IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Traitement du Signal
Vol. 41, No. 5, October, 2024, pp. 2603-2613
Journal homepage: http://iieta.org/journals/ts

Bioelectrical Signals Detection of Hyperglycaemia and Hypertension

Auns Q. Al-Neami

Biomedical Engineering Department, College of Engineering, Al-Nahrain University, Baghdad 10072, Iraq

Corresponding Author Email: auns.q.hashim@nahrainuniv.edu.iq

Copyright: ©2024 The author. This article is published by IIETA and is licensed under the CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).

https://doi.org/10.18280/ts.410533

Received: 16 March 2024
Revised: 17 June 2024
Accepted: 10 July 2024
Available online: 31 October 2024

Keywords:
pregnant women's diseases, diabetic mellitus, hyperglycaemia, bioimpedance analysis, gestational diabetes mellitus (GDM)

ABSTRACT

Hypertension and Gestational Diabetes Mellitus (GDM) are critical conditions that can significantly impact both maternal and fetal health during pregnancy. GDM, a form of diabetes first identified during pregnancy, impairs cell glucose utilisation, leading to elevated blood sugar levels. This condition not only jeopardises the pregnancy but also affects the unborn child's well-being. Effective management of GDM, through diet, exercise, and medication when necessary is crucial for maintaining maternal and fetal health and preventing complications during labour. The study examined Iraqi pregnant women's hypertension and GDM rates and development. These circumstances were detected and monitored using bioelectrical impedance analysis. The study sampled 12 pregnant women for blood pressure, glucose, and bioimpedance measurements. The study found that gestational age raised blood pressure and glucose, indicating hypertension and hyperglycemia. Bioimpedance varied with frequency and gestational age. These findings highlight the potential benefits of early screening and intervention for pregnancy-related health issues. An oral glucose tolerance test (OGTT) with a 75g glucose challenge was used between 24 and 28 weeks of gestation. The study included 12 women from Al-Elwea Maternity Hospital, averaging 22.55 ± 5.3 years old. The results showed differences in amniotic fluid index, positive CRP in all patients, and pulse rates between 95-115 beats per minute. All individuals had positive cardiotocography (TOCO) and foetal heart rates of 130-140 beats per minute. Blood pressure ranged from 110/70 to 140/85 mmHg, and blood glucose levels averaged 133-161 mmol/l over four post-OGTT periods. Bioelectrical impedance was 3.805-6.03 ohms, with phase angles of 9.469-15.037 degrees. The study emphasises early detection and treatment of hypertension and GDM in pregnant Iraqi women. Bioelectrical impedance analysis is an innovative way to detect and monitor these disorders. Early screening and treatment can reduce pregnancy problems.

1. INTRODUCTION

Pregnancy abnormalities and complications can demonstrate from mild and annoying disquiet to severe, lethal, complaints, and illness. Sometimes, it can be very problematic for a pregnant to distinguish which disorders are normal and which of them are not [1]. Bioelectrical impedance technique employed today to consider the body arrangement and prominence of hydration. This method signifies a reliable, non-invasive, and genius experimental method that is healthy-looking abided by abnormal one. A bioimpedance with segmental mode extent is beneficial for pregnancy interval, especially in late pregnant state [2]. Besides that, the complications during pregnancy may embrace physical and mental status that affects the health of the mother, the fetus, or both of them [3, 4]. These complications are produced from or can be ended inferior by being pregnant. Many complications are sensitive and effective but not develop; however, when they occur, they may hurt the pregnant woman or her child [5, 6]. Managing these complications and problems requires continuous follow-up, especially during the last weeks of pregnancy.

Therefore, the pregnant must always interact with her physician and prenatal care provider if she has any distress during pregnancy [7, 8]. Figure 1 demonstrates most of the crucial pregnancy risks [9].

An electrical Bioimpedance analysis (BIA), is a method utilised for identifying, diagnosing, and tracking various health conditions in the human body. This technique has been acknowledged for its safety, speed, accuracy, simplicity, and cost-effectiveness [10]. The BIA is a method of measurement that utilises the dielectric and conductive characteristics of human tissues as electrophysiological parameters [11, 12]. The spectroscopic measurement bioimpedance method is required during the measurement of two sets of electrodes this is called a tetra-polar method. One of these electrodes applies the current (I) to the skin of the individual body and the other one of electrode to measures the resultant voltage drop (V) between two terminals on the skin of the pregnant woman area [13-15], as shown in Figure 2. The electrode must be has a specific characteristic such as; relatively of a low impedance compared to both of the impedance of the skin and with the input impedance of the electrical circuit designed for the measurement [16-18]. Transfer of impedance *TZ* verified

based on to Eq. (1).

$$T_Z = \frac{Z_t}{1+Z_t\left[\frac{4Z+Z_y+Z_s}{Z_yZ_s}\right]+2Z\left[\frac{2Z+Z_y+Z_s}{Z_tZ_t}\right]} \quad (1)$$

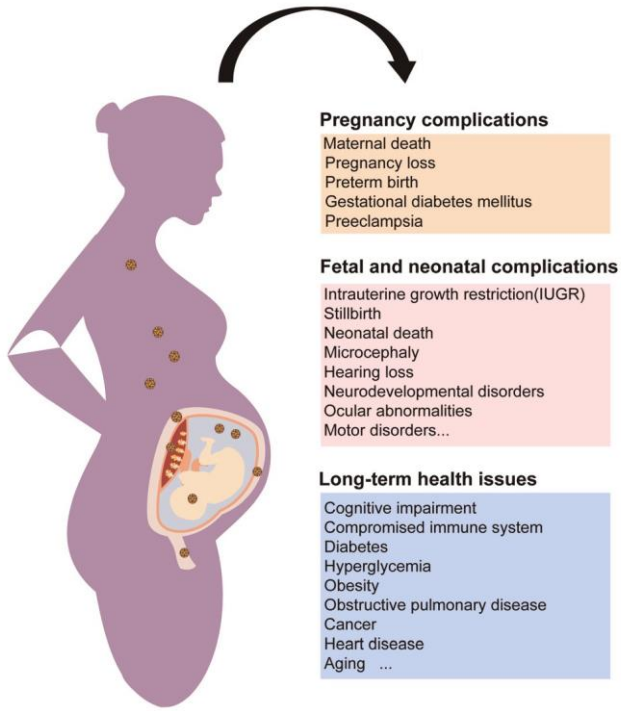


Figure 1. The associated complications influence the pregnant and the fetal during gestational age [9]

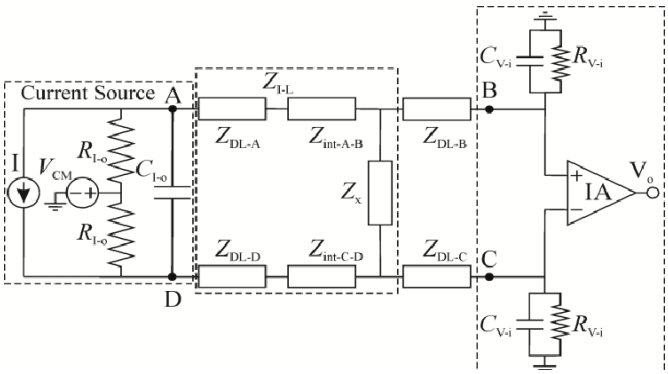


Figure 2. Bioimpedance tetra polar measurement method [19]

The body composition index (BIA) is a commonly used tool for this purpose [4, 5]. According to recent research, BIA can be used to quantify raw bioimpedance factors as resistance, angular phase, and reactance to verification clinical outcomes and health status markers in clinical populations [6, 7]. In order to monitor and investigate various illnesses and conditions, such as death, nutritional procedure, dialysis, diabetes, heart disease, liver fibrosis, and so on, PA has been thoroughly studied as an essential marker [8, 10]. Past research has shown that phospholipid concentration (PPa) is proportional to the mass of the cell membrane, making it a good measure of the quantity of intracellular and extracellular water present in cells as well as the electrical charge that these membranes are capable of retaining [11], according to these studies, there appears to be a strong correlation between PA and cellular action or the metabolic rate of the human body [12, 13]. Several research studies have demonstrated the analytical value of PA in diabetic patients [9, 14]. Body composition has been examined in bioimpedance studies as a probable danger features for diabetes disease [15-17]. In recent times, individuals with diabetes mellitus have been subject to direct analysis of various sensitive bioimpedance parameters, including the PA, resistance, and reactance, at different frequencies [18]. However, to develop more practical applications of Multiple Frequency Bioimpedance Analysis (MF-BIA) and its Predictive Algorithms (PAs) for diagnosing and monitoring diabetes, a more comprehensive understanding is needed [19]. Figure 3 depicts the directed current way within different frequency ranges (from low to high) values, via the pregnant body tissue [20-23].

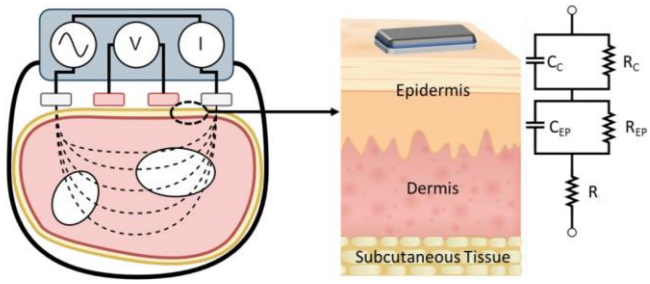


Figure 3. The applied pulse during the time through the tissue [20]

From investigations and studies number of studies and investigations associated with the present study deals with bioimpedance with the abnormal states of pregnant women as demonstrated below: In a retrospective study conducted in Zhang et al. [21] utilised bioelectrical impedance analysis (BIA) to measure maternal of the body composition and predict the danger of the gestational diabetes mellitus (GDM). The system applies data from the Chongqing Health Center for Women and Children's Electronic Medical Record database in China from January 2014 to December 2015, with a sample size of 22,223 women. The study discovered a substantial correlation between the risk of gestational diabetes mellitus (GDM) and factors such as body fat, bone minerals, and body fat percentage. These results offer reference ranges for Chinese women using BIA measures of body fat, bone minerals, and visceral fat throughout pregnancy to assess their risk of gestational diabetes mellitus (GDM). Mumtaz et al. [22] provided an illustration of the disease related with GDM in addition to the present approaches of showing, analysis and managing with the purpose of primary respect and inhibition of difficulties to both the pregnant and foetus. Amarish et al. [23] concentrated on the molecular apparatus intricate in the pathophysiological behavior of GDM and the possible bio-markers, which help for the main analysis of the disorder. The primary analysis of the metabolic syndrome, greatest rather in main trimester of condition, will cause to its actual long-term managing, decreasing foetal growing problems and death laterally with care events for the pregnant. Teh et al. [24] investigated the dangerous of different parameters for the GDM applying for the methods of windowing based on specific references and guidelines. Bassaw et al. [25] provided a review of related critical parameters, and severity of GDM. It also located the advantages of windowing of selected scenes. Based on this overview, we concluded specially in lower countries such as the Caribbean, adoption of a universal windowing with the method of two-step. From the previous

survey most of the researchers studied the effect of GDM and review the method of diagnosis and factors affected on GDM. While the present study included an experimental work which use the electrical bioimpedances technique in pregnant women under different values of frequencies and recorded many parameters associated with the measurement and monitoring the status of patients during the pregnancy. So, this technique is the most non- invasive method for continuous glucose monitoring systems rather than the others which is an invasive method. The relevance, novelty, and contribution of the present study is the implementation of a developed, safe for the human, non-invasive, and radiation-free method for determination, monitoring, and diagnosing the condition of the pregnant women, who they are normal or abnormal, through the use of bioelectrical impedance. It was compared with the traditional methods which are invasive methods.

A Gestational diabetes mellitus (GDM) is a form of diabetes that is first detected during pregnancy period in women that not affected diabetes previously. It can occur in multiple pregnancies for some women and is typically seen in the middle of the pregnancy. The recommended time for doctors to test for GDM is between 24 and 28 weeks in period of pregnancy. GDM is characterised by impaired glucose tolerance during pregnancy and can lead to complications for both the mother and baby, as shown in Figure 4 [26].

Pregnancy and neonatal death rates, as well as healthcare costs, can be impacted by GDM [27]. Various risk factors can influence the occurrence of GDM. Previous studies have indicated that factors as a past of GDM, a family past of diabetes, and polycystic ovary symptoms can associate the infection of GDM in pregnant women [28].

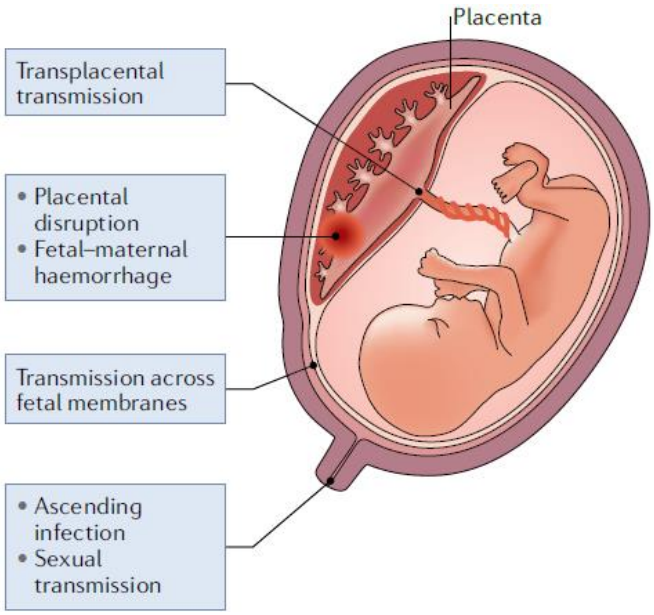


Figure 4. Maternal and neonatal complications [28]

In other words, these factors significantly raised the risk of GDM in pregnant women. Women who are pregnant and do not have these risk factors may nevertheless acquire GDM. Unfortunately, screening strategies for suspected GDM in pregnant women with a low GDM risk are limited. It appears that body structure measurement could be a viable method for detecting suspected GDM. Diabetes is associated with several high-risk characteristics, including body composition [29], pregnancy-induced high blood pressure [30], and preeclampsia. Individual composition, such as waist circumferences, is deemed to be closely correlated to glucose metabolism in individuals [31]. Also, gestational diabetes can be controlled through eating the right nutrition and healthy foods and regular and applied exercise. Sometimes, some pregnant diabetic woman with gestational diabetes needs insulin to overcome this problem. High blood glucose that can't be controlled with the desired criteria for the pregnant woman with gestational diabetes leads to some malfunctions and problems for the mother and the baby, as follow:

An Ultra-Large Baby:

Uncontrolled diabetes during pregnancy results in elevated blood glucose levels in the foetus. In this instance, the infant is overfed; hence, it burns enormously. This results in maternal pain throughout the final months of gestation. Additionally, risks and complications may arise with the delivery of a mother and her extremely large child. As a result, she may require a caesarean section in order to deliver the infant. This issue may result in nerve injury to the infant because of the increased pressure placed on the infant's shoulder throughout the procedure [32].

C-Section (Cesarean Section):

A Caesarean section (C-section) is recommended in cases of existing gestational diabetes mellitus (GDM) to deliver the baby. Women with poorly managed diabetes have a higher likelihood of requiring a C-section for childbirth. Recovery from childbirth is typically longer when a C-section is performed to deliver the baby [33].

High Blood Pressure (Hypertension):

A woman who is pregnant and has high blood pressure will have protein in her urine, and her fingers and toes will swell. A lot of pregnant women have this problem, which needs to be managed and controlled. High blood pressure can hurt both the mother and the baby she is carrying. It could lead to complications, seizures, or a stroke in the woman during the operation, which can damage the brain by clotting blood or bleeding in the brain. Girls and women with diabetes are more likely to have high blood pressure than girls and women without diabetes [34].

Low Blood Glucose (Hypoglycemia):

It is necessary to continuously check blood glucose levels since hypoglycemia is far more harmful than hyperglycemia and can cause death or numerous problems. People with type 1 or type 2 diabetes who use insulin or other drugs for their condition might achieve extremely low blood glucose levels. Without rapid treatment, dangerously low blood glucose levels during pregnancy can be fatal for the mother. So, if pregnant women diligently check their blood glucose levels and promptly treat low blood glucose, they can avoid complications. Babies born to mothers whose diabetes was poorly managed during pregnancy are at increased risk of developing low blood glucose levels. For a few hours following the procedure, the infant's blood sugar levels need to be monitored [35].

Hypertension (High Blood Pressure):

Blood pressure is the pressure exerted by the blood on the walls of the arteries as the heart beats. When this force is too high, it is known as high blood pressure or hypertension. This chronic condition is challenging to control and can pose risks to both the pregnant woman and her fetus. Complications associated with high blood pressure during pregnancy include preeclampsia, placental abruption, and gestational diabetes. Additionally, there is an associated likelihood of birth outcomes such as time of delivery, heavy birth weight, and

infant death. It is crucial to address blood pressure concerns with a healthcare provider prior to pregnancy to ensure appropriate treatment and control. Managing high blood pressure is critical before, during, and after pregnancy [36].

Pregnancy can be associated with various forms of hypertension:

Gestational hypertension is a condition characterised by elevated blood pressure during pregnancy, typically occurring after 20 weeks gestation. It is often asymptomatic and generally resolves within 12 weeks after delivery without causing harm to the mother or baby. However, it does increase the risk of future high blood pressure. In severe cases, it can result in low birth weight or premature birth. There is also a possibility of developing preeclampsia in some women with gestational hypertension.

Chronic hypertension is hypertension that begins before you get pregnant or before your 20th week of time of pregnancy. Although some women may have known they had it before becoming pregnant, it wasn't until their prenatal blood pressure was monitored that they found out. Preeclampsia can also occur in cases of persistent hypertension.

Preeclampsia is a condition characterised by a sudden rise in blood pressure occurring after the 20th week time of pregnancy. Typically, it manifests in final trimester, but in rare instances, symptoms may not emerge until after childbirth, known as postpartum preeclampsia. This condition also involves indications of organ damage, such as the liver or kidney, which can be identified through the presence of protein in the urine and extremely high blood pressure. Preeclampsia poses an important dangerous for both the woman and the child, potentially leading to suffer from side effect and complications or even life-threatening situations as demonstrated in Figure 5 [37-39].

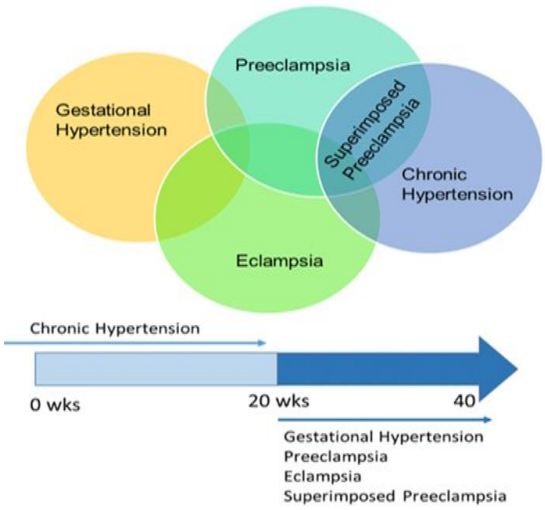


Figure 5. The hypertension types in pregnancy [27]

2. MATERIALS AND METHODS

Methodology:

The present study includes a selection of populations of pregnant women who suffer from gestational diabetes Mellitus and high blood pressure diseases together and estimates their states by measuring the bioimpedance of the pregnant skin to facilitate the diagnosis and observe and follow up the pregnancy condition. Figure 6 illustrates the diagram of the present study.

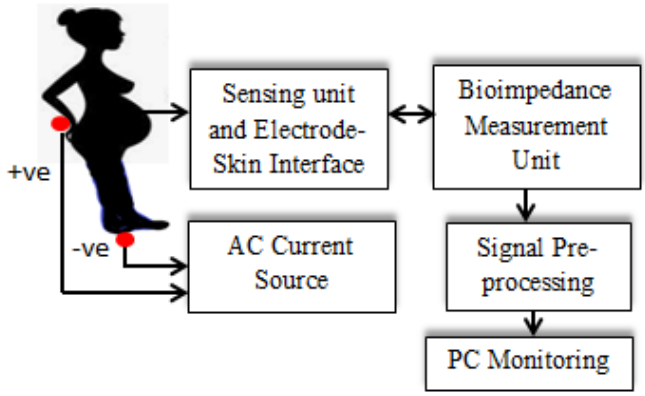


Figure 6. The block diagram of the present system

The Sample Specifications:

The general specifications of the 12 pregnant women are illustrated in the Table 1. The average age was (22.55 ± 5.3years). The average height was (160 ± 3.7 cm). The mean body mass index (BMI) was (25.3± 5.1 kg/m^2). The body weight average was (65.2±11.5) kg.

From Table 1 multiple parameters are measured for investigate the changing of electrical bioimpedances in the abnormal pregnant women. Also the fasting blood glucose and random blood glucose measurement applied to these samples as shown in Table 2 for studying the change in the body behavior and knowledge the effect of the changing in blood glucose on the electrical impedances of the body.

The schematic diagram of the system shown in Figure 7, it's based on tetrapolar measurement type.

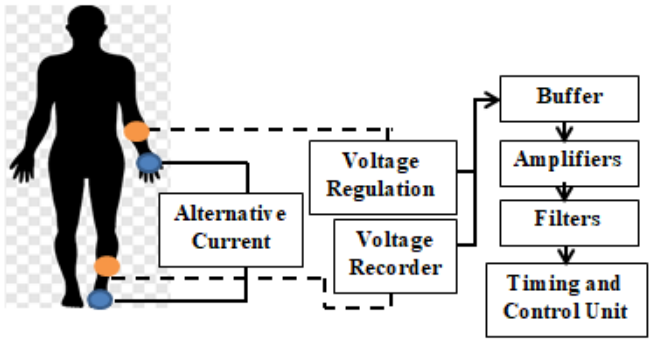


Figure 7. The circuit diagram and the measurement present system

The System Setup:

This includes the bioelectrical impedance measurement by using the LCR meter which measures the resistance (R) and the reactance (X), after that measuring the impedance (Z) and its phase angle (∅) with specific frequencies. The system contains different measurements with different ranges of frequencies as (5, 50, 500, and 5000) KHz. The selected frequencies realised an accuracy of about 0.01%. The applied current to the pregnant tissue ranges between (40-500) µA for the test based on the selected frequency value and the tissue's nature. The values of the bioelectrical impedances with these different frequencies are illustrated in Table 3.

Table 1. Characteristic of the present pregnant women

Case No.	Gestational Age (GA) (Week-Day)	Amniotic Fluid Index (AFI) (cm)	C-Reactive Protein (CRP) mg/l	Blood Pressure (mmHg)	Pulse Rate (PR)	Fetal Heart (FH)	Temperature (°C)	Cardiotocography (TOCO)
Case1	34 w	2	+ve	120/80	100	140	36.1	+ve
Case2	33w 4 d	4	+ve	110/70	96	135	36	+ve
Case3	37 w 2d	2	+ve	140/85	110	135	36.5	+ve
Case4	33 w 5d	4	+ve	135/80	100	130	36.3	+ve
Case5	37 w 1d	2	+ve	120/80	98	130	36	+ve
Case6	29 w 6d	5	+ve	110/80	95	130	36.1	+ve
Case7	30 w 3d	4	+ve	120/75	100	135	36.5	+ve
Case8	36 w	2	+ve	130/80	110	135	36.7	+ve
Case9	36 w 6 d	2	+ve	135/80	115	140	37	+ve
Case10	34 w 2d	2	+ve	130/75	115	135	36.8	+ve
Case11	35 w 3d	2	+ve	120/75	98	130	36.3	+ve
Case12	34 w 8d	2	+ve	130/80	100	135	36.8	+ve

Table 2. Changing in the glucometer system for fasting and random blood measurement

Case No.	Fasting PG Mg/dl (mmol/l)	1-Hour PG Mg/dl (mmol/l)	2- Hour PG Mg/dl (mmol/l)	3-Hour PG Mg/dl (mmol/l)	Mean PG Mg/dl (mmol/l)
Case1	98	180	165	140	146
Case2	110	185	160	145	150
Case3	126	190	170	155	160
Case4	95	170	158	130	138
Case5	128	195	168	150	160
Case6	90	170	155	130	133
Case7	110	192	178	160	160
Case8	133	195	177	140	161
Case9	132	190	181	150	163
Case10	97	160	145	130	133
Case11	95	162	150	128	134
Case12	110	172	158	125	141

Table 3. Bioelectrical impedance values for the pregnant women during different frequencies

Case No.	Bioelectrical Impedance (BIM) (Ω) at Frequency (f)= 5 KHz	Bioelectrical Impedance (BIM) (Ω) at Frequency (f)= 50 KHz	Bioelectrical Impedance (BIM) (Ω) at Frequency (f)=500 KHz	Bioelectrical Impedance (BIM) (Ω) at Frequency (f)=5000 KHz	Bioelectrical Impedance (BIM) Mean Value	Phase Angle (Degree)
Case1	5.60	4.31	3.62	2.50	4.007	14.285
Case2	5.33	4.23	3.53	2.13	3.805	15.037
Case3	6.23	5.91	5.33	4.73	5.55	10.298
Case4	5.94	5.34	4.54	3.98	4.95	11.547
Case5	5.61	4.48	3.22	2.72	4.007	14.285
Case6	5.11	4.10	3.01	3.02	3.855	14.858
Case7	5.41	4.42	3.42	2.55	3.95	14.492
Case8	6.61	5.66	5.31	4.62	5.55	10.298
Case9	6.91	6.01	6.24	4.96	6.03	9.469
Case10	5.32	5.33	5.78	3.53	4.99	11.454
Case11	5.62	5.34	3.76	2.51	4.30	13.315
Case12	6.32	5.63	5.38	4.50	5.45	10.482

The Procedure of the Measurement:

The present study uses the whole body wrist-ankle measurement type during the measurement of the bioimpedance, this includes the following aspects, as in Figure 8:

• The pregnant lies down on the bed in a comfortable position, Figure 8a.

• Entering the pregnant information such as age, height, weight, gestational age, ... etc., on the instrument database to store the information for facilitating follow-up, Figure 8b.

• Preparing the terminals of the bioimpedance measuring system, Figure 8c.

• To apply the surface electrodes, refer to Figure 8d for the desired locations. Two electrodes are used to apply the current (I) and should be putting on the dorsal proximal surfaces to joints of the metacarpal-phalangeal and metatarsal-phalangeal of the right hand and foot, respectively. For voltage reception (V), two electrodes should be placed on the mid line between the flat ends of the right radius and ulna of the wrist and the central line between the medial and near malleoli of the right ankle.

• Adaptation of the electrode-skin interface, Figure 8e.

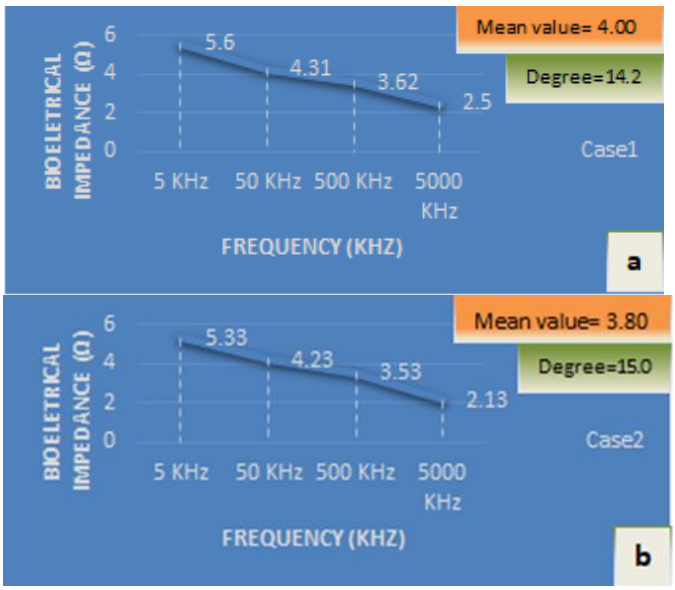
• Determining the electrical impedance by operating the device and extracting the results, Figure 8f.

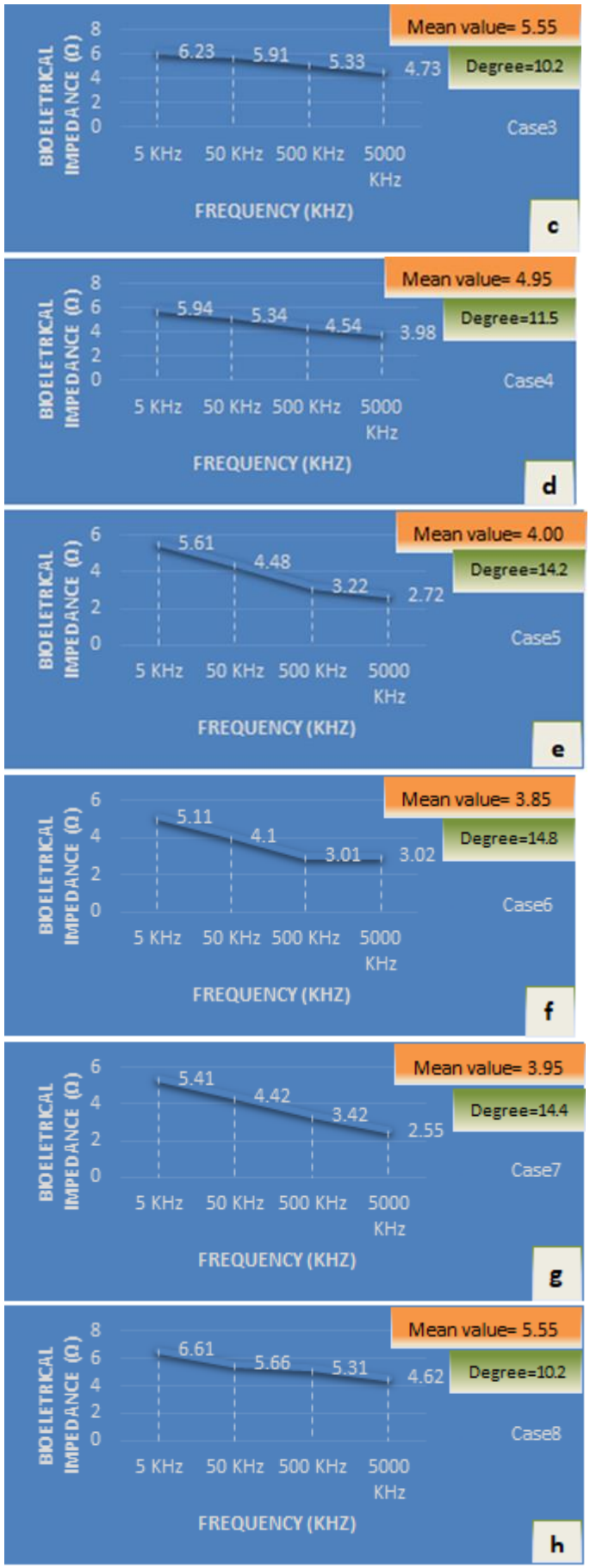
• Providing electrical protection and insulation for safe measurement procedures is done by ensuring that the meter cables must not touch the ground, be pregnant, any metal objects, or twisted near the high voltage sources and equipment.

Figure 8. The procedure of the measurement of the present system

3. RESULTS

The present results include different forms of measurements; first is determining the bioelectrical impedances of volunteers and the relation between these electrical impedance values and the frequency variations for all twelve cases. The increase in frequency produces a decrease in impedance values. As shown in Figure 9, the bioimpedance decreasing with increasing of frequency for all the cases in normal, Hyperglycaemia, and Hypertension.





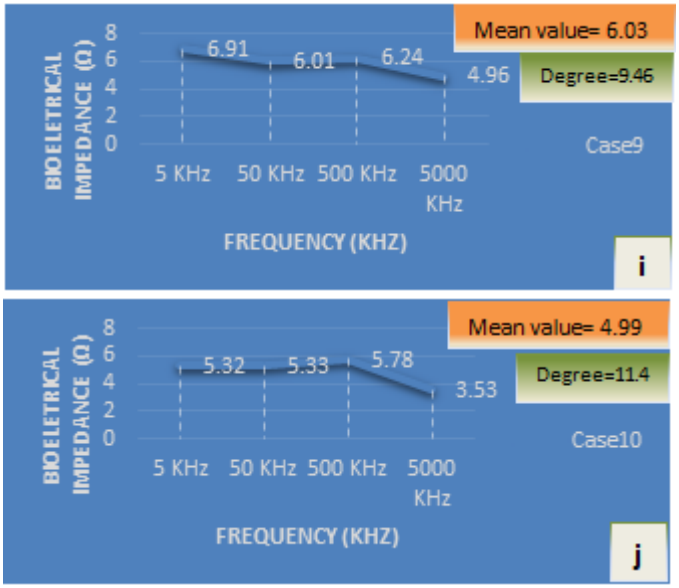


Figure 9. Relation between bioelectrical impedance and frequency responses

Meanwhile, the phase angle values of the present cases increase with increasing frequency. The bioelectrical impedance values were proportional directly to the gestational ages. The mean bioimpedance value of 3.85Ω for 29th week, and mean bioimpedance value of 5.55 Ω for the 37th week. While the phase angle values proportional inversely with the gestational age as shown in the results they are 14.8 and 10.2 degrees for the 29th and 37th gestational ages, respectively.

The results include the determination of Hyperglycaemia, hypertension, and normal pressure of patients demonstrated in Figure 10 a and b show the values of systolic and diastolic responses respectively. The histogram of these values is depicted in Figure 11.

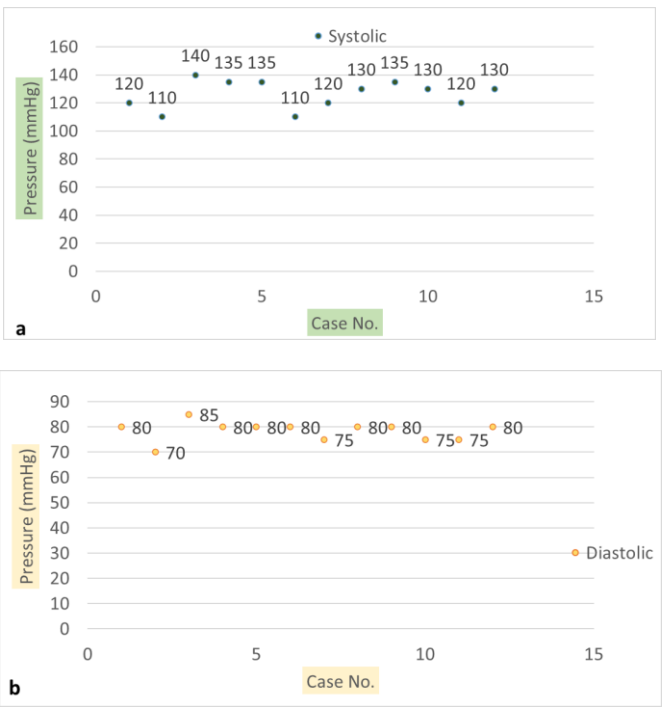


Figure 10. Pressure responses: (a) a systolic (b) a diastolic of the present cases

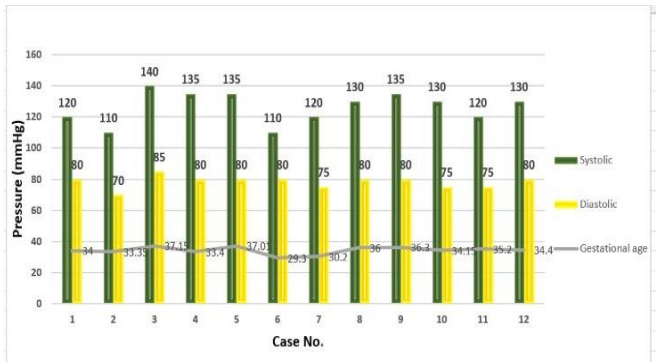
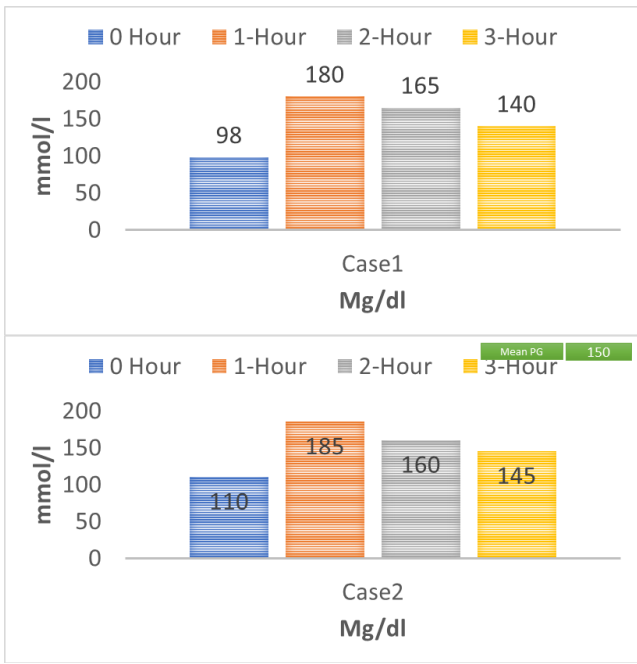


Figure 11. Hypertension and hypotension values of the cases

From the results, the pressure for (29th -33th) week systolic is (110-135) mmHg and the diastolic is (70-80) mmHg, for (34th-35th) the systolic is (120, 130) mmHg; and the diastolic is (75-80) mmHg. The advanced gestational ages of (36th-37th) week the values of these systolic and diastolic pressure are (130-140) mmHg and (80-85) mmHg respectively. We notice that systolic and diastolic pressure for all patients increases with increasing gestational age, as in 29th week lowest diastolic pressure is 110 mmHg, while the highest diastolic pressure is in the 37th week is 140mmHg, as well as the diastolic pressure for these two ages is 70 to 85mmHg respectively. In the increasing gestational ages the heart rate of the mothers and fetal are increased too, the fetal heart rates ranged between (130-140)b/min and the mother's heart rate is (95-115)b/min for all cases. The temperature of the pregnant women is (36-37)°C.

Hyperglycemia was monitored by measuring glucose levels at multiple periods, as shown in Figure 12, for all cases during fasting and after one, two, and three hours. These results indicate an increase in glucose levels after one hour, which gradually decreases after two and three hours. The mean values of the glucose level depended on the woman gestational age. Since; the phase angle value decreases with the progression in gestational age as illustrated in Table 3.



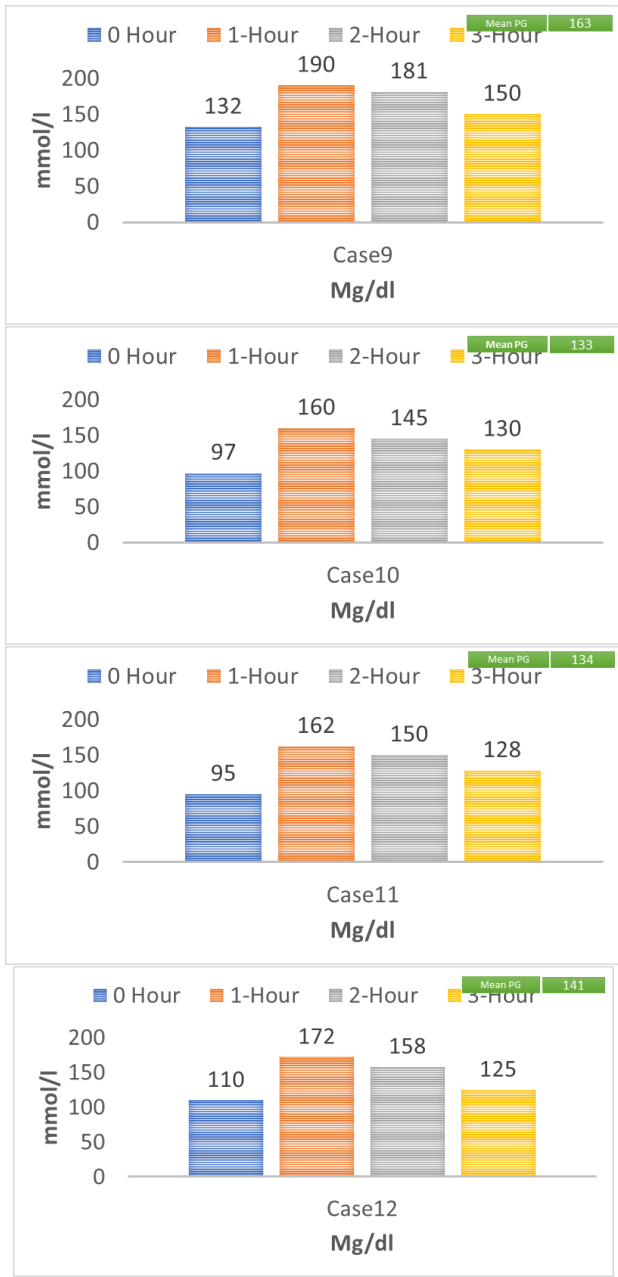


Figure 12. Hyperglycaemia values of the present cases

In the gestational age of approximate (36-37), a high Fasting PG value about (128-133) mmol/l and after one-Hour PG increases to (190-195) mmol/l, and after two-Hour PG, and 3-Hour PG starts to decrease to (181-168) mmol/l and (150) mmol/l respectively, and their mean value is (163-160) mmol/l.

The current results were presented to specialized in this field to diagnose normal and abnormal cases, and these results were used in diagnosis. The selected samples from the pregnant women were checked from healthy, normal, returned samples, who do not affected from continuous diseases, and their ages are similar and others were abnormal samples. The results were compared with the standard readings in the hospital and clinics, and the results were demonstrated to specialist to precision the results. In the future we will apply some forms of correlation analysis to the data.

4. DISCUSSION

Pregnancy abnormalities and complications as

Hyperglycaemia and hypertension can demonstrate from mild to severe, lethal, complaints, and illness. Sometimes it can be very problematic for a pregnant to distinguish which disorders are normal and which of them are not, as shown in Fig.8 the relationship between bioelectrical impedance and frequency responses are is inversely proportional to each other so when the bioelectrical impedance is low the frequency is high and vice versa. For the twelve cases of study the mean values are approximate to each other with average of 3.85Ω for 29th week, and 5.55 Ω for the 37th week which indicate that the bioelectrical impedance increases with the advance pregnancy due to an increase in the size of fetal inside the uterus. While the phase angle values are decrease with advanced pregnancy, as shown in the results 14.8 degree for the 29th and 10.2 degrees for 37th week which is inversely proportional to the gestational ages.

Hyperglycemia, hypertension, and normal pressure of patients are shown in Figure 9 which indicate the systolic and diastolic blood pressure are increase with gestational age as seen in Table 4.

Table 4. Blood pressure change with gestational age

Week	Systolic	Diastolic
29th-33th	(110-135) mmHg	(70-80) mmHg
34th-35th	(120, 130) mmHg	(75-80) mmHg
36th-37th	(130-140) mmHg	(80-85) mmHg

The study results confirm the presence of preeclampsia in pregnant women after 20 weeks of pregnancy, as evidenced by increases in both systolic and diastolic blood pressure for all cases. Hyperglycemia was assessed by measuring glucose levels at various time points (fasting, one hour, two hours, and three hours) for all cases, as shown in Figure 11. Comparing the results to the blood pressure measurements, it is evident that hyperglycemia increases with gestational age, particularly in the one-hour reading. Bioelectric impedances were measured using a bioimpedance analyzer to assess bioimpedance and phase angle. The current results were presented to doctors specialized in this field to diagnose normal and abnormal cases, and these results were used in diagnosis. All the selected samples from the pregnant women were distinguished from healthy, normal, recovered patients who not have from chronic disorders, and the ages of them are the same. The comparison of the results was achieved with the reference readings in the centers, hospitals, laboratories, and clinics, and the results were introduced to specific doctors to verification the results.

In general, as the gestational age increases, the electrical impedance increases. For example, in case 5 and case 6, which are approximately 37 and 29 weeks of gestational age, respectively, the electrical impedances were increasing with high gestational age under constant frequency during measurement.

As you know, the procedure of the bioelectrical impedance includes taking a different range of frequencies, so as the frequency increases, the electrical impedance of the body decreases.

As for the blood glucose level for pregnant women, as the gestational age increases, in the case of fasting, the glucose level is higher, and the measurement is after an hour. The glucose level is also higher with the increase in gestational age, so it requires continuous monitoring of the pregnant woman so that this does not pose a risk to the child.

5. CONCLUSIONS

Monitoring hyperglycemia and hypertension in pregnant women is a critical aspect, particularly for those with a history or genetic predisposition to these conditions. The study, which involved twelve women, confirmed that elevated glucose and blood pressure levels are linked to the progression of pregnancy and pose a high risk in the later stages, potentially impacting the well-being of the fetus and even leading to mortality.

The suggestions for future work include increasing the number and size of samples to apply statistical techniques and make determinations. Also contains using a broad range of frequencies during measurement to obtained rather precision results. The future work deals with other diseases related to pregnant women. Future work also consists of comparing the current results with other additional studies related to the topic of the present work and study the development of specific BIA devices for pregnant women.

ETHICS APPROVAL

Ethical approval was depended on the Ethics Committee of Biomedical Engineering Research in Al-Nahrain University/College of Engineering (Approval number 2-2023).

ACKNOWLEDGMENTS

We would like to thank AL-Nahrain University- College of Engineering for our affiliation to them, and Al-Elwea maternity Hospital in Iraq-Baghdad for providing samples and diseases cases.

REFERENCES

[1] Smith-Whitley, K. (2019). Complications in pregnant women with sickle cell disease. Hematology, the American Society of Hematology Education Program Book, 2019(1): 359-366. https://doi.org/10.1182/hematology.2019000039

[2] Managing complications in pregnancy and childbirth: A guide for midwives and doctors, 2nd ed. Geneva: World Health Organization. https://www.who.int/publications/i/item/9789241565493.

[3] Glover, V. (2020). Prenatal mental health and the effects of stress on the foetus and the child. Should psychiatrists look beyond mental disorders? World Psychiatry, 19(3): 331-332. https://doi.org/10.1002/wps.20777

[4] Sūdžiūtė, K., Murauskienė, G., Jarienė, K., Jaras, A., Minkauskienė, M., Adomaitienė, V., Nedzelskienė, I. (2020). Pre-existing mental health disorders affect pregnancy and neonatal outcomes: A retrospective cohort study. BMC Pregnancy and Childbirth, 20: 1-7. https://doi.org/10.1186/s12884-020-03094-5

[5] Shield, B.C.B. (2022). Racial and ethnic disparities in maternal health. https://www.bcbs.com/news-and-insights/report/racial-and-ethnic-disparities-in-maternal-health.

[6] Kaleelullah, R.A., Garugula, N. (2021). Teratogenic genesis in fetal malformations. Cureus, 13(2): e13149.

https://doi.org/10.7759/cureus.13149
[7] Karrar, S.A., Vadakekut, E.S., Hong, P.L. (2024). Initial Antepartum Care. In StatPearls. https://www.ncbi.nlm.nih.gov/sites/books/NBK570635/.
[8] Artal, R. (2018). Risk factors for complications during pregnancy. In MSD Manual, ed. https://www.msdmanuals.com/professional/gynecology-and-obstetrics/high-risk-pregnancy/risk-factors-for-complications-during-pregnancy.
[9] Yu, W., Hu, X., Cao, B. (2022). Viral infections during pregnancy: The big challenge threatening maternal and fetal health. Maternal-Fetal Medicine, 4(1): 72-86.
[10] Aleixo, G.F., Shachar, S.S., Nyrop, K.A., Muss, H.B., Battaglini, C.L., Williams, G.R. (2020). Bioelectrical impedance analysis for the assessment of sarcopenia in patients with cancer: A systematic review. The Oncologist, 25(2): 170-182. https://doi.org/10.1634/theoncologist.2019-0600
[11] Zhang, Y., Murakami, K., Borra, V.J., Ozen, M.O., Demirci, U., Nakamura, T., Esfandiari, L. (2022). A label-free electrical impedance spectroscopy for detection of clusters of extracellular vesicles based on their unique dielectric properties. Biosensors, 12(2): 104. https://doi.org/10.3390/bios12020104
[12] Ullah, H., Wahab, M.A., Will, G., Karim, M.R., Pan, T., Gao, M., Lai, D., Lin, Y., Miraz, M.H. (2022). Recent advances in stretchable and wearable capacitive electrophysiological sensors for long-term health monitoring. Biosensors, 12(8): 630. https://doi.org/10.3390/bios12080630
[13] Amini, M., Hisdal, J., Kalvøy, H. (2018). Applications of bioimpedance measurement techniques in tissue engineering. Journal of Electrical Bioimpedance, 9(1): 142-158. https://doi.org/10.2478/joeb-2018-0019
[14] Khalil, S.F., Mohktar, M.S., Ibrahim, F. (2014). The theory and fundamentals of bioimpedance analysis in clinical status monitoring and diagnosis of diseases. Sensors, 14(6): 10895-10928. https://doi.org/10.3390/s140610895
[15] Valent, A.M., Barbour, L.A. (2021). Management of women with polycystic ovary syndrome during pregnancy. Endocrinology and Metabolism Clinics, 50(1): 57-69. https://doi.org/10.1016/j.ecl.2020.10.005
[16] Oliveira, C.C., da Silva, J.M., Trindade, I.G., Martins, F. (2014). Characterization of the electrode-skin impedance of textile electrodes. In Design of Circuits and Integrated Systems, pp. 1-6. https://doi.org/10.1109/DCIS.2014.7035526
[17] Tsui, E.Y.A. (2020). A guide of tetrapolar bioimpedance sensor measurement for healthcare application. Imperial College London.
[18] Areny, R.P. (2018). Tetrapolar bioimpedance measurements compared to four-wire resistance measurements. Journal of Electrical Bioimpedance, 9(1): 1-2. https://doi.org/10.2478/joeb-2018-0001
[19] Simini, F., Bertemes-Filho, P. (2018). Bioimpedance in Biomedical Applications and Research (p. 279). New York: Springer. https://doi.org/10.1007/978-3-319-74388-2
[20] Abasi, S., Aggas, J.R., Garayar-Leyva, G.G., Walther, B.K., Guiseppi-Elie, A. (2022). Bioelectrical impedance spectroscopy for monitoring mammalian cells and tissues under different frequency domains: A review. ACS Measurement Science Au, 2(6): 495-516. https://doi.org/10.1021/acsmeasuresciau.2c00033
[21] Zhang, R.Y., Wang, L., Zhou, W., Zhong, Q.M., Tong, C., Zhang, T., Han, T.L., Wang, L.R., Fan, X., Zhao, Y., Ran, R.T., Xia, Y.Y., Qi, H.B., Zhang, H., Norris, T., Baker, P.N., Saffery, R. (2022). Measuring maternal body composition by biomedical impedance can predict risk for gestational diabetes mellitus: A retrospective study among 22,223 women. The Journal of Maternal-Fetal & Neonatal Medicine, 35(14): 2695-2702. https://doi.org/10.1080/14767058.2020.1797666
[22] Mumtaz M. (2000). Gestational diabetes mellitus. Malaysian Journal of Medical Sciences, 7(1): 4-9.
[23] Sharma, A.K., Singh, S., Singh, H., Mahajan, D., Kolli, P., Mandadapu, G., et al. (2022). Deep insight of the pathophysiology of gestational diabetes mellitus. Cells, 11(17): 2672. https://doi.org/10.3390/cells11172672
[24] Teh, W.T., Teede, H.J., Paul, E., Harrison, C.L., Wallace, E.M., Allan, C. (2011). Risk factors for gestational diabetes mellitus: Implications for the application of screening guidelines. Australian and New Zealand Journal of Obstetrics and Gynaecology, 51(1): 26-30. https://doi.org/10.1111/j.1479-828X.2011.01292.x
[25] Bassaw, B., Horace M., Fletcher, Carole A., Rattray, Garth M., Vrunda S., Sarisha S., Adesh S., Javed C., Screening for gestational diabetes mellitus: A Caribbean perspective. Journal of Obstetrics and Gynaecology, 38(8): 1035-1038. https://doi.org/10.1080/01443615.2018.1467389
[26] Saleh, Z.S., Al-Neami, A.Q., Raad, H.K. (2021). Smart monitoring pad for prediction of pressure ulcers with an automatically activated integrated electro-therapy system. Designs, 5(3): 47. https://doi.org/10.3390/designs5030047
[27] Shan, D., Qian, M., Ji, Y., Jiang, X., Xu, J., Chen, K. (2016). The change of electronic transport behaviors by P and B doping in nano-crystalline silicon films with very high conductivities. Nanomaterials, 6(12): 233. https://doi.org/10.3390/nano6120233
[28] Megli, C.J., Coyne, C.B. (2022). Infections at the maternal–fetal interface: An overview of pathogenesis and defence. Nature Reviews Microbiology, 20(2): 67-82.
[29] Abd-ul-Amir, D.Q., Hashim, A.Q., Ameer, A.H. (2019). Design and implement an exoskeleton arm for reinforcement the human muscles after stroke. Al-Nahrain Journal for Engineering Sciences, 22(4): 252-258. http://doi.org/10.29194/NJES.22040252
[30] Jones-Muhammad, M., Warrington, J.P. (2019). Cerebral blood flow regulation in pregnancy, hypertension, and hypertensive disorders of pregnancy. Brain Sciences, 9(9): 224. https://doi.org/10.3390/brainsci9090224
[31] Alneami, A.Q., Khalil, E.G., Mohsien, R.A., Albeldawi, A.F. (2018). Effect of electrical current stimulation on pseudomonas aeruginosa growth. In Journal of Physics: Conference Series, 1003(1): 012112. https://doi.org/10.1088/1742-6596/1003/1/012112
[32] Rowan, J.A., Rush, E.C., Obolonkin, V., Battin, M., Wouldes, T., Hague, W.M. (2011). Metformin in gestational diabetes: The offspring follow-up (MiG TOFU) body composition at 2 years of age. Diabetes Care, 34(10): 2279-2284. https://doi.org/10.2337/dc11-0660

[33] Bachache, L.N., Hasan, J.A., Al-Neam, A.Q. (2021). A review: Non invasive sensing system for detection glucose level. In Journal of Physics: Conference Series, 1963(1): 012125. https://doi.org/10.1088/1742-6596/1963/1/012125
[34] Kintiraki, E., Papakatsika, S., Kotronis, G., Goulis, D.G., Kotsis, V. (2015). Pregnancy-induced hypertension. Hormones, 14(2): 211-223. https://doi.org/10.14310/horm.2002.1582
[35] Hasan, J.A., Bachache, L.N., Al-Neami, A.Q. (2021). Noninvasive glucose sensing system based on modified SPO2 sensor. In AIP Conference Proceedings, 2372(1): 030007. https://doi.org/10.1063/5.0065363
[36] Bachache, L.N., Hasan, J.A., Al-Neami, A.Q. (2021). Acousto-optic design to measure glucose level for diabetic patients non-invasively. In Journal of Physics: Conference Series, 1818(1): 012147. https://doi.org/10.1088/1742-6596/1818/1/012147
[37] Nayak, V.K.R., Raghurama Nayak, K., Vidyasagar, S., Kamath, A. (2018). Body composition analysis, anthropometric indices and lipid profile markers as predictors for prediabetes. PloS One, 13(8): e0200775. https://doi.org/10.1371/journal.pone.0200775
[38] Bachache, L.N., Al-Neami, A.Q., Hasan, J.A. (2021). Noninvasive acousto-optic glucose sensing system for diabetic COVID-19 patients. Journal of Engineering Science and Technology, 72-81.
[39] Bachache, L.N., Al-Neami, A.Q., Hasan, J.A. (2022). Error grid analysis evaluation of noninvasive blood glucose monitoring system of diabetic Covid-19 patients. International Journal of Nonlinear Analysis and Applications, 13(1): 3697-3706. http://doi.org/10.22075/ijnaa.2022.6147