistance of 0.565 kOhm. In the K1 group, the amount of sugar concentration dissolved using distilled water was given to the mice every day, namely 0.3 grams/mice. The results obtained have a higher line than the control data. This means that the resulting impedance value is higher. The higher the frequency, the smaller the impedance than the group K0 impedance. In contrast to the resulting glucose value, at week 1 the highest glucose value was in the K2 group, namely 184 mg/dL. However, the resulting line is not above the blue line. In week 2, the resulting capacitance value was 5037.066 nF and the resistance was 0.570 kOhm. In the graph plot of Figure 5.7, the impedance value of the K1 group is greater than the impedance value of the K4 group, even though it has the same glucose value. This week, the highest glucose value was the K1 and K4 groups with a value of 158 mg / dL. This result can be seen in figure 1.
Figure 1. Plot Graphs of the Impedance Containing the Glucose Values over a Given Frequency Range. (a) Week 1, (a) Week 2, (c) Week 3, (d) Week 4.
The concentration of sugar dissolved in distilled water for the K4 group every day was 2.1 grams/mice. However, with this glucose value, the K4 line does not line up with the K1 line. The higher the given frequency, the lower the resulting impedance than the K0.

In week 3, the highest glucose value was obtained from the K3 group, namely 144 mg/dL by giving the concentration of sugar dissolved using distilled water, namely 1.5 grams/mice. However, the impedance value produced by the K3 group is not on the highest line. The highest line on the plot of this graph is the K1 group with a low sugar value of 93 mg/dL. This week the resulting capacitance value is 4213,819 nF and the resulting resistance is 0.598 kOhm. The higher the frequency used, the resulting impedance value of the treatment group is below the impedance value of the K0.

The resulting capacitance and resistance values for week 4 in Figure 5.8 is 4520.793 nF and 0.596 kOhm. The highest impedance value was obtained from the K4 group. However, the highest glucose value was obtained from the K3 group, namely 148 mg/dL. Meanwhile, the impedance value of the K3 group is not on the highest line. Likewise, the K2 group had a high glucose value of 132 mg/dL but had a lower impedance value than K0. The concentration of sugar given to the K2 group every day was 0.9 gr/mice and the K0 did not give sugar drink concentration, but only feed and drink it.

Each resulting graph plot, high impedance values were obtained from the treatment group. The reason the control group (K0) did not produce the highest impedance value compared to the treatment group (K1, K2, K3, K4) on week 1 to week 4 graph plot, was because the K0 group was only given feed and mineral water (not purified water). However, an anomaly was found where several treatment groups had smaller impedance and glucose values compared to the K0 group. Collecting data for group K0 is only 1x, where this data is used as a reference for the treatment group. The reason for using experimental mice is because of their small body size, which can be controlled in feeding and drinking. Meanwhile, the reason for not using human blood is because the human diet cannot be controlled, the human age range is different (children, adolescents, adults, elderly), and there are unknown diseases. Some of the hypotheses that can lead to instability of glucose data and impedance from week 1 to week 4 for 1 month are the metabolism of mice, life patterns, and animal size and weight. Besides, several other factors need to be considered, namely time, human error, the tools used for data collection, and the environment.

Capacitance and resistance that has been measured automatically using BIS-DAQ software, information can be obtained during material being tested. The meaning of the change in the capacitance value is that there are many process events in the cell, where the cell has interactions with the membrane and interactions between other cells. It is said that the capacitor occurs when the cell membrane is in contact with the electrodes [5]. Such properties can yield information that can be used to study cells. From this, the electrical capacitance is possible to be used as a source of information in physical-chemical science. The weakness of maximum frequency that can be used in BIS-DAQ only up to 100,000 Hz. If the resistance used has been determined, which is 0.5 Ohm, then the capacitance value generated from the test material will automatically be around ± 6000 nF. If the capacitance value is lower or equal to the standard value (in this study ± 6000 nF), chances are the sensor has been set correctly. However, if without using capacitance, the resulting value will fluctuate. If the resulting capacitance value exceeds the usual (> 7000 nF), the membrane layer is damaged by producing a low reactance value. So that the sensor needs to be replaced to avoid this incident. Whereas resistance is used to analyze cells, so the impedance value depends on the resistance.

In this study, there were changes in data retrieval using detection tools. This is due to the lack of cleaning blood stains/samples on the IDT electrodes, resulting in slightly deviant values. If the value is deviant, it should be repeated until you find the value according to the target/literature. The effect that resulted from giving natural sugars was that all weeks resulted in different and random glucose values. However, when viewed from the nature of sugar in all weeks, it is still classified as normal, where there is no sugar deficiency or excess sugar. Whereas the effect on impedance is that the higher the frequency is given to blood containing glucose and fluids, the graph plot will continue to decrease until it reaches a constant condition. This statement is following from the literature. The correlation obtained in this study has not been found. This is because there is an abnormality with a high sugar value that is not in line with the resulting impedance value. Previous research has explained that the higher the blood
glucose value, the lower the resulting impedance value. It’s just that in previous studies using frequencies ranging from 100 Hz to 10 kHz and using eight subjects with different frequencies [10]. When compared with the research tools that researchers use, it ranges from 100 Hz - 100 kHz. The two tools that researchers use are non-invasive.

4. Conclusion
Whether a blood tissue is healthy or not, we actually can know it by electrical impedance. The electrical impedance depends on the frequency and the material used. Because each material has a different electrical impedance. Meanwhile, the glucose value in each experimental animal was different. The correlation between electrical impedance and blood sugar cannot be found. This is because there are several factors, including time, human error, the tools used for data collection, and the environment. The factors of the experimental animal itself are the influence of metabolism, life patterns, size, and body weight. During the 1-month study, several mice experienced fattening or gained weight, but mice were passive in terms of movement. For glucose values generated from week 1 to week 4 with a range of 94 mg/dL - 184 mg/dL. The researchers hope is to learn more using the BIS-DAQ tool using interdigital transducer electrodes in conditions of damage to blood cells.

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