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Design and Application of an Electric Appliance for Measuring the Systolic and Diastolic Pressure

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ABSTRACT

Blood pressure is one of the factors that can reflect human health and indicate any abnormalities of the cardiovascular system in the body. The balance between the contraction and relaxation phases refers to the stability of the system and determines a person's blood pressure status, where cardiac pumping supplies all tissues and organs with oxygenated blood. The heart cycle starts during its down halls (ventricles) is contracted. This effort causes blood to the lungs and all the body, this represented as systole. While during the ventricles fill with blood from the up halls of the heart (atria), this represented the diastole. This study aimed to design and implement a cost-effective system for determining the electrical activity of contraction and relaxation in a group of volunteers with different body specifications and artery sites and sizes. The proposed system can be used in educational and clinical training settings in developing countries where cost of commercial equipment and apparatus is a major obstacle. The volunteers were divided into four groups based on their ages as follows: 40-50, 30-40, 20-30, and 10-20 years old. Our proposed system consisted of sensors, processing unit, control unit, and display unit. The results of the study indicated clear changes in the contraction and relaxation pressures for the different groups according to certain criteria such as age, weight, gender, height, body mass index, chronic disease and pathological state, and medication. The average values of blood pressure for contraction and relaxation differed. On the basis of types of arteries, this study dealt with three types: brachial, radial, and posterior tibial arteries. The pressure from the brachial artery of the left arm was higher than that of the right arm. In the radial and posterior arteries, the results were approximately the same for all the age ranges. In abnormal cases such as diabetes mellitus, the pressure was higher than normal; however, the pressure was not affected for the asthma case. The temperature measurements referred to the increase in blood pressure during elevations in the body temperature.

1. INTRODUCTION

Measuring blood pressure is some of the basic factors for the diagnosis of many diseases. Controlling blood pressure prevents many dangerous diseases such as strokes, heart attacks, eye diseases, etc.

In many developing countries, the deployment of educational and training equipment can be a huge challenge which may impede the learning journey of students and trainees due to unaffordability reasons.

The proposed system is characterized by its ability to measure blood pressure through many different areas and arteries, such as Brachial Artery, Radial Artery, and Posterior Tibial Artery. The system is also characterized by being small in size and ease of use; and it can be used as an educational device in biomedical engineering laboratories to view its parts and work on it for its ease of opening and use, in addition to using it for clinical training purposes. Also, the present system is convenient for use on the body and comfortable to the patient. It is also easy to maintain in the event of malfunctions because it is built in a modular fashion using inexpensive and widely available electronic components. Furthermore, the quantity of blood pressure of the present system is stable at different temperatures. Finally, the accuracy of present system is high by comparing its results with standard, commercially available systems.

The proposed system can be used in educational and clinical training settings in developing countries where cost of commercial equipment and apparatus is a major obstacle.

2. BACKGROUND

In many people, the imbalance in the electrical activity of the contraction and relaxation of the cardiac muscle causes increased blood pressure, which could be caused by excessive tension, nervousness, or psychological distress [1, 2]. This silent killer may cause a silent death, because people who are exposed to high blood pressure do not suffer from any symptoms [3, 4]. Uncontrolled high blood pressure increases the risk to different problems and may lead to complications, and dangerous conditions, for example: heart failure, stroke, kidney damage, aneurysm, and heart attack [5, 6]. The cardiac cycle is the stage of cardiac effort during the progression of pumping blood between two pulses [7]. The cardiac phase defines the pass of blood into the heart chambers and it's carrying in it, in addition to its leaving from the heart and the accompanying functional changes [8]. The length of time that a heart cycle takes be determined by the rate of the heart per minute, as the heart phase takings a minute distributed by the heart beats number per minute [9, 10]. The cardiac phase contains two main modes of the heart activity, namely, contraction (systolic) and relaxation (diastolic) cycles, for atria and ventricles together [11, 12]. The cycle of contraction can be separated into two amounts: atrial and ventricular contraction [13, 14], as illustrated in Figure 1.

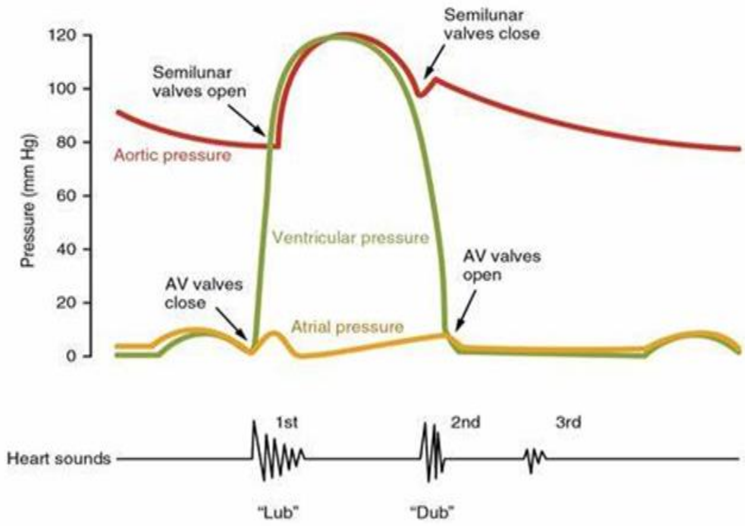

Figure 1. Two complete contraction (systolic) and relaxation (diastolic) processes [15]

It is well known that the heartbeat is caused by the heart muscles relaxation and contraction; the relaxation period is called "relax," whereas the period of contraction is called "activity" [16, 17]. In relaxation, the heart chambers are filled with blood and pressure decreases; in contraction, the blood is pumped from the heart and from the large blood vessels and goes to all organs and tissues [18, 19]. Therefore, for blood to be pumped to all parts of the body, the heart must contract and then relax in a process called the cardiac cycle. This cycle begins when the two atria contract, which pump the blood into the ventricles. The ventricles also contract, allowing the blood to exit from the heart [20, 21]. Electricity is generated due to a change in the concentrations of sodium and potassium inside and outside the cell due to the presence of gates in the cell wall that open and close by a system that allows the generation of electricity necessary to move from one cell to another until the heart muscles contract [22, 23]. However, any error in one of these stages will lead to an electrical imbalance, as shown in Figure 2 [24, 25].

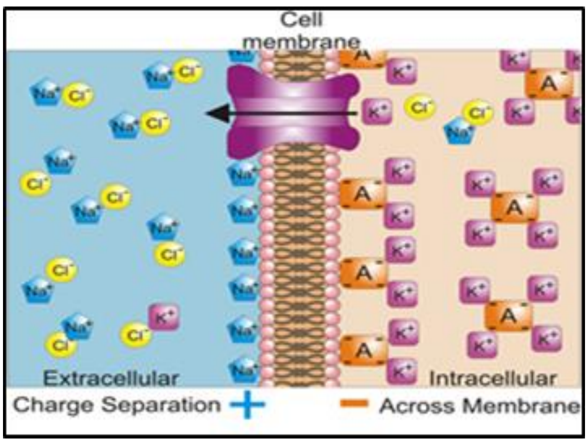

Figure 2. Ions concentration gradients [26]

To determine the electrical activity and convert the chemical reactions of the cells to an electrical potential via Eq. (1), the Nernst equation is expressed as [22, 23]:

$$E = E^{o} - \left(\frac{RT}{nF}\right) ln\, Qc \tag{1}$$

where,

E = potential of cell (V) in particular environments;

E^o = potential of cell at standard status environments;

R = ideal gas constant = 8.314 J/mol·K;

T = temperature (Kelvin), which is commonly 25℃ (298 K);

n = moles of electrons number which transported in the balanced equation;

F = the charge of a mole of electrons (Faraday's constant) = 95,484.56 C·mol^{-1};

$LnQc$ = the normal log of the response quotient at the instant in time.

In electro-chemistry, the Nernst formula is a thermo-chemical thermo-dynamical association that allows the determination of the decreasing electrical response (half cell potential or full cell potential response) from the reference potential of the electrode, temperature, the electron number intricate in the response, and activity as a concentration of the metal suffering from decreasing and increasing [23].

When measuring blood pressure, two values are always displayed, namely, contraction and relaxation values. The standard normal values are 120-80 mmHg as in Table 1 [24, 25] but this range does not apply to females and children because their blood pressure is less than the abovementioned range [26, 27]. For diabetics and people with kidney disease, high blood pressure is likely [28, 29].

The polarization of the cell is a vital phase in the movement, enlargement, and association cell of eukaryotic, in single and multi-cell stages together. Investigation in cell mechanisms that provide increase to the cell polarization, and association of polarization within a cell has directed to a developed theory in cell biology cellular science. In this study, we related with some of the experimental and theoretical features of this branch, in addition to certain stimulating reactions and chemical interaction for generation the electricity and giving the desired responses.

Table 1. Standard normal values of blood pressure

Blood Pressure Type	Contraction (Systolic) mmHg(High)	Relaxation (Diastolic) mmHg(Low)
Normal	Less than 120	Less than 80
Prehypertension	120-139	80-89
High Blood Pressure (Level 1)	140-169	90-99
High Blood Pressure (Level 2)	160 or higher	100 or higher

The source of electricity during the contraction and relaxation phases consists of two electrical plants: main and backup. The main, which generates electric current in the atrial node, is placed in the heart right atrium; it is measured the central source of electricity in the heart [30, 31], as the heart muscle moves and distribute blood to many portions of the body. The backup is positioned at the end of the right atrium, and it passing the electrical current to the heart over electrical paths called "the right and left electrical bundles" [32, 33]. The right atrium wall of the heart, which consists of a group of cells that form the sinus node, can produce an aortic electrical stimulus that travels through the heart and through the electrical conduction system, which causes it to contract (Figure 3).

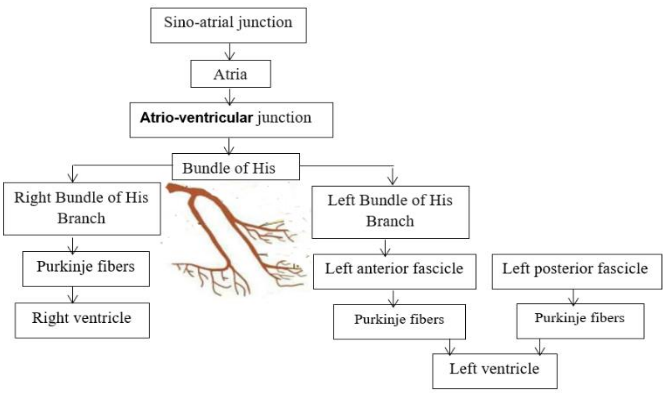

Figure 3. Electrical conduction system of the heart

The sinus node cells start functional voltage differences by passing through the heart, influencing and contracting it. This is caused by the movement of ions, that is, atoms charged through the cell membrane [34, 35]. The initial contraction of the heart is produced from the atria depolarization atria. Arterial depolarization spreads from the Sino atrial node (SA node is a group of cardiac cells specialized in delivering the stimulating signal between the atrium and ventricle of the heart, and it is part of the cardiac conduction system) toward another node known as the atrioventricular node (AV node is also a group of cardiac cells specialized in conducting the stimulation emission between the atrium and ventricle of the heart. It is part of the cardiac conduction apparatus) and occurs in the right atrium to the left one. The period after that is the electrical stimulated pulse which required traveling from the sinus node to the AV node. Fast depolarization of the right ventricle and left ventricle then arises. Meanwhile, relaxation phase represents repolarization of ventricles after total depolarization [36, 37]. There are some related investigations and studies associated with the present system as follow: Hoseinzadeh et al. [38] constructed a designed Lab View for analyzing a cardiovascular health monitoring disorders based on measuring the high frequency sampling of blood pressure values; Feng et al. [39] included electronic system design for testing the pressure of the blood. Sharman et al. [40] measured the variation and oscillation in the human pressure of the blood automatically. This can be as the indirect quantity technique, in addition to automated blood pressure approach which was applied in the groundbreaking epidemiological and medical prosecutions that revealed the status of great blood pressure as a cardiovascular health monitoring disorders hazard aspect, also the assessment of antihypertensive management to decrease cardiovascular health, actions and death.

The current system has some specifications and features that make it different from other similar appliances; since it has an innovative and simplified design, small in size, easy to use, maintainable and repair when malfunctions occur, its results are accurate and highly reliable, it has a low cost and high reliability, and portable that can be carried to various places. The system represents an educational and clinical system which was used in developing the field of biomedical instrumentation.

3 MATERIAL AND METHODS

This study included the implementation the design of a biomedical measuring system for blood pressure and the contraction and relaxation of the heart for different volunteers classified to different specifications. It also included a comparison between the contraction and relaxation phases for these various persons. During the present measurement, many factors were found to be associated with the sample of people examined: nature of the person, ages (most people with the disease are middle-aged or older advanced), weight, gender, height, body temperature, body mass index (BMI), pathological state, genetic nature, smoking, overweight status, unhealthy nutrition, and stress.

3.1 Hardware design

The present system design included construction of an electrical circuit diagram to measure the heart phases and blood pressure. Figure 4 depicts the system block diagram.

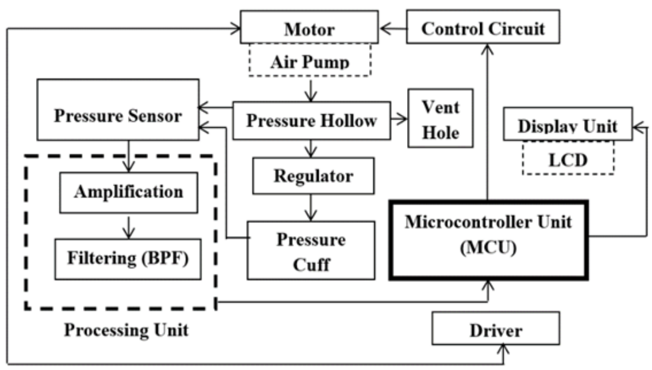

Figure 4. Block diagram of present system for measuring contraction and relaxation of the heart

The schematic electrical circuit diagram of the present design used very simple, available, and reliable components and devices in the biomedical engineering laboratory, all these components have been calibrated in the measurement. The output measured and observed values are validated with traditional blood pressure devices. The layout circuits of the proposed design are shown in Figures 5 and 6, respectively, which were used in the blood pressure measurement.

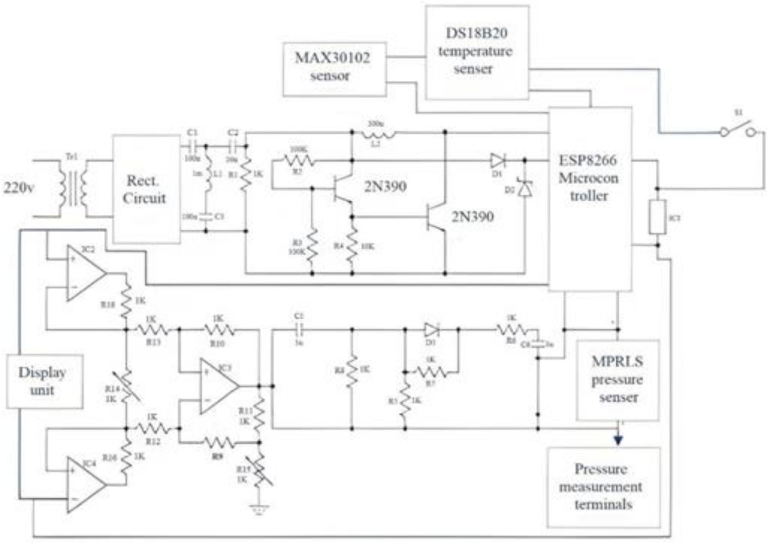

Figure 5. Schematic diagram of the electronic circuit used in the blood pressure measurement

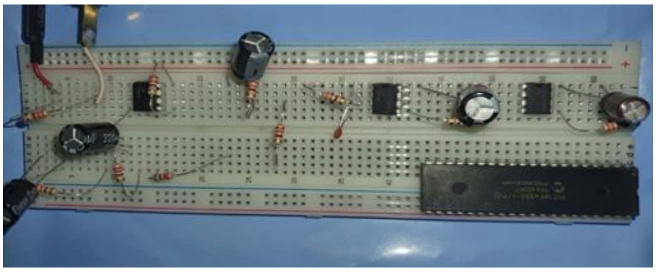

Figure 6. Layout of the proposed electronic circuit used in the blood pressure measurement

The hardware system design consisted of the following aspects:

- The ESP8266 microcontroller: it's powerful module and cost-effective with combined Wi-Fi MCU, which is used widely for IoT applications. It is useful for applications in biomedical engineering because it can be operated under a wide temperature range. It also features an integrated chip and a weak exterior isolated component count. The chip provides reliability, solidity, and strength. ESP8266EX is combined with a 32-bit Tensilica process, typical digital marginal interfaces, antenna alterations, RF specification, weak noise receiver amplifier, some filters, power amplifier, and power organization modules.
- DS18B20 digital temperature sensor: This sensor has a practical temperature range of 55℃-125℃ (-67°F to +257°F) and changeable resolution of 9-12 bit. It requires only one interface wire and one digital pin for communication. It stores a 64-bit chip ID, and multiple sensors can share one pin. Sensor accuracy has a range of ±0.5℃, from -10℃ to +85℃. The power/data usable is from 3.0 V to 5.5 V. Finally, the query time value is less than 750 ms.
- MPRLS pressure sensor: This sensor uses an I2C protocol, and it can be easily integrated with any microcontroller. It contains silicone gel, which covers the gauge of the pressure sensor with a 24-bit ADC pre-calibrated module.
- Voltage Booster MT3608 Boost Voltage (DC-DC Adjustable Step-up Boost Converter MT3608) This booster regulates and sets up the level of voltage from input voltage between 3 and 24 V to an output voltage between 5 and 28 V with an equilibrium frequency of 1.4 MHz and small current. It is designed for small usage and low power. Small and cheap elements such as capacitors and coils can be used to reduce the size of the chip.

The pressure sensor data is converted into corresponding blood pressure readings based on the resistive principles, since the present sensors is a resistive sensor that convert the electrical response into corresponding pressure value according to an appropriate equations and software program design for these components and microcontroller. Figure 7 demonstrates the proposed system block diagram.

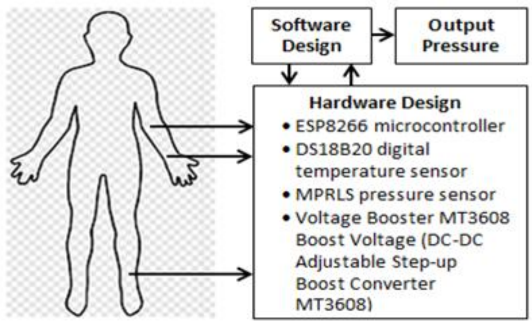

Figure 7. The hardware and software design

3.2 Testing protocol and procedure of the measurement

This section illustrates the testing protocol and the procedure of the measurement during the test and the selection of the ideal location according to the anatomical structure of the human body to give an accurate and optimal measuring value of the blood pressure results. This differed from location to other. The test includes selection of appropriate arteries to the locations of the measurement for giving the desired readings as shown in Figure 8, for the upper limb, two arteries are used for measurements, namely, the brachial artery (♯1) and ulnar artery (♯2). Their locations are shown in Figure 8(a). measurement in the lower limb includes the radial artery (♯3), as shown in Figure 8(b).

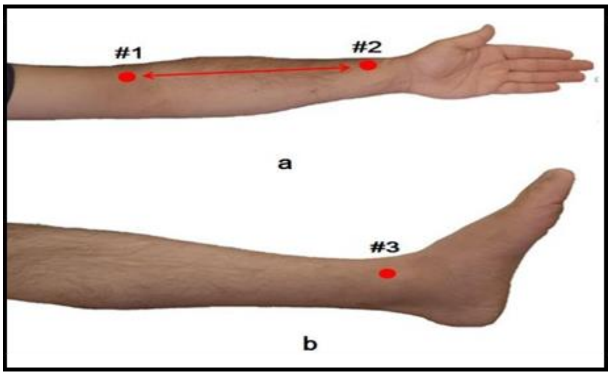

Figure 8. Locations of the measurements: (a) measurement in the upper limb and (b) measurement in the lower limb

The location of the Numerous Iraqi volunteers participated in the present pressure measurements. The average values of their specifications and properties as: gender, age, weight, height, and body mass index BMI are illustrated in Table 2.

3.3 Comparison between the contraction and relaxation phases

The contraction pulse is the critical stage for each cardiac pulse when pumping blood to the body. Cardiac contraction dysfunction is one of the most common reasons for heart failure, and this affects the left ventricle, which pumps blood to all over the tissues from the heart. Table 3 illustrates the cardiac contraction of the three arteries.

Cardiac relaxation dysfunction occurs during the ventricle (left) is incapable to seal with blood in the relaxation time; this leads to a decreased quantity of blood to be pumped to the human body. In this case, heart must raise the pressure inside the ventricle to complete the lost blood, which may origin heart failure. Table 4 shows the cardiac relaxation of the three arteries.

Table 2. Specifications of the present volunteers

Person Age's Range	Age (Year)	Gender	Weight (kg)	Height (cm)	BMI (kg/cm^2)
40-50	42-50	5 male-3 female	55-89	155-185	2.289-3.046
30-40	33-38	5 male-5 female	45-91	148-190	2.054-2.520
20-30	24-27	3 male-1 female	62-90	158-188	2.483-2.546
10-20	11-17	2 male-1 female	41-58	150-170	1.822-2.006

Table 3. Cardiac contraction from different arteries

	(Right) Brachial Artery	(Left) Brachial Artery	(Right) Radial Artery	(Left) Radial Artery	(Right) Posterior Tibial Artery	(Left) Posterior Tibial Artery
40-50	13	12.4	14	14	15	15
30-40	11.9	11.6	11.8	11.7	12.2	12
20-30	12	11.97	11.96	11.83	11.825	11.8
10-20	11	10.95	10.9	10.87	10.9	10.88

Table 4. Cardiac relaxation from different arteries

	(Right) Brachial Artery	(Left) Brachial Artery	(Right) Radial Artery	(Left) Radial Artery	(Right) Posterior Tibial Artery	(Left) Posterior Tibial Artery
40-50	8	8	9	9.5	10	10
30-40	7.85	6.85	7.35	7.1	9	8.9
20-30	6.8	6.75	6.85	6.89	7	6.95
10-20	8.2	8.15	8.1	8.025	8.075	8

4. RESULTS: THE CASES OF THE PROPOSED SYSTEM

In this section, the results of the study included measurement the blood pressure readings from different sites as illustrated in the x-axis of the results. The pressure readings in millimeters of mercury (mmHg) are written as contraction and relaxation pressure, which is represented on the y-axis of the cases. Some Iraqi study sample cases are as follows:

4.1 CASE (1)

The first group included the contraction results of the age range of 40-50 volunteers, which consisted of 5 males and 3 females. They were 42-50 years old, with weights of 55-89 kg, height of 155-185 cm, and average body mass index of 2.289-3.046 kg/cm^2. The results of contraction and relaxation pressure of this case are shown in Figures 9 and 10, respectively.

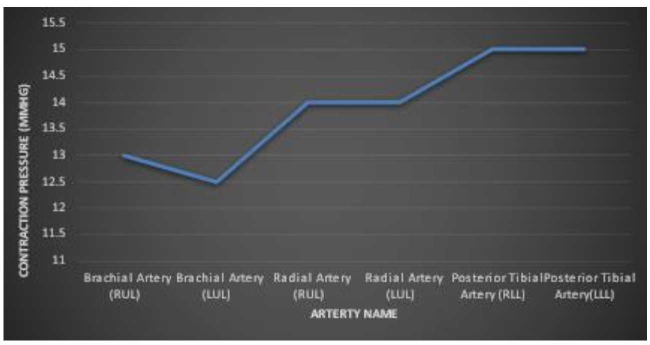

Figure 9. Contraction pressure of Case (1)

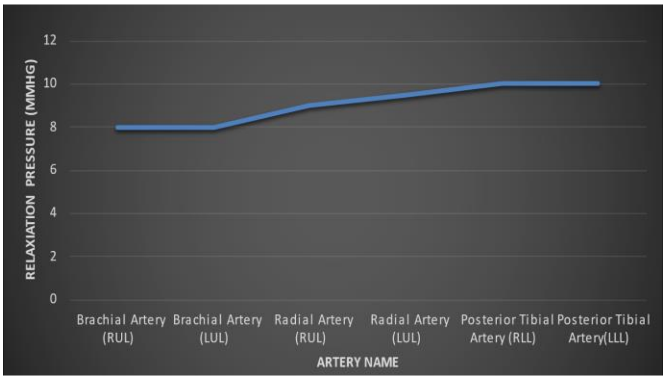

Figure 10. Relaxation pressure of Case (1)

4.2 CASE (2)

The second group comprised the contraction results of the age range of 30-40 years. The volunteers of this group involved 5 males and 5 females, with ages of 33-38 years, weight of 45-91 kg, height of 148-190 cm, and average BMI of 2.054-2.520 kg/cm^2. The results of contraction and relaxation pressure of Case (2) are illustrated in Figures 11 and 12, respectively.

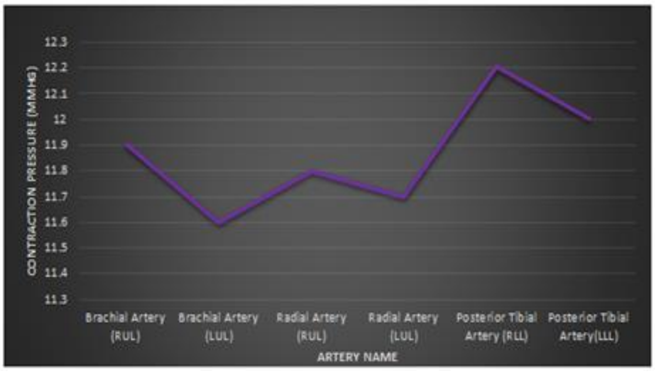

Figure 11. Contraction pressure of Case (2)

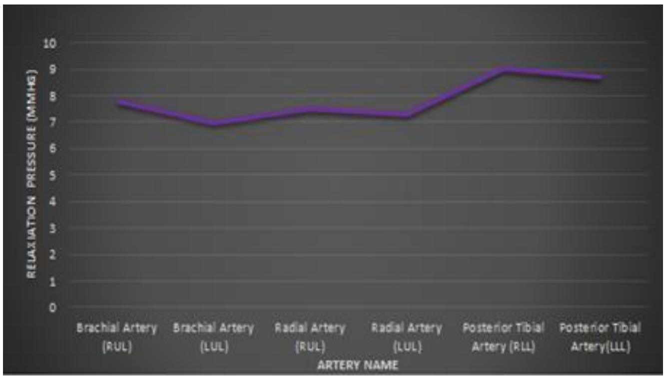

Figure 12. Relaxation pressure of Case (2)

4.3 CASE (3)

Case (3) illustrates another group of volunteers who were 20-30 years old. This group comprised 3 males and 1 female. The volunteers had an average age of 24-27 years, weight of 62-90 kg, height of 158-188 cm, and BMI of 2.483-2.546 kg/cm^2. The results of contraction and relaxation pressure of this case are shown in Figures 13 and 14.

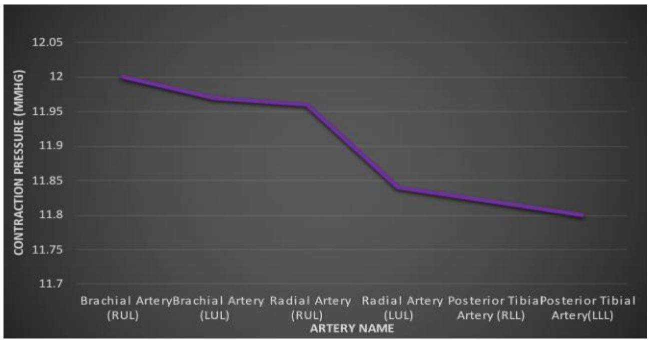

Figure 13. Contraction pressure of Case (3)

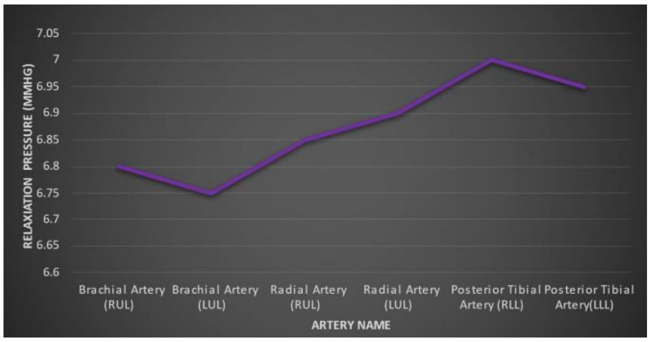

Figure 14. Relaxation pressure of Case (3)

4.4 CASE (4)

The last group showed the results of Case (4), which represented the age range of 10-20 years. This group consisted of 2 males and 1 female, with ages of 11-17 years. This group had an average weight of 41-58 kg, height of 150-170 cm, and body mass index of 1.822-2.006 kg/cm^2. The results of contraction and relaxation pressure are shown in Figures 15 and 16.

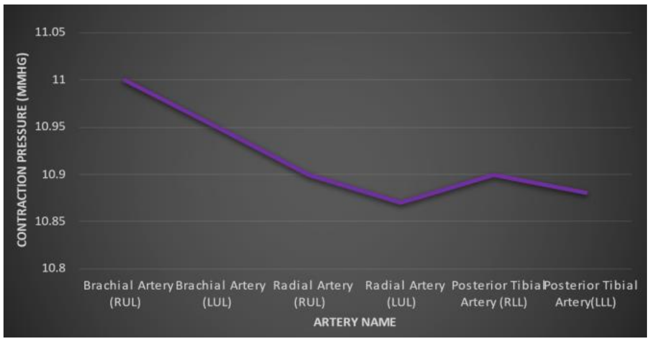

Figure 15. Contraction pressure of Case (4)

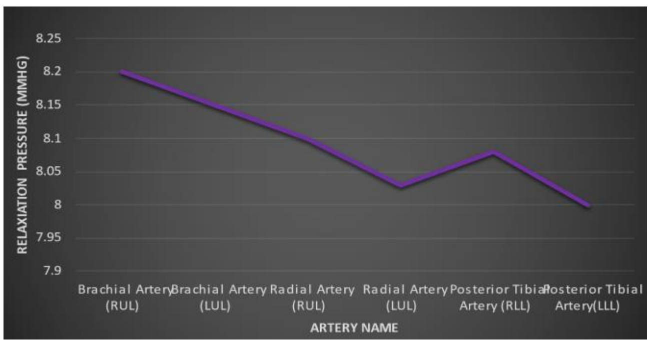

Figure 16. Relaxation pressure of Case (4)

The results also illustrated the relation between age and type of artery. The response of the contraction and relaxation of each artery differed depending on the volunteers' ages. Figures 17-19 show the pressure from the brachial, radial, and posterior tibial arteries, respectively.

The temperature was measured in the current system by using the temperature sensor. The temperatures were in the ranges of 37.8°C-37.9°C, 37.75°C-37.78°C, 37.5°C-37.6°C, and 37°C-37.3°C for the different age ranges used.

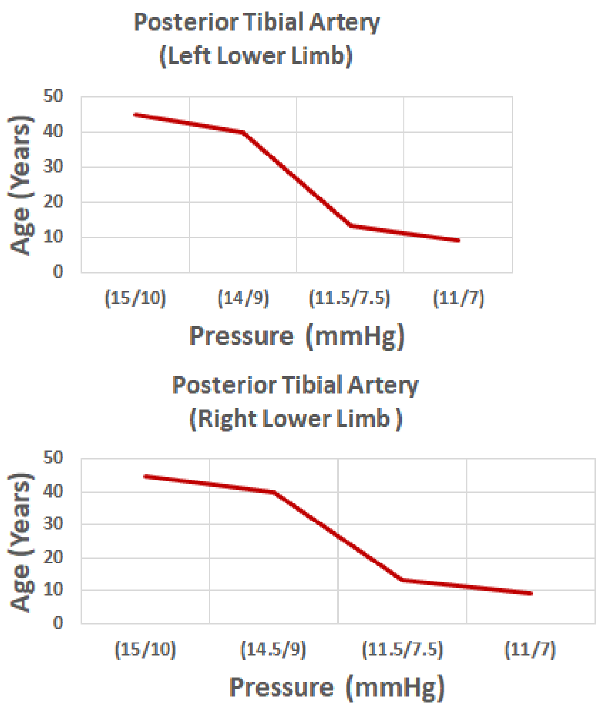

Figure 17. Relation between pressure from the Brachial artery and the age

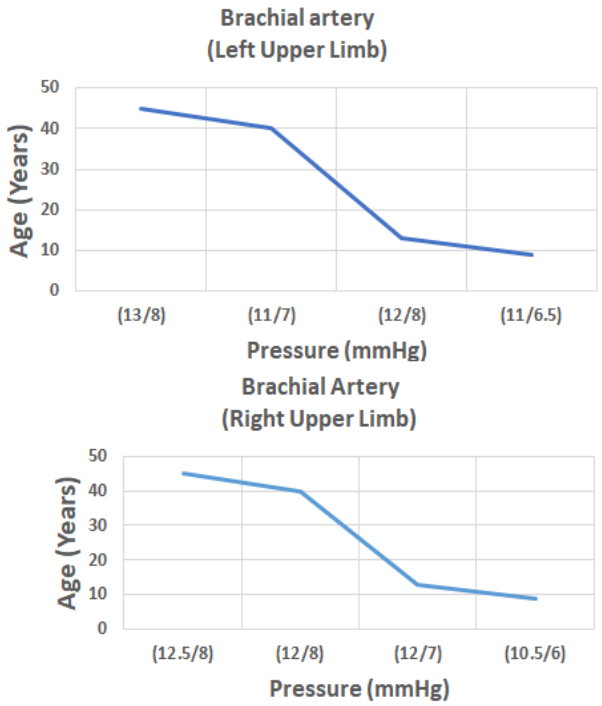

Figure 18. Relation between pressure from the Radial artery and the age

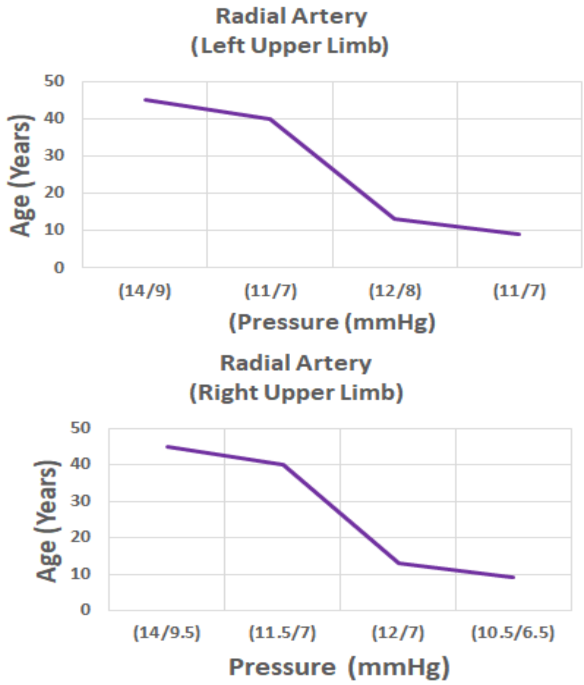

Figure 19. Relation between pressure from the Posterior artery and the age

5. DISCUSSION

As shown in the previous results of current, the average values of blood pressure for contraction and relaxation of the Brachial artery from the right arm respectively are; (13/8) for the (40-50) age range, (11.9/7.85) for the (30-40) age range, (12/6.8) for the age range of (20-30), and (11/8.2) for the (10-20) age range. While for the left arm the average values are (12.4/8), (11.6/6.85), (11.97/6.75), and (10.95/8.15) for the age range of (40-50), (30-40), (20-30), and (10-20) respectively.

The study includes measuring the blood pressure for the Radial artery from the right arm as demonstrated in the following results for contraction and relaxation; (14/9), (11.8/7.35), (11.96/6.85), and (10.9/8.1) of the age ranges of (40-50), (30-40), (20-30), and (10-20) respectively. Since these values for the left arm are as follows; (14/9.5), (11.7/7.1), (11.83/6.89), and (10.87/8.025) for (40-50), (30-40), (20-30), and (10-20) respectively.

Finally, for the Posterior Tibial artery, the average values for contraction and relaxation of the heart for the right leg in the age range of (40-50), (30-40), (20-30), and (10-20) are (15/10), (12.2/9), (11.825/7), and (10.9/8.075) respectively. While these values for the left leg are (15/10), (12/8.9), (11.8/6.95), and (10.88/8) for the (40-50), (30-40), (20-30), and (10-20) age range respectively.

The current system has been tested in several different places according to the external environment at home and abroad. As well as for people of different physical conditions such as; age, gender, weight and pathological status and found that the device works with the same efficiency and reliability where the measurement is done instantaneously on the proposed device and the commercially available devices approved and where there is no difference in readings, which indicates the performance accuracy of the implemented device. The proposed system was applied to a large number of people such as; students, teachers at the university, adults, and another people suffer from unstable blood pressure, and the readings were taken from them were very accurate. In the future, modern statistical methods will be applied to extract statistical results, which are importance in the medical engineering field. In the upcoming study, it is probable to raise the volunteer number and application different statistical approaches. So, this is can be considered from the limitation; the limitations of the present system include, it is probable to escalation the samples size and use advanced statistical applications. The new device can be packaged using an appropriate material and preparing for marketing it, also we can introduce the device to obtain an international patent to benefit from this method of measurement.

6. CONCLUSION

The present study includes the development of an affordable electric device for measuring systolic and diastolic blood pressure which is timely and relevant, especially for its potential application in educational and clinical settings in developing countries. The study is considered an innovative and holds significant practical implications and with an accurate effect relative to the conventional pressure systems. The Biracial artery is the best artery for giving accurate values of pressure during measurements at the capital fossa site. In (Case (1)), one of the volunteers is diabetic, so the range of contraction and relaxation of blood pressure is larger than the normal person. While in (Case (2)), one of the volunteers is asthma her range of contraction and relaxation of blood pressure is not affected by the blood pressure value. It is difficult to obtain blood pressure from the lower limb artery (Posterior Tibial artery) because the artery is deeper. The blood pressure on the left side is higher than its value on the right side. The range of values of contraction pressure is wider than that of relaxation pressure. The values of blood pressure in the lower limbs are higher than in the upper limbs.

The overweight of the present person has the effect of increasing the pressure values. The present study is an accurate and precise method in different situations by comparing them with the traditional methods. Results of the study demonstrated high accuracy and illustration that the blood pressure measurement is affected by the location of the fixated cuff on the human body besides the effects of other factors such as age, weight, health status, and psychological state for the same external environmental effects.

The motivation and novelty of this study is the implementation of a new, safe for the patient, accurate method, and low cost approach for measuring the pressure of the human blood, whether they are normal or abnormal, by using the modified and developed electrical circuit design with using specific components and devices in the lab. It was matched with the conventional method by the use of a standard blood pressure device.

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