An Empirical Measurement of Body Hydration using Galvanic Coupled Signal Characteristics

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ABSTRACT

Galvanic coupled Intrabody communication signals use the human body as the waveguide. The signal characteristics change in gain and or loss by the body's physiological state. Because galvanic coupling contains the signal in the body, the technology can be suitable for finding alternative application in biomedical sciences. In this work, we investigate the use of a galvanic coupling circuit to study the hydration status of a human body from the changes in the signal characteristics. We show that below 5 MHz conductivity increases with hydration at the average rate of 0.24 dB/minute after fluid restriction from night to 10 am. During the process pre-hydration, hydration and post-hydration measurements were taken at 5, 10 and 15 minutes intervals. The measurements were taken after abstinence from fluid as stated above. Prior measurements of conductivity were taken at the stated intervals before fluid restriction as experimental control. Measurements of dehydration were taken after absorption has ceased and the subject urinated; it was observed that conductivity at dehydration decreased at the average rate of 0.92 dB/minute and the rate of hydration was quickest at 1.03 MHz while dehydration was fastest at 2.9 MHz.

Keywords

Galvanic Coupling, Intrabody Communication, Pre- hydration, Hydration, Post-hydration, Conductivity, and Fluid restriction.

1. INTRODUCTION

Intrabody communication (IBC) is a wireless communication system that uses the human body as the medium for signal transmission. The signals are transmitted through the electrode interface connected to the body. The received signal strength is affected by the coupling method used and the electrical and physiological characteristics of the body. IBC technology is antenna free and enables low power budget for biomedical sensor communication. In sensor networks, short range communication uses radio frequency (RF) wireless links like Bluetooth and Zigbee which radiate electromagnetic energy into the air thereby requiring excessive power to operate. Our experiment focuses on the use of a galvanic coupling circuit to study the hydration changes in the human body by observing the changes on the received signal attenuation in response to variations in the hydration state of the volunteers. The IBC galvanic coupling circuit shown in Fig.1 uses four terminal electrodes. In our experiment we used an silver-silver chloride electrode which is insoluble in aqueous solution and has the ability to reduce the effects of motion artifacts and reflection.

Previous experiments in IBC propagation mechanism focused more on the development of equivalent electrical circuit models [13] and Wegumuler [3] investigated the effects of the coupling mechanism, electrode types and transmitter orientations. However, there are still important areas that has not been investigated especially in biomedical applications. For example, the use of IBC technology to study hydration changes in human beings has not been investigated before.

Measurement of human body hydration is required to describe either deficiency or excess of water in relation to a health risk or sports performance. The knowledge of hydration status will assist in formulating appropriate interventions against hydration disorders such as dialysis patients [5], sports performance and body agility [4][2][11]. Some techniques for measuring body fluid in humans involves tissue resistance to applied pressure, and the use of bioelectrical impedance analysis [10]. The most widely used methods of determining hydration status includes monitoring body weight changes by measuring sweat losses and site specific sweating and measuring urine specific gravity using refractomer or urinalysis method [12][9]. Urine specific gravity and urine osmolarity measurements are only marginally useful. Armstrong *et al* [1] suggested that there is a difference in the exactness of the related measures of hydration using urine specific gravity, urine osmolarity, and urine

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color. Similarly, measurement of hydration by other means such as body weight changes does not appropriately account for fluid intakes, weight losses through exercise and fluid losses through urination. The available measurement methods ranging from simple to complex have limitations and some degree of measurement errors which challenges the reliability of their results.

In this paper, we investigate the use of the galvanic coupling circuit to carry out empirical measurements to study hydration changes in human body under 3 body fluid states. First, the control was set to measure the pre-hydration state, which is the state of normal water balance in the body [8]. The second state is called the hydration state. This is the state measured after induced water reduction. The measurement was taken after fluid abstinence from night to 10 am with an empty belly. The quantity of water is calculated in proportion to the subjects' weight. Finally, the third state is the post-hydration or dehydration state which was taken after urine excretion as the body returns to the initial state of water balance. We compare the empirical measurements of the hydration and post-hydration states with reference to the pre-hydration state. The rest of the paper is organised as follows: In section I, we introduced our work and explained the basic principles of hydration and body osmotic balance. In section II we present the experimental setup. This is followed by the experimental results and the discussion in section III and section IV is the conclusion.

1.1 Water and body liquids

Water is an important and major constituent of body cells, tissues and organs and contributes about 60 percent of total body weight (TBW) of an adult [8]. It has strong electrical polarity which makes it easy to dissolve other polar molecules. Ions in the body are hydrated by the dipole nature of water making the cells to be surrounded by aqueous electrolytes which causes electrolytic conductivity [6]. Excess or inadequate water intakes are corrected by sudden hormonal changes in the body which are activated to prevent the effects of abnormal conditions. These include hormones such as antidiuretic hormones (ADH) in response to the feeling of thirst to top up the body water requirement and, in cases of excess fluid, the kidneys modify the body osmotic pressure with a suppression of ADH secretion in response to excess water in the body leading up to urine formation and excretion. In general, a normal hydration state is the condition of water balance in the body [8] which we shall set as the control for our experiment. This will be followed by measurements of conductivity after water intake at the end of fluid restriction and measurements after urinating using the galvanic coupling circuit.

2. EXPERIMENTAL SETUP

The measurement setup is shown in Fig.4. A miniVNA Pro, frequency range 100 kHz to 200 MHz, manufactured by Mini Radio Solutions, baluns (Coaxial RF transformers, FTB-1-1+, turns ratio of one, manufactured by Mini-Circuits, and frequency between 200 kHz and 500 MHz), and round pre-gelled self-adhesive Ag/AgCl snap single electrodes (1 cm diameter, manufactured by Noraxon) were used. The baluns are used to electrically isolate the two ports of the VNA to ensure the return current does not make a loop through the common ground of the two ports. The VNA is set to sweep the constant interval frequency of range 300 kHz to 10 MHz in 49 points with 0 dBm output power, which is well below the safety limit set by International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998) and World Health Organization (WHO, 1993) [7]. Since we are observing conductivity at different hydration states of the body over a range of frequencies, we could not use a signal generator because it takes frequency input one at a time and will not be able to span the range of frequencies we wanted and produce the body response simultaneously as required. The Noraxon self-adhesive Silver/Silver-Chloride electrodes (Ag/AgCl) are preferred because it reduces the effects of motion artifacts and reflection compared to polarizable electrodes. The distance between the transmit and receive electrodes and the inter electrode separation is 20 cm and 4 cm respectively. A small harmless electrical current (<1 mA) is transmitted in a galvanic coupling circuit into the arm using a pair of noraxon surface electrodes (transmitter electrodes) and received 20 cm at the sink. The protocol group defined in this experiment is a healthy volunteer measured 5-10 minutes after abstinence from fluid and 5 minutes interval after intake of 600 ml of water calculated in relation to the weight of the subject. The subject was allowed to sit on a plastic chair with arms by the side to ensure the current is confined within the arm by avoiding external physical contact. To minimise the measurement uncertainties due to errors associated with cable and body movement, each measurement was repeated five times within 1 minute and the average was used.

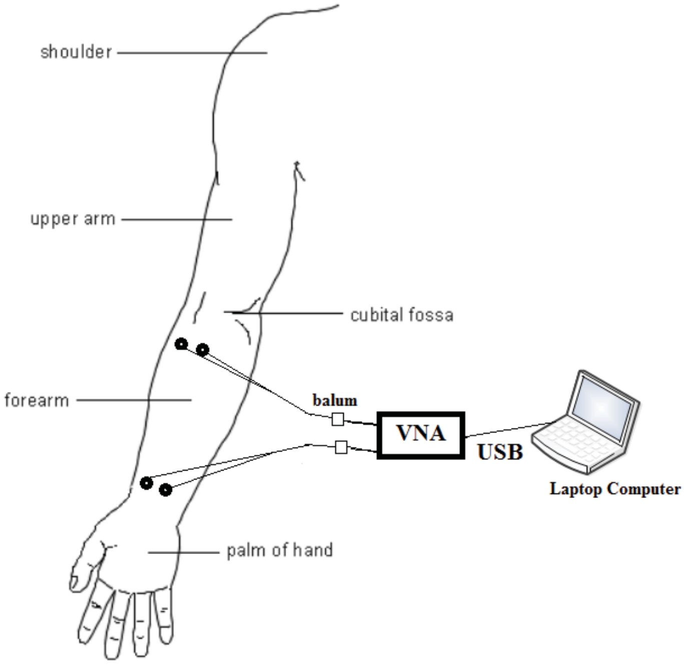

Figure 1: IBC galvanic coupling circuit on the lower left arm of the subject, the four terminal silver-silver chloride surface electrodes are attached to the body and connected to a VNA, the output signal shows on the laptop screen fitted with the VNA software

3. RESULT AND DISCUSSION

Fig.2, Fig.3 and Fig.4 show the effects of hydration and dehydration on IBC signal characteristics. Using the S-parameters, the value of the S_{21} transmission coefficient signifies the magnitude of the attenuation between the transmitter and the receiver electrodes which is calculated as the ratio of the logarithmic value of the receiver voltage to the transmit voltage expressed in dB. By setting the control as described in section I and taking the measurements as explained we have the graphs shown in Fig.2 - Fig.4 and the rate of hydration and dehydration given in table I.

The data points on graphs corresponds to $f1$ to $f8$ on the frequency axis and shows the attenuation from 800 kHz to 5.4 MHz. The low frequency signals have higher attenuation in all the graphs. We shall limit our discussion to 5 MHz in order to isolate the influence of the high conductivity of some body tissues (example skin and muscle at high frequencies [6]) from the observed signal response. Table I shows the list of the tested frequencies and the measurements of the changes in hydration and dehydration within 5 minutes, 10 minutes and 15 minutes. At the start of the experiment, before fluid abstinence we measured the signal attenuation. We have that at 800 kHz for example, the attenuation at point zero was -73 dB, 15 minutes later the attenuation stood at -74 dB. Similarly, frequencies $f2$ to $f8$ did not measure more than 1 dB difference between point zero and 15 minutes later.

In Fig.2 for example, the graph shows the signal characteristics at pre-hydration, hydration and post-hydration states. At time zero of $f1$ (during hydration) the attenuation started with -81 dB because the electrolytic carrier has been reduced through fluid abstinence and the water just taken has not circulated properly. However, 15 minutes later absorption has occurred and the measured attenuation became -75 dB (Fig.3). This showed a rise in signal attenuation from -73 dB at pre-hydration state (the control) to -81 dB as a result of the fluid restriction. As hydration occurs the signal increased in conductivity and peaked 15 minutes after. The increase in conductivity is observed by the drop in attenuation which at 15 minutes became -75 dB (about 2 dB difference from the control). The increase in conductivity or drop in attenuation is because the body fluid volume was increased by the electrolyte carrier (water) thereby accelerating the ease with which the ions and cations move within the cells. As the process of hydration stabilizes, the attenuation gradually shifts to return to the pre-hydration state of normal water balance. Again, frequencies $f2$ to $f8$ had similar observations. The measured conductivity increased every 5 minutes. Table I shows the average rate of hydration and dehydration at different frequencies. Hydration was quickest at 1.03 MHz while dehydration was fastest at 2.9 MHz. It is important to note that we could not ascertain if the measured rate of absorption was the same in other parts of the body since our experiment focused only on the arm. It is possible that the rate of absorption and dehydration were affected by other pre-existing conditions of the body and the environment.

Frequencies $f1$ to $f8$ in Fig.4 shows the changes in signal attenuation at the post-hydration experiment very clearly. Five minutes after (Fig.2), $f1$ is -68 dB which is -5 dB dif-

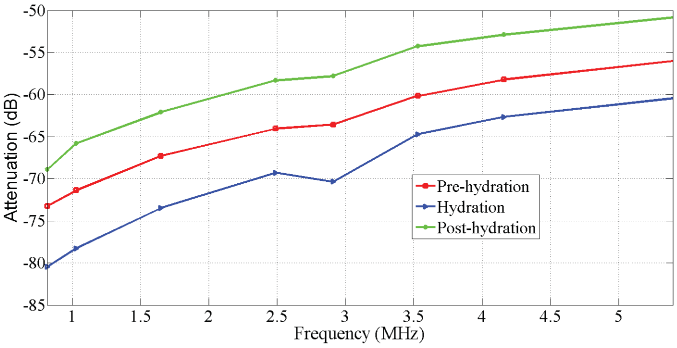

Figure 2: 5 minutes trend across the frequencies for pre-hydration, hydration and post-hydration states

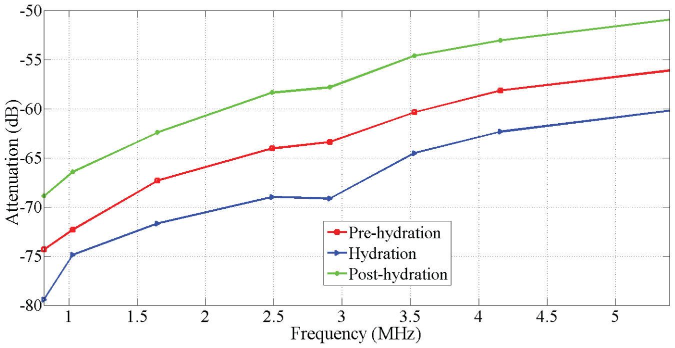

Figure 3: 10 minutes trend across the frequencies for pre-hydration, hydration and post-hydration states

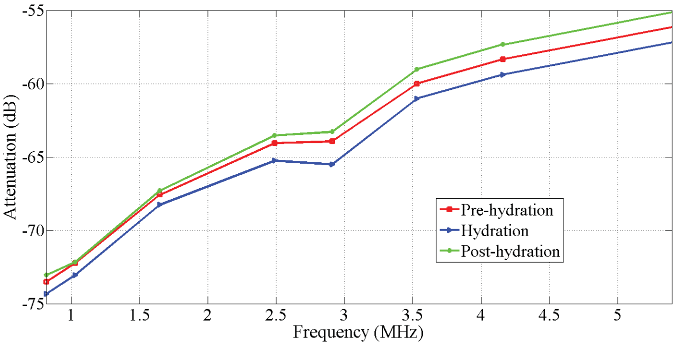

Figure 4: 15 minutes trend across the frequencies for pre-hydration, hydration and post-hydration states

ference from the start of the pre-hydration experiment and about -13 dB from the hydration graph. The low attenuation means that the conductivity was still high and the medium through which the electrolytes are conducted are unaffected yet. After 10 minutes (Fig.3), the attenuation has begun to increase and by 15 minutes the conductivity has decreased by -5 dB. This means that the fluid volume has began to shrink through the processes of the body's osmotic balance. Again, we observe the signal returning to the pre-hydration state. The signal maintained similar pattern of attenuation at frequencies $f1$ to $f8$ in line with the changes in the body's hydration state.

The difference between the hydration and pre-hydration attenuations was -5 dB across the frequencies $f1$ to $f8$. After 10 minutes, there was a -6 dB difference between hydration and post-hydration while the hydration and the pre-hydration maintained a difference of -5 dB. However, in Fig.3 hydration was 1 dB across frequencies $f1$ to $f8$. The post-hydration was <1 dB between 800 kHz and 2.5 MHz and about 1 dB in other frequencies.

Table 1: Average rate of hydration and dehydration

Frequency (MHz)	Rate of Hydration (dB/Minute)	Rate of Dehydration (dB/Minute)
f1 = 0.82	0.20	0.82
f2 = 1.03	0.68	0.82
f3 = 1.65	0.36	0.97
f4 = 2.4	0.06	1.03
f5 = 2.9	0.24	1.09
f6 = 3.5	0.24	0.88
f7 = 4.1	0.06	0.86
f8 = 5.4	0.05	0.84

4. CONCLUSION

The measurement of human body hydration using IBC galvanic coupling signal characteristics is reported for the first time. The result shows that the rate of hydration differs slightly at different frequencies; however, the differences in hydration measured by the hydration changes is only clearly significant after 15 minutes as shown in table II. Between 1 MHz and 1.6 MHz the conductivity of the body or rate of water absorption is between 0.68 dB/minute and 0.36 dB/minute and about 0.05 dB at 5.4 MHz. The average rate of dehydration across the frequency range under investigation is 0.92 dB per minute. Dehydration rate increased as the frequency increased and is faster than the rate at which the water is absorbed in the body before returning to osmotic balance. Hydration was quickest at 1.03 MHz while dehydration was fastest at 2.9 MHz. By observing the signal attenuation after or during absorption and de-absorption, the rate of hydration or dehydration can be rightly observed. The noticeable difference resulting from the decrease or increase of water level in the body can be used in detecting body fluid disorders. Further experiments will help us to generalise if the rate of hydration and dehydration can be measured the same way in other parts of the body and if there is time differences in the rate of absorption by the different parts of the physical body. We also shall investigate these results by age, sex and environmental conditions and if this is affected by skin types.

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