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Fluid Shift and Fluid Resuscitation in Burn Patients with the use of Bio-Electrical Impedance Spectroscopy to Monitor Fluid Levels

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Fluid Shift and Fluid Resuscitation in Burn Patients with the use of Bio-Electrical Impedance Spectroscopy to Monitor Fluid Levels

An Honors Thesis submitted in partial fulfillment of the requirements for Honors in *Mechanical Engineering*

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ABSTRACT

The purpose of this research is to explore the current methods of fluid resuscitation and other possible methods of measuring the body fluid levels of burn patients in order to fully understand the fluid increase patterns in the torso area. This will be done primarily by focusing on the concept of bio-electrical impedance spectroscopy to measure the fluid levels only in the human torso area. Three similar tests were carried out by measuring the resistance values after ingesting 500ml of water. This was repeated until a total of 1500ml of water was ingested. It was found that the resistance in the extracellular fluid (R_0) appear to not be significantly affected by the increase in fluid intake but the resistance in the intracellular fluid (R_∞) show a greater difference. This can be due to a variety of conditions including the path flow of the ingested water content. The resistance measurements from the back of the torso posed to be more accurate than that of the front of the torso. This can also be connected to the water path flow. In order to further study the chosen electrode placements and understand the cause of the difference between the front and back torso results, more focused tests will be carried out in the future.

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1. INTRODUCTION

FLUID SHIFT AND THIRD SPACE

There are two major fluid compartments in the human body; intracellular and extracellular fluid compartment. Like the names imply, intracellular fluid is fluid inside the cells while extracellular fluid is fluid outside the cells which consist of intravascular and interstitial fluid. Fluid shift occurs when a substantial amount of the fluid in the intravascular compartments moves into the interstitial compartment, also known as third space, which can lead to a number of health issues/complications and death. The levels of sodium, albumin, fluid pressure, amongst other things are factors that affect the fluid in the intracellular and extracellular compartments. When these factors are abnormally affected, it can cause a significant amount of fluid to shift form the intravascular to interstitial compartment. There is a large number of things that can affect these factors; some of which are diarrhea, liver diseases, malnutrition, alcoholism burns and so on [1]. This research is mainly focused on how burns causes fluid shifts and a new approach on reversing these effects. When a body burns, the capillary permeability increases which leads to edema and a large amount of fluid in the intravascular compartment is forced to transfer to the interstitial compartment. The severity of the fluid shift is related to the percentage of body burns. In order for the body to heal, the lost fluid will have to be resuscitated in the right amount [2 – 4].

FLUID RESUSCITATION

The first 24 – 48 hours after burn occurs is the most crucial part of the healing process. There would be a loss of fluid in the intravascular compartment which needs to be

resuscitated in order to prevent the body from going into hypovolemic shock. The process is performed on burn patients with greater than 15% total body surface area (TBSA) burns [5]. Over the years, many methods have been developed for fluid resuscitation with the aim of reducing morbidity and mortality rate and properly administering fluid to burn patients. The most common method used now is the Parkland and modified Brooke's formula [6].

BROOKE FORMULA

The Brooke formula was introduced in the early 1950's after the Evans' formula [7]. These were the first fluid resuscitation formulas to be developed and it was noticed that the mortality rate decreased as a result of the use of the formulas. The dose given is different over time as the fluid levels changes and should be replaced in the appropriate amount to avoid over- or under- resuscitation. In the first 24 hours after burn, 2 mL/kg/%TBSA should be given with three quarter of the dose as crystalloids and the other one-quarters as colloids [7 – 9]. This is given with 2000 mL glucose in water. Half of the total calculated dose is to be given in the first 8 hours and the other half over the remaining 16 hours. In the next 24 hours, half of the dose for both crystalloids and colloids calculated for the first 24 hours is administered, after which the dose is adjusted based on the urine output of the patient. This is used to measure the body fluid level based on the urine produced per hour. If the urine output is less than 30 mL per hour, an increase of 25% of crystalloids is to be administered and if the output is more than 50 mL per hour, the administered crystalloid is to be decreased [10, 11]. Later on, the modified Brooke's formula was developed which is similar to the Brooke formula except the total

calculated fluid is administered as crystalloids alone instead of crystalloids and colloids [9]. This is more often used than the Brooke formula today.

PARKLAND FORMULA

The Parkland formula was developed by Baxter and Shires in the 1960s [12]. It is more used than the modified Brooke formula today. Like the Brooke formula, it is dependent on the weight and burn percentage of the burn patient. In the first 24 hours, 4 mL crystalloid/kg/%TBSA is given with half of the dose being administered in the first 8 hours and the other half over the next 16 hours [5, 8, 9]. During this period, no colloids should be administered to the patient but can be administered in the next 24 hours while adjusting the dose based on the urine output like with the Brooke formula.

OTHER METHODS

Asides from the Parkland and Brooke formula, other formulas were developed although they are not popularly used today. The Evans formula, as stated earlier, was developed in the early 1950's before the Brooke formula. It uses the same formula as the Brooke formula and is administered over the same time frame. However, the dosage of crystalloids and colloids is different. Of the 2 mL/kg/TBSA to be administered, half is to be crystalloids and the other colloids [8, 9]. The Monafo formula is different to the previously stated formulas. It requires a fluid containing 250 mEq Na, 150 mEq lactate and 100 mEq Cl to be administered in the first 24 hours [9]. It is solely dependent on the urine output as this is the criteria used to determine the amount of normal saline to be given with the liquid in the next 24 hours.

The introduction of these fluid resuscitation formulas has reduced the morbidity rate significantly since the 1950's and even more with the use of the modified Brooke and Parkland's formula. However, it was observed that the use of these formulas often leads to excess fluid being administered to the patients. This concept was named Fluid Creep by Basil Pruitt in the year 2000 [13]. It was found that the use of urine output as a measure for the body fluid level was not accurate [11, 13]. It often shows the patient requires more fluid than needed which leads to the excess fluid being administered. This over-resuscitation leads to a number of complications including pulmonary edema, limb compartment syndrome, abdominal compartment syndrome, slower healing rate and these complications are known as resuscitation morbidity [10]. It was noticed by Baxter that some patients with alcohol or drug addiction, electrical injury, or inhalation injuries require more fluid than the resuscitation formula recommends. In this case, there is a potential for such patients to be under-resuscitated. However, when none of these criteria are present, the excess fluid leads to complications which in turn may lead to death [13, 14]. This research is being conducted to find a more efficient way of measuring the fluid level in burn patients so as to avoid under- or over- resuscitation and this would be done using a Bio-electrical impedance spectroscopy approach [15, 16].

MONITORING FLUID LEVEL USING BIO-ELECTRICAL IMPEDANCE SPECTROSCOPY

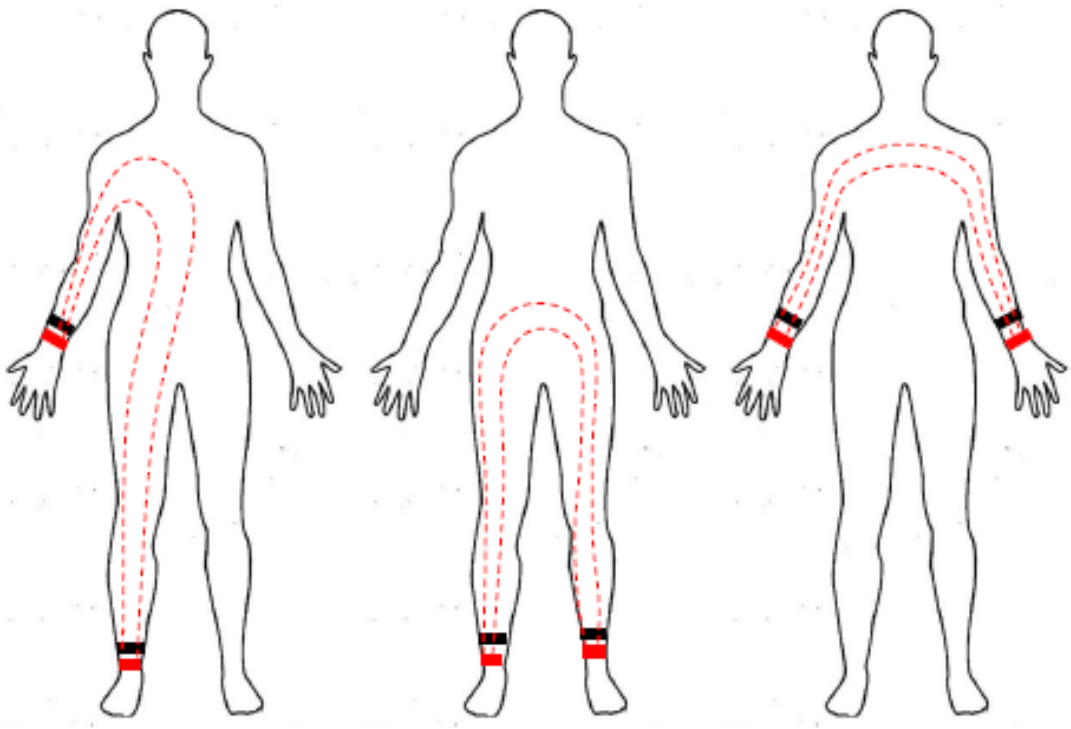
Bio-electrical impedance Spectroscopy is measure of the extra cellular fluid (ECF), intracellular fluid (ICF), fat mass (FM) and fat free mass (FFM) of a body with the use of

electrodes placed and different parts of the body. The placed electrodes allow for small alternating current to flow through the body over frequencies ranging from 4 – 1000 kHz. It measures the body resistance and reactance which generates a cole-cole curve. With this data, the device determines the resistance at zero and infinite frequencies as R_0 and R_{inf} respectively [17, 18]. The ECF and ICF are dependent on the R_0 and R_{inf} respectively, as well as on the age, weight, and height of the test participant. With these variables, the fluid volume is calculated using the expression shown below.

$$V = K_B \times \rho \times \frac{L^2}{R} \tag{1}$$

Where V is fluid volume, ρ is resistivity, L is the height of the participant, R is the resistance and K_B is a value dependent on the body shape of the participant. This formula, as shown in Eq. (1) is used by the BIS device to generate the fluid volume of the test participant [18].

It is widely used today for various purposes ranging from clinical to personal use. It is used for health treatment like hemodialysis, cancer treatment, heart failure treatment, and also used personally for weight management or sports [19 – 21]. The measurements can be taken as whole body or segmental BIS measurements determined by the placement of the nodes [17, 19, 22, 23]. To measure the whole-body fluid and mass, four electrodes are placed; two on the wrist and two on the corresponding ankle, as shown in Figure 1 [22]. This allows for the current to flow from one electrode to the corresponding opposite thereby flowing through the whole body. Segmental BIS measurements can be taken as the lower body measurements, measured from ankle to ankle (as shown in Figure 2), or upper body measurements, measured from wrist to wrist (as shown in Figure 3) [24 – 26].



(a) (b) (c)

Figure 1(a): This figure shows the current path flow in the human body when measuring the whole-body BIS. It is seen that the electrodes are connected to the right wrist and ankle to allow the current flow across the whole body.
Figure 1(b): This figure shows the current path flow in the human body when measuring the segmental BIS. It can be seen that the electrodes are connected to both ankles to allow the current flow only across the lower body.
Figure 1(c): This figure shows the current path flow in the human body when measuring the segmental BIS. It can be seen that the electrodes are connected to both wrists to allow current flow only across the upper body.

The testing to be done for this research was intended to be targeted on the human torso area alone. Current studies have shown that this segmental measurement should be done by placing the electrodes on both wrists, as shown in Figure 3. However, this has proven to not produce accurate result. With the severity of the resuscitation treatments of burn patients, these measurements need to be very accurate, so the possibility of taking measurements by multi-placements of the electrodes was explored.

2. METHOD

ELECTRODE PLACEMENT

For this research, the concept multi-electrodes were explored to determine if the chosen electrode placement can accurately measure fluid increase in the human torso area. This was done by using a total of 16 electrodes; 8 on the upper torso area and 8 on the lower torso area. These electrodes were numbered 1 to 8 for the upper and lower areas being measured. For the upper torso area, electrodes 1 to 4 were placed on the chest, right under the clavicle, of the test subject in order from left to right and electrodes 5 to 8 were placed on the upper back, below the trapezius, from right to left. For the lower torso area, electrodes 1 and 2 were place on the left upper femoral, below crotch level, electrodes 3 and 4 were placed on the similar location on the right femoral and the process was repeated for electrodes 5 to 8 placed from right to left. This allowed the current to pass through the full torso while taking account of all the organs in the area. An image of the electrode placement can be seen in Figure 2 below. The testing was done using the Impedimed SFB-7 device, as shown in Figure 4, and because this device only allows for the connection of 4 electrodes, two multiplexers had to be designed that will allow the connection of 8 electrodes each which were then connected to the SFB-7 with only 2 wires. One was used for the upper torso area and another for the lower torso area. Both multiplexers can be seen in Figure 3.

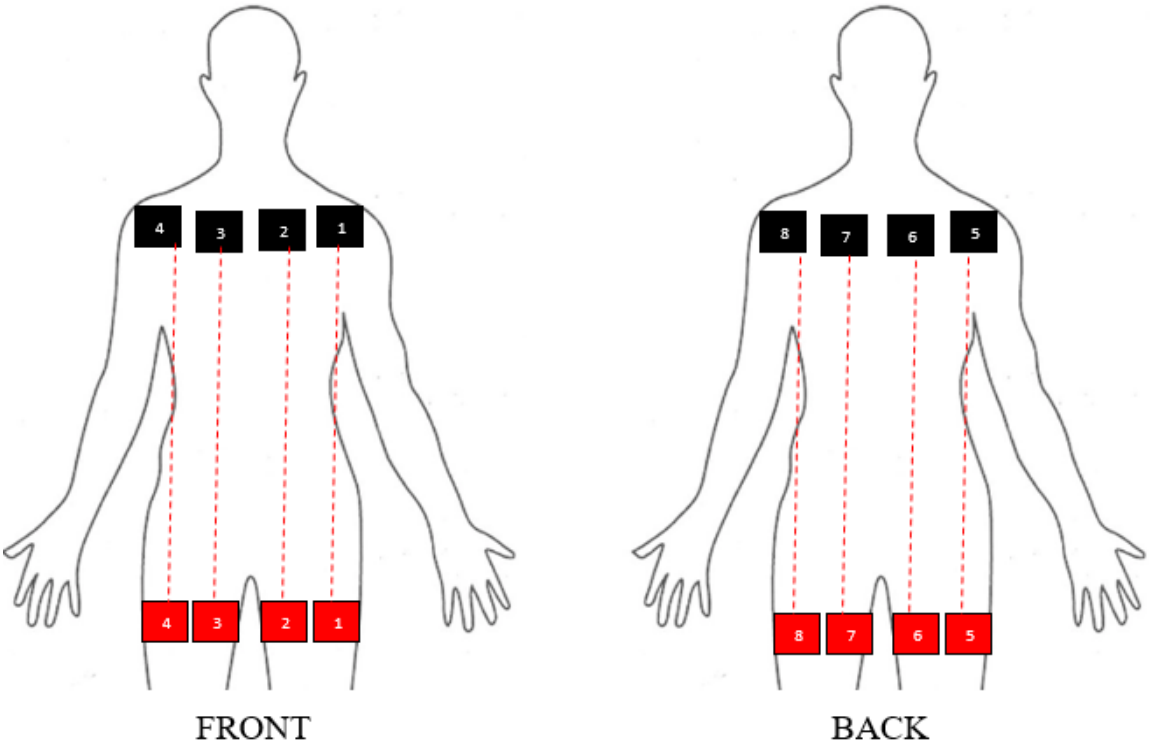


Figure 2: The electrode placement for the torso area measurement can be seen in the figure. The upper electrodes are placed right below the shoulder area and on the chest while the lower electrodes are placed below crotch level.

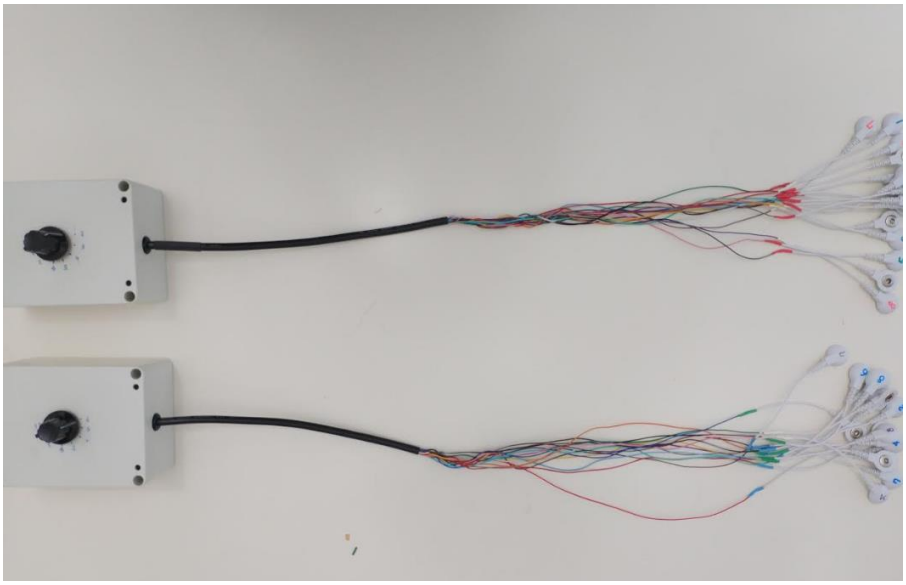


Figure 3: The two multiplexers can be seen in the figure. It consists of 8 electrode wire each with a knob numbered from 1 to 8. Each number represents the connection to the corresponding numbered electrode.

Figure 4: The SFB7 device used to collect the resistance readings can be seen in the figure.

TESTING

Three tests were carried out on a male subject who is right-handed and actively involved in sports requiring the use of the right arm. The subject's torso was measured with no water intake, then again after ingesting 500ml of water each time for a total of 1500ml of water. The subject was placed in a supine position while the measurements were taken. The knob was turned until all the electrode connection between the upper and lower torso was achieved. Each electrode connection was measured for three trials and then the average was calculated.

3. RESULTS

After all measurements were taken, a bar chart was plotted to compare the fluid level symmetry in the electrodes as shown in Figures 7, 10 and 13. A line graph was also plotted to show the fluid level increase for each 500ml of water as shown in Figures 5, 6, 8, 9, 11 and 12. The tables showing the collected data set can be found in Appendix A.

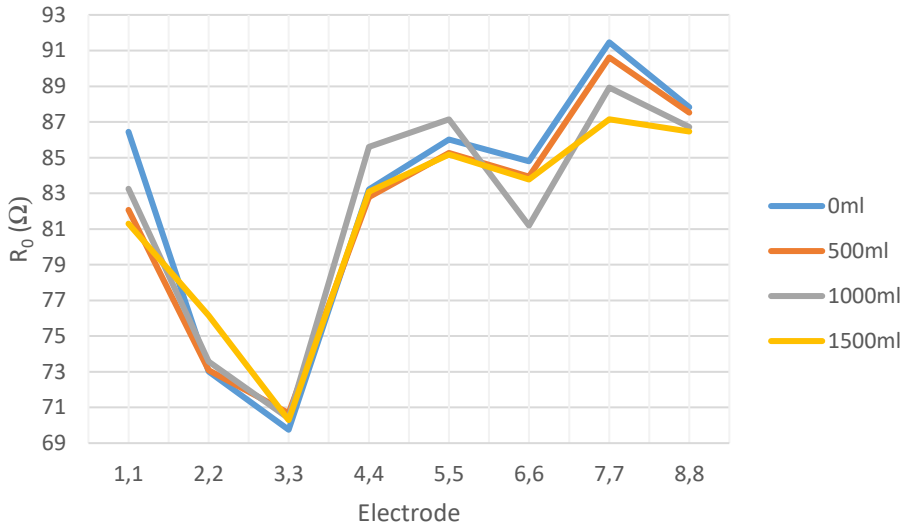


Figure 5: The plotted line graph of the R_0 values versus the electrode placements can be seen in the figure. It shows the increase in fluid level for each 500ml water intake done for the first test.

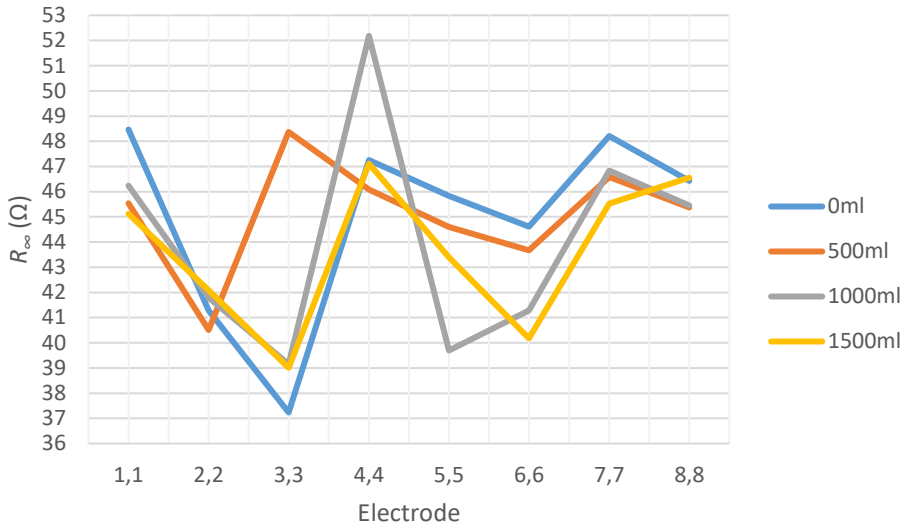


Figure 6: The plotted line graph of the R_∞ values versus the electrode placements can be seen in the figure. It shows the increase in fluid level for each 500ml water intake done for the first test.

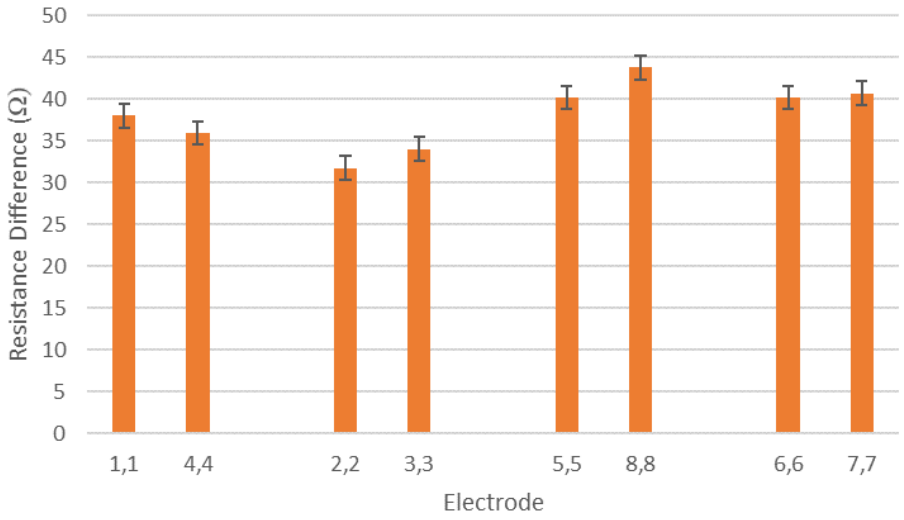


Figure 7: The plotted bar graph of the resistance difference versus the electrode placement can be seen in the figure. It shows the symmetry relationship, in the first test, between electrodes on opposite halves of the subject's torso with no fluid intake.

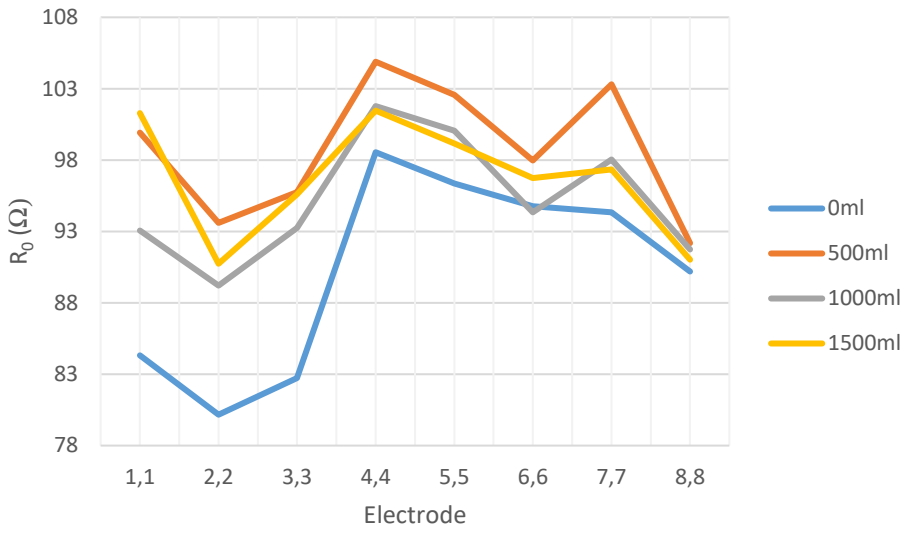


Figure 8: The plotted line graph of the R_0 values versus the electrode placements can be seen in the figure. It shows the increase in fluid level for each 500ml water intake done for the second test.

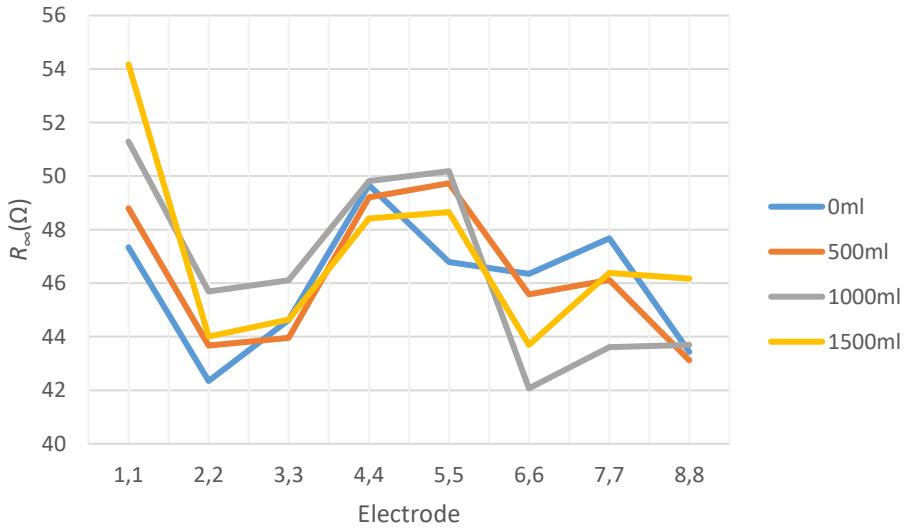


Figure 9: The plotted line graph of the R_∞ values versus the electrode placements can be seen in the figure. It shows the increase in fluid level for each 500ml water intake done for the second test.

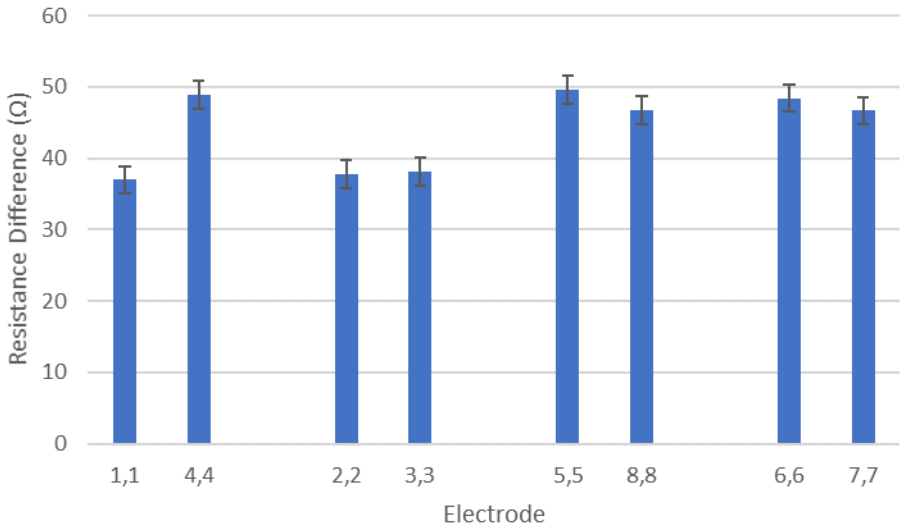


Figure 10: The plotted bar graph of the resistance difference versus the electrode placement can be seen in the figure. It shows the symmetry relationship, in the second test, between electrodes on opposite halves of the subject's torso with no fluid intake.

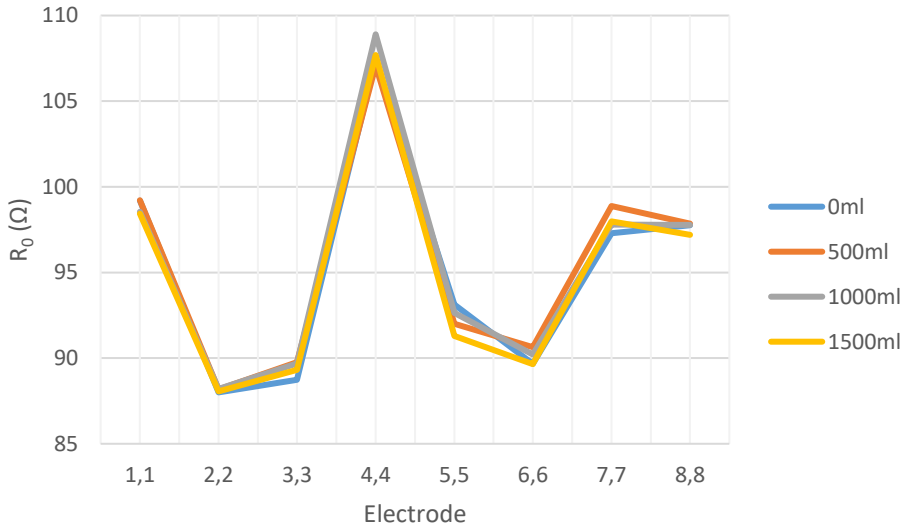


Figure 11: The plotted line graph of the R_0 values versus the electrode placements can be seen in the figure. It shows the increase in fluid level for each 500ml water intake done for the third test.

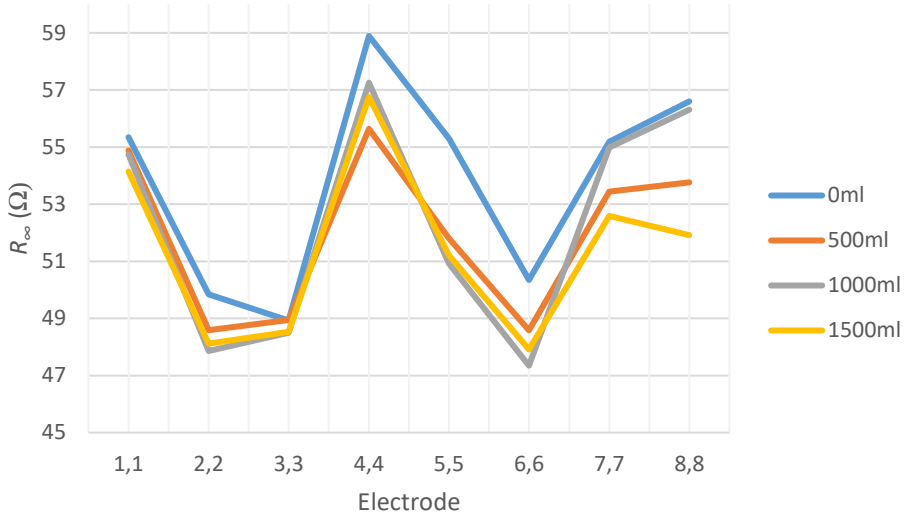


Figure 12: The plotted line graph of the R_∞ values versus the electrode placements can be seen in the figure. It shows the increase in fluid level for each 500ml water intake done for the third test.

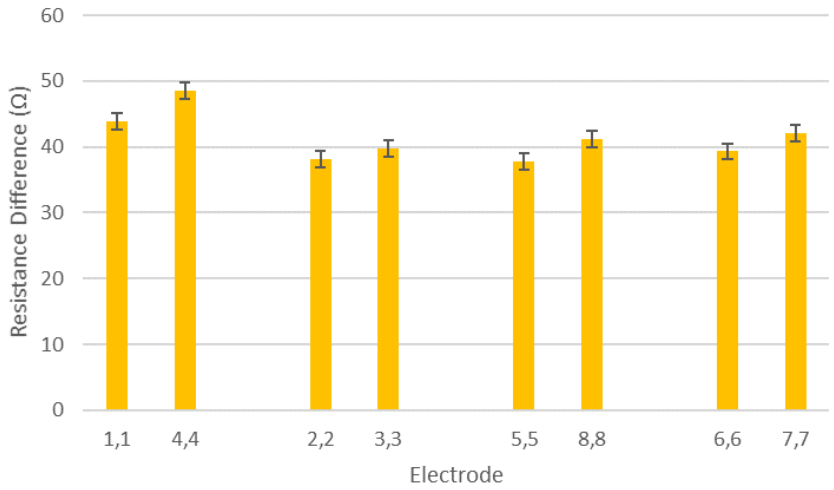


Figure 13: The plotted bar graph of the resistance difference versus the electrode placement can be seen in the figure. It shows the symmetry relationship, in the third test, between electrodes on opposite halves of the subject's torso with no fluid intake.

4. DISCUSSION

The test 1 results showed some inaccuracy and outliers in the graph. A noticeable increase in resistance was observed for the electrodes placed on the back; however, the front electrode measurement posed to be random. In order to verify the data collected, a

second test was carried out while following the same protocol. Test 2 showed a clearer visualization of data and higher accuracies, but the expected results were still not depicted. It was expected that there will be a clear increase in fluid levels shown in the plotted graph as a decrease in resistance values which will prove that the electrode placements chosen was appropriate for measurement, but the plotted graphs did not show this. Test 3 was conducted with greater care to ensure a higher level of accuracy. The R_0 resistance values show no significant change with the increase in fluid intake. The difference can be slightly seen in some electrodes, but the lines appear to be overlapping on other electrodes. The R_0 values represent the resistance in the extracellular fluid and the R_∞ values represent the resistance in the intracellular fluid [27]. In the case of water ingestion, the fluid level changes are expected to mostly affect the extracellular fluid. Similar to the other tests, the difference in resistance values on the back side can be seen more clearly than the front side. Like mentioned earlier, the test subject was in a supine position while the measurements were being taken. Gravity is expected to act on the ingested water; this can be an explanation for the back readings being considerably different from the front. The water flow may also not have been completed at the start time that the measurements were taken (1-1 electrodes) and may have significantly changed towards the end of the testing process (8-8 electrodes).

In all three tests, the impact of the subject being right-handed could be seen from the data analysis. The 4-4 electrode typically showed a much higher resistance value compared to the others. This can also be seen in test 2 and 3 symmetry comparison bar charts. While the other corresponding symmetrical electrode showed similar values, the resistance in the 4-4 electrode was higher than that in the 1-1 electrode. This can be due to the fact that

the test subject is right-handed and active in sports that require greater use of the right hand therefore, the body composition on the right side is expected to be different from the left side.

There were some issues that arose during the testing process. The most crucial one was that to SFB-7 failed to collect readings when some of the tests were ran. It was later discovered that the because the adapter made use of a mechanical switch, after continuous testing, the contact point became dirty. This was preventing a proper connection to be made between the adapter and the SFB-7 device. To resolve this, the contact point was cleaned with a simply cleaning solution. Another factor that may have caused the results to not be as expected is the position of the test subject while measurements were taken as well as the flow path of the water as it moved through the body.

5. CONCLUSION

The analysis derived from the three conducted tests shows that there needs to be more focus put into the front measurements. The three tests correctly showed the difference in resistance between the less and more dominant sides of the subject. This can be seen from the spiked resistance value in the 4-4 electrode. This justifies that the chosen electrode placement has the potential to accurately measure the fluid levels, provided more focused testing are carried out. It did not however, fully reveal the impact made on the front of the torso. Because of this, more studies have to be carried out to justify whether the current chosen electrode placement is suitable for future uses. In the process of doing this, other

electrode method placements can be studied in order to achieve the maximum level of accuracy possible.

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APPENDIX A

Table 1: The test 1 R_0 resistance values of the vertical path electrodes used to plot line graph shown in Figure 5 can be seen in the table.

Electrodes	Resistance (Ω)			
	0ml	500ml	1000ml	1500ml
1,1	86.4513	82.06748	83.24887	81.29585
2,2	73.02226	73.08928	73.57495	76.16032
3,3	69.75111	70.68111	70.39366	70.29261
4,4	83.2147	82.78543	85.60933	83.09035
5,5	86.01739	85.26465	87.15348	85.17527
6,6	84.80169	83.9416	81.18714	83.77577
7,7	91.46304	90.61527	88.92701	87.1486
8,8	87.82929	87.52994	86.70999	86.46593

Table 2: The test 1 R_∞ resistance values of the vertical path electrodes used to plot the line graph shown in Figure 6 can be seen in the table.

Electrodes	Resistance (Ω)			
	0ml	500ml	1000ml	1500ml
1,1	48.46758	45.53406	46.23221	45.12066
2,2	41.28541	40.50922	41.79822	42.08558
3,3	37.23515	48.3703	39.1522	39.00768
4,4	47.24991	46.08259	52.18477	47.11042
5,5	45.82895	44.60332	39.69353	43.39541
6,6	44.60578	43.67188	41.28743	40.17841
7,7	48.20624	46.58278	46.83757	45.52494
8,8	46.42325	45.37739	45.45338	46.55878

Table 3: The test 1 resistance values used to plot the symmetry comparison bar chart shown in Figure 7 can be seen in the table.

Electrodes	Resistance Difference (Ω)
1,1 4,4	37.98371 35.96479
2,2 3,3	31.73685 34.00885
5,5 8,8	40.18844 43.76193
6,6 7,7	40.19591 40.69747

Table 4: The test 2 R_0 resistance values of the vertical path electrodes used to plot the line graph shown in Figure 8 can be seen in the table.

Electrodes	Resistance (Ω)			
	0ml	500ml	1000ml	1500ml
1,1	84.32608	99.91762	93.06393	101.296
2,2	80.16383	93.60558	89.20802	90.73877
3,3	82.72199	95.75039	93.25245	95.59074
4,4	98.54982	104.889	101.7807	101.4644
5,5	96.35973	102.5699	100.0504	99.16293
6,6	94.76581	97.9627	94.35197	96.74631
7,7	94.33336	103.2971	98.02875	97.35434
8,8	90.19538	92.18171	91.73773	91.02817

Table 5: The test 2 R_∞ resistance values of the vertical path electrodes used to plot the line graph shown in Figure 9 can be seen in the table.

Electrodes	Resistance (Ω)			
	0ml	500ml	1000ml	1500ml
1,1	47.33718	48.80114	51.29035	54.17297
2,2	42.34562	43.6749	45.6957	44.00596
3,3	44.62167	43.9597	46.10851	44.6355
4,4	49.66321	49.20716	49.81169	48.41614
5,5	46.78667	49.73437	50.19041	48.65084
6,6	46.35318	45.57852	42.07033	43.69548
7,7	47.66948	46.12357	43.61197	46.37847
8,8	43.43324	43.11773	43.69732	46.16932

Table 6: The test 2 resistance values used to plot the symmetry comparison bar chart shown in Figure 10 can be seen in the table.

Electrodes	Resistance Difference (Ω)
1,1 4,4	36.98889 48.8866
2,2 3,3	37.81821 38.10033
5,5 8,8	49.57306 46.76214
6,6 7,7	48.41264 46.66388

Table 7: The test 3 R_0 resistance values of the vertical path electrodes used to plot the line graph shown in Figure 11 can be seen in the table.

Electrodes	Resistance (Ω)			
	0ml	500ml	1000ml	1500ml
1,1	99.19132	99.21337	98.54083	98.43079
2,2	88.00072	88.17387	88.20268	88.05938
3,3	88.72662	89.75645	89.68382	89.31207
4,4	107.3726	107.0771	108.9023	107.6928
5,5	93.11802	91.99499	92.64319	91.29911
6,6	89.66981	90.63867	90.21196	89.65244
7,7	97.29093	98.88274	97.78791	97.98768
8,8	97.76541	97.8465	97.76732	97.20337

Table 8: The test 3 R_∞ resistance values of the vertical path electrodes used to plot the line graph shown in Figure 12 can be seen in the table.

Electrodes	Resistance (Ω)			
	0ml	500ml	1000ml	1500ml
1,1	55.34201	54.89055	54.7448	54.14021
2,2	49.84673	48.58965	47.85383	48.11696
3,3	48.9255	48.93967	48.49288	48.52556
4,4	58.89327	55.63851	57.255	56.75479
5,5	55.29468	51.80402	50.91884	51.21236
6,6	50.35049	48.58278	47.34367	47.91263
7,7	55.19135	53.44032	54.98753	52.58693
8,8	56.59768	53.75945	56.31164	51.91509

Table 9: The test 3 resistance values used to plot the symmetry comparison bar chart shown in Figure 13 can be seen in the table.

Electrodes	Resistance Difference (Ω)
1,1 4,4	43.84932 48.47933
2,2 3,3	38.15399 39.80112
5,5 8,8	37.82335 41.16773
6,6 7,7	39.31932 42.09957